STEEN BROCK

Niels Bohr's Philosophy of Quantum Physics

in the Light of the Helmholtzian Tradition of Theoretical Physics

λογος

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Introduction[1]

Introductory remarks

Niels Bohr lived from 1885 to 1962. He is one of the greatest innovators within the physical sciences. He received the Novel Prize once, in 1922, but had deserved to get it four times. He not only developed the shell model of the hydrogen atom in 1913, he elaborated the principles for the periodic system of basic nuclei around 1920, and in the nineteenthirties he invented both the liquid drop model for nuclear systems, and designed the "compound object" theory for nuclear reactions. In relation to quantum mechanics he did not contribute much as a physicist. His contribution was instead a philosophical assessment of the new theories of Heisenberg (1925) and Schrödinger (1926).

Niels Bohr could thank his father, a professor in physiology, for learning to take philosophy seriously. It was in fact his father, Christian Bohr, that introduced the idea of complementarity that is often associated with Bohr's philosophy. It was when Heisenberg tried, in the early months of 1927, to reflect more philosophically on the newly constructed quantum mechanics, that Bohr suddenly realized an interesting parallel to his father's idea of complementarity. Bohr consequently suggested that the notion of complementarity should be recognized as expressing a general line of thought that might help us not only in physics and in physiology, but also in all areas of experience. Bohr became quite obsessed with this idea and to such an extent that his fellow physicists often misunderstood what he was getting at. Where and when Bohr wanted to explain the implications of the general idea of complementarity, colleagues like Einstein and Schrödinger interpreted Bohr's statements as part of a muddled and confused attempt to express a kind of completion of quantum mechanics in order to assess its fundamental character. Where and when Bohr tried to express a critique of traditional ontology, he was thought to be doing the opposite. His colleagues usually found that he was defending a new and very strange, subjectivist, ontology in respect to the atomic realm.

Given that Bohr was so anxious to express himself philosophically one might wonder why he was not taken seriously within philosophical circles. But the reason is very simple. The kind of philosophy that Bohr draws upon was among philosophers considered outdated; it was seen as metaphysical overkill. Positivist, logical constructivist, operationalist, and pragmatist movements were beginning to dominate philosophical quarters. So Bohr's mixture of neo-Kantian notions and Romantic-philosophical ideas was hardly intelligible to the mainstream philosopher. The current literature on Bohr's philosophy show, despite the fine efforts of Catherine Chevalley and John Honner to go against the stream, that in this respect, things have not really changed.

Most books that deal with Niels Bohr's philosophy contain a lot of stories about the person Bohr. They also usually present a detailed historical account of the development of quantum physics. Further, most of the books discuss, extensively, how Bohr and Albert Einstein were not in agreement about the understanding of quantum mechanics. I guess that for many people, this is exiting stuff; but usually when reading such books,

[1] This Introduction was not contained in the reviewed version of the dissertation that constitutes the present book.

I find that the problems, ideas, and experiences that the real person Niels Bohr himself found very exiting are almost totally neglected.

I would love to write carefully about how nice and how impressive Niels Bohr, according to all records, seems to have been. I also find his various debates and intellectual exchanges with colleagues very interesting. But in the present book, the agenda is quite different. I hope to arouse some of the excitement concerning post-Kantian, Romantic philosophical ideas that, in my view, meant so much to Bohr.

My book discusses the way in which neo-Kantian epistemology and the development of new forms of physical theory mutually had an influence upon one another. But in contrast to for example Ernst Cassirer, I will argue that Bohr associated this mutual impact as leading to a crisis within physics the overcoming of which was not insight; although a certain remedy, called complementarity, was at hand to help us in this troubled situation. In relation to this, I will present Bohr as a philosopher that insisted, perhaps unsuccessfully, on associating a post-Kantian, neo-Romantic position with a full-blooded version of scientific realism. I will also argue that Bohr thought that all the older forms of philosophy should be supplemented with a philosophical reflection of the nature of language; a reflection that was not yet developed. In that sense, Bohr's philosophy points to kind of *Prolegomenon* to a future philosophy.

The agenda of the present book

For a more precise and full account of the content of the present book, I refer to the Summary at the end of the text. Here, I will only try to continue writing an invitation to read it. I will try to encircle what it is all about; but I will not be very specific about what the text actually says.

However, the title of my book is meant to state accurately what its content is. It says: There was a certain tradition in *physics* which, for instance to Niels Bohr, gave rise to certain *philosophical* considerations. My book contains a philosophical discussion of these, Bohrian, philosophical themes. The text does not primarily give a historical account of how a part of physics gave rise to a part of philosophy. Instead, it aims at giving a quite systematical, philosophical, account of a variety of philosophical issues that Bohr found important; important in general and not only in the context of physics. However, the structure and logic of my exposition makes it necessary to include extensive historical material. This is due to the fact that

(a) my presentation focus on an important feature of the tradition in physics that the present book addresses; namely the fact that this tradition has its roots in Kant's metaphysics of Nature. I argue that what I call the Helmholtzian tradition of theoretical physics, and which was commonplace among physicists in the period between approximately 1850 and 1940, makes little sense and is hardly justifiable if one does not acknowledge its Kantian roots.

(b) my presentation of Bohr's philosophical thoughts centers on a certain view in respect to the development of quantum physical theory.

The two things are connected: Bohr thought that the development of quantum physics challenged some of the elements within the metaphysical and methodological principles of the Helmholtzian tradition. Thus, the present book discusses how Bohr analyzed

this challenge to Kantian metaphysics of Nature. My exposition therefore examines concepts like "intuition" (*Anschauung*), "schematism", "unity of thought", "empirically based judgment", "objectivity", "rationality" etc.

My book argues that what should rightly be called "classical physics" is a quite modern construct, formulated around 1870 when, first, the concept of energy was introduced into physical theory and the principle of energy-conservation energy was formulated as a derivation from Hamilton's, and Helmholtz's, formulation of the principle of least action. The book also argues that quantum physics was originally (until 1932) a quite desperate attempt to recognize the principles of this (new) tradition of *classical* physics. The *unity* between classical physics and quantum physics is far more important than the difference between any classical theory and any quantum theory.

Quantum physics investigates human action just as much as atoms

It might be thought that quantum theories provide a new revolutionary insight into the structure of physical reality. But any justifiable physical theory does that. The only special thing about a quantum theory is its having a specific reference to, say, atoms, nuclei, or elementary particles. However, there *is* a revolutionary feature of quantum physics. By recognizing it as an adequate form of theoretical thought we are forced to challenge some of the epistemological presuppositions (or prejudices) from which the natural sciences have suffered.

According to Bohr, it is "our position as spectators and actors" within physical nature that we must reconsider. In other words, our issue is not the ontological or epistemological implication of any kind of physics, *as such*. Our issue is the very relation between physical reality (seen as a field of inquiry) and our empirical, experimental methods of investigation. Our issue is not what modern physics tells us about the reality of things. Our issue is how the world makes the *tradition and practice* of theoretical physics possible. The "deep truth" about physical reality that nevertheless comes to the fore within this practice does not correspond to the content of a set of physical theories, as such. The "deep truth" comes forth (to put it in a Wittgensteinian fashion) when we realize that the reality of things is such that they can be investigated *like this*.

It is in fact right to say that quantum physics does not, merely, concern the basic structure of a micro-physical reality. It also concerns *human capacities*. It concerns human action just as much as it concerns the action of elementary particles. When we design an experimental arrangement we arrange an interplay between our actions and the activity of the physical realities we want to investigate. Experimentation, measurement, and observation are deliberate attempts to change, influence, and manipulate whatever we are investigating. Our scientific physical knowledge of the world is knowledge of what happens *when we perform a set of actions*. Following Bohr, I argue that this "subjective relativity" of quantum physical phenomena does not make quantum theories less objective nor prevent them from referring to the real structural properties of atoms.

So this is the general philosophical implication of quantum physics: Objective experience must be seen as a matter of actively trying to influence what is at issue. As such, this is an old truth within philosophy. There is a sense in which one must "preserve", or "save", or "take care" of what one tries to experience. In experience, one has

to be careful, one has to be cautious, and one has to let the reality of things manifest itself. This precisely requires an *active* preparation for experience and an *active* attainment of attitude. What quantum physics adds to all this relates only to the question of *how* certain forms of observational activity form part of the preparation for certain kinds of experience.

The idea of a new mechanics

Before saying something about the special features of quantum mechanics, one should note its similarity with the (newly introduced) classical tradition. My reconstruction of the way in which physicists like Helmholtz, Planck, and Heisenberg formulated and elaborated the (new) "classical" tradition of theoretical physics underscores two things: First, the foundation of physics is a new mathematical formulation of the principle of least action, a formulation usually called the Hamilton principle, according to which one can associate the concepts that enters into the formulation of the principle with a new principle of energy-conservation. Second, the specific laws concerning the possibilities for changing the physical states of given physical systems, the so-called phase-space, should be recognized as forming a unity between a kinematical and a dynamical feature of the objects of the systems in question. The main example would be; the mechanical laws of a given system expresses a unity between the kinematics of the moving items and the dynamics of the system due to the possible motion of its constituents.

The idea of a "quantum mechanics", which Heisenberg formulated, was therefore simple; the new "mechanics" should be associated with a unity between a new kind of "kinematics" and a new kind of "dynamics" (the unity between Bohr's shell model of the atom and certain "quantum effects" like those discovered by Compton, Stern, and Gerlach).

The construction of a new kind of mechanics shall be seen as an attempt to construct an "atomic theory", a theory about the possible interaction between atomic constituents. An atomic theory must, because it deals with such things as electrons, deal with *all* features of physical regularity; mechanical, electro-dynamical, optical, thermal. Electrons form part of *all* sorts of physical systems. So the idea that all concepts and all laws of physics are in some sense connected is not only an abstract methodological principle but was a necessary presupposition for formulating an atomic theory. The development of atomic theory *had to* raise the Kantian issue of how the "unity of Knowledge" expresses "the unity of Nature".

It was Heisenberg who first saw the link between the need for constructing a new mechanics, and the fundamental philosophical issue of analyzing the unity of thought and intuition. This had in a way already been an explicit concern of Helmholtz, but it was first Heisenberg's formulation of the so-called Indeterminacy Relations that that displayed a *systematic* connection between the construction of a new kind of physical theory and the introduction of a new kind of intuition.

What Bohrian complementarity is about

The new kind of *Anschauung* concerns a set of principles for the description of physical experiments. So, Bohrian complementarity, in the context of physics, is supposed to explain how a variety of quantum theories can, each in their particular way, correspond to certain principles for the description of experiments.

One should note that Heisenberg's "quantum mechanics" was only meant to form part of a specific physical theory, atomic theory, within a variety of "quantum theories": What "quantum theories" have in common is the fact that Planck's constant enters into the mathematical formulation of the respective theories. Bohr thought that such quantum theories were, each, examples of a *new kind* of physical theory because the principle of energy-conservation had to be adjusted corresponding to a new understanding of the link between

(a) intuition (space-time co-ordination)
(b) the formulation of specific physical laws.

Thus, to Bohr, what matters about quantum mechanics is, and is only, the way in which the development of this particular theory exemplifies the "new kind of theory" that characterizes quantum physics.

Bohr's so-called framework of complementarity does not especially relate to the understanding of such a "quantum mechanics". But quantum mechanics, as Heisenberg originally formulated it, is a *clear example* of the new kind of physical theory that, for Bohr, had certain philosophical implications. Bohrian complementarity concerns *two Kantian philosophical concepts*, intuition and thought; or better, it analyzes the unity of *Anschauung und Denken*. It presents in a new fashion the relation between space-time co-ordination and the lawful character of what the concepts of theoretical thought refer to. Complementarity does not, I argue, express the duality between features of physical theory *as such*, say "particle"/"wave", "energy"/"time", "dynamical quantities"/"kinematical elements". The precise link between the task of constructing a new mechanics and the idea of a new kind of *Anschauung* is this: kinematics (the description of physical change in space and time) and dynamics (the account of the basic kinds of physical interaction that must be involved in any physical process or regularity) shall be seen as relating *both*

(a) to the principles for the description of experiments
(b) to the characterization of atomic stabilty as well as of atomic change.

The Indeterminacy Relations symbolizes that there is a systematic coupling between the kinematics of the atomic elements and the dynamics of the *experiment*, as well as a similar coupling between the dynamics of the atom and the kinematics of the *experiment*.

Many people wrongly see these couplings as expressing a "complementarity". That is confused. Instead, the couplings express what constitutes a quantum physical, experimentally produced, phenomena, and thus also express how we can understand the quantum effects, like the Compton effect, as characterizing atomic physical systems and processes. The Indeterminacy Relations tells us that a given set of experimental

equipment can be described and used in two different ways that mutually exclude one another. In one case it is a certain kinematical feature of the experimental design that matters in the production of a given phenomenon (that display a dynamical feature of the atom investigated), in another case it is a dynamical feature of the design that matters in the production of a phenomenon (that display a certain kinematical feature of this atom).

In this sense the indeterminacy relations tells us *what* is mutually exclusive. In contrast, Bohrian complementarity tells us *what it means* that different phenomena are produced under experimental conditions that are mutually exclusive. Bohrian complementarity concerns the issue of what it means that there are *lawful* relations between experimentally conditioned phenomena. That is the sense in which the framework of complementarity is a new post-Kantian schematism: The framework expresses how an empirically given experimental apparatus can be associated with certain forms of relation between the phenomena that can be produced by means of the apparatus. Thus, to Bohr, complementarity is supposed to be a *generalization* of the Kantian, schematized, concept of causation.

The general framework of complementarity

The present book ends, in Part Six, by presenting and discussing what I call Bohr's "general framework of complementarity". In the previous Parts I investigate, in Part Four, questions about scientific rationality, scientific realism, and principles of physical experimentation, and in Part Five, I critically examine three of the recent, major books that deal with Bohr's philosophy of quantum physics. So on the face of it, it may seem as if the final Part Six is a kind of appendix to the former Parts. However, that is not how the author sees his text: The discussion of experimentation and causality centers on the kind of "subjective relativity" that I mentioned above. The various chapters in Part Four provides a very detailed account of the way in which human action and human deliberation forms part of the enterprise of quantum physics. I also discuss the role of models in science in relation to the view of Rom Harré, with whom I agree to a large extent. By introducing the notion of models it is stated very clear that objective experimental scientific knowledge is a matter of extending and enlarging a *human space of action*. It is also explained, very carefully, how Bohrian Complementarity in the original context of quantum physics exemplifies a new kind of *Kantian Schematism* concerning the causal aspects of physical experimentation.

Similarly, my critical comments to the three major books on Bohr that I present in Part Five all point in the same direction. I criticize these works for maintaining an unacceptable orthodoxy about *classical* physics. Their respective account of quantum physics hinges on the postulate that – even if quantum physics supposedly is something quite special – it has incorporated a "classical part". In effect, such an interpretation pictures the (new) quantum physics as in some sense "generalizing" or extending the (old) classical physics. I argue that this picture is much too simple. So we need another model for the paradoxical situation that something new is both radically different and still preserves a kernel of something old. So it should be noted that my discussion in Part Five ends by considering certain questions about the foundation of *mathematics*, and that I in this discussion introduce Michael Dummett's notion of a *conservative ex-*

tension of a linguistic practice. That discussion has a direct and systematic connection to the theme, in Part Six, what a generalization of the idea of complementarity between physical phenomena might mean. This is also why, after having explained the general framework of complementarity, I conclude by turning back to the semantic issues of Part Five in order to integrate those issues more firmly within the philosophical issues that the idea of a general framework of complementarity brings forth.

The general framework of complementarity deals with the issue how one can learn to see a connection between different kinds of phenomena that one has so far not related to one another. The general framework of complementarity is in a sense a logic of metaphysical discovery. By utilizing this logic, or method, one discovers how the mutual exclusion between certain forms of phenomena manifest the existence of a variety of "manifolds", "totalities", or "harmonies", within Nature. Bohr thought that complementarity, in general, reveals something about the existence of an atom, a living organism, a personal consciousness, a culture, and – even – the Spirit that is associated with being a citizen of the world as exemplified by a range of international co-operations within the various sciences and in politics.

I think the visions and ideas that the invocation of the general framework of complementarity put to the fore were extreemly important to Bohr; because I believe that he was deeply influenced by certain thoughts of Goethe, and other Romantic thinkers, and that it would be highly interesting to draw some parallels and point to some contrasts between Bohr's philosophical ideas and those of Goethe. However, in the present account I stick to the examples and works that Bohr explicitly mentions, and I try not to make extensive comparisons to the works of other philosophers, just for the sake of it, however interesting it would be to do so. My only ambition in the present book is to clarify and discuss what I see as Bohr's explicit philosophical thoughts.

However, there is, as stated above, one issue in relation to the elaboration of the general framework of complementarity that *systematically* relates to the earlier philosophical questions about physical causality and atomic stability; namely the question of how an account of the unity of knowledge can also be said to imply an elucidation in respect to the question of the unity of Nature. This Kantian theme forms the heart of it all.

The question is; if we can – as it seems we can – generalize the notion of *Anschauung* – within modern forms of empirical research – can we then not also generalize the notion of a schematism, the idea of an intuitive presentation of what it means for an object to be subsumed under a certain concept? The framework of complementarity within the context of quantum physics is indeed an example of such a generalization. But can it be further generalized so as to cover, also, all the branches of natural sciences and even cover all fields of experience? To this question the answer is "no". But there is, if you like, a family resemblance between a variety of different generalizations of the original Kantian schematism corresponding to the category of causality. The general framework of complementarity expresses this family resemblance, and there being this resemblance is seen as revelation of the ultimate unity of Nature, according to my interpretation of Bohr.

By the way, this is an example of how I make use of the later Wittgenstein in my discussion. However I am not trying to draw a close parallel between Wittgenstein and Bohr. My reference to Wittgenstein primarily says something about my own philosoph-

ical position, and about why I at some points *disagree* with Bohr. The present book is not a defense of Bohr but a *critical* exposition of his philosophy.

As a philosopher, Bohr cannot stand on his own. You have to supplement his views with those of other philosophers. But regardless of which philosopher you choose – and my choice would be Wittgenstein and Cassirer – it should also be recognized that no *philosopher* could stand on his own; because, true to the argument of the present book, any kind of philosophy should be informed by the development of certain kinds of empirical research. In that sense, Bohr may be called an important partner to a future philosophy, and to have understood Bohr as elaborating a *Prolegomenon* to a future philosophy, along the lines that I present in this book, may well be a valuable key for understanding what is going on in philosophical works, proper, like those of Wittgenstein and Cassirer. Finally, let me remind the reader that there is a more detailed and systematic summary of the present book at the end of the text.

I am thankful to a number of people for their support, encouragement, and specific help on a number of questions. Especially I have to thank Louis Klostergaard for convincing me to study the works of Kant much more thoroughly than I was first prepared to do. I am indebted to David Favrholdt and Rom Harré who both, at an early stage of the present work, helped me to realize some of the crucial aspects of Bohr's philosophy. I am greatful to Hans Fink, Bill Newton-Smith, and Dugald Murdoch for valuable criticism of earlier drafts of the text. I was strongly encouraged to pursue the present work by Join Michael Krois, and my discussion with him and my listening to his vivid explanation of Goethe's influence of Ernst Cassirer, has been a constant source of inspiration. I am also thankful for the encouragement given by M. Heidelberger as to my reading of Helmholtz and by Ole Knudsen as to my presentation of the principles of the early quantum physics. I must express my gratitude to Michel Bitbol for inviting me to present part of my text at the Sorbonne in Paris in 1999, since it forced me to clarify my thoughts on a number of issues. I thank both Stacey Cozart of the University of Aarhus and Kevin Weinfurth (formerly) of Georgetown University in Washington, for an extensive revision of my english grammar and formulations. The remaining grammatical shortcomings of the revised text are my responsibility. Neither Stacey nor Kevin has seen the final draft in which I have added and changed things to the best of my, limited, ability for writing in English.

Finally, I thank my colleague Anders Moe Rasmussen for so many inspiring and stimulating philosophical discussions, throughout the years, on a number of issues that I address in the book; and I thank my former teacher in philosophy, and longtime colleague, Uffe Juul Jensen, whose lectures and works have had a lasting influence on my own philosophical thinking. I dedicate the book to my wife Lone Brock. Without her love and support I could not have finished the present work.

Steen Brock
Aarhus, January 2003

1 The Semantics of Kant's Transcendental Analytic and its implications for Natural Philosophy

1.1 The Kantian Tables

The functions of Judgment

As this texts unfolds I hope that a broader and sufficient picture of Kant's philosophy emerges, but since, in our context, it is Kant's reconstruction of Newton's laws that is essential, and since this reconstruction is systematically connected with Kant's exposition and explanation of the table of categories; I have chosen to begin my presentation of Kant by focussing directly on this table and the corresponding table of Judgments:

The functions of Judgment form the heart of Kant's idea of an "analytic"; the idea of a systematic unity of the operations of thought. The functions of Judgment are conditions for the possibility of having a justified and *conceptually* mediated knowledge of things. As is well known, Kant wanted to model the table of possible forms of conceptualization (the table of categories) in accordance with an already given table of the functions of Judgment. Kant adopted this strategy because he thought that this given table was clear in respect to what he called the *Beweis-Gründe* of the various forms of Judgment. I consider such proof-grounds as corresponding to the *logical structure* of the forms of Judgments, analogous to the notion of *Sachlage* that the early Wittgenstein was later to advance; in other words, analogous to the logical positions of possible state of affairs.

The basic difference between *logical functions* of Judgment and the categories, qua functions of *the Understanding*, is this: The former are functions of *knowledge* thanks to which our Reason manages to install a clear and definite logical structure into its determinate judgments. The latter are functions of *objectivity* thanks to which it becomes clear and evident *how* possible conceptualizations embody concepts of *objects*. In both cases, a "function" means an act of the Human *Gemüt* through the function of which a stock of representations acquires a certain order. In short, the functions of Judgment provide the logical syntax of thought. The categories condition the possibility of a meaningful "logical space", a possible complete and adequate objective *domain* of thought. The actual experience relative to such domains (as we shall see below) is secured by those basic forms of *application* of concepts that Kant calls "transcendental schematizations".

Consequently, a judgment, according to Kant, is more than a fixation or recognition of something. It involves recognizing *how* something presented in thought is (logically) posited in thought. A function of Judgement expresses, as the very term *Urteilen* shows, that the function constitutes a basic (*ursprünglich*) way of dividing things up. So this expresses the rationality in distinguishing the various functions of Judgment:

Quantity
One Man, Socrates, is mortal (x is P)
Some Men are mortal (the number of mortal Men is not zero)
All Men are mortal (no Man is immortal)

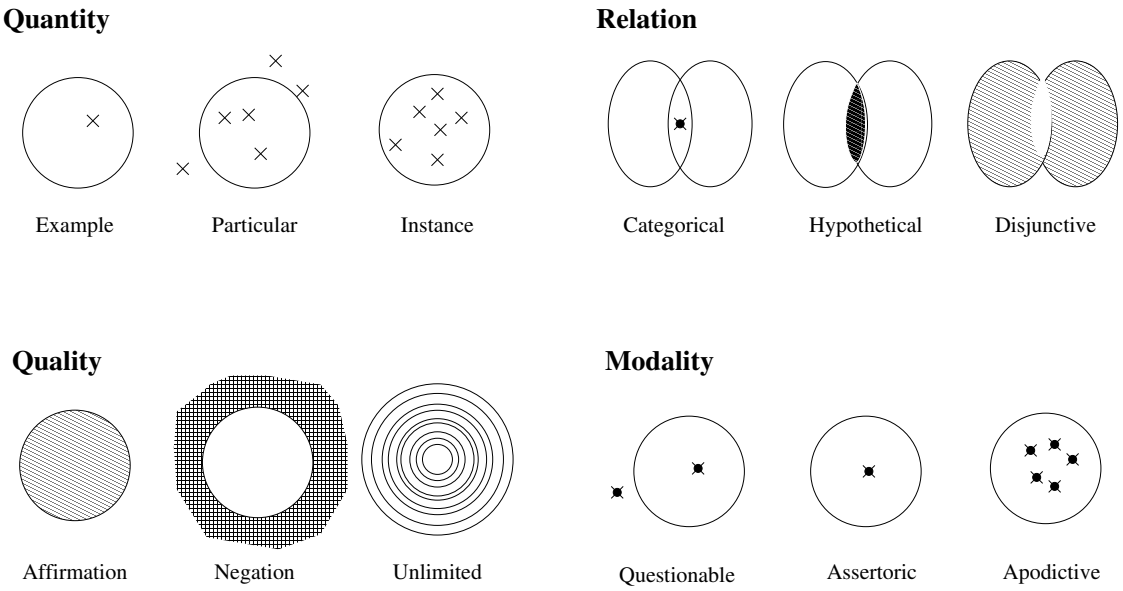
Quality
Socrates is (definitely) mortal
God is (definitely) not mortal
Socrates is one of the countless mortal men (infinite)

Relation
Socrates is one of the Mortals
If Socrates is a Man, Socrates is mortal (hypothetical)
There is a definite color, belonging to a range of colors,
which is the color of Socrates' hair (disjunctive)

Modality
Socrates is possibly mortal
Socrates is, as a matter of fact, mortal
Socrates has to be mortal

As I hope it has struck the reader, I thus propose to explain the table of Judgments, the system of logically possible forms of Judgment, as presented by Kant, in accordance with a *set of Euler diagrams* by means of which one may expose a "complete" set of logical positions; or in Kantian terms, a complete set of synthetic forms. This set is a framework for the *possible content* of objective thought, as well as for a determinate *number* of possible, but as yet "indeterminate" objective states of affairs. Each such logical position determines a *Sachlage* in the sense of Wittgenstein's Tractatus. As such, each logical function of Judgment constitutes a way to survey a given field of knowledge. The functions lay bare the basic logical forms – the possible *Sachlage* – that any determinate state of affairs objectively might be thought to exemplify.

The Table of Judgment illustrated by Euler-diagrams



Some of the diagrams show that a certain unspecified member of the class of X's can be either an example of such a member, or be a particular member, or be just an instance of several members. Also, other diagrams express the possible extension of class membership, including the possible interrealation between such. The symbol ⋇ marks that there exist a real instantiation corresponding to the specific kind of judgment.

The categorical forms of thought

The categories should be regarded as expositions of the logically elementary forms of thought. As such, they constitute the possible forms of predicative synthesis – the possibilities of picturing concepts as constituents of possible judgments. By contrast, the table of the functions of the Judgment show instead the *way* in which given representations acquire a synthetic unity within the unfolding of human Thought. As was mentioned before, the logical functions of the Judgment have to do with a way of "surveying" a manifold of possible representations. Here the focus is on the possible world-thought connection. What is important is the notion of a possible content. In respect to the categories, the focus is different (B 144). The important thing is the relation between matters of fact and knowledge – or instead, between fact and reflection. The issue is no longer *how* given structures of thought come about, but *that* they do, and always as involving a relation to possible forms of objects – as involving a certain form of *Gegenstands-Bezug*.

The logical functions of the Judgment lie so much at the heart of Kant's transcendental philosophy, that they are taken for granted without further notice. Thus, the famous Transcendental Deduction of the table of categories presupposes these functions. Consequently, Kant pursued the following strategy: Given that there are the mentioned twelve logical functions of Judgment, one may raise the question of what must be involved in the application of such kinds of judgment to various kinds of objects. So by

answering this question one makes explicit the *Rules* in terms of which, alone, one may conceive of an object. The answer is given by the following "categorical claims":

Quantity
Any "object" must have some determinate form of manifestation in space and time (criteria of identification)

Any "object" must be clearly and characteristically separated from any other object of the same kind (criteria of individuation)

Quality
Any "object" must have some determinate "shape" in comparison to other objects of the same type (criteria of magnitude)

Relation
Any "object" must be regarded as forming a single part of all Being of its kind (criteria of substantiality)

Any such single part, any such "object", must stand in some determinate relation to any other such part (criteria of causality)

It should be noted that these "criteria" (the possibility of which was secured by the table of judgments) does not yet constitute what Kant called "the transcendental *principles* of the Understanding" (which first the schemata does). However, there is one transcendental principle already involved in the transcendental deduction of the categories, namely the principle that the table of categories represents the structure of our possible experience. The table of categories is but a way to represent, in a systematic and logically unified way, what might constitute a set of possible forms of *determinate* experiences. In other words, the table represents, in uniform fashion, the ontologically possible forms of particular *Erscheinungen*; the unified set of possible *forms* of experience, and the epistemologically possible *objects* of experience.

The exhibition of thought

In (B 179) Kant makes clear that the Transcendental Deduction of the categories aimed at representing, in philosophical thought, the grounds of the possibility of objects of knowledge, *according to their form*. However, Kant says in § 26, he has not yet represented the categories as the grounds of the possibility of objects of knowledge *according to Lawfulness*. This distinction between form and lawfulness cannot be stated without first pointing to another distinction, that between "form" and "matter". I agree with Brigitte Falkenburg that this latter distinction hinges on the pair *Bestimmung / Das Bestimmbare*, a distinction between that which is involved in the elaboration of determination and that which can be determined (shaped up). In respect to Kant's analysis of the Understanding, the "matter" of the Understanding is the series of perceptions that – each or in combination – can be variously considered as representations. The "form" of the Understanding is what is exposed by the table of categories. As was mentioned above, the categories express the possible forms of objects that can be clearly represented in Thought. Through the Transcendental Deduction Kant aimed at clarifying the grounds of the possibility of these "forms" (which was done by revealing that only

in respect to these forms, corresponding to the table of judgments, would the unity of the thinking and conscious Subject be at one with the unity of the objects posited in thought). So, as stated by Kant in § 26 of *The First Critique*, what still needs consideration is that it has not yet been revealed how the possible objects of thought can have a determinate representation within intuitive thinking; in other words, it has not yet been revealed that the possible forms of objects that the transcendental deduction brings forth do in fact constitute possible objects of *human Understanding*. The unity between Thought and Intuition – the very veritative synthesis that essentially characterizes *Human* Thought – has not yet been taken into account. The mediating role of the Imagination that is necessary for the possibility of any *well*-formed judgment, has not yet been accounted for.

As I see it, to Kant, the Imagination provides the unity between the *Gegenständlichkeit* and the *Gesetzmässigkeit* of the Understanding. The Imagination mediates the unity between the Intuition and the Understanding in order to constitute the kind of objectivity and lawfulness that makes the particular thoughts and representations – that are produced in accordance with this mediation – fit for objective, truth-directed, determinate judgment. The Imagination provides a foundation for the determinate Judgment by means of mediating in a special way between the Intuition and the Understanding. This mediation, termed *Ein-Bildung*, constitutes the possibility that the products of the Understanding are "well-formed", that they are *logically* structured – that they become possible candidates of conceptual analysis.

This is why we have to take into account what Kant calls "the original transcendental synthesis of the Imagination", which is the synthesis that secures that the various kinds of conceptualization within the Understanding can be "figurative" – such that that which can be objectively represented in thought might always be given within the Intuition. In short, it is only due to this mediating synthesis of the Imagination that we can make sense of the idea (of Reason) that Human Thought is something that can be *applied* to whatever is given in consciousness, and thus also in experience. That is the sense in which Kant, in § 26 of the *First Critique*, says that the categories do *not* form a "pre-formation *system*".[2] There is no conceptual frame as such, of which we can truly say, that that constitutes the set of concepts that we can meaningfully apply to any given object.

Put in modern terms, it is one thing to expose the possible conceptual structures that characterizes a form of thought, it is another to demonstrate how the possibility of these structures embody a *semantics*. As I see it, this is the main claim of what Kant calls "the main principle of synthetic judgment" (B 197), which says that (a) the possibility of there being objects of experience and (b) the possibility of experience, as such, should be regarded as one and the same possibility. They are *gleich-ursprünglich*.

Another way of expressing this is by saying that the original synthetic unity of The *Apperception* – that this intellectual Synthesis – is at one with the empirical synthetic unity called *The Apprehension*. Which is to say that Human Thought must always be mediated – that Human Thought is necessarily *discursive*. Human Understanding is essentially an effort to *make sense* of the given. This points to the fundamental *semantic* character of our perception (*Wahr-nehmung*). The possibility that we perceive

[2] Kr. d. r. V. B 167

things is already the possibility that whatever is presented to us in consciousness may have the kind of unity and structure that makes it possible for us, meaningfully, to posit objects within the Intuition – and thus make it possible to posit objects as fit for forming objective judgments about these posits.

However, according to Kant, the possible candidates for such objective claims must not only have a determinate logical form, they must also be "well"-formed. They must be "sentences", since they must be posited (*gesetzt*). This is for Kant the main synthetic role of the Imagination in respect to determinate Judgment, because the products of the mediating operation of the Imagination are – precisely – posited (*gesetzt*). So this is the sense in which the categorical forms that are exposed through the Transcendental Deduction embody the possible *original meanings* of the categorical forms of Understanding. So the question that still needs consideration is how to represent these meanings in reflective Thought. Kant called these representations both "schemata" and *Grundsätze*. The rational principles associated with the representations he called the Transcendental Principles of the Understanding. Kant mentions four kinds of such representations, or schemata:[3]

The axioms of intuition
The anticipations of perception
The analogies of experience
The postulates of empirical thought

The table of categories was supposed to expose "the rules of identity" – of objective conceptual thought. So, as stated in § 26, what must still be considered is what it means to *apply* such rules. This is the issue in Kant's account of the special way of applying concepts which he calls *subsumption*. According to Kant, this is a basic feature of determinate Judgment, the feature of subsuming the particular under the *allgemein*. It may seem as if Kant is suggesting that we have rules for applying rules – rules for applying the categories which are themselves rules. But this is not so. Indeed, we can never establish such "rules of rules". Or as Kant put it, we can never have a true *canon* for determinate Judgment. At best we can establish a "doctrine" by means of which it is revealed, a priorily, what a possible candidates for being subsumed under the categorical forms of thought could be. In this way we elucidate what could characterize a particular object such that it is a possible a candidate for our making a determinate *geometrical* judgment about it (i. e. what is it for an object to have a definite spatial form). Similarly, we elucidate what could possibly be a candidate for our making a determinate *dynamical* judgment about a particular object (i. e. what it is for different objects to stand in certain temporal relations to one another).

It is not just that Kant asks how the categories can have an empirical application. Instead, he asks *what it means* that the conceptual forms are applied to something else: Kant asks whether there is a "matter" external to the lawful operation of the Understanding itself that is fit for categorical subsumption. Kant thinks that he can provide an affirmative answer to this question by revealing how the *form* of some synthetic operation of the Understanding corresponds to the possibility of there being a cer-

[3] Since the original version in the reviewed version of my dissertation was muddled, I have clarified this and the following paragraph to some extent.

tain subject-matter. As mentioned, we can never say what fully *constitutes* this ability or possibility. There can be no *such* doctrine. There is however something a priori to point out about what must be involved for the kind of application – for "subsumption" – to be possible. Importantly, we have here to do with "rules for the determination of the Intuition" (A 141), which, in short, means that there can be no cognition without a possible *re*cognition. There can be no criteria of identity in respect to possible objects of thought if these criteria are not associated with some material criteria of identification. There can be no sense to the claim that, in a given case, we cognize a determinate object, if one has no means of demonstrating how this very object is supposed to be given in thought. Which is to say: The very veritative synthesis between Thought and Intuition is constituted first and foremost by a cooperation between the *possible operations* of Thought and the *possible demonstrations* within the Intuition. The systematic objective unity of the former presupposes the systematic unity of the latter. There could be no apophantic synthesis (no possibility of true judgment by means of well-formed sentences) if the veritative synthesis could not be regarded as mediating the former. The very idea that we can make true (composite) judgments about something presupposes some idea in respect to how this object, about which we judge, may *demonstratively* count as a possible candidate for being subsumed within such judgment. So this the fundamental issue in Kant's account of the necessary "schematization" of the categories.[4]

The schematism of categories

The aim of introducing transcendental schemata is to represent, in thought, how the possibility of perceiving objects may be associated with certain a priori time-determinations. The point of this kind of representation is that such determinations can already be regarded as having an adequate uniform character. Thus, the unity that is given within any possible time-determination of given representations – say within a possible succession of such – becomes itself exposed within the apprehensive unity of perceptions. So this is the sense in which the synthesis within The Apprehension may be regarded as *figurative*. It becomes possible to conceive of objects presented as corresponding to a kind of order, namely to the various forms of temporal order the a priori possibility of which is constituted by the original veritative synthesis.

This all implies that we can make *judgmental* sense of concepts. If there could be no schematism we would be left with an idea only about what it means for concepts to enter into possible thoughts – entering as rules for the determination of a certain logical kinds of object. We would thus only have the rules constituting the possibility of a *Sachverhalt* in the sense of Wittgenstein's Tractatus. However, due to the schematism of the categories, it now makes sense to recognize that the way concepts enter into thoughts may correspond to the way in which intuitively given objects enter into objective judgment (as a possible Tractarian *Tatsache*).[5] To give an example of such a

[4] We shall see further on, how this also lies at the heart of Kants's philosophy of physics – of his metaphysics of Nature – especially in his account how to transform a rationally constituted dynamics into an adequately regulative mechanics.

[5] Note not included in the reviewed version of my dissertation: the possibility (the empirical meaning of) a *Tatsache* does not yet constitute a factual state of affairs involving specific objects. The shematism

schematism, I may conceive of an orange as being round, in the sense that I may correlate a determinately given object – say, the object that is placed on a certain plate – with the idea of objects having the specific shape 'round', and where the latter simply means that it is possible to trace points on the surface of the object successively in time in a specific manner. In short, to conceive of an object as having a particular identifiable form, about which we may then make a judgment, presupposes that one can conceive of a possible way in which that form might in itself have been constructed, namely by the development of a certain trace or pattern in space-time.

It is such a method of temporal construction that Kant calls a schematization. He further calls the shapes thus produced the *pictures* of the schematization. When we reflect how various such temporal constructions are possible; in other words, when we characterize any one of these synthetic operations – we then introduce what Kant calls *schemata*. These are objective judgmental schemes (i. e. tables) that represent the various possible forms of schematization of the categories. Such a table is a representation of the way in which the Imagination provides a picture corresponding to given concepts. In modern semantic terms, it is an account of how there may be well-defined conditions of application (i. e. "pictures") relative to which the use of concepts may objectively embody the specific criteria of identity that the Transcendental Deduction of the unity and system of categories demands.

The possibility of schemata thus in a sense presupposes the possibility of certain *abstract* objects, because there must be a kind of proto-sense – an apriori sense, in which the constructed pictures may be said to correspond to something objective. We must be able to regard the prototypically constructed spatio-temporal forms as possible forms of objects. That is the importance of the discipline of *Geometry*. Within that discipline there is no gap between what it means to correspond to a certain shape and what it means to *be an object* of a certain kind. Abstract objects embody criteria of individuation that, effectively, form a bridge between certain modes of presentation (that may constitute the conditions of application for certain concepts) and specific criteria of identity.

This is why, in order to ground the possibility of mathematical physics, one has to introduce a range of mathematical objects (a) the unity and structure of which may be seen as an exposition of the categorical structure of objective thought (in the sense explained above), and (b) that may be regarded as forming the canonical modes of presentation of the kind of objects posited in theoretical physical thought, such as "motions", "systems of motions" and "lawful alternations of the state of motion of a system of objects". In short, in order to construct a kinematics, a dynamics, and a mechanics one has to construct a set of schematisms in terms of which, alone, it makes sense to make objective judgments in physical thought.

This again explains the rationality of the schematisms. As mentioned, the Judgment is concerned not with the determination of a determinate content of particular judgments as such. The Judgment is concerned, instead, with the issue of how certain forms of *part-whole* relations comes to the fore within such determination. This is the idea (of Reason) behind the Kantian notion of *substance*. Thus, the schematisa-

demonstrates what it means for such objects to exist. Below a further element will be added within the metaphysical principles of the natural sciences to the effect that it is clear what it is for the objects to exist *physically*.

tion of the categories makes it possible to conceive of possible objects of knowledge as "simple" *substances* – to conceive of them as those substantial parts of Nature that can be represented in the simple mathematical fashion that is utilized within theoretical physics.

Extensive and intensive magnitudes

This means first of all that the schematization provides the sense in which possible objects of knowledge may be regarded as *magnitudes*. Indeed, Kant stipulates that "the pure picture of all magnitudes is Space", and that "the pure picture of all objects is Time". Similarly, "the scheme for the concept of magnitude is The Number".[6] These three stipulations express the sense in which (a) to be extended in space, as well as (b) to be in a state of motion, must be regarded as a fundamental aspect of physical Reality. We can represent the physical state of any possible object of knowledge in terms of numbers. Within this scheme, it makes sense to represent the *reality* of the physical nature of things in terms of numbers. This is what it means to regard "motions", "system of motions", and "lawful alternations within a system of motions" as, together, forming the characteristic and basic features of physical Reality. There is according to Kant a special "scheme for reality" that corresponds to the way in which possible perceptions of certain objects may endure and how intense they may be. This means that the idea, mentioned above, concerning the *extensive* character of possible objects of physical theoretical knowledge, must be adjoined to some idea concerning the *intensive* character of these objects. The "extensive" character of physical Reality means that there can be no conception of the whole of this kind of reality except by reference to some of its parts, and means that any minor part of any specific part of that kind of reality still counts as being of that same kind (i. e. any part of any substance is still itself a substance). There is neither an "ultimate" nor a "smallest" part of physical Reality. The "intensive" character of physical Reality means that there is no limit to the way in which it may be divided; and means that any part must be seen as a unity (*Einheit*). This implies both that physical Reality must be regarded as some sort of continuum, and that the basic features of any physical object can be proportionally related to one another.

It must be assumed that Kant here made use of the newly developed mathematical tools of Euler concerning the algebraic structure of a mathematical space as well as concerning the concept of a *continuum*. Thus, the aim which Kant meant to pursue by formulating the schematizations was, clearly, to explain how certain rules of mathematical construction could be seen as providing transcendental principles of determinate judgment, in the sense that the exposition of these rules could be regarded as an exposition of the kind of *unity* and *system* that objective knowledge requires. In short, the philosophical aim and rationality of formulating Kantian schemata is to elucidate and investigate *what it might possible mean to follow rules* within objective thought. Indeed, Kant's section on The Transcendental Principles of the Understanding, the formulation of the four kinds of schemata – the axioms of intuition, the anticipations of perception, the analogies of experience, and finally the postulates of empirical thought

[6] Kr. d. r. V. A 142 / B 182

– may be regarded as the "rule-following considerations" par excellence in philosophical thought.

1.2 Transcendental and Metaphysical Principles

Principles of empirical thought

The superscript for the paragraphs in *The First Critique* that discusses the schematism of categories is *Die Analytik der Grundsätze*. To be precise, the *Grundsätze* of the Understanding are the very axioms of intuition, anticipations of perception, analogies of experience and postulates of empirical thought. They expose (*darstellen* the transcendental forms that must necessarily be involved in our understanding of the content of given appearances. They thus represent the transcendental forms of *Setzung* by means of which human reasoning acquire a rational outlook (*Vorsicht*). They are schemes through the employment of which rational thought "acquires a ground", both in the sense that we establish ontological prescriptions concerning any possible object of experience, and in the sense that our possible empirical judgments acquire a *Beweisgrund*.

Kant explains and exposes these *Grundsätze* in terms of certain *principles*. These are the so-called transcendental principles of the Understanding – the principles concerning the extensive, the intensive, the substantial, and the modal character of the possible successions and relations betwen appearances. The rational point of these principles is to clarify the way in which the application of the categories, in accordance with the *Grundsätze* – and thus also with the various Schematisms –, can and must embody principles of *necessity*.

However, by making this claim, we face a tension between two perspectives – the perspective of the Understanding and the perspective of Reason. In the perspective of the Understanding, we expose schemata in order to represent the general modal character of our experience. But in the perspective of Reason, we can see that there is a more fundamental link between necessity and possibility *within* the very possibility of experience, as such. The transcendental principles of the Understanding are expressed in the perspective of the Understanding. But the point of there *being* such principles is an issue of Reason, because it is one thing to demonstrate that a certain categorical scheme makes sense when applied in certain ways to a certain range of objects. It is another to reflect *what it means for there to be* such applications; what it means that there is a set of concepts that is in a sense necessary in respect to certain domains of reality.

In *The First Critique* we do not get an answer, nor even an attempt to answer, this deep issue. In other words, some of the fundamental and deep issues of Kant's philosophy only come to the fore if one takes into account the program and thesis of *all* his major works – concerning the principles of theoretical thought including not the least the *Prolegomenon* as well as the *Metaphysische Anfangsgründe der Naturwissenschaften*; but also, as I shall explain shortly, *The Third Critique*. I thus agree with Brigitte Falkenburg who reminds us,

> "Daß Kant selbst seine Erkenntnistheorie nur als die erkenntniskritische Grundlage für ein noch zu errichtendes System der Metaphysik betrachtete" *(Falkenburg 1987, p. 17)*

As Falkenburg puts it, one might consider the transcendental analytic of *The First Critique* as a "propaedeutic", an instructive teaching that circumscribes the character and possible content of theoretical knowledge.[7] As I see it, there are two essential aspects that, for Kant, should be at the center of the program of establishing a *system* of metaphysics in the light of the transcendental analysis, (a) the aim and possibility of establishing a system of rational speculative thought and (b) the aim and possibility of securing an ever growing *encyclopedic* conception of what there is to know. These are the two aspects I will try to pursue in the following, and I will try to show that there is an intimate bond between the two aspects, such that it must be seen as a shortcoming of various readings of Kant, Falkenburg's included, that this connection is not pointed out more clearly.

It should be noted that Kant makes a very important distinction between *metaphysical* and *transcendental* principles. In general, the distinction between "the transcendental" and "the metaphysical" is a direct expression of the distinction between the Understanding and Reason. I want to quote with approval Falkenburg's formulation of this:

> "Der Verstand liefert den Maßstab für eine Selbstkritik der Vernunft, nach der ihr selbst keine erkennbaren Objekte zukommen, und stellt ihr sein Gebiet als einzigen 'Boden' zur Verfügung. Umgekehrt zeigt die Vernunft dem Verstand die Grenzen des Gebiets, auf dem es konstitutiv für Erkenntnisobjekte ist, und bietet ihm ihre spekulativen Ideen wie einen Spiegel an, mittels dessen er sich den Bereich jenseits des jeweils empirisch Gegebenen zielgerichtet erschließen kann. Die Vernunft macht dabei dem Verstand die Unvollständigkeit seiner Synthesis von empirischen Erscheinungen deutlich und ist erkenntnisleitend für ihn mittels regulativer Prinzipien. Außerdem gibt erst die Vernunft dem Verstand die Idee einer a priori begründeten und systematisch organisierten Wissenschaft vor".
> *(Falkenburg 1987, p. 25)*

I will return to discuss several of the things formulated in this quote. But at this point the main thing is to see how the distinction and relation between the Understanding and Reason embodies three other distinctions, namely the distinctions between

Reason / The Understanding

1. metaphysics / natural science
2. nature as Domain / nature as the sum total of possible things
3. substance / matter

This implies that the idea of a natural science has two sides to it. One may either view such a science as a *rational employment* of the resources and principles of the Understanding, or one may view it as being in accordance with a mode of thought that is characterized by the fact that it is guided by some of the metaphysical ideas of Reason. So for each of the right sides of the distinctions we have two perspectives; whereas the left sides must always be seen in the perspective of Reason.

[7] (Falkenburg 1987, p. 18)

As we have already seen, there is a further distinction that, as such, belongs entirely to the right side; namely the distinction between the *two concepts of reflection* form and matter. These, Kant says, are the basic concepts of reflection in the sense that the employment of all other concepts can be reflected in terms of them.[8] The concept of "form" means something like a "manner of determination", especially by pointing to various forms of *synthesis* within the possibilities of thought. Above all, the concept of "form" relates to the very notion of *Gesetzmäßigkeit*, to the very idea that given appearances can be shaped and be interrelated in accordance with laws of order. The concept of "matter", then, relates to the "given" in accordance with such a "form". "Matter" means that which is *determinable* in accordance with synthetic principles.

In the perspective of Reason, to say that the reality of things can be known – to say that objective knowledge is possible – is to say something about the *form* of our knowledge. It is to say that Nature is such that our knowledge can be lawful, and that that is what it means for our knowledge to be "objective" – that the possible objects of knowledge are precisely those about which we can have a well-formed understanding. This is the sense, and the only sense there can be, to the claim that we can only have objective or theoretical knowledge about substance(s). As such, substance is the *form* of the reality of things. So particular substances, particular substantial parts of what we may be said to encounter within experience make up the *matter* of real Nature. It should be noted that this distinction between substance and particular substances is *not* the distinction mentioned above between substance and matter. Accordingly, I must explain this last distinction:

It is a metaphysical idea that the items studied within physics have a "material character" (*körperliche Natur*). As we shall see, this idea is connected with a series of metaphysical ideas about "the movable in space". Now, the idea of the material character of things is especially related to one of the distinctions mentioned above – that between metaphysics and natural science. As was mentioned before, the idea of a natural science can be seen both in the perspective of Reason and in the perspective of the Understanding. So, it is important to reflect how these two perspectives can be held together. In other words, there must be a way to view the possibility of a natural science that both makes it clear (a) that it is in accordance with a rational *metaphysics* (in the sense of the *Prolegomenon*) and (b) that it is regarded as a rational application of a system of rules of thought in respect to a *definite* field of experience, i. e. "material items". It is this requirement that is fulfilled by the introduction of *metaphysical* principles to supplement the *transcendental* principles of the Understanding. In the *Third Critique* Kant explains the difference between transcendental and metaphysical principles as follows:

> "Ein transzendentales Prinzip ist dasjenige, durch welches die allgemeine Bedingung a priori vorgestellt wird, unter der allein Dinge Objekte unserer Erkenntnis überhaupt werden können. Dagegen heißt ein Prinzip metaphysisch, wenn es die Bedingung a priori vorstellt, unter der allein Objekte, deren Begriff empirisch gegeben sein muß, a priori weiter bestimmet werden können. So ist das Prinzip der Erkenntnis der Körper, als

[8] Kr. d. r. V. A 260 / B 316

> Substanzen und als veränderliche Substanzen, transzendental, wenn dadurch gesagt wird, daß ihre Veränderung eine Ursache haben müsse; es ist aber metaphysisch, wenn dadurch gesagt wird, ihre Veränderung müsse eine Äußere Ursache haben." *(KdU, AXXVII/BXXIX, p. 90)*

What does a "metaphysical principle" do? It relates an *empirically* given concept (such as "motion") to a metaphysical idea (such as "matter") in order to ground the possibility of an *essential kind of analysis* in respect to the latter. In other words, in order to make it possible to conceive of matter as something structured and measurable. Accordingly, in mathematical physics, we shall deal with a special kind of objects, bodies (*Körper*), the appearances of which will be characterized as "matter-in-motion". As such, the metaphysical principles of physics give shape to an idea concerning what by necessity is physically present whenever we encounter a "body". However, this shaping of certain ideas of Reason is constrained. The metaphysical principles defining a special field of theoretical knowledge must always, as Falkenburg put it, be in accordance with the *Selbstkritik* of Reason as determined and restricted by the transcendental principles and rules of the Understanding.

Kant is anxious to stress that there can be no rational way of studying Nature in the material sense in abstraction from the metaphysical and formal conception of Nature. The latter is the only *Vernunftbegriff der Natur* from which no *Verstandesbegriff der Natur* can be fully detached.[9] So this is the reason why a natural science such as physics has to build upon certain metaphysical principles. Kant says that,

> "Eigentlich so zu nennende Naturwissenschaft setzt zuerst Metaphysik der Natur voraus; denn Gesetze, d. i. Prinzipien der Notwendigkeit dessen, was zum Dasein eines Dinges gehört, beschäftigen sich mit einem Begriffe, der sich nicht konstruieren läßt, weil das Dasein in keiner Anschauung a priori dargestellt werden kann. Daher setzt eigentliche Naturwissenschaft Metaphysik der Natur voraus. Diese muß nun zwar jederzeit lauter Prinzipien, die nicht empirisch sind, enthalten." *(MAN, A VIII, p. 13-4)*

However, the metaphysical principles of the natural sciences cannot be conceived in complete abstraction from the transcendental principles of the Understanding. This is the consideration that leads Kant to claim that,

> "Eigentliche Wissenschaft kann nur diejenige genannt werden, deren Gewißheit apodiktisch ist ... Eine rationale Naturlehre verdient also den Namen einer Naturwissenschaft nur alsdenn, wenn die Naturgesetze, die in ihr zum Grunde liegen, a priori erkannt werden, und nicht bloße Erfahrungsgesetze sind." *(MAN, A V, p. 12)*

Consequently, we have now drawn the background upon which we have to build our conception of a rational empirical natural science – in effect, the idea of a mathematical physics.

One must see the requirements of a mathematical physics in the right light, since the requirements are introduced by Kant at a point where he is well aware that he

[9] See (Falkenburg 1987, p. 26)

cannot, yet, allow himself to regard mathematical physics as paradigmatic in respect to all intelligible thought.[10] The task that Kant set himself in MAN, therefore, is not just to characterize the specific metaphysical principles governing Reason within the rational sciences, but also to try to expose *how* one may view the principles established as paradigmatic in respect to the way in which Reason can be governed at *all* by principles of thought. Accordingly, the aim that Kant pursues in MAN is not just to show that there is a systematic unity within classical physical thought, the aim of MAN is also to show *how* the recognition of *that* system of thought comes to shine over the "idea of system", in general, concerning any territory. Further, this will provide paradigmatic information about what it is, in general, for the Understanding to be "led to its limit".

Interpreters such as Falkenburg, R. E. Butts, and M. Friedman tend to say that the metaphysical principles of the special sciences *specify* the transcendental principles, such that the schematization of the categorical structure and function of the Understanding is specified. However, as I see it, their various accounts involve a too sharp distinction between the transcendental principles (in respect to the conditions of *applicability* of the categories) and the metaphysical principles (in respect to the *criteria of identity* concerning the possible objects of physical knowledge). It is as if the stipulation of a certain range of objects (here, bodies in motion) will be simply a matter of infusing a pre-determined *form* (to infuse the ideal, mathematical structures that are exposed within the schemata) into a new set of theoretical concepts. For instance, Butts says that,

> "Kant distinguishes between transcendental principles as principles representing *a priori* the universal conditions under which objects can be cognized by us, and metaphysical principles, or principles representing *a priori* the conditions under which objects whose concepts are given empirically *'may be further determined a priori'* [Butts' italics]."
>
> *(Butts 1984, p. 89-90)*

I agree with one of Butts' and Friedman's points, that there is no question of providing a definite "chain of deduction" between the transcendental and the metaphysical principles. But in contrast to them, I would stress that the task of providing metaphysical principles for the natural sciences involves more than just accounting for some "trickle down" process that is seen mainly as a specification of the general structure of theoretical thought.

However, I fully acknowledge how Butts and Friedman picture the *systematic* connection between the structure and unity of the transcendental and metaphysical principles. But we must remember that one of the main problems is how to establish guidelines for the Understanding, as it plunges into definite (sub)fields of experience. Even if one claims that this guiding employs the transcendental idea of "unity" – the idea that *all* the principles of the Understanding can function together in a system – the problem still remains to account for *how* this "idea of unity" can be so employed.

The major theme is to explain *how* we can picture the transcendental "idea of unity" as informing any model, any set of principles, of distinct future sciences. Falkenburg

[10] I mean this in a methodological sense. However, as is well known, Kant wrote both the *Prolegomenon* and *MAN* , in 1783 and 1786 respectively, between writing the two versions of the *First Critique*, published in 1781 and 1787, respectively. Certainly, the B-version has the insights of *MAN* written all over it!

points this out as well. She stresses that the possibility of an empirical, natural science requires an ongoing systematic use of concepts that cannot be stipulated in advance by any formal or categorical order. In short, there is no a priorily given perspective in the light of which we can establish, once and for all, *what it is* to "be following rules" in our objectively directed use of concepts. Accordingly, it is part of the rationality of the natural sciences to *establish* such a perspective, and thus to provide a model for the rationality of rule-following – to provide a *Vernunftbegriff* of the natural sciences, at all.

> "Zum Zustandekommen objektiver, wissenschaftlicher Erkenntnis gehört auch ein *systematisches* Vorgehen, das feste Regeln oder Prinzipien für die Abfolge oder den Zusammenhang von Behauptungen (und im Falle des Experiments, von Handlungen) beinhaltet ... Die[se] Forderung ... ergibt sich nicht aus dieser ... Theorie der Verstandeserkenntnis, sondern folgt aus de Systematizitätsforderungen der Vernunft."
>
> *(Falkenburg 1987, p. 21-2)*

As Kant says in the *Prolegomenon* we have first established a rational perspective on the possibility of a rule-governed employment of concepts when we have learnt to conceive of the given categorical structures as embodying distinct Natural Laws,

> "Die Grundsätze möglicher Erfahrung sind nun zugleich allgemeine Gesetze der Natur, welche a priori erkannt werden können. Und so ist die Aufgabe ...: Wie ist reine Vernunftwissenschaft möglich, aufgelöst. Denn das Systematische, was zur Form einer Wissenschaft erfordert wird, ist hier vollkommen anzutreffen." *(Prol., A 90, § 23, p. 59)*

This leads, in the *Prolegomenon*, to the requirement that we learn to see the table of transcendental principles as *eine reine physiologische Tafel* that represents an adequate ontology in respect to a possible form of rational science. Butts makes it clear that the issue is to see how the kind of lawfulness that characterizes the categorical structure and unity of the Understanding also expresses the kind of lawfulness that corresponds to (the formal concept) of nature [N]. But the question remains: *How* can such a unity be exposed *within* the special sciences? *What is it* to pursue such a unity, the unity of a realm of reference? The answer expressed by the *Prolegomenon* concerning this question is often overlooked by interpreters of that work. It is primarily in this work that Kant formulates the requirement that we not only juxtapose the table of categories with the table of judgments, but also juxtapose both with the *system* of the transcendental principles of the Understanding. It is this task that Kant, first, takes on his shoulder in MAN. The introduction of the *metaphysical* principles of the natural sciences helps establish how the various principles and rules of thought can function together in a *distinct* systematic fashion within their rational employment in the natural sciences. As Kant says,

> "Es ist aber von der größten Wichtigkeit, zum Vorteil der Wissenschaften ungleichartige Prinzipien von einander zu scheiden, jede in ein besonderes System zu bringen, damit sie eine Wissenschaft ihrer eigenen Art ausmachen." *(MAN, A XIII, p. 17)*

We must bear in mind that it must be revealed – not just that the possible use of concepts within mathematical physics is in accordance with the principles of the Understanding, thus revealing, so to speak, how the language of physics is "sound" – we have also to show that the language of mathematical physics is "complete", that it covers the entire *ground* of objects, the reference to which is constituted by the form of thought in question. The possible objects of physical experience cannot be stipulated in advance, like the possible objects of experience – *die Erscheinungen* – in general. That is what distinguishes an ontology based on a transcendental analysis, as such, from a rational science based on *physiological* schematizations of un-predictable experiences. In short, my conjecture is that the requirement stated in the former quote is related to the following remark and set of definitions mentioned by Kant in the *Third Critique*,

> "Begriffe sofern sie auf Gegenstände bezogen werden, unangesehen, ob eine Erkenntnis derselben möglich sei oder nicht, haben ihr Feld, welches bloß nach dem Verhältnisse, das ihr Objekt zu unserem Erkenntnisvermögen überhaupt hat, bestimmt wird ... – Der Teil dieses Feldes, worin für uns Erkenntnis möglich ist, ist ein Boden (Territorium) für diese Begriffe und das dazu erforderliche Erkenntnisvermögen. Der Teil des Bodens, worauf diese gesetzgebend sind, ist das Gebiet (ditio) dieser Begriffe, und der ihnen zustehenden Erkenntnisvermögen."
>
> *(KdU, AXVII/BXVII, p. 81)*[11]

Consequently, to demand that the metaphysical principles of the physical sciences form a unity is to demand that physics make up a *ground*, a unified area of objects, in respect to which the set of physical concepts are applicable. Thus, in the *Prolegomenon*, Kant thought he had revealed the possibly of viewing a given "ground", a given realm of reference, as corresponding to a *domain* of theoretical thought (which is that part of the realm of reference that is constituted by the constructed and ideal objects of thought). So, the task of accounting for the systematic unity of the metaphysical principles of the physical sciences is the task of revealing how the realm of things, constituted by matter-in-motion, do *actually* make up a "ground" – that is, revealing that the collection of matters-in-motion that we can possibly encounter, do make up a unified territory, a real territory relative to which we can claim to posses an intelligible application of a set of concepts, namely those characterizing a *mechanics*.

Why is this important? The heart of the matter is the question of what is involved in revealing how a formal system of concepts can be applied within a distinct empirical scientific context? The point is that the idea of a *logic* of concepts – the idea of formula – is connected with the idea that there can be formal *conditions* that constrain the possible use of the concepts in question.

The *Grenzbestimmung* of a field of inquiry will always be in some sense *provisional*, at least until the metaphysical principles of the field are in place in the sense of having been placed distinctively within an entire *system of* metaphysics, within the whole of the architectonic structure of Reason.

[11] See also (Kr. d. r. V, B 753)

Falkenburg would agree with my criticism of Friedman and Butts. She mainly deals with two problems that the Kantian program implies.[12] First there is the problem of how to bring the conceptual structures and principles of the Understanding to bear on the empirical use of our Reason within the natural sciences (that is, the problem of how to turn the analysis of the Understanding into a research program for these sciences). Second there is the problem to what extent this special aspect and ability of our Reason manages to unfold more or less in abstraction from the non-scientific uses of our Reason. According to Falkenburg, Kant had a too skeptical conception of this. There is a sense, Falkenburg argues, in which the rationality of the sciences enable us to grasp the unity and wholeness of its subject matter without having to invoke further transcendental ideas of Reason. She traces the failure of Kant concerning this to his making a too sharp distinction between rational physics and rational *cosmology*. Accordingly, Falkenburg argues that the former can do well without the latter; or instead, that rational physics can achieve something that in a sense completes the latter.

It turns out that Falkenburg points to a *formal* unity within the system of natural laws, especially the basic laws of mechanics such as the law of inertia and the law of gravitation. Falkenburg wants to picture the advent of the theory of relativity as a sort of completion of the idea of a mechanical system and unity. Her point is that this advent brings about a *formal* unity that completes the idea of a totality of *natura naturata*. This means that we have both a formal and a material conception of the unity and totality of a dynamically interacting system of things. This all in all expresses a rational conception of the unity and wholeness of physical Nature. There is, Falkenburg believes, no reason to introduce further cosmological ideas about the unity or *telos* of natural beings.

It is clear from her account that Falkenburg considers this as expressing a way in which *The Understanding* may complete itself as it unfolds within the natural sciences. But here we must be cautious. Falkenburg is right to remind us of the development of theoretical thought after Newton. Following Ernst Cassirer, one could describe that development as a sort of "completion" of the logical structure and system of mathematical physics. But this development of the *discursive* features of thought must be related to a development of the *intuitive* features. Thus one must give an account of the way in which the area of intuitive understanding ("the world of sense") and the area of theoretical understanding ("the real world") could be combined and transformed relative to one another.[13] In other words, when it comes to it, there is no way in which the logical development – and even completion – of theoretical thought can be seen in abstraction from a development in respect to the mediation between the intuitive and the discursive features of thought.

This is a shorthand for saying what I have already pointed out above (a) that there is no way we can regard the development of the formal and logical use of a system of concepts in abstraction from our developing new ways for systematizing the objective conditions of employing the set of concepts in question; and (b) that we have to do with a development concerning our understanding of what is involved in the schematization of the concepts in question.

Like Helmholtz, Planck, and Cassirer, one may criticize Kant for not having fore-

[12] (Falkenburg, 1987, p. 33-4)

[13] This view was formulated by Max Planck and was later adopted by both Ernst Cassirer and Albert Einstein, see below.

seen such a development, and thus criticize him for believing that there are a priori forms of intuition that necessarily will mediate any kind of theoretical thought. However, this criticism does not imply that the transcendental ideas of Reason are *not* involved in the development of formal features of physical theories. On the contrary, the criticism points in the opposite direction. It actually underlines the fact that any formally established kind of theoretical thought, any kind of physical theory, will always relate to certain principles of *Reason*.

For instance, the formal developments of physical theory, including the generalizations of the concepts of energy and force, and the specification of the concepts of space, time, cause, and action, were associated with a parallel development of the concepts of objectivity, observation, lawfulness, and stability. The latter are not just "methodological" concepts that we grasp simply in the perspective of The Understanding. They are intimately connected with an effort to clarify the very *rationality* of the physical sciences. There is no way we can assess this rationality in abstraction from some metaphysical *system* in the sense of Kant's.

1.3 The Structure of *Metaphysische Anfangsgründe der Naturwissenschaften*

The reconstruction of mechanics

I want to sketch the profile of the programme that Kant set himself to pursue in MAN, which in his own words is this:

> "Der Begriff der Materie mußte ... durch alle vier genannten Funktionen der Verstandesbegriffe ... durchgeführt werden ... Die Grundbestimmung eines Etwas, daß ein Gegenstand äußerer Sinne sein soll, mußte Bewegung sein ... Die *metaphysischen* Anfangsgründe der Naturwissenschaft sind also unter vier Hauptstücke zu bringen, deren *erstes* die Bewegung als ein reines *Quantum*, nach seiner Zusammensetzung, ohne alle Qualität des Beweglichen, betrachtet, und *Phoronomie* genannt werden kann, das *zweite* sie als zur *Qualität* der Materie gehörig, unter dem Namen einer ursprünglich bewegenden Kraft, in Erwägung zieht, und daher *Dynamik* heißt, das *dritte* die Materie mit dieser Qualität durch ihre eigene Bewegung gegen einander in *Relation* betrachtet, und daher unter dem Namen *Mechanik* vorkommt". *(MAN, A XXI, p. 22)*[14]

We see that Kant intended to establish a metaphysics in respect to the natural (physical) sciences by means of constructing a concept of *motion*, and to do so in accordance with the logical structure of any of the three tables, the table of judgements, the table of categories, and the table of transcendental principles of the Understanding. In short, the programme was to construct a concept of motion in accordance with the principles of quantity, quality, relation, and modality; and thus in accordance with the principles governing objective thought concerning all real physical *magnitude*.

[14] and the paragraph closes; "das vierte aber ihre Bewegung oder Ruhe bloss in Beziehung auf die Vorstellungsart, oder *Modalität*, mithin als Erscheinung äusserer Sinne, bestimmt, und *Phänomenologie* genannt wird." Which becomes the so-called "Postulates of physical thought", a notion also utilized by Bohr.

What is in question is primarily the principles governing the Understanding in respect to the stability, succession, and interaction of the objective conditions of physical alternation – of the *Zustände* – the alternation of which constitute the physical determinations that characterize material substances.

In order to establish a rational mechanics, the objective features of stability, succession, and inter-action must be determined as relations. Thus, we should establish *metaphysical* principles in respect to the identity, causality, and symmetry of interactions corresponding to the *transcendental* principles for the schemata of the three Analogies of Experience. Each of these represents a logically possible determination-of-relation.

The strategy of Kant's exposition of the metaphysical principles of "mechanics" was, of course, to try to re-formulate the three Newtonian laws of motion in order to demonstrate how they could be regarded as corresponding to these schemata, the Analogies of Experience. I here adopt Butts' presentation of this correspondence, where the letters 'A' refer to the Analogies, and the letters 'M' to the laws of mechanics, as reconstructed by Kant:

A1: In all changes of appearances substance is permanent; its quantum in nature is neither increased nor diminished. (First Analogy)

M1: With regard to all changes of corporal nature, the quantity of matter taken as a whole remains the same, unincreased and undiminished (Kant's first law of Mechanics)

A2: All alterations take place in conformity with the law of the connection between cause and effect (Second Analogy)

M2: Every change of matter has an external cause. (Every body remains in its state of rest or motion in the same direction and with the same velocity unless it is compelled by an external cause to forsake this state.) (Kant's second law of Mechanics)

A3: All substances, in so far as they can be perceived to coexist in space, are in thoroughgoing reciprocity. (Third Analogy)

M3: In all communication of motion, action and reaction are always equal to one another. (Kant's third law of Mechanics). (Butts 1984, p. 85)[15]

It is one thing that the motions of material items can be analyzed in accordance with the principles of Newtonian mechanics. However, it is another that this analytic determination of the possible motion of material substances is lawful. But this is precisely what is secured by reflecting how the schematization in terms of the logical possible time-determinations corresponds to the rule-governed synthetic operations of the Understanding. We must bear in mind that, for Kant, the analysis of the Analogies of Experience is supposed to cast a light on the question of how to elaborate "a doctrine for the Judgment" (A 132/B 171). As such, we have, all in all, to explain and justify the sense in which all physical judgment relates to judgments concerning mathematically demonstrable *measures*, and thus to explain how judgments concerning measures condition the possibility of judgments about the dynamic, lawful behavior of objects that we can posit within theoretical thought. In short, we have to infuse Newtonian

mechanics into our critical philosophy, and to recognize how this mechanics form part of rational metaphysics. This is the program that we should pursue. However, before we engage into the details of this program, we will do well in reiterating the following features of classical dynamics and mechanics, as these were adapted by Kant:

The idea of a dynamic unity of physical nature

I want to point out what is in my view a core element within the basic link between the intuitive and the discursive features of theoretical thought. As we have already seen, the concepts of space and time play a crucial role in Kant's analysis of the foundation of objective thought not only because they represent the a priori forms of intuition, but also because they frame the meaningful *use of concepts*. Indeed, the concepts of substance and cause make sense, and may contribute to objective understanding, only in so far as their employment is associated with certain *constructive* uses of the concepts of space and time. That is one of the points involved in Kant's idea of the schematization of the categories. The point of such "construction" is not just epistemic – that we can know determinately only what we have ourselves constructed. There is an ontological feature as well that Kant explains in the addition to (B 202). In this paragraph, Kant set up a scheme for the logically possible kinds of "connection" (*Verbindung*).[16]

First we make a distinction between connecting what does and what does not necessarily belong together. This is the distinction between "composition" and "combination". Then Kant explains that there can be compositions of items that are alike in form. This characterizes *geometry* and is the paradigm case for making contingent compositions of uniform items. But there can also be necessary combinations of things that have no common form, and that is what characterizes *dynamic* relations such as "causality". The causal combination of things is a necessary feature of their mode of existence.

So, it is part of the job of a schematization of the categories to help us bridge the contingent geometrical and the necessary dynamical features of things. This is how and why the concepts of space and time take on a special significance. To conceive of objects in terms of these concepts is not just a matter of securing a determinate content in our judgments so as to frame a possible synthetic unity of our representations. It is also a matter of making sense of the *reality* of things. Accordingly, that is the issue involved in establishing a *dynamical* conception of Nature. I want to discuss this aspect of Kant's critical philosophy in some detail:[17]

It was not the least this conception of physical nature that Kant thought Leibniz had failed to bring to the fore. The difference between the respective views of Kant and Leibniz concerning the dynamical understanding of physical nature is displayed most clearly by their respective conceptions of "substance". According to Kant, the concept of substance should express a basic dynamic feature of the wholeness of physical reality. The issue for Kant in this respect was to establish which kind of *part-whole* relationship could be associated with the recognition of a set of possible causal relations between physical items. There could be no a priori rational causal understanding of the

[16] For further details, se the quote of B 202 and my discussion of this in the paragraph below, "matter as powers shaped-up by the connection between motions"

[17] In the reviewed dissertation I omitted a section here, explaining how the determinations of time and space define a distinct *form of change*, and how *motion* was considered by Kant as an *exposition* of this form of change within the Intuition

possible real parts of Nature; there could not be any a priori rational understanding of a possible distribution of causal powers in time and space, nor could there be an priori rational conception of the causal character of such distributed beings, Kant wanted to argue, if one could not recognize the distribution and configuration of causally interacting items in space and time as corresponding to a certain conceptual scheme that we for other reasons are already justified in taking ourselves to possess.

According to Kant, Leibniz had in a sense been too much of a rationalist in so far as he had based his metaphysical views on such principles as the principle of sufficient reason, the principle of the identity of indescernibles, and the principle of continuity. At best, Kant believed, such principles could be regarded as regulative principles forming part of a critical philosophy. Thus, for Kant, there can be no way in which we can construct the true objective World in our thought. Our constructions can at best constitute a rational guide that helps to further our ongoing scientific research, and which prevents us from raising certain meaningless issues, including the question of the absolute causal space-time structure of natural processes.

In contrast to Leibniz's rationalistic conception of physical reality, Kant set himself to formulate what Cassirer has called a *critical determinism*, which is mainly concerned with the construction of a physical ontology whose infusion into our Thought would guide a rational physical science. As part of this effort, Kant developed a conception of the "owned forces" of individual beings (*eigene Kräfte*). Kant's aim was to develop a conception of action (*Wirkung*) in terms of which one could explain the possibility of certain "stable forms" of interaction (*Wechsel-Wirkung*). This again led Kant to develop a concept of physical change (*Veränderung*) in accordance with this view of interaction, namely a concept of causal interaction that could be associated with the idea of a "dynamic combination", as was explained above. In terms of this concept, the possible causal relations between things are never simply contingent interactions, but are instead necessary ways in which various parts of physical nature continually are interrelated to one another despite the changes that any of these parts may undergo.

What's more, Kant – like Leibniz – was critical about the Newtonian notions of absolute space and time. Still, Kant's focal point was the critical assessment of Leibniz' views. The latter had proposed a physical and relational view of the concepts of space and time, and had argued that spatial and temporal specifications simply express the logic and order of possible physical relations. Kant wanted to modify this view by means of a critique of Leibniz's conception of the self-contained "monadic" character of individual physical items. As argued by Kant – especially in the paragraph concerning the "transcendental ambipholia" of the *First Critique* – he believed that Leibniz had failed to see how the use of the concepts of space and time should be restricted to the range of possible appearances and should not be applicable to "things in themselves", to noumenon. Consequently, Kant may be said to have wanted to reconstruct a quasi-Leibnizian concept of space and time in terms of a non-Leibnizian notion of causal structure.

As mentioned above, Kant set himself to argue that the possibility of ascribing such structures to individual things must be seen in relation to the possibility of their interactions. Kant wanted to construct a non-Leibnizian account of particularity (*Selbständigkeit*), as well as of the inter-connection of causal structures (*Verbindung*). As we shall see, Kant introduced a special concept of (*physical*) change in order to express this unity. Particular objects may engage in processes of internal change such that the

particularity of the object is maintained in and through its interaction with other objects. Obviously, Kant was trying to establish a conception of gravitational powers, understood not as possible *causes* of change, but instead understood as constituting the *objective possibilities* of dynamical change. That is how the causal structure of individual objects should be seen as being due to their "owning" the physical powers that characterizes their physical interactions.

Kant stated this view, partly, in order to justify and ground the *Lex Inertia* – which says that any change in the state of motions of a particular object presupposes an interacting force. The understanding of the powers of gravity as "own(ed) forces" makes it possible to both (a) recognize the *Lex Inertia*, and (b) to picture the Solar System as stable and harmonic. This system is not physically stable because of a very lucky, contingent, balancing of powers. Neither is it physically stable because the solidity of the Planets makes them withstand the play of forces around them. On the contrary, the dynamics of the system is functioning because of the "own(ed)" powers of its elements! This can all be explained without having to stipulate that the Solar System constitutes a privileged frame of reference, or to stipulate definite motions of the Planets in absolute space and time.

In arguing this, Kant must of course make one assumption – the assumption that the Solar System really does constitute an *inertial system*. Kant intended to show – in a way that neither Newton nor Leibniz had managed to do – how the Galilean principle of the relativity of motions was compatible with the *Lex Inertia*. Kant thought he had found a way to explain the difference between "fictitious" and "real" forces, by demonstrating how to distinguish relative motion between things, and motion relative to a given space. Accordingly, Kant was critical of Leibniz' use of the principle of the identity of indescernibles in conjunction with the principle of sufficient reason. In terms of these principles, Kant argues, one cannot establish a sufficient reason to distinguish between fictitious and real motions. Consequently, Kant's effort to establish new conceptions of "substance" and "causality" was essentially related with his modification of Leibniz' dynamical conception of physical Reality.[18] Thus Kant associated the latter conception with his own transcendental conception of experience.

Concerning this, both R. E. Butts and M. Friedman argue that the ultimate aim of Kant's philosophy of physics was to justify the Universal Law of Gravitation. I would say, instead, that the issue concerns the uniformity of the powers distributed in material space, and thus concerns the issue of what constitutes a mechanically unified system, the dynamics of which is given by the "owned" forces of its constitutive elements. By asking why and how there can be stable mechanical systems that are *not* machines, I believe that Kant, instead, analyzed the question of how such self-subsisting mechanical systems are possible.[19] The status of The Universal Law of Gravitation (UG) within the system of mechanical laws is important because it implies that there can be no real inertial frames; in other words, that the idea of there being such frames is incompatible with UG. Now, since UG had to be modified within the general theory of relativity, and since the latter theory might be said to supply physical theory with a kind of logical completion that Kant – and wrongly so – had ruled out beforehand, one should criticize Kant's interpretation of UG.

[18] One may summarize this view, as does E. Cassirer, by the following phrase *"Das Sein wird erst im Gesetz, der Gegenstand erst in der Synthesis, gewonnen"*. (Cassirer 1902, p. 255)

[19] Compare, the notion of a "dynamical natural philosophy", in contrast to a "mechanical natural philosophy" (a *Korpuskularphilosophie*), (MAN, A 101). It is the former which is Kants main concern.

However, despite this critical remark, one should still assess Kant's effort to conceive of the dynamic unity of mechanical systems as an effort to elaborate the regulative idea of a physical stable *system* of motions. Accordingly, I consider this the most important example of how the "idea of system" is elaborated within Kant's critical philosophy.[20]

So one should note that the unity of physical Nature, according to Kant, shall be regarded as the unity of a *dynamical system* such that the powers of no particular thing can be seen in isolation from its possible action on other things. This is an essential aspect of what comes to the fore within what Kant elsewhere calls the *encyclopedic* introduction of the concept of matter-in-motion, a concept that is supposed to characterize the completeness and ontological uniformity within the territory of physical objects.[21] Things may not actually interact, but the possibility of this interaction will always correspond to the possibility of motion relative to something *else* – and not just relative to empty space.

Spaces as movable

For each of the four metaphysical principles of kinematics, dynamics, mechanics, and phenomenology Kant gives a varying number of "explanations", the priority of which is marked by numerals. The following overview of the 'number one' explanations may be fruitful:

Kinematics:	Matter is the movable in space
Dynamics:	Matter is the movable insofar as it fills a space
Mechanics:	Matter is the movable insofar as it owns a moving force
Phenomenology:	Matter is the movable insofar as it can as such be an object of experience

The first principle of kinematics / phoronomy states that "matter is the movable in space". This principle, like all *metaphysical* principles, has an empirical background given by the fact that *matter*, to Kant, could be regarded as a paradigmatic (*Glänzend*) example corresponding to the general concept of "the movable in space", such that (a) the concept of matter corresponds to the idea of a substance, and (b) we need only ascribe a few metaphysical characteristics in order to establish a complete ontology. Only a few determinations will thus be needed in order to bridge the gap between the transcendental principles of The Understanding and a rational *Körperlehre*. However, the metaphysical principle that *par excellence* specifies the objective character of matter is this, and this alone:

> "so wird ... der Materie hier keine andere Eigenschaft beigelegt, als die *Beweglichkeit*." *(MAN, A 1, p. 25)*

It should be noted that the precise stipulations of the metaphysical principles of kinematics concern the physiology of *space*. As Kant explains, the first material individuals are "spaces",

[20] I have already given my reasons for believing that Falkenburg's critique of Kant's view on the impossibility of achieving a logical completion of our scientific understanding is too strong in it's disregard of this effort of Kant's.

[21] Kr. d. Uk., Erste Fassung, p. 57

> "Metaphysische Anfangsgründe der Phoronomie, Erklärung 1: *Materie* ist das *Bewegliche* im Raume. Der Raum, der selbst beweglich ist, heißt der materielle, oder auch der *relative Raum*; der, in welchem alle *Bewegung* zuletzt gedacht werden muß ..., heißt der reine, oder auch *absolute Raum*." *(MAN, A 1, p. 25)*

Kant goes on to explain that, since space is the condition of *objects* of experience, space must itself be an object. In accordance with footnote 17, Kant argues that all possible objects of experience, if represented in thought, must be associated with a certain unified, spatial representation. Matter must be *apprehended* in our experience as something movable, and since being movable constitutes the only possible apprehensive representation of items that we encounter, any such encounter will by necessity involve the projection of a unified spatial representation (such as the representation of a particular house corresponding to a certain arrangement of the representation of the constitutive features of that particular house, to mention one of Kant's own examples). Consequently, the apprehension of objects must necessarily involve the production of a *relative* space, relative to which that particular object is movable. Thus, for any possible movable thing there must be a possible representation in thought as something movable relative to a certain relative space.

Importantly, it must be possible to represent such relative spaces in the same way as we can in general represent movable objects. In that sense, relative spaces must be *material* and therefore themselves *movable*. Kant calls such objective, relative spaces, "empirical spaces" (these are, of course, usually called either "frames of reference" or "co-ordinate systems"):

> "In aller Erfahrung muß etwas empfunden werden, und das ist das Reale der sinnlichen Anschauung, folglich muß auch der Raum, in welchem wir über die Bewegungen Erfahrung anstellen sollen, empfindbar, d. i. durch das, was empfunden werden kann, bezeichnet sein, und dieser, als der Inbegriff aller Gegenstände der Erfahrung und selbst ein Objekt derselben, heißt der *empirische Raum*. Dieser aber, als materiell, ist selbst beweglich." *(MAN, A 3, p. 26)*

Kant continues by answering a possible challenge to this view. For have we not implicitly introduced a notion of *absolute* space. Have we not introduced a notion of the space in which all material spaces moves? No, as Kant explains,

> "Ein beweglicher Raum aber, wenn seine Bewegung soll wahrgenommen werden können, setzt wiederum einen anderen erweiterten materiellen Raum voraus, in welchem er beweglich ist, dieser eben sowohl einen andern, und so forthin ins Unendliche. Also ist alle Bewegung, die ein Gegenstand der Erfahrung ist, bloß relativ; der Raum in dem sie wahrgenommen wird, ist ein relativer Raum." *(ibid.)*

As Kant is about to explain further, the notion of an "absolute space" is an idea of Reason that makes sense all right, but not because it refers to some real object, which it does not. It simply refers to the methodology of *not* stipulating a fixed limit in respect to the possible extension of empirical, relative spaces.

Thus, Kant wanted to reveal how the possible experience of any material object presupposes an action of the Understanding that involves the exposition of a material space. In respect to any such exposition, we have to acknowledge the possibility of exposing a further material space that is *wieder-um* the former. Being *wieder-um*, as I understand the notion, does not mean "larger" in respect to any measure of extension. It means – not, that there is a definite *distance* to represent between the two spaces – but means instead that it is intelligible to represent some *motion* "in between" the spaces; because, we must bear in mind that the whole section on phoronomy/kinematics is supposed to show how – given the necessary exposition of material spaces in our representation of material objects – it thereby becomes possible to represent a *new kind of objects* (i. e. motions) that can be rationally investigated within mathematical physics.[22] It is the very possibility of observing and representing *motions*, as well as systems of such, that form the subject matter of mechanics.

One may say, as does R. E. Butts, that Kant's reflections on infinity in the Transcendental Dialectic of the *First Critique* implicitly introduces the concept of an absolute space. The idea of infinity is an idea of Reason, which therefore cannot be seen as entirely without sense. The concept of infinity, however, must not be related to any determinate judgment of the Understanding. To acknowledge the sense of the concept of infinity, one need only recognize how it forms part of the condition of possibility for a certain kind of judgments of reflection. The intelligibility of certain judgments of reflection makes it intelligible to talk about material spaces as being "in" each other.

Accordingly, what Kant is arguing, in my view, is that there can be no *determination* of the idea of an absolute space. Consequently, the reflective notion of an "absolute space" simply express the regulative character of metaphysical thought, and does not involve any objective determination. As Kant summarize the issue,

> "Der absolute Raum ist also *an sich* nichts und gar kein Objekt, sondern bedeutet nur einen jeden andern relativen Raum, den Ich mir außer dem gegebenen jederseits denken kann, und den Ich nur über jeden Gegebenen ins Unendliche hinausrücke, als einen solchen, der diesen einschließt und in welchen Ich den ersteren als bewegt annehmen kann."
>
> *(MAN, A 4, p. 27)*

On the background of these considerations we can now proceed to discuss Kant's account of kinematics. Kant explains this issue as follows.

Kinematics as algebraic topology

> "so ist die Phoronomie eine Lehre der Zusammensetzung der Bewegungen eben desselben Punkts nach ihrer Richtung und Geschwindigkeit;

[22] I still agree with Butts that *Objekte* are not yet to be seen as real objects of *knowledge – as phenomena* in the Kantian sense. I consider motions *Objekte*, and not appearances, because they are to be understood as conditions for there being a neccessary unity within our manner of perceiving things. That is, motions are "objects" in the sense of forming objective conditions for the possibility of ascribing definite measures to the properties that we may come to ascribe to material particulars.

d. i. die Vorstellung einer einzigen Bewegung, als einer solchen, die zwei und so mehrere Bewegungen zugleich in sich hält." *(MAN, A 19, p. 37)*

"Phoronomie ... als reine Größenlehre der Bewegung, in welcher die Materie nach keiner Eigenschaft mehr als der bloßen Beweglichkeit gedacht wird, enthält also nichts mehr als ... [den] Lehrsatz von der Zusammensetzung der Bewegung und zwar von der Möglichkeit der *geradlinichten Bewegung* allein, nicht der *krummlinichten*. Denn, weil in dieser die Bewegung kontinuierlich (der Richtung nach) verändert wird, so muß eine Ursache dieser Veränderung, welche nun nicht der bloße Raum sein kann, herbeigezogen werden." *(MAN, A 29, p. 45)*

Kant thought that phoronomy/kinematics is a pure science of magnitude (of number and of measure). Kinematics shall bring us an algebraic account, a calculus, by means of which we can analyze any combination of motions. Kant believed that we can achieve this by taking only linear motions into account. This choice seem contingent, but is useful when it comes to specifying the corresponding scheme, the kinematic axiom of intuition. We face a choice in respect to the determinate geometry – not of the space in which things move – but instead in respect to the geometrical principles that constitute the conditions for the possibility of figurative representations of the magnitudes of motions. Kant thought that a representation of motions by means of straight line-segments is the most simple way to achieve all this. However, there is, and was, no special mathematical reason for choosing that method of representation.[23] But then, the specific choice is not so important, the significant thing is what you get regardless of the chosen method of representation.

However, there is especially one kind of simplicity that interests us. We would want to make sure that our kinematics makes possible a simple kind of dynamics concerning the possibilities of representing physical change. In kinematics we can meet this requirement by taking advantage of the idea of material spaces corresponding to the relative motion of any individual material point. As Kant explains, we must concentrate on the issue of how the material character of space should already be regarded as an objective property of *things* – that a material space is a way for causally (inter)acting things to *be*, and is not primarily something immaterial in which things move around. To be sure, Einstein was not the first to link the concepts of space and matter. It is, Kant says,

"... unserem jetzigen Geschäfte, in welchem wir den Raum ganz notwendig als *Eigenschaft* der Dinge, ... behandeln müssen."

(MAN, A 9, p. 30)

The context of this remark is as follows: We have learnt from the *First Critique* that the possibility of change "belongs" to the possibility of a certain form of subsistence. Consequently, in order that we can represent the possible change that motions may entertain, we shall need a concept of the materially stable *Zustände* of motions. It is of course the *Zustände* of the possible motions of *things* that is the task of dynamics, but – and this is the point and task of kinematics – before we can expose such *Zustände*, we must first be able to expose the *Zustände* of the possible motion of *spaces*; because, that is a necessary condition for the possibility of associating definite physical things

[23] Butts (1984, p. 191ff) gives a good summary of Kants mathematical method of (de)composing motions.

with certain *places* in time and space. We could not ascribe any determinate place to anything if we could not determine the places of those material spaces relative to which we have to represent the possible motions of things. This is what leads Kant to state the following

> "[Erklärung 2. der Metaphysischen Anfangsgründe der Phoronomie]: Bewegung eines Dinges ist die Veränderung der *Äußeren Verhältnisse* desselben zu einem gegebenen Raum." *(MAN, A 5, p. 27)*

> "Nur von einem beweglichen, d. i. physischen *Punkte* kann man sagen: Bewegung sei jederzeit Veränderung des Orts." *(MAN, A 6, p. 28)*

Here we must recall the metaphysical principles of kinematics and dynamics as expressed by their "number one" explanations: In respect to kinematics, matter is the movable in space. In respect to dynamics, matter is the movable in space in so far as it *fills* the space. Thus, as I will explain shortly, things "fill the space". Empirical, material spaces as such, however, do not "fill" spaces. The *Zustände* of their motions do not ground any physical influence on other objects. They, as it were, move around each other without entertaining any repulsive or attractive forces. Material spaces simply "occupy" space. The notion of a "material space" *is* the notion of a section of space being singled out, being "marked" (*gekennzeichnet*) or being "materialized". It is the very idea that matter can and must be *placed*. To formulate this in accordance with the general principles of the Understanding in a simple fashion, we must consequently introduce and distinguish two distinctions,

First Distinction between

A change within the determination of *places*

A change within the determination of *physical points*

Second Distinction between

A possibility for the motion of objects for being in *a state of* rest

A possibility for spaces, and for objects for being *at* rest,
for being continuously present at determinate places.

In accordance with the *Lex Inertia* we can then stipulate that the motion of a physical thing, even in a state of rest, may well correspond to a possible change in the place of the presence of the object. To see this, one need only consider the case of the motion of the Sun relative to any fixed ruler placed on the surface of the Earth. Kant explains these considerations further in the following:

> "Ruhe ist die beharrliche Gegenwart ... an demselben Orte; *beharrlich* aber ist das, was eine Zeit hindurch existiert, d. i. dauret."
> *(MAN, A 10, p. 31)*

> "In einem *beharrlichen Zustande* sein und *darin beharren* ... sind zwei verschiedene Begriffe, deren einer dem anderen keinen Abbruch tut. Also kann die Ruhe nicht durch den Mangel der Bewegung, der sich, als = 0, gar nicht konstruieren läßt, sondern muß durch die beharrliche Gegenwart an demselben Orte erklärt werden." *(MAN, A 13, p. 33)*

Within kinematics we shall learn to recognize how spaces may move around each other. But the motions of spaces relative to one another do not have any real *duration*. I perceive a thing in correspondence with a representation of a space; in other words, I see the thing as placed somewhere. I look again, and still see the thing placed *there*. As argued above, "time" in the transcendental sense primarily means the possibility that I can continuously generate such representations. Thus, time is an objective feature of the possibility that I can see a thing as being "still there". Call this the possibility of being at rest (that is, to be "at rest within some possible determinations", *darin beharren: Ruhe*).

Being at rest in this sense, Kant importantly tell us, cannot be understood as "lack of motion", as motion lacking a certain magnitude; because, we are just about to explain the very possibility for the motions of *things* to have magnitude. That a thing can be ascribed a "place" is not yet to say anything about the moment at which this place is "occupied". So the idea of a single object that is continuously "placed" at the same "place" does not relate to such time-determinations (does not relate to temporal measures). This is exactly what the very notion of a "material space" was meant to indicate. Such a space (*Raum*) "gives room". It exposes possible places within which objects might appear in a figurative manner. A material space is a background that grounds the possibility that individual objects can be ascribed a certain shape.[24]

Spaces, as objects, do themselves acquire a shape. The form of their "own" ground can, so to speak, be exposed. Regarded as *material* objects they can therefore be said to expose a special kind of spatial stability. They can be said to be at rest with the places they "make room" for. That is the transcendental sense – and the only sense – in which the shapes of material items be stable, and in which given motions can be said to occupy space.

As I see it, this is where Kant's criticism of the metaphysical idea of the *solidity* of things comes into play. It is a criticism to the effect that the frame of reference cannot in itself be ascribed any of the physical attributes that this frame grounds. Kant formulates the view by reference to what he calls "the general principle of dynamics":

> "Das allgemeine Prinzip der Dynamik der materiellen Natur ist: daß alles Reale der Gegenstände äußerer Sinne, die das, was nicht bloß Bestimmung des Raums (Ort, Ausdehnung und Figur) ist, als bewegende Kraft angesehen werden müsse; wodurch also das so genannte Solide ..., als ein leerer Begriff, aus der Naturwissenschaft verwiesen." *(MAN, A 82, p. 83)*

To summarize; the fundamental aim that Kant attributed to kinematics was to establish an algebraic exposition of possible motions, in order to be able to represent motions as magnitudes – magnitudes in respect to which we can then formulate clear rules that not only govern the ways in which the magnitudes of different motions can be added or subtracted, but also govern the ways in which individual motions can be composed

[24] Compare Heidegger (1936, p. 156) about *Raumsein* as "giving room".

out of certain kinematical elements. As Butts rightly says, this strategy is based on the possibility of applying the schematization of the pure concept of quantity that Kant demonstrated in the axioms of intuition:

> "Construction of the additivity of points in motion 'borrows' nothing from experience. The principle of quantity of the axioms of intuition tells us that all intuitions have quantity. Schematized and ready to apply to experience, this principle yields that all possible experiences are quantifiable, and have measurable features. The schematized concept of quantity is now idealized mathematically, the resulting construction giving us rules for selecting the kinds of observables that can be adequately theorized in this epistemic formalism". *(Butts 1984, p. 193)*

A summary of the metaphysical principles of kinematics therefore comes to this: The idea that matter is the movable in space must correspond to the method of representing motions as *numbers* in accordance with the transcendental principles of schematization. As such, kinematics a priorily represents possible motions (qua their being *Zu-stände*, and thus also possible objects of experience). So far in our account, these are the *only* possible objects within objective experience. However, once well-formed experiences of *Zustände* is available one has already established a ground wherein the change of a range of objects can exist. To actually establish such a ground is the task of dynamics:

Matter as powers shaped-up by the connection between motions

Till this point we have only considered material spaces as objects that may be said to *occupy* a space. Turning to dynamics, Kant now introduces the concept of objects *filling* spaces. Kant explains the difference between "filling" and "occupying" spaces as follows:

> "einen *Raum einnehmen*, d. i. in allen Punkten desselben unmittelbar gegenwärtig sein, um die *Ausdehnung* eines Dinges im Raume dadurch zu bezeichnen ... so ist *einen Raum erfüllen* eine nähere Bestimmung des Begriffs: einen *Raum einnehmen*." *(MAN, A 33, p. 47-8)*

To *occupy* a space means to display a contemporary presence in more than one material point. It is to be extended. For a motion to occupy a space is for it to exist such that its being situated *there* can be exposed simply by the means of a number (i. e., by means of an index). For a motion to *fill* a space, however, is to occupy a space such that this occupation can be ascribed its "own" moving force. For a motion to fill a space is to occupy it in such a way (a) that the motion will "with-stand" the occupation of the same space by other motions, and (b) such that this with-standing is *due* to the state of motion of the object. So this with-standing can be recognized as an effect of the own(ed), and moving, powers of some *things* – the characteristics of which we can, as yet, not describe. The with-standing, however, should never, as such, be understood as a manifestation of a kind of "solidity". According to Kant, there is no such thing as the solidity of matter, in general. Kant defines the notion of filling a space as follows:

> "Metaphysische Anfangsgründe der Dynamik, Erklärung 1.: *Materie* ist das *Bewegliche*, so fern es einen *Raum erfüllt*. Einem Raum *erfüllen*

> heißt allem Beweglichen wiederstehen, das durch seine Bewegung in einen gewissen Raum einzudringen bestrebt ist. Ein Raum, der nicht erfüllt ist, ist ein *leerer Raum*." *(MAN, A 31, p. 47)*

> "Dieses ist nun die dynamische Erklärung des Begriffs der Materie. Sie setzt die phoronomische voraus, aber tut eine Eigenschaft hinzu, die sich als Ursache auf eine Wirkung bezieht, nämlich das Vermögen, einer Bewegung innerhalb eines gewissen Raumes zu widerstehen." *(MAN, A 31, p. 47)*

Given these stipulations, we can now – and only now – transform the transcendental notion of an "object" into a *metaphysical* notion; namely that of a *body*:

> "Ein *Körper*, in physischer Bedeutung, ist *eine* Materie *zwischen bestimmten Grenzen* (die also eine Figur hat)." *(MAN, A 85, p. 85)*

Here, the word "between" refers to the filling of a space, and does not merely refer to spatial extension (occupation). It is one thing – for any point in time – that an object may be recognized as being spatially extended, it is another that it *acts* so as to be thus extended:

> "Die Materie erfüllt einen Raum, nicht durch ihre *bloße* Existenz, sondern durch eine *besondere bewegende Kraft*." *(MAN, A 33, p. 48)*

> "Die Ursache einer Bewegung heißt ... bewegende Kraft. Also erfüllet die Materie ihren Raum durch bewegende Kräfte, und nicht durch ihre bloße Existenz." *(MAN, A 33, p. 48)*

We cannot, yet, regard the spaces that are filled by attractive and repulsive forces as "mass-points", but one might say that those spatial regions that can be ascribed a "mass" are already shaped up and "marked" by the introduction of the concept of "filling" spaces.[25] Concerning the notion of matter, Kant says that,

> "Materielle Substanz ist dasjenige im Raume, was für sich, d. i. abgesondert von allem anderen, was außer ihm im Raume existiert, beweglich ist." *(MAN, A 43, p. 55)*

Thus, that which is substantial will always be movable, even in physical isolation. We shall therefore say that material substance "owns" the power to entertain physical changes. However – in contrast to the view of Leibniz – this feature of matter, the feature of its owning powers, is conditioned. The causal structure of the owned powers of matter-in-motion is constituted by the requirements corresponding to the concept of filling a space. The logic of this structure has to do with the following geometric considerations.

There are two kinds of owned forces, *repulsive* and *attractive*. The first kind constitutes the condition for the possibility of material substantiality; in other words, for the possibility of filling spaces). However, this possibility presupposes an internal characteristic of moving bodies, namely an attractive kind of force. Kant writes,

[25] That is to say, the criteria of application for the concept of mass is available, but as yet we have no criteria of identity concerning the measure corresponding to the mass an individual object.

> "Diejenige Eigenschaft, auf welcher als Bedingung selbst die innere Möglichkeit eines Dinges beruht, ist ein wesentliches Stück derselben. Also gehört die Zurückstoßungskraft zum Wesen der Materie eben so wohl, wie die Anziehungskraft, und keine kann von der anderen im Begriff der Materie getrennt werden." *(MAN, A 58, p. 66)*

In kinematics we recognized how to represent bodies as occupying a space in accordance with the transcendental schematization of *extensive* magnitudes. In dynamics, we now recognize how to represent bodies in accordance with the transcendental schematization of *intensive* magnitudes. This will enable us to establish a *measure* of physical magnitude; in other words, enable us to introduce the concept of mass.

Mass as a measure of the inpenetrability of motions

By reference to both the transcendental notion of quality, and to the associated principles of the second analogy of experience, the anticipation of perception, Kant accordingly reminds us how these few principles might enter into the constitution of a complete and adequate dynamics:

> "Allgemeiner Zusatz zur Dynamik: ... die *Qualität* der Materie unter den Titeln der *Realität, Negation* und *Limitation*, so viel es einer metaphysischen Dynamik zukommt, (ist) vollständig abgehandelt worden."
> *(MAN, A 81, p. 82)*

We thus see that in order to express the metaphysical principle of material particularity, we have only to express how the actions – performed by, and on, material bodies – condition and constrain their possible motions. If we manage to express this – in accordance with the schematic anticipations of perception, then, and only then, can we make sense of the idea of a material *measure*. As was mentioned, the point is to express the *intensive* magnitude of material items in terms of the concept of filling spaces.

Before we can introduce any specific concept of a measure of power, we have to take into consideration a certain set of definitions and statements that Kant mentions in the First Critique. We shall especially need to stipulate two things. The first stipulation has to do with the "mathematical" character of things. As previously mentioned, Kant believed that there can be such a thing as a *contingent connection between uniform items*. Indeed, this was implied by the principles of kinematics concerning the possible existence of the relative motion between different empirical spaces. In dynamics, we have to remind ourselves about a second transcendental claim to the effect that there can be such a thing as a *necessary connection between dissimilar items*. In the *First Critique* Kant wrote that,

> "Alle *Verbindung* (conjunctio) ist entweder *Zusammensetzung* (compositio) oder Verknüpfung (nexus). Die erstere ist die Synthesis des Mannigfaltigen, was *nicht notwendig zueinander gehört*, ... und dergleichen ist die Synthesis des *Gleichartigen* in allem, was mathematisch erwogen werden kann ... Die zweite Verbindung (nexus) ist die Synthesis des Mannigfaltigen sofern es *notwendig zueinander* gehört, wie z. B. ... die Wirkung zu der Ursache, – mithin auch *als ungleichartig* doch a priori verbunden vorgestellt wird, welche Verbindung ... ich darum *dynamisch* nenne, weil sie die Verbindung des *Daseins* des Mannigfaltigen betrifft." *(B 202)*

This is perhaps one of the most important metaphysical considerations made by Kant concerning the formal features of the structure of being. Without it, for instance, it would not make sense to regard the notion of "gravity" as a fundamental physical quality. That is why the notion of "elastic powers" forms a main link between dynamics (in the sense in which we have just constructed it) and mechanics (that we have not yet considered). According to Kant, the link between elasticity and gravity corresponds to the basic, transcendental idea of Zusammenhang:

> "*ursprüngliche Elastizität* ... und die Schwere machen die einzigen a priori einzusehenden allgemeinen Charaktere der Materie, jene innerlich, diese im äußeren Verhältnisse aus; denn auf den Gründen beider beruht die Möglichkeit der Materie selbst: *Zusammenhang*."
>
> *(MAN, A 72, p. 75-6)*

As we have seen, the schematism that corresponds to the transcendental concept of intensive magnitude permits us to view the succession of *Zustände* of motions as forming a representation of a *Zusammenhang* between such. In a further schematization – in an analogy of experience – we can then try to characterize the particular form of that *Zusammenhang*. This – call it the *causal* form of connectedness – can now be seen as a characterization of Newtonian Mechanics, and will consequently lie at the heart of our transforming any adequate dynamics into a complete mechanics. As such, the introduction of a causal concept implies a link between the two concepts of substantiality and causality corresponding to a certain idea of how a whole system of material things may in principle constitute physical unity.

To conclude, once we have established a way to represent matter-in-motion in accordance with the transcendental principles of extensive and intensive magnitude, we may associate material bodies with a certain *form* of connectedness (*Zusammenhangsform*) that we shall call physical causality.

In his demonstration of how an adequate dynamics constitute the conditions for a possible and complete mechanics, Kant wants to demonstrate certain "formal" aspects of the intensive qualities of interacting material objects; especially two features that, essentially, characterize the causal *Zusammenhangsform*. Kant calls these two features, *Anziehung durch Berührung* and *Widerstand gegen Trennung*. He writes,

> "Anziehung, *so fern sie bloß als in der Berührung wirksam gedacht wird*, heißt *Zusammenhang*." *(MAN, A 87, p. 86)*

> "Der Widerstand gegen die *Trennung* sich berührender Materien ist der Zusammenhang." *(MAN, A 89, p. 88)*

Consequently, our strategy comes to this: First, the principles of dynamics are formulated as rules concerning the physically possible spatial distribution of individual bodies. Second, these rules shall then be regarded as expressing a set of logical *exclusion-relations* that shall regulate our investigation into the structure of the causal interplay of things. This formal "arrangement" of possible causal structures will then be said to constitute the *form of any material quality*. It follows that *the demonstration of the formal aspects of physical powers enables us to introduce the criteria of identity* for the *objects* belonging to a certain range of objects of possible experience; a range into which we can conduct rational causal investigation.

At this point, Kant has accomplished the following. He has explained how to conceive of the change within the *Zustand* of a motion as corresponding to a change in the "inner", or material, conditions of the movable in space (in so far as the motions can be said to fill a definite space). Thus, in order to be able to introduce the concept of mass, we transform the concept of the *form* of the possibility of change within the states of *motions* into a concept of the material substiantiality of *things* that subsist within such dynamical processes of change. This is the reason for making the conclusive claim that,

> "Dies ist nun alles, was Metaphysik zur Konstruktion des Begriffs der Materie, mithin zum Behuf der Anwendung der Mathematik auf Naturwissenschaft, in Ansehung der Eigenschaften, wodurch Materie einen Raum im bestimmten Maße erfüllet, nur immer leisten kann, nämlich diese Eigenschaften als dynamisch anzusehen und nicht als unbedingte ursprüngliche Positionen, wie sie etwan eine bloß mathematische Behandlung postulieren würde." *(MAN, A 105, p. 99)*

Concluding remarks on Kant's metaphysics of Nature

Kant's (theoretical) philosophical position is best captured by the term "Critique of Pure Reason". His project was to lead Reason to its own limit by means of transcendental philosophy. The first part of this project, the analytical part, analyzed the conditions for the possibility of performing objective judgments by means of concepts of experience, and the second part, the dialectical part, formulated principles for the meaning of *Weltbegriffe* to the effect that Reason was provided by regulative principles for grasping certain transcendental and cosmological ideas such as "God", "Soul", "I", and "Nature."

The empirical sciences are in a sense independent of this metaphysical project, but the matter of which concepts of experience that can form the basis of the project is crucial. Thus, it is crucial how the elaboration of a range of objective conceptual determinations, a range of *Natura Naturata*, is seen to be at one with the idea of Nature as a *lawful* order, *Natura Naturans*. The empirical experience of things must be said to correspond to a certain idea of Nature as constituting a lawful order as well as a unified range of phenomena. This is achieved by connecting certain formal mathematical principles for constructing concepts in the intuition (i. e., the principles of geometry) with certain transcendental principles for representing empirical objects (such as motions) within a general logical scheme. The connection between the mathematical and the dynamical principles is shown to correspond to the systematic unity of both the table of judgments and the table of categories. This is how a dynamical concept of Nature emerges, in the sense that Nature is seen to embody an open-ended range of interaction between particular motions in space and time. Nature thus understood is not constituted by a certain kind of matter. The essence of Nature is rather that *whatever* exists in the material sense must, in order for us to have the possibility of representing the thing in question, be a *movable* item according to the transcendental principles of Understanding.

This is a matter of necessity. *What* exists in our experience is however contingent. It turns out that what exists in physical experience is *matter*. This is a metaphysical idea in that the notion of "matter" is particular and concrete in relation to the universal

and abstract notion of "substance". "Matter" is characterized by being movable in the sense that it *fills* and *occupies* spaces. Matter is 'the movable' in space in the sense that attractive and repulsive *forces* are distributed in space and time. Consequently, the structure of the possible distribution and interaction of forces corresponds to the formal features of the logical table of judgments. In that sense, the possible objects of experience, the physical systems undergoing changes in their dynamical states, are constructed (in thought) and are posited within a general causal scheme. This is the sense in which the unity of kinematics and dynamics constitutes a *mechanics*.

Nature does not correspond to a mechanics in the sense of clockwork, but rather in the sense of constituting a *territory of objects*. Nature contains all sorts of objects but they all conform to certain (metaphysical) principles of change, i. e., to certain causal principles. Consequently, physical reality is not to be associated with a pre-determined field of possible objects of knowledge, but rather with a uniform feature that, by necessity, must be attributed to any physical system insofar as we should be able to represent the given items within a systematic rational ontology. Nature (*Natura Naturata*) corresponds, as it were, to a certain *model* of the world. The fact that we *both* can base our experience on that model *and* continuously and systematically pursue *new* physical items in our experience by means of this methodology forms the background upon which we can try to grasp the lawful character of Nature as such (*Natura Naturans*).

A major theme throughout the rest of this book is the key role played by all these Kantian considerations in the development of both the (Helmholtzian) tradition of theoretical physics and in the philosophical discussions among physicists concerning the question of how to interpret and assess the new forms of physical theory that emerged in the early twentieth century. On the one hand, I claim that these developments in physical theory make little sense without the Kantian considerations; on the other hand, I also present how the Kantian metaphysics of Nature was challenged and modified in two major respects. First, the forms of intuition (space and time) are not seen to be a priori and it is shown how they must give way to new forms of intuition. Second, the idea of a unified and uniform schematization of the basic theoretical concepts is given up. Instead there is a much more complex story to tell about the possibility of applying theoretical concepts to objects within the empirical reality that corresponds to the (new) forms of intuition. These are important modifications of the Kantian position. However, calling them post-Kantian says a lot more than it would if one were to associate the respective views of a range of the great physicists of the early twentieth century with any other established philosophical standpoint.

2 The Helmholtzian Tradition of Theoretical Physics; Helmholtz and Planck

2.1 The Principles of Classical Mechanics

The Hamiltonian Method and Poisson Brackets

The mathematically simplest way to represent physical motion is by means of continuous curves that represent the motion of individual bodies along geometrically well-defined paths – as in the case of rectilinear motion (along a straight line). A continuous line in a Cartesian coordinate system can represent each such motion, with a time-variable associated with the x-axis, and a distance-variable associated with the y-axis. In the case of circular or elliptically shaped paths, the motions are most adequately represented by polar coordinates (r, Θ) where r stands for the distance to the center of rotation and Θ stands for the numerical expression of an angle, such that a curve in the polar coordinate system can be associated with, say, the angular velocity or momentum of a given motion.

Thus, in order to represent the motion of rigid bodies, extended in space, it is mathematically adequate to represent the motion as a combination of two motions, a rectilinear *translation* and a curved *rotation* around the center of mass of the system. This again gives rise to the idea of a *coordinate-transformation*, such that the motion is represented "principally" in a polar coordinate system with the center of mass of the physical system in question at its origin.

Now, considering the general case of an N-particle system, one might worry that the standard representation in terms of orbital motions is no longer adequate. Commonly, the motion of an individual body is represented such that it corresponds to a *geometrical picture* of the possible motions of the coordinate systems (the very frames of reference) themselves. That is the point of the Kantian method of analyzing motions by representing them as composed in such a way that certain elements of the composite motion corresponds to the possible ways in which different frames can be moved relative to one another.

However, we may also choose a means of representation that does not primarily express kinematical possibilities of the *frames* of reference, but expresses, instead, dynamical characteristics of the physical *systems* represented. That is the point of the Lagrangean method of representation. By introducing this method we take seriously the idea that the possible interactions and combinations of individual motions constitute a range of possible *states*, each of which can be expressed in terms of the concept

of a general state-function. So, instead of analyzing individual motions in terms of their component translations and rotations, the method analyzes motions in terms of some general dynamical characteristics. In the established modern notation, the Lagrangian energy function (L) is expressed as the numerical difference between the kinematic and the potential energy associated with a given state of motion $(L = E_{kin} - E_{pot})$. Thus, in the Lagrangean method of representation, the dynamical magnitudes of physical systems are represented as functions of a set of "generalized coordinates" that need not be distances or times. The mathematically adequate choice of generalized coordinates in terms of which one can state the Newtonian laws of motion, happens to be a set of variables $(q_1, \ldots, q_n)$ that represents distances, and a set of variables $(p_1, \ldots, p_n)$ that represents momentum (though that choice of variables is in no way necessary). The reason why it is adequate to choose these sets of variables is because there is a simple mathematical way to express the *conservation laws* of so called conservative systems. These are physical systems whose dynamical stability does not essentially depend on the causal influence of a certain kind of physical force – such as gravitation – and thus, the system is said to be conservative in respect to that kind of force.

The question of what should be considered the canonical mathematical expression of specific physical conservation laws led to the Hamiltonian reformulation and extension of the Lagrangean method of representation. In the Lagrangean case, the possible dynamical changes are represented as curves in a multi-dimensional coordinate system – the configuration space – the space that is spanned by the generalized coordinates. This space functions like a kind of map that maps the possible values of a certain measure of energy [the time-derivative of the difference between two partial derivatives of the Lagrangean], and such that (a) any point of the map can be seen as lying on a series of *different* lines drawn on the map, and (b) each of these lines represents a lawful, physically possible time-development of the system at issue in respect to a given set of dynamical variables. The time development of the system can thus only be specified if some initial condition (an integration constant) is determined in advance, so as to determine in advance one of the possible lines running through a given point on the map.

It is in overcoming this complexity that the Hamiltonian method proves its utility. The Hamiltonian (H) of a physical system – represented in terms of a set of generalized coordinates – is a measure of the total energy of the system. Thus, it is a condition for energy-conservation that the explicit time-derivative of the Hamiltonian is zero. The Hamiltonian is composed of two additive parts, one representing the Lagrangean, the other representing a general sum (over all pairs of variables in respect to which a special relation holds) of a measure of the time derivative of the *action* associated with each pair. This is the way in which the concept of *conjugate variables* is introduced. For each dimension of the system, the choice of conjugate coordinates is governed by the rule that the product of any two conjugate variables represents a physical action.

Now, there is a way to construct a *geometrical* representation of all the various actions associated with the pairs of conjugate variables, namely by constructing a product-space such that to each pair there is associated a cell in this space. This construct is called the *phase-space* of the system. So, the phase-space is a logical representation of all the distinct, physically possible, dynamical states of given, stable physical systems. In this space one can represent the possible time-development of given systems in a much simpler manner. One need only draw one line in the phase-space, and not indefinitely many as in the Lagrangean case.

My physical understanding of the matter is this: We want a method of representing how the lawful time-development of any dynamical quantity corresponds to the total action of the system. Thus, the first component of the Hamiltonian H is constructed as a general measure of this "conservative" character of the system itself, whereas the latter component, the Lagrangean L, is an expression of the potency of the system to respond dynamically to an "impressed" (outer) physical field (a "potential").

The geometrical representation of possible dynamical states, the phase-space has a specific physical significance, because we can regard a transformation of a set of *conjugate* variables into another set of generalized variables as a way of changing the (logical) stratification of the different physically possible, dynamical states of the system at issue. For, in given cases we may ask if the new set of variables also constitute a set of conjugate variables? If so, we shall then say that there is a special physical characteristic of the system that is preserved through the transformation. There is a sense, we shall then say, in which the system must be seen as constituted by essentially the *same* set of dynamical states in this new mathematical representation as it was in the former.

Concerning physical theory, this means that we have acquired a method by means of which we can express clearly and explicitly what is to count as a *constant of motion*. Thus, the criterion for this will be that there must be a way in which the mathematical representation of the dynamical magnitude in question can be seen as *invariant* respect to those kinds of coordinate-transformations of conjugate variables where the new set of coordinates are also conjugate. The general mathematical tool for expressing such invariance (in respect to such canonical transformations), it turns out, is the *Poisson bracket*. This mathematical tool is an operator that operates on functions that represents the dynamical variables. The Poisson bracket may also be characterized more narrowly as a kind of product between such functions. Indeed, Poisson brackets are usually introduced in terms of some algebraic rules that must be satisfied by the variables of the functions, represented in the Bracket.

In this way, the idea of pairs of conjugate variables is associated with certain algebraic rules, such that the conjugate transformations of the phase-space that characterize given physical systems acquire an analytic-geometrical interpretation. This is because the set of conjugate transformations can be said to constitute a sub-space within the phase-space. So the Poisson bracket operates as a kind of projection rule. If a function that expresses a certain dynamical variable should be recognized as equivalent to, or "parallel" to, some conjugate transformation, then its Poisson-projection into the subspace of conjugate transformations must be zero. To be precise, if the Poisson bracket of a dynamical variable and the *Hamiltonian* of the system $[q, H]$ is zero (if the variable is not explicitly a function of time) then the variable shall count as a constant of motion.

The importance of this criterion for any constant of motion is that its formulation is *in*dependent of the choice of conjugate variables. What is a constant of motion in any Hamiltonian representation of the dynamics of a given system in relation to a certain set of conjugate coordinates will be so in relation to all other such sets. By advancing this general Hamiltonian criterion in respect to constants of motion we have established a significant way to express the *dynamical* character of a given system.

The Principle of Least Action

One might, as does E. Cassirer, claim that some version of the principle of least action dates back to antiquity. Or one might claim, as does Helmholtz, that Leibniz introduced the basic version. Certainly what came to the fore through the works of Leibniz was the conception of equations of motions, that these be given in the form of differential equations. This conception, of course, made it possible to invoke certain mathematical forms of analysis of differential functions.

Take the example of a body at rest. What is it to claim that such a physical phenomenon in some sense embodies a principle? How does the possibility of a body's being at rest reflect anything essential concerning physical nature? Well, one way to answer these questions is to picture the situation as if nature had "solved a problem" such that the motion of the body (in this state of rest) had a special character. That is what is expressed by saying that the action associated with the state of rest is a minimum. In general, when a body is moving one might ask the reason why nature allowed *this* actual motion, and not some other motions that might have been realized. This is a general question that relates to motions. As such it invites us to say something about the fundamental relationship between the *path* of the motion, the *time* it takes to create a displacement of some measure, and the *velocity* with which the motion takes place. Might nature not have chosen a slightly different path?

Leibniz and others introduced certain principles in order to answer a similar question regarding a range of *specific* kinds of mechanical motion. Thus it became commonplace in physics to explain why physical bodies moved along their observed path by revealing that the action performed by that motion was at a minimum when compared with other motions (that one might posit in mathematical thought). Thus, one reason why this approach became acceptable was the fact that a new kind of mathematical reasoning was ready at hand, the variational calculus, that allowed the formulation of well-defined questions and answers concerning the "chosen" paths of nature itself. Thus, what dates back to Leibniz is the method of associating any newly proposed set of theoretical concepts in physics with a (mathematical) minimum-principle.

The very expression "principle of least action" must be ascribed to the French physicist Maupertuis.[26] It was Maupertuis, and not Leibniz, who associated the physical notion of certain mathematical minimum-principles with an understanding of the very intelligibility of physical nature. To Maupertuis, the principle of least action expressed the perfect Reason of God. The idea that processes of physical change (literally speaking) "took place" so as to perform, given certain conditions, a minimum of action, was seen by Maupertuis as an expression of the "economy" of the powers that God had attributed to physical beings.

For Helmholtz, when he dealt with the issue late in his career, all of this was of mainly historical interest. To him something crucial happened when, successively, D'Alembert, Lagrange, and Hamilton formulated new versions of the (Newtonian) equations of motion. More accurately: Each of these pioneers formulated a general principle of physical thought in terms of which one could *derive* the Newtonian equations of motion. Also, it is possible to understand the three principles of D'Alembert, Lagrange, and Hamilton, respectively, as a series of generalizations of the same principle – namely the principle of least action – formulated for the first time in terms of the basic notion of *Energy*. From this principle follows not only the Newtonian (as well as

[26] See the learned discussion of this in (Pulte 1989, p. 56ff).

the Maxwellian) laws of Nature, but also the very principle of energy conservation.

D'Alembert's principle fuses an idea of virtual displacement with a principle of *balancing powers*. The principle formulates a way to represent composite systems in terms of a set of powers such that the system of centers-of-gravity moves in a stable fashion. The principle states that such a configuration may subsist when so-called "additional powers" perform an action on the system, in so far as such additional powers counter-balance each other. In this way, the basic notions of Mechanics are associated with a principle of *force-equilibrium*. To Helmholtz, the importance of D'Alembert's principle was its use in reducing the number of independent variables when constructing the equations of motion for a given system. This involves specifying the degree of freedom, say, when different parts of the system in question are rigidly connected.

Consequently, Helmholtz linked this D'Alembertian conception of mechanical systems with the generalized equations of motion formulated by Lagrange. The importance of this link, Helmholtz explained, is to turn D'Alembert's principle of mechanical equilibrium into a general principle of *dynamics*; in other words, to represent the dynamics (the acting powers) of a static distribution of powers as a "moment" within the more general dynamical situation of powers changing over time:

> "Die Lagrange'schen Bewegungsgleichungen unterscheiden sich von den für die Statik beim Bestehen fester Bindungen gefundenen Gleichungen wesentlich nur dadurch, daß die Kraftsummen welche damals gleich Null waren, hier gleich den positiven Zusatz-kräften gesetzt werden, welche die Thatsächlichen Beschleunigungen der Massenpunkte erzeugen. Jene Gleichgewichtsbedingungen stellen also nur ... [einen] ... Spezialfall der *Lagrange*'schen Differential Gleichungen dar."
>
> *(Helmholtz 1903, p. 309)*

The basic problem that the mature Helmholtz faced was to develop a general kind of dynamics in terms of which one could unite the various forms of dynamics (the mechanical, the electromagnetic, the thermal, and if possible, all of the new forms associated with statistical mechanics, the theory of electrons, and more). According to Helmholtz, such a general dynamics was in some sense already waiting around the corner. So this was the strategy that Helmholtz pursued in order to establish such a General Dynamics. The fusion of the Lagrangean equations with D'Alembert's principle had made it possible to associate given principles of physical thought, including the principle of least action, with a certain conception of composite physical systems. However, one could not yet regard that principle, in its pre-Hamiltonian form, as the framework from which to derive the fundamental physical conservation laws. The establishment of that very deductive link is one of the crucial aspects of Hamilton's contribution to theoretical physics.

One part of this achievement was the formulation of the so-called Hamilton Principle that, Helmholtz wants to show, may be regarded as a new formulation of the principle of least action, no longer in terms of differential functions, but in terms of integration of functions: The principle of least action had become an integration principle in respect to state-functions of physical systems, and was no longer associated with analyzing the differential functions representing the motion of individual carriers of power and energy along well defined paths in space-time. Another part of Hamilton's achievement was the use he made of the Lagrangean functions by adapting them into

the framework of the generalized equations of motions that Hamilton had himself developed. However, it would require Helmholtz's effort to point out what was important in Hamilton's generalization of the framework of classical mechanics. Interestingly, that was how the notion of Energy, as we know it today, became a well-defined and fundamental concept of physical thought. Notions such as "kinetic energy" and "potential energy" are only understandable against the background established by Helmholtz in that analysis.

Helmholtz, first of all, made an important suggestion concerning the magnitude expressed by the function H introduced by Hamilton. Helmholtz suggested interpreting H as symbolizing the difference $(F - L)$ between the "potential energy" of the system (F) and the Vis Viva (L) (later called the "kinetic energy") of the system. Consequently, Helmholtz used the term *kinetic potential* to express what the function H represents. It refers to that part of the total energy of a physical system that is not directly associated with certain motions.[27] It follows that $(F + L)$ is supposed to represent the total energy of the system. However, given the original interpretation of the Hamiltonian equations, there exists the precondition that only "conservative" forces are taken into account, i. e. forces that act along the direction of the centers of gravity. Now since both Newtonian and Maxwellian forces are conservative, in the sense explained, this does not yet impose any serious restraint on the range of application of the Hamiltonian formula.

The Hamiltonian equations of motion are in a sense equivalent to the Lagrangean ones. They however have the advantage of relating to the possible motions of a composite system alone in terms of the possible transformations of the energy configuration of the system, without referring to any *specific* state of motion situated in space-time. This of course is the point of introducing what is today called the *phase-space representation* of the possible physical processes taking place within a given system under well-defined conditions.

As was mentioned earlier, in terms of mathematics the step from the Lagrangean to the Hamiltonian method of representation has another important aspect. Before Hamilton one had formulated the minimum-principles of mechanics as *differential* principles. Now, given the Hamiltonian method of representation it was possible to formulate an *Integration*-principle.

$$\delta \int_{t_0}^{t_1} (F - L) dt = 0$$

Consequently, the time variable enters only as a difference (dt) that is integrated from t_0 to t_1. Then, what is of primary interest is the time-span, the period of energy-transformation, and not any specific time point over which any magnitude varies in a special (mathematical) way. For Helmholtz this would prove important when trying to generalize the Hamiltonian Principle so as to cover *ir*reversible processes. But in fact, the prime importance of the introduction of integration principles was that it created the possibility of applying the integration to *dis*continuous forms of physical change. Heisenberg certainly made use of this possibility when he first set up his Matrix Mechanics. With these considerations at hand, let us now review Helmholtz's original

[27] That part of the energy may be specified by a series of *couplings*, bound within the system. Which is of interest because Niels Bohr would later stress how the quantum theory had to make use of such a concept of energy.

formulation of the Hamilton Principle. It should be noted how the Principle can be regarded as a generalized version of the principle of least action and how it is formulated in terms of the notion of kinetic potential:

> "Das Prinzip der kleinsten Wirkung kann dann so ausgesprochen werden: *Der für gleiche Zeitelemente berechnete negative Mittelwerth des kinetischen Potentials ist auf dem wirklichen Wege des Systems ein Minimum (beziehlich für längere Strecken ein Grenzwerth) im Vergleich mit allen anderen benachbarten Wegen, die in gleicher Zeit aus der Anfangslage in die Endlage führen*". *(Helmholtz 1887, p. 205)*

Given this formulation of the principle of least action, Helmholtz generalized it so that it covered not only mechanical forms of change, but all physical forms of change. We see that he turned to Kantian terminology in order to state his agenda:

> "Jedenfalls scheint mir die Allgemeingültigkeit des Prinzips der kleinsten Wirkung so weit gesichert, daß es als heuristisches Prinzip und als Leitfaden für das Bestreben, die Gesetze neuer Klassen von Erscheinungen zu formulieren, einen hohen Werth in Anspruch nehmen darf". *(Helmholtz 1887, p. 210)*

As he wrote these lines Helmholtz could not have imagined how right they would prove to be. He had himself developed a generalization of Hamilton's principle in his analysis of "monocyclic systems".[28] He would also show later how the principle could be seen as forming the basis of electrodynamics.[29] But it was the following that convinced Helmholtz about the universality of the Principle:

> "Hamilton's Prinzipalform des Prinzips der kleinsten Wirkung hat den Vortheil, daß in ihr der Werth der Potentiellen Energie auch von der Zeit abhängig sein darf, und das sie also Glieder aufnehmen kann, welche veränderliche äußere Kräfte enthalten, oder Kräfte, die nicht zu den konservativen reinen Bewegungskräften gehören, vielmehr die Einmischung anderer physikalisher Prozesse erfordern." *(Helmholtz 1892a, p. 477)*

This is the precise expression of the value of formulating the principle in terms of Integration. It opens up the possibility of analyzing complex physical systems in a new fashion. It becomes possible to single out the conservative *mechanical* part of the system governing the translational motion of the centers-of-gravity, while including in the analysis non-mechanical forms of interaction. This made it feasible to model the possible physical processes of the system as an ongoing transformation of its energy states. No wonder this became the major guide in setting up a dynamical model for the atom. Helmholtz later concluded the value of the Hamiltonian principle as follows:

> "[der] Hamilton'schen Prinzip ... sagt also mehr und Bestimmteres aus über den besonderen Charakter der Naturkräfte, als was in ihrer Bezeichnung als konservative Kraft bereits ausgedrückt ist ... Man ist daher zu der Annahme berechtigt, daß dieses Prinzip eine Universelle Gültigkeit

[28] (Helmholtz 1884a)(Helmholtz 1884b)
[29] (Helmholtz 1894)

> hat, daß man es in Gebieten, wo die Beweise für seine Richtigkeit noch fehlen, doch mit Nutzen als Leitfaden für die Auffindung der Gesetze benutzen kann, deren Bestätigung oder Widerlegung dann Aufgabe der experimentellen Forschung ist." *(Helmholtz 1903, p. 373)*

This is perhaps the ultimate expression of the principle of least action, as given by Helmholtz. Also it states exactly how the principle was regarded as the cornerstone of theoretical physics by his successors.

2.2 The Principle of Least Action and The Quantum Theory[30]

Planck on the generalization of the Principle

Heidelberger rightly says,

> "Planck ... adopted an essential part of Helmholtz's philosophy of science: the principle of least action, freed from its mechanistic interpretation, served him as an abstract substitute for what Helmholtz had called the real substance, the objective behind appearances. Thus substituted, Planck carried Helmholtz's philosophy of science into the 20th Century"
> *(Heidelberger 1993, p. 497).*

Accordingly, we now consider Planck. Planck introduces the principle of least action very much as a transcendental principle of the Understanding in the sense of Kant's. It is especially noteworthy how Planck stresses the point that the principle is meant to cover appearances that we have still not experienced. The principle is thus very far from being one of logical induction:

> "Solange es eine physikalische Wissenschaft gibt, hat ihr als höchstes erstrebenwertes Ziel die Lösung der Aufgabe vorgeschwebt, alle beobachteten und noch zu beobachtenden Naturerscheinungen in ein einziges Prinzip zusammenzufassen ... dafür sprechen daß, das ideale Problem kein rein utopisches, sondern vielmehr ein eminent fruchtbares ist und daher gerade vom praktischen Standpunkt aus stets im Auge behalten zu werden verdient." *(Planck 1914, p. 91)*

After having stated the central position of the principle of least action, Planck then reiterates Helmholtz's view that there is a sense in which the only principle to rival it – the principle of the conservation of energy – may be seen as "derived" from the former. Planck explains this by reminding us that the principle of least action is a principle of variation whereas the principle of the conservation of energy is not. Like Helmholtz, Planck associates this difference with the economy of reducing the number of independent dynamical variables in respect to which, for any given system, there will be a special variational characteristic (i. e. be "constants of motion").

Now the variational requirement does not merely form a link between the number of independent variables and the number of equations of motion that are required for expressing the dynamics of the given system of objects. The *form* of the variational

[30] It is perhaps premature to include this paragraph before the presentation of Quantum Theory. But I thought it best to continue my discussion of the principle of least action.

requirement also characterizes the *kind* of physical quantity in respect to which there may be constants of motion (that again may underlie conservation laws). This is where it becomes important to distinguish between *differential* and *integral* forms of variational principles. The former kind has, Planck says

> "... das charakteristische Kennzeichen der wirklichen Bewegung in eine Eigenschaft der Bewegung verlegen, die für einen einzelnen Zeitpunkt oder ein Zeitelement Bedeutung hat". *(Planck 1914, p. 94)*

In contrast to this

> "... wenn man das Variationsprinzip als Integralprinzip auffasst, dadurch, daß man es von vornherein auf ein endliches Zeitintervall bezieht. Dann ist unter allen virtuellen Bewegungen die wirkliche Bewegung durch die Eigenschaft ausgezeichnet, dass für irgendeine zulässige Variation von ihr ein gewisses Zeitintegral verschwindet. In den wichtigsten Fällen läßt sich diese Bedingung auch so aussprechen, daß für die wirkliche Bewegung ein gewisses Zeitintegral, welches als die *Wirkungsgröße* oder die *Action* der Bewegung bezeichnet wird, kleiner ist als für jede beliebige andere mit den vorgeschriebenen Bedingungen verträgliche Bewegung". *(Planck 1914, p. 94)*

So this is the way in which Planck formulates Hamilton's Principle. He regards it's pre-Helmholtzian version as paving the way for a break with a mechanistic conception of nature. The Hamiltonian Principle does not relate to the dynamical properties of any specific point in space-time. What matters when analyzing possible motions in terms of the *difference* $(L - F)$ between kinetic and potential energy, is the variation of the product $[(L - F) * t]$ of the "free" energy of the system with the time period under consideration.[31] This Planckian reconstruction of the Hamiltonian form of the principle of least action entails several points:

First there is an issue that, unfortunately, cannot be stated clearly until we have given a detailed outline of Planck's philosophy of physics. Planck wants to grant Hamilton this much: Hamilton provided physics with a way in which to make sense of natural laws without elaborating "complete descriptions of natural processes".[32] We need only point to adequate forms of *intuition* in respect to any specific form of lawfulness. The main example here is that the possibility a *statistical* mechanics was in some sense already at hand due to Hamilton.

Another point of Planck in reconstructing the Hamiltonian principle is his view that the principle secured the first step in the direction that was followed by the theory of relativity. It turns out that the magnitude introduced by the canonical Hamiltonian equations, the magnitude of "generalized" action, is *Lorentz-invariant*. The magnitude is thus a possible constant of motion in accordance with the requirement that characterizes the theory of relativity in respect to the co-variation of physical laws under coordinate-transformation.

The third reason Planck has for reconstructing Hamilton's Principle is that it makes it possible to introduce Helmholtz's version as a special generalization of the principle

[31] Here, I maintain the letters "F" and "L" used by Helmholtz, whereas Planck uses the more common letters "T" and "U".

[32] (Planck 1914, p. 95)

of least action. Planck takes seriously Helmholt's use of the term *kinetic potential*, because it involves a generalization of the concept of *energy*.[33] As Planck was to discuss later, there is a continuing development of the intuitive representation of that which carries energy; from the intuitive concept of *substance* to the notion of a *Potential*, to the Boltzmannian idea of statistical distributions of forces, and finally to the intuitive concept of a probability field.[34] When Planck wrote in 1914, he knew only the three first members of this series, but in 1926 he could add the last to the list. So in effect Planck came to picture Helmholtz's generalization of Hamilton's Principle as belonging precisely in the same category as Heisenberg's generalization of the Helmholtzian version of the principle of least action. Planck had in fact, in 1914, anticipated the fundamental role that the principle, in some generalized Helmholtzian form, would play in respect to the formulation of a quantum mechanics:

> "Helmholtz zeigte ... daß das kinetische Potential eine Form annehmen kann, in der es gar nicht mehr als Differenz von kinetischer und potentieller Energie erscheint. Gerade dieser Umstand läßt die Universalität des Wirkungsprinzips besonders deutlich erkennen; denn außerhalb der Mechanik ist eine Unterscheidung zwischen kinetischer und potentieller Energie gar nicht möglich." *(Planck 1914, p. 100)*

At first blush it might look as if Planck in his later years after the establishment of quantum theory lost sight of the principle of least action. In the important essay of 1926 "Gesetzlichkeit im Lichte neuerer Forschung" he does not mention the principle at all. In the follow-up essay to his 1908 essay on the unity of thought "Zwanzig Jahre Arbeit am physikalischen Weltbild", he only mentions it once briefly. In the essay of 1930 where he seeks to characterize "Theoretische Physik" it is only mentioned in order to mention an attitude of what he regards as some of his most important successors. And the principle is not mentioned at all in the significant essay from 1932 on "Der Kausalbegriff in der Physik". Yet, like Ernst Cassirer, I find that there is no reason for believing that Planck changed his original Helmholtzian view concerning the status of the principle.

The essay on the changing senses of the concept of lawfulness in fact presupposes some Archimedean point from which to access various such senses. Whats more, the essay associates this point with a Kantian notion of *Gesetzlichkeit als Vorbedingung den Kausalbegriff*.[35] In other words, any form of lawfullness must be seen as involving a concept of the form of law in terms of which causal relations may be expressed. Now what can such an a priori concept of form be but the concept of action; seen as the kind of concept involved in formulating the principle of least action, and from which all specific forms of physical lawfulness are derived?

In considering Planck's postulate concerning the limited divisibility of action, one should recall the ontological considerations of both Leibniz and Kant about the essential connection between the notions of substantiality, force, and causality. Planck relates this group of ideas to a notion of *einfache Gesetzlichkeit*. Importantly, this is what the father of the quantum hypothesis himself saw as the fundamental aspect of its introduction

[33] (Planck 1914, p. 99)
[34] Planck 1926, p. 162ff, 169)
[35] (Planck 1926, p. 159)

> "... es hat sich gezeigt, daß diese einfache Gesetzlichkeit bei einer gewissen Grenze der Teilung ein Ende hat ... die zu einer Atomisierung der raum-zeitlichen Wirkungsgröße, also zu der Annahme von Wirkungselementen oder Wirkungsatomen drängt." *(Planck 1926, p. 170-1)*

It should be noted how Planck combines the quantum hypothesis concerning the limited divisibility of action with the possibility of distinct space-time elements as corresponding to the *distribution* of physical action. This implies a restraint on the kind of "elements" that can have lawful relations in physical space.[36]

So the quantum hypothesis of Planck's must be seen as forming part of an effort to make sense of a new kind of lawfulness. This involves formulating a generalized concept of causality, such that this new kind of lawfulness may be regarded as the latest element in the series that characterizes the rational historical development of physical theory, and which includes the gradual generalization of the conception of conservation laws. Consequently, the essay on lawfulness implicitly deals throughout with the utilization of the principle of least action. Given that Planck knew of the use made of this principle by both Heisenberg and Schrödinger, these considerations of his can hardly surprise.

Heisenberg's and Schrödinger's different versions of the principle

The utilization of the Hamilton Principle became the cornerstone of the new quantum theory. To take Schrödinger's wave-mechanics first, the following statement of Cassirer's illustrates the matter nicely,

> "Schrödinger began directly with Fermat's principle and from here effected the transition from Fermat's 'geometrical ray optics' to a new 'physical wave optics' in which matter itself is explained as a wave-process. He bridged the gap between Fermat's optical principle and the general principle, which Hamilton had set up for mechanics. The latter was thus generalized so that it could deal with motions of particles and wave processes in closely related fashion and as subject to the same laws ... A complete coincidence between the dynamic laws governing the motion of a mass point and the optical laws governing the motion of a light ray was established. Thus matter had 'become' waves; for the nature of a physical object is determined by nothing other than the laws it obeys."
>
> *(Cassirer 1936, p. 50)*

Before Schrödinger, Heisenberg – as Born and Dirac interpreted him – had already made use of the Hamiltonian Principle in the following way. Heisenberg generalized a formula of Euler in terms of which one can formulate a special conservation law – the law of the conservation of angular momentum for a moving rigid body. This law has a canonical formulation. By a suitable choice of coordinate system, one can express the angular momentum by means of a so called tensor – a linear-transformation – of the rotation of the body around the origin of the coordinate system, on the condition that the body has a definite moment-of-inertia. According to Euler's equation, we can express the fact that the law of the conservation of angular momentum holds for a given system by saying that there *must* exist a coordinate system in which its associated tensor,

[36] (Planck 1929, 192)(Planck 1932, p. 230)

written as a *matrix*, is a diagonal matrix. This was the idea used by Heisenberg in his original formulation of matrix mechanics. In this formulation, the diagonal elements should represent the possible transition processes permitted in a two-body system with a given electron configuration – with a determinate set of possible energy-states of the electron bound within the hydrogen atom, corresponding to the phase-space of this particular physical system.

The Euler Principle states that there must be a certain canonical representation of a special Conservation Law. We may now ask if *any* conservation law must be said to have a similar canonical representation? We can answer this question in the affirmative, if we adopt the Hamiltonian-Poisson representation that was described above: For there is a very close equivalence between the algebraic rules associated with the Poisson brackets and the Eulerian requirement in respect to a diagonal matrix-representation. The former can indeed be seen as a generalization of the latter. This was already acknowledged within classical mechanics.

On this background, matrix mechanics could well be seen as a mechanics based on principles that are analogous to those of the generalized Hamiltonian ones.[37] Heisenberg himself did not realize this at first, but his Göttingen collegue, Max Born, soon realized the essential algebraic aspect of Heisenberg's construction of matrix mechanics.[38] However, the full understanding of the fundamental character of the diagonal-method was first realized a little later, by P. A. M. Dirac. In his first construction of matrix mechanics in 1925 Heisenberg had made use of a generalized Hamiltonianian, but he had not yet realized the correspondence between the diagonal-method and the use of Poisson brackets. As Mehra explains,

> "He reinterpreted the expression for the Hamiltonian of the anharmonic occillator ... he found that no time-dependent terms remained in the kinematically reinterpreted Hamiltonian. The example of the anharmonic occillator showed him that a dynamical problem in quantum theory could be solved with the help of his scheme." *(Mehra 1987, p. 31)*

Thus, it fell to Dirac to construct what became the canonical formulation of quantum mechanics. The original non-relativistic representation of Dirac, from 1925, was the first to explicitly link the algebraic rules of matrix mechanics to the rules governing the operations of the Poisson Brackets. Mehra summarizes this as follows,

> "Dirac tried to connect Heisenberg's quantum-theoretical reinterpretation of kinematical quantities with the action-angle variables of the Hamilton-Jacobi theory ... it occurred to Dirac that the commutator might be the analogue of the Poisson Bracket ... From the quantum conditions expressed in angular variables Dirac found the correspondence between Heisenberg's commutation Brackets and the classical Poisson Brackets for [two dynamic variables X and Y, with respect to two generalized coordinates p and q] Dirac was now safely back on Hamiltonian ground ... He developed a quantum algebra, derived Heisenberg's quantization rules, and

[37] One finds an *excellent* account of these "classical" Hamiltonian principles in Herman Weyl's *Raum, Zeit, Materie*, published in Germany in 1921 – a volume that explains the adequacy of the tensor calculus with impressive clarity. No wonder that Heisenberg came to make use of the mathematical tools developed by his Göttingen colleagues and friends.

[38] See (Mehra 1987, p. 32)

obtained the canonical equations of motion for quantum systems."
(Mehra 1987, p. 35)

However, Planck tended to see Schrödinger's Wave Mechanics as the most complete form of quantum mechanics. For, according to Planck, it is the possible *Eigenschwingungen* of Matter-waves, which constitute those elements in configuration space to which the quantum hypothesis refers.[39] The concept of such *Eigenschwingungen* is supposed to be analogous to the classical concept of the motion of individual material points. Thus – in analogy to the classical canonical equations of motion that govern the possible interplay of such motions, and given that the real motion of a composite system is to be seen as a Fourier-like superposition of harmonic elements in a mathematical Hilbert-space, that each symbolizes the motion of a material "point" of the system – we can now regard the dynamics of given matter-waves as constituted by a set of interactions between individual harmonic elements analogous to the classical Helmholtzian idea of a "kinetic potential".[40]

In a later chapter on Heisenberg we shall see how he holds a view similar to Planck's including the view that the quantum theory involves a generalization and utilization of the principle of least action. To Planck, following the statistical interpretation of the quantum theory as formulated by Born, this has to do first of all with the possibility of associating the notion of matter-waves with a generalized concept of energy. It turns out that we need only introduce a general form of Integral that spans the entire configuration space; such that these integrals can be interpreted as forming elements of a certain Probability Calculus, so that we can define the possible values of any constant of motion that might characterize atomic systems. Here is Planck's formulation of the matter:

> "Wenn aber das Energieprinzip auch für die Wellenmechanik gelten soll, so muß die Energie einer Materiewelle sich darstellen lassen nicht nur durch die Schwingungszahl, sondern auch durch ein über den ganzen Konfigurationsraum der Welle erstrecktes Integral ... [so] daß das Quadrat des absoluten Betrages von [der Wellenfunktion] W ... als die Wahrscheinlichkeit dafür [gilt], daß sich das materielle Punktsystem an der betreffenden Stelle des Konfigurationsraum befindet, und haben damit einen anschaulichen Ausdruck für die gesuchte physikalische Bedeutung der Wellenfunktion W gefunden." *(Planck 1929, p. 194-5)*

Thus, one can derive the principle of the conservation of energy, also in the context of the quantum theory, by formulating a way to interpret a mathematical expression symbolizing a kind of lawfull relation. This is what is required to demonstrate how the formula expresses a framework for certain kinds of conservation laws to hold.

It is important to Planck that the understanding of the possibility of such new forms of conservation laws involves a new kind of *intuition*. In classical physics one can picture or visualize lawful dynamic relations as positioned in space and time. Within

[39] (Planck 1929, p. 193)

[40] Of course, the interpretation of Schrödinger's Wave mechanics will have to be discussed in further detail. Here, I only want to stress how the understanding of the principles of *classical* physical thought, which Planck put forward in 1914, was essentially maintained by Planck after his acknowledgement of both Heisenberg and Schrödinger. Certainly; The Quantum Theory does not involve the radical change in physics which some thinks it does!

the quantum theory, however, one might at best represent dynamic relations in respect to elements in a non-visualizable configuration space, representing the distribution of physical action of possible kinematical elements in a *real*, but abstract, physical space. So in contrast to the classical case:

> "... bietet die Wellenfunktion der Quantenmechanik zunächst überhaupt keinen Anhalt für eine unmittelbare Deutung für die Sinneswelt, schon deshalb weil sie sich gar nicht auf den gewöhnlichen Raum bezieht, sondern auf den Konfigurationsraum ... Sodann aber – und das ist das Gravierende – ergibt die Wellenfunktion nicht etwa die Werte der Koordinaten als Funktionen der Zeit, sondern nur die Wahrscheinlichkeit dafür, dass die Koordinaten zu einer bestimmten vorgegebenen Zeit irgendwelche vorgegebene Werte besitzen." *(Planck 1932, p. 230-1)*

Thus, there is every reason to say that Planck maintained the fundamental status of the principle of least action. He advised us to see quantum theory as involving a generalization of the concept of energy, which again should contribute to the task of our developing a generalized conception of physical lawfulness; a conception needed in order to advance in our search for a more and more objective *Welt-Bild* (I shall say more on this in the following chapter on Planck).

The Histories of the History of The Principle of Least Action

It may be asked how much other writers influenced Planck's viewpoint regarding The Principle of Least Action. The history of the principle was first given with some detail in Adolph Mayers *Geschichte des Prinzips der kleinsten Wirkung* (1877) to which Helmholtz refers. As early as 1871, Ernst Mach had in a way already told an important part of the history of the principle. However, to Mach the principle was but a form of the Principle of Energy Conservation. Thus there are two ways in which Planck considers himself as arguing against Ernst Mach. First, Planck believes that the Machian view of the identity of the action principle and the energy principle compromises the essential character of the former. Second, Planck is critical of the Machian form of *positivism*. Indeed, Mach was also very critical of Planck and it certainly makes sense to read Planck's essay of 1914 on the principle of least action as having the Machian view as a primary critical target.

Mach's conception of the equivalence of a range of physical principles is based on his view that the concept of energy is essentially associated with the idea of the impossibility of a perpetual motion. For Mach "the whole of mechanics is based on this idea".[41] This again, to Mach, is combined with a certain neo-Humean view, namely the view that the theoretical concepts of physics must arise from empirically given impressions. Concepts, including causal concepts, are but mental constructions of empirical observations.[42] Like Hume, Mach makes certain concepts central for the entire cognitive operation of consciousness. Thus the mechanistic view that the world should be seen as some sort of machine is, according to Mach, the primary principle of causal thought. The universe must be regarded like a machine, but not like a clock; any part of the universe behaves in determinate ways relative to any other part. However, the machine *as a whole* has no determinate behavior.

When theoretical physicists generally abandoned the mechanistic viewpoint at the turn of the century, Mach's program suffered a blow. It was however revived by Philip Jourdain in a series of papers published 1912-3.[43] This series of papers provides one of the most detailed mathematical accounts of the history of the principle of least action ever given. I am quite sure that Jourdain's conception of a *mathematical* form of generalization of the principle influenced later writers' understanding of the history of the principle. Yet there is no doubt that Jourdain's considerations as to the *physical* character of the principle were not adapted by any of the leading quantum physicists whom I shall discuss in this volume.

Jourdain's account is Machian despite its many critical remarks about Mach. Jourdain follows Mach in regarding the series of different formulations of the principle of least action as constituting a certain "equivalence class". According to Mach they are all some form of D'Alemberts principle. That is, they all embody a mechanical principle of dynamical equilibrium. In order to uphold this view Jourdain presents the various formulations as each reflecting a variational law of a general mathematical kind.[44] Jourdain points out that the mathematical notion of a variation was gradually generalized in a way not strictly in accordance with the mathematical theory of the

[41] (Mach 1871, p. 32)
[42] (Mach 1871, p. 61-2)
[43] (Jourdain 1913)
[44] (Jourdain 1913, p. 64)

calculus of variation, proper.[45]

This has to do with a way in which Lagrange deviated from Euler's original formulation of an Action Principle in accordance with Lagrange's own mathematical conception of a variation (Jourdain 1913, p. 55). Thus, Lagrange altered the strict mathematical scheme when relating it to a physical principle of variation. This new scheme was not given a mathematical justification until 1896, when Otto Hölder gave an account of the mathematical character of the principle of least action.[46] Hölder had a definite agenda by giving his account. For he was convinced that developing a new mathematical account of variations would be an essential part of a justification of the theoretical scheme of physics formulated by Heinrich Hertz. Hertz had raised the issue of the possible range of application of the principle of least action in his *Die Prinzipien der Mechanik in neuem Zusammenhange dargestellt*, from 1894. There he writes:

> "The application of Hamilton's Principle to a material system does not exclude fixed connections between the coordinates chosen, but it requires that these connections can be exposed mathematically by means of finite equations between the coordinates; it does not permit of such connections as can be exposed only by means of differential equations. But nature itself appears not simply to exclude connections of the latter kind". *(Hertz 1894, p. 19ff)*

This made Hertz propose a distinction between *holonomous* and *non-holonomous* physical systems in order to give a precise mathematical distinction between those multiple-body systems for which the physical principles can be given in the form of a Principle of Integration, and those systems for which they can be given only in the form of differential laws. Against this background it is now possible to characterize the possibility of mechanical systems in a new way. By definition, a mechanical system, as such, is non-holonomous. However, given that the equations of motion in differential form can be derived from the principle of least action, this gives us a way in which to represent a part of any mechanical system as holonomous. As Jourdain puts it:

> "In deducing equations of motion from, say, Hamilton's Principle, we so to speak divide the system into a holonomous and a non-holonomous part." *(Jourdain 1913, p. 60)*

From Hertz's perspective this indicated the need for developing a principle that was *more general* than Hamilton's Principle, a principle that would also govern the behavior of non-holonomous systems. Certainly this formed part of Hertz's wish to *justify* the mechanistic viewpoint and to give a general philosophical account of the logical character of World-Pictures. For both Jourdain and Planck, the suggestion shall be understood differently.

Jourdain follows Hölder in wanting to associate the Hertzian account with a formal notion of the mechanical. There is every reason to say that the early Wittgenstein, and with him the Logical Positivists, adapted this reading of Hertz; a view which is most clearly expressed in the work of Wittgenstein's later pupil, the physicist W. H. Watson, in his interesting book *On Understanding Physics* from 1938. How Planck adapted

[45] (Jourdain 1913, p. 53ff)
[46] (Hölder 1896)

elements of Hertz's philosophy to the mainly Helmholtzian program that figures prominently in Planck's philosophy will be discussed later in the chapter on Planck. But first, I will present the central elements of that program. This will prove helpful, because not only Planck, but also – on my view – Heisenberg and Bohr were to inherit this program.

2.3 Hermann von Helmholtz's Philosophy of Physics

The Background of the Philosophical Program of Hermann von Helmholtz

Hermann von Helmholtz was a professional physician. Because of his special interest in the physiology of the senses, he gradually developed an interest in fundamental issues in physics as well as in epistemology. Helmholtz was influenced by the work of his teacher, the physiologist J. Müller. Müller had advanced The Law of Specific Nerve Energies on the basis of careful empirical research. To Helmholtz, Müller's notion signified an important correction to Kantian epistemology. On the basis of Müller's theory it seemed unwarranted to accept the traditional Kantian notion of *universal* Forms of Intuition; at least it seemed necessary to take into account the *specific* ways in which the different human senses play a fundamental role in the formation of objective appearances. However, just as much as these considerations challenge one aspect of Kantian epistemology they also support some of the other aspects thereof. First of all, Helmholtz maintained the Kantian notion of *appearance* (*Erscheinung*) pointing to a fundamental connection between the directedness of appearances (their *Gegenständlichkeit*) and their lawfulness (their *Gesetzmäßigkeit*). A Kantian appearance is an *intuitive* representation of particular objects in accordance with a lawful conception of these objects. The lawfulness allows that the objects in question are presented as fit for forming meaningful thoughts about them, and for forming coherent judgments about them, e. g. say about the possible causal relations into which the objects may participate.

Helmholtz's adaption of the Kantian notion of appearance would come to play a central role in Helmholtz's mature epistemological writings, especially in the primary work *Über die Tatsachen in der Wahrnehmung*. But it is important to recognize how the idea of objective-lawful appearances took center stage already in the pioneering work *Über die Erhaltung der Kraft*, which of course was the work that soon placed Helmholtz as one of Germany's leading mathematical physicists. The significance of this early work of Helmholtz can hardly be exaggerated. It gave physics a new and clear understanding of the character of *theoretical* physics. It supplied physics with a significant new conception of the character and importance of conservation-principles in physical thought. Last, but not least, it suggested a new perspective on the unity of the physical world – a unity not between individual entities in accordance with this or that causal law, but between such laws themselves. Thus, the primary value of Helmholtz's early work, was the fact that it put forward an idea about the *system* of physical laws. It was Helmholtz's vision to conceive of such a system on the basis of empirical investigations; namely investigations about the possible interaction between different *kinds* of physical phenomena.

Today one might be tempted to formulate Helmholtz's pioneering thoughts as simply launching the notion of "transformation of energy forms" in accordance with the law of energy conservation. Yet, as the title of Helmholtz's groundbreaking text indi-

cates, the present-day notion of energy was still not clearly formulated. *Über die Erhaltung der Kraft* was written at a time when a variety of particular physical disciplines became associated, one by one. The works of Clausius and Carnot indicated the mechanical aspects of thermal systems. Joule had revealed how the notion of mechanical *work* associated with thermal processes could be analyzed in terms of a specific conservation law. Thus one needed to formulate a theoretical thermo-dynamics. Similarly Faraday had revealed how to adapt the notions of electricity developed by Oersted, Biot, Savert, and Ampere into a strict electro-dynamics in terms of which Faraday's own discovery of electromagnetic induction became intelligible. However, it was one thing to associate the individual physical disciplines, the individual fields of physical inquiry, one by one. It was another issue whether they could *all* be incorporated into the same theoretical scheme! It was the latter issue that Helmholtz primarily considered in his groundbreaking work of 1847.

Helmholtz is in a sense a proponent of *mechanicism*, the view that all physical laws have a mechanical character. However, it is important to see what this meant for Helmholtz. He never wanted to reduce, say, electrodynamic laws to mechanical ones. To suggest that all dynamical effects of electromagnetic interaction must be prolonged through a certain "medium" is not necessarily to reduce electrodynamic forces to gravitational ones. Instead the crucial idea is that of physical *action*. As we have seen, there is a principle concerning this concept, *the principle of least action*, that forms a basic part of the mature Helmholtz's vision of a new and unified theoretical physics. We saw how Helmholtz will explain the importance of this principle in a way that would become the cornerstone of all later significant developments of physical thought. However, let us remind ourselves of another aspect of *mechanism*; namely that there is a basic distinction between spatial and other forms of physical change.

At the beginning of *Über die Erhaltung der Kraft* Helmholtz explains his use of terms as follows: The *being* (*Sein*) of what is movable is termed "Matter". But in so far as an individual motion involves the performance of *action* such a motion may be pictured as being carried by a distinct natural object. Thus, in accordance with this picture, the only change which Matter, as such, affect on *itself* is spatial "displacements", whereas the distinct *parts* of the Matter – the specific objects of Nature – instead, undergo changes in respect to the *forces* in accordance with which they interact. That is the sense in which motions have "causes"; to say that two material entities causally interact is to say that there is a possible motion (a possible redistribution of matter in space) that is *characterized* by the way in which the motion involves a spatial redistribution of forces.

Thus, following Helmholtz, one cannot separate the two concepts of Matter and force. Both are abstractions that are necessary for the conception of Nature. The kind of reality we can know theoretically is Matter, in so far as Matter is characterized as "that which is movable in space", and where the phenomenon of motion is understood in terms of a spatial redistribution of forces. In the first edition of *Über die Erhaltung der Kraft*, Helmholtz states these metaphysical views plainly without further justification or explanation. Later he added the following footnote:

> "Die Philosophischen Erörterungen der Einleitung sind durch Kant's erkenntnistheoretische Ansichten stärker beeinflußt, als ich jetzt noch richtig anerkennen möchte." *(Helmholtz 1847, p. 53)*

Indeed, Helmholtz's introduction and explanation of the fundamental concepts of the-

oretical physics is largely in line with Kant's analysis and programme in his *Metaphysische Anfangsgründe der Naturwissenschaften*. Fabio Bevilacqua has explained Helmholtz's adaption of Kant's program nicely:

> "if a general application of the principle of 'force' conservation allowed the reduction of all natural phenomena to the effects of attractive and repulsive forces whose intensities depended only on distance, then 'empirical' causality would match 'transcendental' causality and the goal of physical science would be reached; an 'intelligible' nature would be 'understood'." *(Bevilacqua 1993, p. 308)*

Let me explain this further. Helmholtz first of all follows Kant in his recognition of what is at stake in positing a principle of conservation; namely the very *substantiality* of Nature. This, again, relates to a precondition for acquiring knowledge of Nature. Enter the concept of *transcendental causality*. Appearances may, according to Kant, be attributed a substantial character, as well as attributed a form of interdependence termed "causality", if and only if these attributions refer to a *lawlike* form of interdependence. The possibility of such attributions secures the objective validity of the empirical judgments one might make in respect to these kinds of appearances. That is the transcendental unity between the objective (*Gegenständlich*) and the lawlike (*Gesetzmäßig*) aspect of possible knowledge. Transcendental causality, then, refers to a principle of knowledge, that every appearance associated with material objects *must* have a cause.

This is the Kantian principle of causality. It is a principle in respect to the analysis of possible experiences. It is what Kant called "a Postulate of Empirical Thought", a precondition for entering into rational knowledge-seeking physical research. But it is not an ontological prescription in respect to the determinate causal interrelations that may characterize specific physical systems.[47] In order to describe such interrelations one must introduce *determinate concepts* of possible causal relationships, such as the concepts in terms of which the laws for given kinds of physical systems are formulated, say, Newton's or Maxwell's equations of motion.

So what Bevilacqua rightly observes about Helmholtz's program is this: Regardless of the causal concepts one might introduce into specific physical areas of discourse, they all have to conform to the very principle of causality, to the transcendental notion of causality. Only on the basis of that principle does it make physical sense, Helmholtz would say, to associate any experienced causal effect of given physical occurrences with determinate, objective forms of physical change. Only in the perspective of the principle of causality does it make physical-theoretical sense to regard chains of events as examples of real physical transformations within nature.

There are two things about Kant's notion of a substance that it is important to note. First, Kant followed Leibniz in turning the static notion of substance, as found in Descartes, into a dynamic notion. A "substance", according to both Leibniz and Kant, exists only in so far as it is *changeable*. Thus, what characterizes a substance is not something that remains essentially unaltered through processes involving physical change. What remains constant through change is the form of change (which was what Kant, as later Helmholtz, called the *Wechsel* of the *Zustände* of composite system of

[47] On this, see E. Cassirer's excellent account in (Cassirer 1936) – an account I will refer to below in my discussion of Bohr's understanding of the principle of causality.

objects). Accordingly, one way to describe how the mature Helmholtz inherited the Kantian program is as follows: Helmholtz associated the basic Kantian notion with the Hamiltonian scheme of classical physics, thus forming what today is called the *phase-space representation* of physical processes. After Helmholtz, conceiving well-defined transformations of the energy-*zustände* of given composite systems is the best conception of physical processes.

Second, Kant did not regard the concept of mass as fundamental to the substantiality of (systems of) physical objects. On the contrary, before introducing that concept, Kant first introduced the notion of force (repulsive and attractive) in order to connect the notion of space-time distribution with the notion of causal relations. For Kant as well as Helmholtz, the concept of individual masses is only a derivative of the concepts of force and motion, whereas the general metaphysical notion of matter may be considered as basic. In other words, there is no a priori way in which to associate the idea of substantiality with any a priori notion of solidity. The distribution of masses in Nature is characterized solely by the lawful character of the interplay of forces. This is also a crucial aspect of the program elaborated in *Die Erhaltung der Kraft*.

To the later Helmholtz – and here he breaks with the original Kantian view – the concept of force points back to the received notion of *Vis Viva* (*Lebendige Kraft*) that we would today associate with the concept of kinetic energy. However, the respective force-concept was attributed to material points the motion of which was seen, so to speak, as carrying a force. Motions should be seen not simply as *consequences* of causes. Motions are not "caused", but causally *positioned* in space and time. Where there is matter in motion, there is a power at play, the action of which keeps the particular motion of specific objects – as well as the interplay between these – going. One example illustrating these considerations is the picture of the constant motions of the planets in the solar system as forming a stable system of *forces*.

The action of the motion of material points is expressed by the product $(m * r * v)$ of the mass, displacement, and velocity associated with the motion. The German word for this characteristic feature of possible motions is *Wirkung*. As Helmholtz put it in the following quote, the concept of action is connected with a concept of the *Wirksamkeit*, the interactive character of physical beings. You may call it power – the ability to produce effects on other physical entities. In 1881 Helmholtz expresses the point as follows:

> "Ich habe mir erst später [in 1881, that is] ... klar gemacht, daß das Princip der Causalität in der That nichts anderes ist als die Voraussetzung der Gesetzlichkeit aller Naturerscheinungen. Das Gesetz als objektive Macht anerkannt, nennen wir Kraft. *Ursache* ist seiner ursprünglichen Wortbedeutung nach das hinter dem Wechsel der Erscheinungen unveränderlich Bleibende oder Seiende, nämlich der Stoff und das Gesetz seines Wirkens, die Kraft. Die ... Unmöglichkeit beide [i. e. cause and effect] isoliert zu denken, ergibt sich also einfach daraus, daß das Gesetz einer Wirkung Bedingungen voraussetzt, unter denen es zur Wirksamkeit kommt." *(Helmholtz 18, p. 53)*[48]

[48] This is the continuation of the footnote where Helmholtz compares his early views with those of Kant's. This part of the quote states some insights which Helmholtz achieved after having written *Über die Erhaltung der Kraft*. But they only go to stress his Kantian influences!

The crucial thing is the association of the idea of action with a notion of *configuration*, in the sense of a stable, jointly shaped interplay of forces. Thus, there is an intimate link between the notion of natural powers and the notion of material structure. Indeed, Helmholtz understood himself as being in line with both Leibniz and Kant inasmuch as he was trying to articulate a basic connection between the substantiality and the potential power of material beings. In fact, the notion of *Inertia* expresses precisely this connection, as is better expressed by the German term *Trägheit*. Things are powers and powers are things, in the sense that a physical object may be said to "subsist" within a possible *Über-tragung*, a possible exchange of power with other physical objects. As Helmholtz states:

> "aus dieser [i. e. Leibniz's] Verwendung des Begriffs der Action wird doch deutlich, was ihn bewogen hat die Fortsetzung der eingeleiteten Bewegung unter dem Einfluß des Beharrungsvermögens nicht als einen passiven Zustand, als Inertia, sondern als Actio aufzufassen; denn sie ist Trägerin eines Arbeitsäquivalents, einer Potentia, deren Unzerstörbarkeit er vermuthet, und deren Übergang in andere äquivalente Arbeitsformen, er schon kennt" *(Helmholtz, 1887, p. 252)*

Consequently, Helmholtz wants us to follow Leibniz in picturing *Trägheit* as a Leistung des *Beharrungs-vermögens*; to picture Inertia as a source of action due to the stable character of the items in question. If you like, inertial mass is but a kind of energy. The ability of a given system to subsist through change and the ability to exchange powers with other systems, is one and the same. So causality is not something that may *happen* to material items. Causality is a way of *being* – the kind of being referred to as "material", where "to be" and "to be able to exchange powers" are regarded as the same.

This is why one should conceive of physical objects as always being in motion. Physical "rest" is a state of motion, because the unity of substance and action is exactly what the concept of motion is supposed to embody. So one ought to look closely at the very title of the essay "Über die Er-*haltung* der Kraft". The invocation of the German term for "conservation" (*Er-haltung*) provides a clue. Helmholtz thinks that motion is but one way in which the powers of things can be kept in store. Motion is but a way in which the powers of things acquire a definite and limited spatial configuration, any of which will always stand in some interactive relation to other such configurations.

In relation to all this, it should be noted that Helmholtz intends – as he put it later – to inquire into the ways in which "Systeme unter dem Wirkungen der Kräfte *stehen*".[49] Thus, a real change in Nature implies that physical systems interact so as to "bring systems to a halt". Of course, this involves transforming such systems into stable conditions (*Zu-stände*), and implies the resolution to a determinate energy-state. This is the *uniformity* required of any physical process of change. So, the principle of the conservation of power that was introduced by Helmholtz in 1847 – and which not until several years later was called the principle of the conservation of energy – is in no way just a principle concerning a *measure*. There is no quantity that is kept constant in Nature. What is kept constant is the *uniformity of possible interactions* between different, lawful kinds of physical systems. This is all in accordance with the Kantian view, adapted by Helmholtz, that the subject matter of theoretical physics concerns the

[49] (Helmholtz 1903, p. 303, italics mine)

way in which lawful physical relationships may form part of the stable configuration of given physical systems of objects.

These considerations are contained in Helmholtz's later formulation of the aim of theoretical physics.[50] It will never suffice to know merely about the existence of lawful relationships. Indeed, that is what comes to the fore when the principle of least action becomes the cornerstone of theoretical physics: The point of the principle is precisely that it shall be a regulative principle concerning what it might mean that there are physical processes (within specific systems of physical objects) that can be regarded as lawful in certain respects, e. g. by relating the processes in question to some Conservation Laws). As we shall see, this perspective on the possibility of physical processes characteristic of atomic systems played a fundamental role in both Heisenberg and Bohr's explanation of the principles of the quantum theory.

The Philosophy of the mature Helmholtz

There is no short and easy way to characterize Helmholtz's philosophical thoughts.[51] He was well acquainted with philosophical literature, especially the works of Kant, Fichte, and Goethe. But although his own views were formed under the great influence of a series of important German philosophers from Leibniz on, Helmholtz deliberately wanted to modify a number of their respective philosophical concepts. In a sense, he even wanted to shift the focal point of some of their philosophical inquiries as well. However, one issue remained important to Helmholtz, namely the issue of how the knowledge obtained by the natural sciences should be fitted into a broader system of knowledge. This issue comes to the fore in the two essays "Über das Verhältnis der Naturwissenschaften zur Gesammtheit der Wissenschaft" and "Über das Ziel und Fortschritte der Naturwissenschaft".[52] Also, it colors the content of the two essays that Helmholtz wrote about his understanding and estimation of the theoretical works of Goethe.[53]

At the outset of the essay on the relationship between the natural sciences and other forms of science, Helmholtz reminds his readers how the critical philosophy of Kant was directed at an inquiry into the sources of knowledge. This leads Helmholtz to claim that if we refer to any proposition as being a priori and necessary in respect to the possibility of acquiring various forms of experience, then we are merely proposing a "rule for the method of conceptual thought". Consequently, according to Helmholtz, the claims we make concerning the a priori status of such propositions do not themselves have a "positive content". Moritz Schlick, who was one of the editors preparing the publication of Helmholtz's epistemological works, understood these words of Helmholtz as implying a fundamental break with the original views of Kant. Helmholtz, Schlick stated, turned the *constitutive* rules of the Understanding into *regulative* rules for human Reason. This again implies turning the Kantian constitutive

[50] Helmholtz formulates the aim as that of reaching a "Kenntnis des Be-stehens eines Gesetzlichen Verhältnisses" (Helmholtz 1878, p. 128)

[51] For a detailed and brilliant study of the various phases in Helmholtz's understanding of natural philosophy in general, and mechanics in particular, see (Schiemann 1997). Schiemann and I seem to have slightly different views on the early Helmholtz's idea of mechanics; and that is perhaps because we also have different views on Kant's natural philosophy. Anyway, this is the reason why, in the following, I consider only the philosophical thoughts of the "mature" Helmholtz, from 1862 and on.

[52] (Helmholtz 1884)

[53] (Helmholtz 1853)(Helmholtz 1892)

principle of causality into a regulative principle in respect to scientific methodology. However, although there *is* something to what Schlick says about how Helmholtz followed and did not follow Kant, this succinct characterization is incomplete.

As we have seen, the Kantian principle of causality was never simply a constitutive principle for the Understanding; it indicated a postulate of empirical thought governing the formation of any specific *concept* of causality. This again has to do with the requirement that the categories of the Understanding be schematized; which again has to do with the possibility of producing an intuitive exposition of these concepts. Given all these parts of Kant's epistemological program, there will be, and have been, many ways it may be modified. The mature Helmholtz, in line with Fichte and Schelling, first of all challenged the Kantian notion of a "form of intuition". This implies denying that the notions of "space" and "time" are a priori in respect to the intuitive representation of things. There can be various such forms of intuitive representation, all of which have equal significance and justification in different contexts.

The important thing is what this view implies in respect to the essential link between intuitions and concepts. Importantly, one thing that follows is a renunciation, or modification, concerning the requirement of schematizing concepts. Therefore, there emerges a different view about the link between intuitions and concepts, and accordingly a different answer to the question concerning the point of there being a canonical exposition of how the objects of given concepts can be intuitively represented. In other words: It is the Kantian idea of a Doctrine for Conceptual Judgment that is modified. As Catherine Chevalley has pointed out, Helmholtz's modification of Kant was based partly on one of Kant's own ideas – the idea of a "symbolic" representation that Kant introduced in his *Third Critique* – but was also based partly on the way in which Goethe turned Kant against himself by using elements of the *Third Critique* in a critical assessment and modification of the *First Critique*:

> "What is especially interesting in Helmholtz's thought [as to this] is that he systematically suggested enlarging the Kantian concept of 'Intuition' in order to make room for the activity of Symbolization, in the mood of Goethe's 'rational empiricism'. This was the general aim of his famous 1878 lecture on 'The Facts in Perception', which began with an evocation of, notably, Goethe, Schiller, Kant, Herder, W. Humboldt, Schleiermacher, and Fichte. Here Helmholtz adopted three different points of view. First he recalled that his own theory of visual and acoustic perception entailed that our sensations were only symbols and signs, and not images, since they bore no resemblance with the object represented ... Second, Helmholtz asserted that language and art exhibit the same feature; to learn a language is to learn 'symbolic correlations' and similarly art is no copy, but a means to create a new kind of 'visible reality' ... Third, Helmholtz described Riemann's works on non-Euclidean geometry together with his own to conclude ... that there was no necessary connection between the axioms of geometry and the Kantian forms of intuition ... Therefore perception, language, art, and science were all on the same level, none of them being exactly a representation in the Kantian sense, but rather a mode of Representation (*Vorstellungs-Art* – in Goethe's wording) which did not require a direct representation of the concept in sensible intuition [not require a 'Schematism']." *(Chevalley, 1994, p. 46-7)*

This is why it becomes important to ask whether it makes sense to talk about various *forms* of intuition such as "sensuous", "mathematical", "psychological", "intellectual", or "artistic". If such talk is considered sensible, one might suggest that for any of the related fields there will be different ways in which the unity between intuition and thought comes about. Thus it would be reasonable to inquire into the history of the development of forms of intuition, and it would be possible to see this as a way in which to inquire into the history of conceptual thought. This would provide us with an overview of the different ways in which human thought could be situated within the very World to which all the various forms of intuition are directed. Something similar to these considerations was articulated by many of the writers who seem to have inspired Helmholtz.

Recalling this line of thought helps us understand how Helmholtz, despite his clear insistence on giving philosophical concepts a factual sense, nevertheless maintained a definite metaphysical conception of the natural sciences. These intellectual practices are seen as forming one, and only one, out of a range of many intellectual practices whereby a harmony is establish between Nature and Spirit.[54] One might suggest that Helmholtz simply latches on to the term *Spirit* because it refers back to the German term for the human sciences (*Geisteswissenschaften*), but this is not so. It is very clear in Helmholtz's writings how he uses the term within a more general framework.

In relation to this, it is worth noting how the mature Helmholtz invokes the concept of *trust* (*Vertrauen*). One might even say that the later philosophical program of the mature Helmholtz is based on a notion of trust that he adopts from Goethe. The view in question refers to the development of the various ways in which human beings may establish a trust in what they experience. According to Goethe, the concept *trust* reflects a possible form of harmony between *Welt* and *Geist*. It refers to a form of immediate contact, allowing Spirit to dwell within the *World-as-experienced* in a way that does not require any form of reflection. In such a situation of trust there is no need for an intellectual understanding of the coherence within a range of experiences. Trust is in itself a coherent way in which a co-existence of the World and an embodied Spirit is actualized.

The important thing about all this, for Helmholtz, was to realize how a law of nature must necessarily be instantiated in individual observations. One should recognize this when asking how a law of nature is part of a *system of laws* defining the possible causal relationships. It is this, which brings Helmholtz to associate the original Kantian principle of Causality with Goethe's notion of trust; namely *a trust in the lawful character of Nature*:

> "Jeder Induktionsschluß stützt sich auf das Vertrauen ... Es ist dies ein Vertrauen auf die Gesetzmäßigkeit allen Geschehens. Die Gesetzmäßigkeit, aber, ist die Bedingung der Begreifbarkeit. Vertrauen in die Gesetzmäßigkeit ist also zugleich Vertrauen auf die Begreifbarkeit der Naturerscheinungen. Setzen wir aber voraus, daß das Begreifen zu vollenden

[54] The term *Spirit* (*Geist*) is used in the sense of the German Romantic philosophers. The notion points to a form of self-conscious Being, transcending any of the particular forms of human Reason, while still embodying the movement whereby new such forms can be established. As such it refers to the very rationality of developing human Reason, although it is implied that no particular form of Reason, as such, can ever constitute that rationality. As we shall see, neither Planck nor Bohr shies away from making use of such a concept of Spirit.

> sein wird, das wir ein letztes Unveränderliches als *Ursache* der beobachteten Veränderungen werden hinstellen können, so nennen wir das regulative Prinzip unseres Denkens, was uns dazu treibt, das *Kausalgesetz.* Wir können sagen, es spricht das Vertrauen auf die *volkommene Begreifbarkeit* der Welt aus." *(Helmholtz 1878, p. 133)*

In his essay on progress in science Helmholtz explains this further: The observation of things in nature is important, not just because we successively observe individual occurrences, but also because we make observations about the lawlike character of *individual* occurrences. As Helmholtz explains:

> "Ein Naturgesetz ist aber nicht bloß ein logischer Begriff ... Wir müssen sie vielmehr in den Thatsachen *entdecken*". *(Helmholtz 1869, p. 39)*

To give an example referring to the biological sciences, Helmholtz states:

> "daß auch hier die einzelne Beobachtung nicht als einzelne ihren Werth hat, sondern weil sie zur Kenntnis der Gesetzlichen Regelmäßigkeit im Körperbau einer ganzen Species von Organismen verhilft".
> *(Helmholtz 1869, p. 39)*

So what does it mean to observe the laws of Nature in the individual facts? The issue has to do with the interrelation between intuition, conception, and representation. It also has to do with the issue of how this interrelation may become gradually qualified. Indeed, this is the primary theme of *Die Tatsachen in der Wahrnehmung*. In that essay Helmholtz declares:

> "Ich verlange für den Beweis der Anschaubarkeit nur, daß für jede Beobachtungsweise bestimmt und unzweideutig die entstehenden Sinneseindrücke anzugeben seien, nötigenfalls *unter Benutzung der wissenschaftlichen Kenntnis ihrer Gesetze*, aus denen, wenigsten für den Kenner dieser Gesetze, hervorgehen würde, daß das Betreffende Ding oder anzuschauende Verhältnis tatsächlich vorhanden sei".
> *(Helmholtz 1878, p. 123, italics mine)*

Thus, according to Helmholtz, there is an interplay between concepts, laws, and whatever is produced by memory in the process of observation. It should be noted how Helmholtz illustrates the issue: He wants to clarify the notion of "the fact in Perception". In other words, he wants to associate any observation with the production of certain impressions (*Sinneseindrücke*). However, Helmholtz thinks, an "impression" is but *a sign*, in the sense that is has no necessary resemblance to what it refers to.[55] So, to make an *observation* is more than just noting what is signified by some experience; it is more than noting the presence of something. Observing is also becoming conscious of *how* it is that the presence of the given thing includes a representation thereof. So this is how the *form* of intuition is more than an un-analyzable precondition of the representation of things. The observation involves the observation that a given item represented in experience counts as a manifestation of a certain form of intuitive understanding. This is the sense in which our observations may transcend any immediately given form

[55] (Helmholtz 1878, p. 115)

of intuition, such that the intuitive and the discursive sides of our observations become reflected in one another.[56]

This Goethean view of Helmholtz has implications for the analysis of the possible structure of conceptual thought, and thus also for what counts as an adequate understanding of the various domains within Nature. Chevalley has presented these implications as follows:

> "Goethe moved on to a study of the symbolic and metaphoric nature of scientific language in general. He became convinced that the 'symbolism' of scientific concepts was rooted in what Kant had called the 'anthropomorphism of language' and he presented himself as a 'rational empiricist'. All scientific languages originate in experience; however, they do not copy or represent what is given in the experience. Rather they represent that which we already grasped through former linguistic modes of expression. 'Objects' (*Gegenstände*) of Nature are thus like 'acts' (*Tätigkeiten*). Language is dynamical, contributing essentially to the building up of scientific knowledge. – Epochs of science are also specifically characterized by the use of particular sets of metaphors." *(Chevalley 1994, p. 45)*

However, in addition to Helmholtz's acknowledgement of these Goethean considerations, to the effect that the practice of scientific conceptualization involves observing a unity between human Reason and the World, there is another Kantian theme that comes to the fore – the issue of how human action is constrained and conditioned; and so, the issue of human freedom. On the one hand, we can never escape conditions imposed by the reality of things. On the other, it would be an empty gesture to point to any pre-given conditions for human action, either due to the nature of things or to our own nature if it was not further explained *wherein* the possibilities allowed under the given conditions consist. This means first of all that we should be able to specify what the characteristic features of *human* action should be. We must be able to give an account of what is at stake in the interplay between conditions and possibilities in respect to the interests, motives, powers, and values of a conscious being.

The paradigmatic case of such an account is, of course, Kant's demonstration of how duty is, and is not, a characteristic feature of any morally adequate action. What Kant wanted to demonstrate was that we must learn to conceive of the conditions that are imposed on our lives as conditions relating to a fundamental requirement that human beings impose on *themselves*. We impose a requirement on ourselves as an expression of our possession of Reason, one of the chief features of which is, precisely, that it must continue to question and challenge itself. As we shall now see, Helmholtz did indeed adopt such Kantian reflections on the interrelation between Nature and human Will. As stated in the following quote, Helmholtz underscored the point that our theoretical Judgment must always have some relation to our practical Judgment; at least in the sense that the separation between the two kinds of Judgment is conceived in a clear and significant manner:

> "Unsere Forderung, die Naturerscheinungen zu *begreifen*, das heißt ihre *Gesetze* zu finden, nimmt so eine andere Form des Ausdrucks an, die

[56] Such a consideration of the variety of possible forms of observation, each being relative to some "arrangement" of the "material" to be observed, would comprise part of Bohr's understanding of the practice of experimental science as well.

> nähmlich, daß wir die *Kräfte* aufzusuchen haben, welche die *Ursachen* der Erscheinungen sind. Die Gesetzlichkeit der Natur wird also als causaler Zusammenhang aufgefaßt, sobald wir die Unabhängigkeit derselben von unserem Denken und unserem Willen anerkennen."
>
> *(Helmholtz 1869, p. 40-1)*

But the interconnection between theoretical and practical Judgment, according to Helmholtz, is even more tight. Our reflections on the nature of things cannot be separated entirely from reflections on the character and shape of the freedom involved in our activities. As highlighted in the quote above, the natural sciences form a case in point. Reflecting philosophically about the possible structure and content of theoretical thought will have to include considerations of what makes possible a "free" scientific *practice*.

So, according to Helmholtz, we must associate these Kantian considerations with those of Fichte in order to be able to make sense of the possibility that new intuitive forms of understanding come about successively. We shall then acquire a certain grasp of how the same intellectual "I" may successively unfold itself in new ways, say, in relation to new scientific methods of observation. Indeed, it was important to Helmholtz to acknowledge such a Fichtean dimension in our philosophical reflections. Thus, I agree with M. Heidelberger's that,

> "it was neither Kant alone nor his epistemology that decisively influenced Helmholtz's philosophy of science. Instead, Helmholtz's philosophy and methodology of science were far more influenced by Kant's metaphysics of nature, by the idealism of J. G. Fichte, and by M. Faraday's views on the nature of force and matter ... *the inner core* of Helmholtz's philosophy of science had its roots in Fichte's philosophy. In particular Fichte's philosophy of Action ... From Fichte Helmholtz appropriated the view that our consciousness comes to shape its conception of the outer world through the limitations we experience in our practical doings".
>
> *(Heidelberger 1993, p. 462-3, italics mine)*

It is interesting, and important, to acknowledge how a similar neo-Fichtean viewpoint was adapted into the philosophy of Niels Bohr. Bohr accepted the principle that the application of any theoretical concept only makes sense if its use is associated with a clear separation between the knowing Subject and the observed Object. However, Bohr would insist, there is no single *division* between the Subject and various objects. The boundary can be placed in different ways. Now, one should not ascribe Helmholtz's particular neo-Fichtean view to Bohr. But it might still be adequate to associate Bohr's principle with a neo-Fichtean tradition. Accordingly, there may be reason to say that Bohr's principle relates to the very distinction between *World* and *I*. This distinction (*Welt/Ich*), it must be clear, is quite different from the distinction discussed in most textbooks in epistemology of the Anglo-American kind between an individual consciousness and the objects which such a consciousness might experience.

The influence on Helmholtz from Kant, Fichte, and Goethe that I have presented are integrated in Helmholtz's analysis of scientific experimentation. The performance of experiments requires methods of observation, which again involve human, reflexive activity. However, we cannot do experiments at will. Nature, or the reality of things, puts constraints on our possibility of performing experiments. But it also gives shape

and power to these. The performance of experiments is, in a sense, an investigation into what Nature allows there to happen in accordance with forms of lawfulness. In a sense, both Heisenberg and Bohr would inherit this neo-Fichtean view, although in a new "linguistic" version, to the effect that what it is possible to say about objective Reality is connected essentially with how we can perform and describe various types of experimentation.

As we have seen above, the reality of things, according to Helmholtz, is demonstrated by revealing a form of *Wirksamkeit* in respect to them – demonstrating, so to speak, their power to withstand regardless of what we intentionally may want to do with the objects in question. The reality of things, as well as of laws, is that they can hit back, proving that we cannot master Nature at will, which leads Helmholtz to state:

> "[es] ist klar, daß eine Scheidung von Gedachtem und Wirklichem erst möglich wird, wenn wir die Scheidung dessen, was das Ich ändern und nicht ändern kann, zu vollführen wissen. Diese wird aber erst möglich, wenn wir erkennen, welche gesetzmäßigen Folgen die Willensimpulse zur Zeit haben. Das Gesetzmäßige ist daher die wesentliche Voraussetzung für den Character des Wirklichen". *(Helmholtz 1878, p. 132)*

It follows from this view – that lawfulness is a characteristic feature of the reality of things – that one must not consider our conceptual grasp of nature in abstraction from our active and skilled performance in carrying out methods of observation. Indeed, the term "Tat-Sache" that enters the very title of the essay *Die Tatsachen in der Wahrnehmung* is an expression of this interdependence between the World and our Thought.

Consequently, for Helmholtz, the experimental tradition of the natural sciences should not be seen simply as part of a knowledge-seeking enterprise. The establishing and development of that tradition, by its very example, form part of an extension and enrichment of human culture. Such considerations brought Helmholtz to make the following statements about the fundamental hierarchical connection between the natural sciences, the social sciences, and the Arts:

> "So haben also die Wissenschaften einen gemeinsamen Zweck, den Geist herrschend zu machen über die Welt. Während die Geisteswissenschaften direkt daran arbeiten, den Inhalt des geistigen Lebens reicher und interessanter zu gestalten ... so streben die Naturwissenschaften indirekt nach demselben Ziele, indem sie den Menschen von den auf ihn eindrängenden Nothwendigkeiten der Außenwelt mehr und mehr zu befreien suchen". *(Helmholtz 1853, p. 33)*

> "Beide, Künstler wie Forscher, streben, wenn auch in verschiedener Behandlungsweise, dem Ziele zu, neue Gesetzlichkeit zu entdecken". *(Helmholtz 1878, p. 135)*

> "Die höchste Art des Anschauens, wie wir sie im Schauen des Künstlers finden, ist ein ... Erfassen eines neuen Typus der ruhenden oder bewegten Erscheinung des Menschen und der Natur". *(Helmholtz 1878, p. 124)*

These views are interesting, not only because they are so typical of the time in which they were formulated, but also because the views were adopted, with some modifications, by both Planck and Bohr.

What is more, all these considerations give an interesting perspective on our historical account of the principle of least action as well as on the view that the principle forms the cornerstone of all physical science. The principle of least action was seen by Helmholtz, not as itself a law but, as E. Cassirer put it, as the *source* from which all laws may spring. So the principle of least action is a symbol for the concentration of human intellectual energy into a deliberate and definite effort to discover new forms of lawfulness within natural appearances. Thus, a picture of human Reason emerges in dialogue with itself. For not only are new kinds of law discovered, there is also a gradual shift in what it means for there to be "lawful" connections between natural appearances.

Consequently, one might view the principle of least action as symbolic of this essential character of our knowledge-seeking enterprise. It symbolizes, as E. Cassirer later put it, that our intellectual grasp of Reality gets more and more concentrated, while it is still receptive to a constantly growing range of different kinds of lawfulness. Cassirer even stated that this feature of concentration forms the most important feature of the quantum theory, in that all possible physical phenomena can be formulated in terms of a few quantum rules, thanks to a revised application of the principle of least action.

In making this claim Cassirer adopted an idea of Planck's concerning the emergence of the so-called *constants of Nature*, like the velocity of light in a vacuum (c), the elementary charge of the electron (e), the mass of the electron (m_e), and so on. The important thing is that these constants are not constants of any substance (like the quantities associated with specific heat, specific mass, viscosity coefficients or electric conductivity).

Now, all of the constants of Nature are in some sense associated with an idea of an "objective" quantum. These ideas, each of which are associated with a certain constant of Nature were, as we shall see, characterized by Bohr as *Postulates*, including the Quantum Postulate associated with the Quantum of Action (h). The Postulates concerning the various constants of Nature all point back to the link between the principle of least action and the principle of energy conservation. Thus, they add a new meaning to our conception of the possible kinds of lawfulness that should be introduced into theoretical physics. That is how our idea of what it means for there to be laws of conservation is gradually modified. The explicit and joint utilization of the series of constants of Nature within the quantum theory accordingly helps us to justify the claim that this theory is the latest and greatest in respect to our understanding of laws of conservation. To sum up: The neo-Fichtean views have led us to consider the character of our understanding of objective lawfulness. This line of thought that Cassirer tried to capture in the term "concentration", and which he related not the least to the idea of quantum numbers, was already developed by Helmholtz. Indeed, the link between "numbers" and the principle of unity, in both Reality and Thought, was a focal point in Helmholtz's long and pioneering essay *Zählen und Messen, Erkenntnistheoretisch betrachtet*.[57] The essay contains a detailed study of the foundations of a mathematical conception of (physical) reality. The upshot of Helmholtz's analy-

[57] (Helmholtz 1887a)

sis in the essay is to demonstrate the intimate relationship between the possibillity of something's being invariant under various transformations [on the one hand] and the possibility of representing physical relations as magnitudes (*physische Verhältnisse als Größe hinstellen*)[on the other hand]. Helmholtz draws a direct connection between the unities of physical magnitude (*Einheiten*) and the concept of unity at stake in the natural sciences that "lies deep in our formation of concepts" (*tief im Wesen unserer Begriffsbildung begründet*). As we shall see, this is indeed an aspect of Helmholtz's thought that was adapted by both Planck and Heisenberg, and to some extent by Bohr. They all wanted to inquire into what lies at the root of the formation of concepts. They all followed Helmholtz in answering this question by analyzing how certain forms of mathematical description have the principal character they have in the experimental sciences. Catherine Chevalley explains the importance of this by alluding once again to Goethe:

> "Goethe pointed to the fact that scientific language operated with ... a symbolic mode. Humboldt extended this to the structure of all known grammars and to the formation of language in general. During the second half of the nineteenth Century, science experienced new developments (notably in the crisis in geometry), and Helmholtz suggested a generalization of the concept of 'Symbol' to all knowledge, which also meant that physical and mathematical knowledge were seen as having the same structure as art and language.
>
> Indeed, the genealogy of the distinction between *Anschauung* and *Symbol* does not stop here. Heinrich Hertz also developed a whole epistemology based on the concept of '*Symbol*'." *(Chevalley, 1994)*

As does Chevalley, one should note how two of Helmholtz's pupils in particular were influenced by his program for theoretical physics. One pupil, Max Planck, inherited it entirely, although Planck would add to it some of the original ideas of another pupil of Helmholtz's, Heinrich Hertz. The latter's approach to Helmholtz's program was more radical. His account of the principles of physics, that differed in several respects from Helmholtz's account, would inspire not only Planck, but also Ludwig Boltzmann and Ludwig Wittgenstein, both of whom presented Hertz's scheme in terms of a set of linguistic principles, freed from the form of Mechanism in which Hertz himself believed.

However, it was certainly the more traditional neo-Kantian approach of Helmholtz and Planck that would be carried over to the quantum theory (as well as to the theory of relativity). But there is one aspect of the Hertzian linguistic approach worth mentioning: Hertz followed Helmholtz in believing that a set of formulas could only be said to express basic physical conceptions if there was a way to analyze the formulas in terms of principles. Thus at least one characteristic Kantian line of thought was maintained by Hertz – namely the idea that the first task to fulfill in order to introduce a theoretical conception in physics will be to state clearly certain principles governing the *formal aspects* of the proposed conceptions in question. The exposition (*Darstellung*) of the proposed concepts shall, in a clearly defined way, count as grounding a definite picture of the kind of physical reality in question. Not only Boltzmann, but also Planck (and of course Wittgenstein) caught on to the idea of such a principle governing the connection between certain forms of mathematical formulas and the *Welt-bilder* in terms of which physical regularities may be *dargestellt*.

Regardless of the influences of Helmholtz's works, one thing is certain. The program of Helmholtz's helped bring about a widespread consensus about the very idea of a coherent form of theoretical physics, including certain ideas about how the set of formulas in physical thought constitutes a conceptual scheme. These ideas however, first became commonplace at the turn of the 19th Century. And almost as soon as they were established, implying the construction of a new canon for theoretical thought, the ideas were challenged. Within twenty years they were even dismantled entirely. Yet, it is these extremely short lived ideas that have earned the name "classical physics".

For it was in fact this recent attempt to systematize physical thought that was attacked and demolished by the advent of Quantum Physics. All of what both Niels Bohr and Werner Heisenberg wanted to say about the relationship between classical and quantum physics, I claim, relates to this recent creation that was articulated in a small number of writings like Helmholtz's *Vorlesungen über theoretische Physik*, Ludwig Boltzmann's *Vorlesungungen über die Prinzipien der Mechanik* and Heinrich Hertz's *Über die Prinzipien der Mechanik*.

However, before our discussion of the dismantling of classical physics can begin, I have to present a number of views held by Planck and Heisenberg because some of these views will lend support to one of the primary theses of this study: That the truly radical but also short lived conceptions of physical thought introduced between 1830 and 1930 never gave rise to any new and radical form of *metaphysics*. The physical theories underwent many revolutions in respect to their mathematical character and their relation to experimental support. Still, all this did not outdate any age old *philosophical* outlook. We shall say, instead, that physics finally caught up with the complexity and richness of certain forms of philosophical thought. This view was precisely the view held by both Planck and Heisenberg, and I shall elucidate their respective accounts of the view in the following two chapters.

2.4 Max Planck and the Philosophy of Unity

Unification and Generalization in physical thought

Max Planck may be remembered mainly because of his bold introduction of the concept of discrete energy states. He made this conjecture as part of his successful attempt to explain the inadequacy of the Raleigh-Jeans radiation law in the case of blackbody radiation, the temperature-dependent radiation of electrodynamic waves from within a small cavity under the condition of thermal equilibrium. Since T. S. Kuhn's historical account of the development of the concept of energy quanta in the works of Planck, it is commonly accepted that Planck, by launching the quantum hypothesis, did not consider himself as breaking with classical physical thought. In fact, Planck is himself quite explicit on this matter. Planck even regarded Einstein's work, including both the special and the general theory of relativity, as forming "the crown of classical theory".[58] It was after the advent of quantum mechanics in the mid-twenties that Planck first acknowledged a break had taken place within the classical form of physical theory.

The interesting thing about the specific moment when Planck, the father of the quantum hypothesis, himself recognized a "quantum turn" is this: It is reasonable to regard the essays of Planck written between 1900 and 1920 as giving a very faithful account of what *classical* physical theory is all about, which perhaps should be no

[58] (Planck 1926, p. 167)

surprise. At a time when the limitations of a given tradition become more manifest, the leading proponents of the tradition will certainly need to explain its principles and aims with careful precision. Helmholtz lived long enough to contribute to doing just that. The same was true of Boltzmann and E. Mach. A younger generation including names like Poincaré, Duhem, Jourdain, H. Hertz, and Planck finished the job. As I stated at the end of the last chapter, the construction of classical theory in a sense took place between 1880 and 1910 and was a dominating agenda of the time.

This view in no way implies that classical theory is *merely* a "construct". The followers of the quite recent tradition of theoretical physics mentioned were certainly trying to analyze the foundations characterizing a tradition that had unfolded since the time of Leibniz, Newton, and Maupertuis; a tradition within Natural Philosophy. But as I shall have occasion to discuss later in my presentation of the philosophy of Niels Bohr, there is a sense in which the canons and principles of a given tradition may stand in need of clarification. Not only was the question raised what was the possible range of application of the concepts employed within theoretical physics, it was also necessary to clarify what should, and should not, be regarded as constituing the differences between theoretical physics and other intellectual traditions within our modern culture.

In this section I wish to present the primary philosophical ideas of Planck. Thus, I will postpone my presentation of Planck's philosophy of quantum physics until the following section. The importance of the philosophical thoughts of Planck lie, in my view, in this: Planck can in many ways be said to have made the views of Helmholtz more precise, in two different senses of the term. The terminology and the questions put forward by Planck are connected with those originally formulated by Kant more clearly and systematically than were those introduced by Helmholtz. But Planck also produced a better and more coherent form of conceptual analysis.

The philosophical program of Planck may be expressed in one sentence: *Vereinheitlichung durch Abkehr von Formen der Anthropomorphismus* (Unity by means of leaving behind various kinds of anthropomorphism). Planck follows Helmholtz in two ways. First he adopts the programme of unifying various forms of lawfulness (*Gesetzlichkeit*) and thereby establish a new kind of unity in physical theoretical thought (*Einheit des Physikalishen Weltbildes*). This idea actually forms the title of Planck's most important philosophical essay, delivered in Leiden in 1908. Second, Planck follows Helmholtz in believing that theoretical concepts, like "force", "energy", and "momentum" are in some sense related to ordinary language. To Helmholtz, but as we will see, not to Planck, the original meaning of physical concepts is associated with an anthropomorphic understanding. For instance, the notion of energy was originally associated with the notion of *Triebkraft* (mechanical power of steam engines or of horses).

But Planck differs from Helmholtz concerning the way in which we can account for a possible change in the meaning of theoretical concepts. This is one of the issues that Planck analyzes more systematically than Helmholtz. The latter followed Goethe's understanding of the issue: When creative and able minds manage to *Schau* the world anew, when a new *Vertrauen* in individual facts come about, it is to some extent left open which concepts it is possible to apply adequately to given states of affairs. For Helmholtz it is only the *philosophical* concepts, like "observation", "experiment", "explanation", "appearance", etc., that would retain their original appropriateness, although they would have to be supplied with a new "factual sense". To Planck, the concepts that retain their adequacy, even if they each may be regarded as expressing "a new sense", are the concepts of theoretical *physics*. Thus, it is Planck who formulates

the idea of a constant universalization of the theoretical concepts of physics; an idea that was later used by Bohr.

Importantly, then, Planck may be said to fuse together the two notions of *Vereinheitlichung* (in the Helmholtzian sense) and *Verallgemeinerung*. This fusion, or instead, the infusion of the notion of *Verallgemeinerung* into the program of Helmholtz, has to do with Planck's adaption of the Hertzian notion of a World-Picture (*Welt-Bild*):This brings us to consider the distinction between a "World of Sense" and "The Real World". I will argue that Planck conceives of this distinction in a more "rigid" fashion than did Helmholtz.

Pursuing the Goethean idea of a *metamorphosis*, Helmholtz advanced a radical view concerning sensual experience. For Helmholtz there is no "sensible" world of colors that can be strictly separated from a theoretically grasped world of electro-magnetic waves. For Planck "the world of sense", so to speak, constitutes a world of its own (in the neo-Kantian sense of a special domain of intuitiveness forming *eine anschauliche Welt*), distinguished from any of the domains of conceptual thought. There is a tension between the Goethean idea of "metamorphosis" and the Planckian idea of the "non-anthropomorphic" features of things. From Planck's perspective, the distinction between what is and what is not anthropomorphic cuts through the entire field of metamorphosis.

The universalization of given concepts is a process that involves giving up commonly used intuitions. On this issue Planck is more radical than was Helmholtz. One might illustrate the difference as follows: The latter would stress that there is an unlimited series of ways to picture, say, material entities, such that original forms of sensual experience play a diminishing role in our physical experience. But some idea about our sensing experiences, within a new *Vertrauen*, will remain. In contrast, Planck would stress that we have to give up the idea of a special link between the concept of a "physical item" and some kind of intuitive representation of a "material quality". So, even though seemingly basic forms of intuitive representation – like the space-time representation of physical states – may go by the wayside, theoretical concepts like "mass" and "energy" may remain.

Later, Ernst Cassirer would summarize the view of Planck by pointing to a gradual shift in the always-crucial link between the intuitive and the discursive features of our experience. The importance of that link remains. It is only the way in which original forms of sense experience may be said to shape the link that is put in question.

But why does the universalization of our concepts go hand in hand with a turning away from an anthropomorphic intuition? In spite of Planck's general Kantian outlook, he saw no special reason to relate the concept of force to some original notion of the power of muscles, as did Helmholtz. Instead, Planck considers the issue of how the conditions for applying a given concept can be related to the triad of the "particular", "general", and "universal" (*einzelnes, besonderes, allgemeines*).[59] Indeed, it is this triad one has to invoke in order to make sense of the notion of *Verallgemeinerung*.

There is a kind of generality in the manner in which the conditions for the possibility of applying any theoretical concept were originally given within a framework of sense experience. Theoretical notions are "general" in the sense that their possible applications span a range of particular instances. But there is another sense in which the

[59] Socrates is *one* man (the particularity of being Socrates). He is a *unique* exemplar of the human kind (the generality of being Socrates) and his being a man is what is *essential* about being what he *is* (the universality of being Socrates).

condition (for uniting the particular and the general) can be conceived as *universal*. It was part of the neo-Fichtean view, which was outlined earlier, that the development of a new theoretical understanding involves gradually becoming aware of a universal character of human intellectual activity. This view was in a sense accepted by Helmholtz. As we saw in the last chapter, Helmholtz held the view that the kind of human reasoning that characterizes the development of the theoretical sciences implies a certain kind of concentration. We saw that this concentration had two sides to it. (a) Human Reason was in a certain dialogue with itself, and (b) our intellectual grasp of things was gradually directed more specifically towards distinct features of the reality of things.

It is the latter – the character of a constant *specification* of human thought – that is at issue, because what seems to be missing in Helmholtz's view is the basic interconnection between such a specification and the Universalization of the objects of human thought.[60] So this, I conjecture, explains the different way in which Planck, and later Cassirer, understood the emergence of the constants of Nature. Each of these constants symbolizes particular forms of lawfulness. To both Planck and Cassirer, the unification of the different constants of Nature (each established within new forms of physical theory) symbolized something profound concerning, not only the unity of Nature, but also the way in which this unity comes to the fore within the unity of thought.[61]

All this is part of a new understanding of what it means to ascribe certain directions to human thought. In the context of theoretical physics, Helmholtz introduced the notion of a direction (*Richtung*) of physical thought. Planck, and with him Cassirer, adapted the notion, but they both associated it with an understanding of the *systematic* inter-relation of such directions. The directions characterizing theoretical thought have, Cassirer put it, an "integrated meaning". It is as if they are unfolding like rays from a common source, from a "point of concentration"; and as if this point of concentration is gradually enriched by integrating ever more kinds of energy. Thus, there is no way to understand the peculiarity of any direction of thought except as follows: One must give an account of how the kind of thought in question unfolds in a special way on the basis of an "integrated" core that form the *common* basis for all kinds of thought, regardless of their directions.[62]

Here, we shall note that there is a way in which we can analyze this common basis for all theoretical physical thought further; for that is precisely the fundamental importance we have already ascribed to the principle of least action. This principle is the best exposition there can be of the basic interconnectedness between the specification and the universalization of theoretical thought. This is because this principle, as both Planck and Cassirer believed, is the one principle from which all other principles of physical thought spring.

This has implications for a point that we have already mentioned. The systematic build up of the variously directed forms of theoretical thought is a process that is *not* conditioned by the human senses. As mentioned, Planck regards the distinction between a "World of Sense" and a "Real World" as a basic, fixed distinction. This makes it possible to talk about a series of revisions (*Um-Bildungen*) of the various theoretical World-Pictures, each picturing a "Real World". It is this *Umbildung* that is first of

[60] This basic interconnection was certainly important to Kant.

[61] As we shall see, these considerations had a definite appeal to Bohr!

[62] Again, such a view concerning the developing and integrative character of what lies at the root of conceptual thought formed a crucial part of Bohr's philosophy. I shall elaborate on this in the final chapter of the present book.

all characterized by Planck as involving a unification of theoretical outlooks (including the unification of different forms of *Gesetzlichkeit*). According to Planck, there has been a continuing broadening of the possible applications of the methodological concept of a *Gesetz*. There has been a development away from a simple notion of a *Satz*, to a Gallilean notion of a *Gesetz*, then to the Helmholtzian notion of a *Gesetz-Zusammenhang*, and further to the Boltzmannian notion of statistical versions of the latter and finally to the Bohrian notion of a *Zusammenhangs Mannigfaltigkeit*. What we have here is a continuing revision of the idea of a fundamental unity of all fundamental forms of connectedness within nature – the idea of a unity between different forms of *Zusammenhang*. This is an idea (of Reason) for which we can have no one adequate concept. However, by viewing the development of a series of symbolic expressions of that idea, we can elucidate, if not the idea itself, then the constant urge to invoke that idea within a certain *Umbildung* of a system of symbolic notions. This forms the heart of the truly Kantian program of Max Planck that I shall elaborate further in what follows:

To conclude, according to Helmholtz, there will be an ongoing enrichment concerning the system of determinations; whereas for Planck, the possibility of there being a systematic unity within our determinations, does itself successively acquire a new symbolic meaning. As Planck says,

> "[es] ist festzustellen, daß es sich bei allen Wandlungen des Weltbildes, im ganzen gesehen ... um eine in einer ganz bestimmten Richtung mehr oder weniger stetig aufwärts fortschreitende Entwicklung, die sich dadurch kennzeichnen läßt, daß der Inhalt unserer Sinnenwelt immer mehr *bereichert*, unsere Kenntnis von ihr immer mehr *vertieft* unsere Herrschaft über sie immer mehr *befestigt* wird." *(Planck 1929, p. 184, italics mine)*

Planck on the idea of the Unity of all World-Pictures

In his essay of 1908 Planck writes:

> "Welches ist denn nun das eigentümliche Moment, welches ... dem zukünftigen Weltbild ... einen so entscheidenden Vorrang verschafft, dass es sich gegen alle früheren durchsetzen kann? – Es ist nichts anderes als die *Einheit* des Weltbildes. Die Einheit, in Bezug auf alle Einzelzüge des Bildes, die Einheit in Bezug auf alle Orte und Zeiten, die Einheit in Bezug auf alle Forscher, alle Nationen, alle Kulturen. Sehen wir nämlich genauer zu, so glich das alte System der Physik gar nicht einem einzigen Bild, sondern viel eher eine Gemäldesammlung; denn für jede Klasse von Naturerscheinungen hatte man ein besonderes Bild. Und diese verschiedenen Bilder hingen nicht miteinander zusammen; man konnte eins von ihnen entfernen, ohne die anderen zu beeinträchtigen. Das wird in dem zukünftigen physikalischen Weltbild nicht möglich sein. Kein einziger Zug desselben wird als unwesentlich fortgelassen werden können, jeder ist vielmehr unentbehrlicher Bestandteil des Ganzen und besitzt als solcher eine bestimmte Bedeutung für die beobachtete Natur, und umgekehrt wird und muß jede beobachtete physikalische Erscheinung in dem Bilde einen Ihr genau entsprechenden Platz finden." *(Planck 1908, p. 23-4)*

In this important section, Planck advances several considerations that Niels Bohr would pursue as well. First of all, there is the idea that physics has reached a quite special moment in its historical development, since all of its different concepts will have to be taken into account and brought into relation with one another. Bohr, like Planck, would see this as a new productive regulative principle of physical thought.

There are three sides to the story of how Planck introduced the notion of a unified World-Picture. (1) There is a *physical* aspect of such unity, (2) there is the issue of a universal kind of *intuition* (analogous to the original Kantian form of universal space-time intuition), and (3) there is the issue of a trans-cultural outlook. I think it is important to reflect on how these three aspects, according to Planck, relate to one another, because in my exposition of the various different aspects of the viewpoint of complementarity that Niels Bohr formulated later, I shall refer back to precisely these three aspects.

First, let us consider the sense in which Planck speaks of *physical* World-pictures. It should be noted how Planck regarded the development of theoretical physics, from Lagrange to Lorentz, as forming a continuing attempt to construct a universal dynamics.[63] In an essay written in the wake of the development of Quantum Mechanics, where Planck deliberately addressed his own early thought of 1908 on "The Unity of Physical World-Pictures", he noted that "dynamics is directly coupled with the kinematics through the Quantum Postulate". The basic equation $E = h * \nu$ of quantum physics expresses a direct link between the "kinematical element" associated with an individual frequency and the dynamical element of the distribution of energy within given physical systems.

So from Planck's perspective, the claim that a new and general mechanics – a quantum mechanics – had been established was justified by a new kind of union between kinematics and dynamics. This new union was no longer limited to a specific domain such as "gravitational dynamics", "electrodynamics", or "geometrical optics". We shall find this view expressed also by both Heisenberg and Bohr. In the ordinary context of theoretical physics, a "mechanics" means a unified domain of physical theory in accordance with certain forms of causal laws. What characterized the new atomic physics was the conception of a new kind of physical system; a system where all sorts of physical laws – that were previously known to govern only the behavior of particular kinds of objects – could now be seen as jointly governing the causal behavior of atomic constituents.

One might see this issue, as did the early Cassirer, as having to do with a gradual turning away from concepts of *substance*. To Cassirer, the intelligibility of introducing new kinds of "function-concepts" (the term used by Cassirer) must still be associated with a new kind of intuitiveness in accordance with which atomic phenomena can be represented in thought. There will still be a need for a certain *Darstellung* of quantum phenomena – or to put it in Kantian terms, a new kind of *schematization* of theoretical concepts would be necessary. Whether Planck was as conscious about this matter as was the early Cassirer is hard to tell. It is clear from his exposition that Planck associates the notion of an ever-growing unified character of our World-Picture with "a fight against received intuitions".[64] Indeed, for Planck "the Intuition is in physics a most questionable instrument".[65]

[63] (Planck 1908, p. 10)
[64] (Planck 1908, p. 28)
[65] (Planck 1926, p. 160)

However, I conjecture that Planck's claim concerning the new and universal link between kinematics and dynamics was related to what I called the second aspect of unity – the unified character of a new kind of intuitiveness. It is in respect to this issue that Planck's idea of a gradual turning away from anthropomorphism comes fully to the fore. As was mentioned before, this brought Planck to consider what is important about the constants of Nature. Importantly, Planck believed that these constants jointly comprise a new kind of non-anthropomorphic intuitiveness. In the early essay on The Unity of World-Pictures, Planck stated that,

> "die ... auftretenden Konstanten, ebenso wie die Gravitationskonstante, einen universellen Charakter besitzen insofern, als sie unabhängig sind von der Bezugnahme auf irgendeine spezielle Substanz oder irgendeinen speziellen Körper. Daher ist mit ihrer Hilfe die Möglichkeit gegeben, Einheiten für Länge, Zeit, Masse, Temperatur aufzustellen, welche ihre Bedeutung für alle Zeiten, und für alle, auch für außerirdische und außermenschliche Kulturen notwendig behalten müssen ... Jene Konstanten ... sind derart, daß auch die Marsbewohner und überhaupt alle in unserer Natur vorhandenen Intelligenzen notwendig einmal auf sie stoßen müssen – wenn sie nicht schon darauf gestoßen sind." *(Planck 1908, p. 21)*

Below, I shall comment on what Planck says here – in relation to the third aspect of the notion of Unity – about the universality of the constants of Nature for all forms of Reason. But first, it is interesting to combine the quote above with this claim made by Planck 18 years later, after the advent of the quantum theory:

> "Darüber gibt schon eine äußerliche formale Betrachtung einigen Aufschluß. Eine jede physikalische Formel enthält außer veränderlichen Grössen, welche in jedem Einzelfall der besonderen Messung unterliegen, gewisse konstante Größen, welche ein für alle mal bestimmt zu denken sind und welche dem in der Formel ausgedrückten funktionellen *Zusammenhang zwischen den veränderlichen Größen das charakteristische Gepräge geben*". *(Planck 1926, p. 164, italics mine)*

The last phrase describes the way in which the joint set of natural constants combine to form an *abstract* form of intuition. They do so in the sense that any possible lawful connection of quantum physical phenomena must already exhibit an inherited *Gepräge*. As we have already seen, Planck followed Helmholtz in believing that physics was close to formulating a universal version of the principle of least action associated with a general Hamiltonian dynamics. We also recall that Planck saw the development of quantum theory as involving a further generalization of the principle of least action. The new more complex kind of statistical-physical lawfulness that characterizes quantum theory must therefore be expressed in terms of certain "quantum numbers", each of which is related to certain constants of Nature in a determinate fashion.

So the interesting thing about the constants of Nature is the way in which they correspond to an abstract form of intuition – a mathematical or purely symbolic form – that does not relate to a common sensibility of space and time. The common schemes for organizing a field of objects are left behind. The intuition of the physical World-Picture is set free from "elements of our own World", as Planck had already put it in the early essay:

> "... so gelangen wir notwendig zu dem eigentümlichen Schluß, daß das charakteristische Merkmal dieser Entwicklung seinen Ausdruck findet in der fortschreitenden Eliminierung der eigentlichen Elemente der Welt aus dem physikalischen Weltbilde". *(Planck 1908, p. 25)*

The elements of the World of Sense become irrelevant for our intuition. Thus, with the introduction of the quantum theory, our World-View, our conception of the Real World, became separated from the World of Sense. Against this background, we can make sense of Planck's statement that physics develops by continually establishing new forms of intuition in respect to conservation laws.[66]

We have seen how two aspects of the notion of Unity hang together, the physical aspect, and the aspect of a universal form of intuition. Now we shall see how they both relate to the third aspect, that of a universal Reason. It turns out that Planck explains this connection in terms of the Kantian notion of *Das Reale* (the objective, real). This notion should never be understood simply as the kind of reality (*Wirklichkeit*) associated with any one conceptual scheme, but should instead be seen as a characteristic of the possibility of *using* a definite scheme. This is how Planck formulates the issue:

> "Das konstante einheitliche Weltbild ist aber ... das feste Ziel, dem sich die wirkliche Naturwissenschaft in allen ihren Wandlungen fortwährend annähert, und in der Physik dürfen wir mit Recht behaupten, daß schon unser gegenwärtiges Weltbild ... gewisse Züge enthält, welche durch keine Revolution, weder in der Natur noch im menschlichen Geiste, je mehr verwischt werden können. Dieses Konstante, von jeder menschlichen, überhaupt jeder intelektuellen Individualität Unabhängige ist nun eben *das, was wir das Reale nennen*." *(Planck 1908, p. 27, italics mine)*

Thus, the notion of "the Real" has to do with there being elements within the given schemes of intellectual thought that will remain part of the structure of objective thought even when a change of perspective occurs. We can thus see the point of the phrase "the Real World". This is the world we relate to, not by applying any particular scheme of thought, but the world that makes it both possible and necessary for us to produce objective thought by utilizing a definite set of linguistic *Hilfsmittel*. The term "the Real" symbolizes our confidence that the gradually progressing unity of thought may be regarded as an expression of an objective unity of Nature. So this is how we can speak of a gradual universalization of human Reason. The Unity of Thought becomes more and more detached from conditions and characteristics of *human* Nature. Instead it becomes more and more guided by the constraints and features that, as it were, Nature *itself* brings to the fore as we try to cope with it.

Thus, the idea of a pure human Reason has two sides to it, the ability of our thought to expose the reality of things by means of binding itself to certain conditions of Understanding, and the ability of Reason, still, to transcend any specific condition:

> "Und wenn der also Beschiedene gleichwohl hartnäckig bleibt und die Vorstellung von einem idealen Geist ... für inhaltsleer und überflüssig erklärt, so ist ihm entgegenzuhalten, daß nicht alle Sätze, welche sich einer logischen Begründung entziehen, wissenschaftlich wertlos sind, und

[66] (Planck 1926, p. 170), see below.

daß er mit seinem kurzsichtigen Formalismus gerade die Quelle verstopft, an welcher Männer wie *Galilei, Kepler, Newton* und viele andere große Physiker ihren wissenschaftlichen Forschungsdrang genährt haben ... [without regard of this Source] ... müsste ein völlig unverständliches Rätsel bleiben, wenn sie nicht zum mindesten eine gewisse Harmonie ahnen ließe, die zwischen der Außenwelt und dem menschlichen Geist besteht."

(Planck, 1932, p. 238-9)

In accordance with this, Planck had earlier made the claim that the aim of physics is,

"*die vollständige Loslösung des physikalischen Weltbildes von der Individualität des bildenden Geistes*".

(Planck 1908, p. 27; emphasis in the original)

This view seems to be as non-anthropomorphic as can be. But it does not mean to endorse a form of "artificial intelligence". Physics should be freed, not from *any* kind of human Spirit, but only from particular forms of such. Physics must necessarily be bound by whatever constitutes a Universal Spirit in the sense of a kind of Reason that is broad enough to embody *all* the essential elements characterizing the given variety of practices within experimental physics. The point is that – what we following Kant might call – a "symbolic anthropomorphism", can be achieved only by a reflection on the tradition and history of the practice of theoretical physics, and that this reflection can be performed only by someone who shares those elements common to all humans. This, I take it, probably excludes artificial intelligence but, according to Planck, not necessarily the creatures from Mars!

Consequently, Planck says that it is Reason, not the Understanding, that is King of the sciences.[67] First of all, our Reason is able to install a discipline and certain modesty into human thought, that requires that we should always remember that any World-View is, but a "eines mennschlichen Kunstproduktes".[68] However, by pointing to a pre-established harmony between Nature and our Spirit, we must also admit an uneliminable "natural" limitation of that Spirit, which means,

"daß der Mensch mit seinen Sinnesorganen und seinen Meßgeräten selber ein Teil der Natur ist, deren Gesetzen er unterworfen ist und aus der er nun einmal nicht herauskann, während eine derartige Bindung für den idealen Geist nicht besteht". *(Planck 1932, p. 238)*

Thus, for example, in recognizing that there is a sense in which The principle of causality is a human construction one also realizes the rationality of following that law.[69] The principle of causality does not *describe* any physical interaction, but instead prescribes physical research, and does so only in a way related to its place in the *history* of physics. It is not a command, nor an instruction, nor a demand. According to Planck, it suggests itself by the very fact that a definite series of theoretical works was shaped in the light of its guidance:

[67] (Planck 1926, p. 181)
[68] (Planck 1932, p. 236)
[69] (Planck 1932, p. 239)

> "Das Kausalgesetz ist weder richtig noch falsch, es ist vielmehr ein heuristisches Prinzip, *ein Wegweiser*, und zwar nach meiner Meinung der wertvollste Wegweiser, den wir besitzen, um uns in dem bunten Wirrwarr der Ereignisse zurechtzufinden und die Richtung anzuzeigen, in der die Wissenschaftliche Forschung vorangehen muß, um zu fruchtbaren Ergebnissen zu gelangen." *(Planck 1932, p. 239, italics mine)*

No doubt the general philosophical views of Planck are very close to those of Kant, closer than any of the other physicists I discuss in this study. Yet there is a noteworthy deviation from the Kantian system. Planck, as we have seen, makes use of the post-Kantian notion of *Geist* in his elucidations of the different "directions" of Reason. Like Helmholtz, he uses the term in a Goethean sense. However, Planck does not follow Helmholtz in the latter's Goeathean insistence that every philosophical notion must be given a "factual sense". This Planck says in so many words:

> "Die Philosophen haben eingesehen, daß es nicht angängig ist, den Naturforschern Vorschriften zu machen, nach welchen Methoden und zu welchen Ziehlen hin sie arbeiten sollen, und die Naturforscher sind sich klar darüber geworden, daß der Ausgangspunkt ihrer Forschungen nicht in den Sinneswahrnehmungen allein gelegen ist, *und das auch die Naturwissenschaft ohne eine gewisse Dosis Metaphysik nicht auskommen kann*." *(Planck 1926, p. 171, italics mine)*

Planck even stated that old forms of abstract philosophy probably might come to the fore with the founding of the quantum theory. Perhaps even antique forms of abstract intuition, say of a Pythagorean kind, would prove significant in a new light. This was a view explicitly held by Cassirer. As we shall see Heisenberg adapted a similar, but slightly more moderate view. Referring to the quantum theory, Planck remarks,

> "... daß dabei gewisse ältere, jetzt in Vergessenheit geratene Anschauungen wieder aufleben und eine neue Bedeutung zu gewinnen anfangen. Deshalb dürfte ein aufmerksames Studium der Anschauungen und Ideen unserer großen Philosophen auch in dieser Richtung sehr förderlich wirken können." *(Planck 1926, p. 170)*

Now let me summarize the last couple of sections: Planck's idea of a growing unity of Reason implies seeing this growth as involving a kind of integration. There is an integration both in the sense of (a) furthering an intimate bond between all forms and parts of Reason, and (b) conceiving of a new kind of integrity in respect to the forms of lawfulness that jointly govern atomic physical systems. Regarding the first kind of integration, it is as if Reason has obtained a better grasp of its own limits and powers. In respect to the second kind of integration, it is as if Reason itself emerges as a unity within the totality of all being, a unity from which objective thoughts spring in all directions.

The connection between the two kinds of integration is expressed by the fact that the development of physics is characterized by a production of certain "pointers", guiding us where to go next in the continuing research, such that

> "... wir nun die verschiedenen sich im Laufe der Zeit wandelnden und einander ablösenden Formen des physikalischen Weltbildes in ihrer historischen Aufeinanderfolge überschauen und nach charakteristischen Merkmalen der Veränderung suchen". *(Planck 1929, p. 183-4)*

So, the emergence of this series of pointers may even be seen as reflecting the gradual development of an ultimate direction in human Reason.

The growth and depth of our conceptually informed experience goes hand in hand with a practical ability to deal with part(s) of Nature. This ability, however, does not consist in the technical ability to handle this or that piece of equipment. This is of crucial importance in respect to the notion of measuring devices. Planck argues that the quantum theory is associated with a certain concept of *what is observable in principle*.[70] This concept, again, is related to the notion of "the principal role" that any measuring device plays in "every observation of a natural process".[71] This finally has to do with the *lawful* fashion in which the function of measuring devices interact with the system of objects we are measuring upon.[72] So, according to Planck, the very objects to which the quantum theory may be applied are objects whose *structure* depends on the structure of measuring devices. The reality of atomic systems is as objective as can be. But the only way in which we can grasp the structure and causal characteristics of that kind of Reality will be by reflecting on the possibility of using certain forms of devices in the production of certain kinds of phenomena. One might say that Planck, by proposing this set of views, merely reiterateed the claims of either Bohr or Heisenberg. But the interesting thing is how easily Planck thought that their respective views could be adapted to his own philosophical framework. There is not the slightest suggestion in Planck's account that the quantum theory involved any radical break with the tradition of experimental, theoretical physics, on the contrary.

Vor-gang als Zusammen-hang

The influence of Hertz on Planck's understanding of the universality of the principle of least action must certainly be recognized. Indeed, Planck regarded Heinrich Hertz as the most distinguished proponent theoretical physics.[73] Planck's recognition of Hertz was important because it led Planck to focus on the distinction between reversible and irreversible processes. Planck associated Hertz's views with a general conception of the mechanical, and the focal point of this association was precisely the physical character of reversible and irreversible processes. Therefore, Planck was led to consider the metaphysics involved in applying the concept of a physical process (*Vorgang*).

For a Kantian like Planck, the question concerning the adequacy of any concept of a physical process relates to the possibility of regarding the concept as expressing some form of *connectedness* between different features of Reality that participate in a certain dynamical interaction. The issue is learning to see *Vor-gang als Zusammen-hang*. Of course, this is precisely what the original Kantian concept of causality expresses. Consequently, making sense of the character of irreversible processes centers on the

[70] (Planck 1929, p. 201) Here, I have omitted a couple of idle sentences from the reviewed version of my dissertation.

[71] (Planck 1930, p. 218)

[72] (Planck 1932, p. 231).

[73] (Planck 1930, p. 210)

question of how we can picture irreversible processes as resulting from a peculiar form of physical connectedness that characterizes certain forms of physical system.

This is the point at which Planck's understanding of Heisenberg's Indeterminacy Relations comes to the fore. Planck assures the *determinate* character, relative to the quantum theoretical configuration space, of physically possible matter-waves – by pointing out that these particular forms of irreversible processes are only describable in terms of probability-functions.[74] After this assurance Planck continues,

> "auf diese Weise erklärt sich auch die scheinbar paradoxe Behauptung, daß, wenn ein physikalisches Gebilde durch einen ganz bestimmten Vorgang aus einer bestimmten Konfiguration während einer bestimmten Zeit in eine bestimmte andere Konfiguration übergeht, die Frage nach der Konfiguration in der Zwischenzeit im allgemeinen gar keinen physikalischen Sinn hat". *(Planck 1929, p. 229)*

The development of a generalized conception of *Vorgänge* is thus part and parcel of a generalized *concept* of causality that still leaves the Kantian *principle* of causality intact. Planck accordingly states the following:

> "Das neue Weltbild der Quantenphysik ist gerade dem Bedürfnis entsprungen, die Durchführung eines strengen Determinismus auch mit dem Wirkungsquantum zu ermöglichen". *(Planck 1932, p. 229)*

However one thing must be noted:

> "Allerdings muß hervorgehoben werden, daß bei dieser Art der Betrachtung der Sinn des Determinismus ein etwas anderer ist als der früher in der klassischen Physik übliche. Denn dort war die Konfiguration determiniert, hier in der Quantenphysik aber sind es die Materiewellen, welche determiniert sind. Der Unterschied ist deshalb von Bedeutung, weil die Konfiguration mit der Sinneswelt viel unmittelbarer zusammenhängt als die Materiewellen." *(Planck 1929, p. 206)*

This is how there is a new sense of causality involved in the quantum theory. The notion of a *lawlike* causal relationship between the alternating physical states of a given system is no longer associated with any determinate visualizable kind of configuration. So the quantum theory can at best include a form of non-visualisable intuitiveness. According to the general Hamiltonian Scheme, the configuration of a physical system is the set of possible states that can exist under the following conditions:

(a) They are "defined" by the sum total of the combination of possible motions of various parts within the system, and

(b) this definition determines the physically possible state-transitions of the system under certain external forms of action.

Thus, to say with Planck that such configurations are no longer determined in a visualizable form is to deny a certain link between (a) and (b). As Bohr put it, the balance is broken between the possibility of state-definition and the possibility of obsering their phenomenal manifestations.

[74] (Planck 1929, p. 205)

Ultimately, we require a change in the sense of the concept of lawfullness. A new generalized kind of *Gesetzlichkeit* arises encapsulating a certain form of *Gegen-Satz* that had to surface in relation to the formerly accepted notion of a *Gesetz*.[75] The *Gegen-Satz* in question precisely relates to the contra-position of reversible and irreversible processes. There is, according to Planck, a distinct form of *Gestetzlichkeit* associated with each of these causal forms (i. e. the lawfulness associated with an atomic constituent vs. the 'opposite' lawfulness associated with the set of possible state-transitions within the atom). However, with the development of the generalized principle of least action it has now become possible to consider the respective forms of lawfulness together.[76] Thus emerges a notion of *entgegen-gesetzter Arten von Gesetze*, of "opposed form of lawfulness", the adequate juxtaposition of which guides the introduction of a new conception of lawfullness.

Planck uses the term *Gebilde* in order to express this generalized notion of lawfulness. Consequently, Planck advocates that we should regard the unity between an experimental arrangement on the one hand and the objects under scrutiny on the other as a certain form of "wholeness", namely as a Gebilde. In this way we can introduce new kinds of physical laws covering such cases, introduce new "*Gesetze für die Bewegung eines physikalischen Gebildes*".[77] That is to say,

> "... daß man das Gebilde stets als ein Ganzes ins Auge faßt und seine Bewegung zusammengesetzt ansieht aus einzelnen diskret von einander verschiedenen Eigenbewegungen des Gebildes. Damit hängt eng zusammen, daß nicht die lokale Kraft, wie in der Newtonschen Mechanik, sondern das Integral der Kraft, das Potential, in die Grundgleichung eingeht, ferner daß es keinen Sinn hat, von dem Zustand eines materielle Punktes als von dem Inbegriff seiner Lage und seiner Geschwindigkeit zu sprechen." *(Planck 1930, p. 218)*

So for Planck, the quantum theory embodies a new metaphysical understanding of physical part-whole relations. Not only is that relation freed from the classical Kantian notion of the extensive character of substance. It is also abstracted from the ordinary forms of intuitive representation of physical relations. Still, this new metaphysical outlook does in no way imply that we renounce the invocation of any ordinary idea of determinate local action. This is a very important reminder to give to the would-be quantum-theoretical "indeterminist". There is no standpoint from *without* the quantum theory from where one might state its "indeterminate" character.[78] As is clear from the following quote, Planck justified this view as part of explaining the significance of the notion of "what is observable in principle":

> "... die Entscheidung darüber, ob eine physikalische Größe prinzipiell beobachtbar ist, oder eine gewisse Frage einen physikalischen Sinn hat, läßt sich niemals a priori, sondern immer erst vom Standpunkt einer bestimmten Theorie aus treffen". *(Planck1929, p. 201)*

There is no doubt that Planck, in saying this, and rightly so, considered himself in agreement with Niels Bohr. However, as we shall see, it is not obvious how to compare

[75] (Planck 1926, p. 163ff)

[76] That is, with the Hertzian generalization of Helmholtz's version of the principle.

[77] (Planck 1930, p. 218)

[78] On this page, I have added a few clarifying remarks not included in the revised version of my dissertation.

the views of Bohr with those of Planck. Even though there are only few points of disagreement, yet their respective philosophical viewpoints come out different. Cassirer is probably the most prominent philosopher to have acknowledged that Planck managed to express the philosophical thoughts embodied in the quantum theory better than anybody else, including Bohr. Cassirer's primary work on the philosophy of physics, *Determinismus und Indeterminismus in der modernen Physik*, is in fact one long appreciation of the views of Planck, combined with an effort to associate these views with other views formulated by Cassirer himself.

I certainly acknowledge the importance of Planck's philosophy of physics. One cannot say that Bohr ever challenged any basic part of the views held by Planck. Instead, Bohr tried to move ahead, trying to take the philosophy of physics where it had never gone before. I shall not argue that Bohr consciously affiliated his philosophical reflections on the quantum theory with any particular form of philosophy. What I argue is only that, if today, one should want to consider the possibility that the quantum theory had a lesson to teach that might be of help within certain forms of philosophical thought, then one could profit from Bohr's philosophy in a way that one cannot from that of Planck. I shall indeed argue that Bohr's philosophical horizon never escaped the Romantic philosophical tradition of his predecessors. It is just that this tradition is much more complex and rich than is usually acknowledged. Because of his grasp of this richness, Bohr's philosophy of physics is in a sense deeper or more complete than, for instance, that of Planck.

Now before I turn to present the views of Bohr, I shall go into more detail about the physical principles of the quantum theory, and especially the way in which these principles were originally analyzed and justified by Heisenberg. So, this will be the subject of the following chapter.

3 Assessing the Early Quantum Mechanics: Heisenberg and Bohr

3.1 Werner Heisenberg's original understanding of the Principles of The Quantum Theory

The original point of the indeterminacy relations

In March 1927, Heisenberg submitted a paper for publication entitled *Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik*. The paper is famous for introducing the so-called uncertainty-relations, i. e., the idea that the product of two canonically conjugate variables cannot be smaller than the value of the Planck constant h. However, the paper may not have been widely read, because it seems that Heisenberg's various claims and arguments in the paper are rarely mentioned. This is unfortunate, especially when trying to assess Niels Bohr's misgivings – both early and late – about Heisenberg's original understanding of the indeterminacy relations, as they should rightly be called. Neither "uncertainty-relation" nor "indeterminacy relation" are Heisenberg's terms. Heisenberg sometimes makes use of the expression "imprecision" (*Ungenauigkeit* concerning observables (*Wahrnehmungen*, or *bekannte Werte*).[79] Yet cognitive notions are not the primary focal point of the very relation that the paper introduces; the main point of introducing "the relation" is an a priori "indeterminacy" in respect to those possible *experiments* that, in given cases, are required in order that *certain classical concepts make physical sense*. Below are Heisenberg's exact words (italics original):

> "*Alle Begriffe, die in der klassischen Theorie zur Beschreibung eines mechanischen Systems verwendet werden, lassen sich auch für atomare Vorgänge analog den klassischen Begriffen exakt definieren*. Die Experimente, die solcher Definition dienen, tragen aber rein erfahrungsgemäß eine Unbestimmtheit in sich, wenn wir von ihnen die simultane Bestimmung zweier kanonisch konjugierten Größen verlangen."
>
> *(Heisenberg 1927, p. 179).*

We will see below why this should be considered an a priori judgment within physical theory and what consequences should in principle be drawn from it. Before we come to

[79] (Heisenberg 1927, p. 197)

that, I want to mention how Heisenberg in fact ended the paper by stating not only what these consequences are, but also what they are *not*. Here, Heisenberg distances himself from two conclusions. First, the difference between classical and quantum physical theory is *not* that the former is associated with some sort of epistemic certainty whereas the quantum theory, by contrast, is merely statistical. One should rather say that both classical and quantum theory are statistical but are so in different senses of the term. Secondly, one should not disclaim the ability of quantum theory to represent physical reality. There is no physical reality that quantum theory must forever escape or that will remain hidden. Rather, one should say that quantum theory deals with physical reality in the fullest sense of that term – but does so differently from classical theory. Now, let us take a closer look at the structure and argument of the paper.

The problem with which the paper is concerned is that of what it takes to understand any physical theory *intuitively* (*anschaulich*). Heisenberg claims without argument that this first of all requires that the concepts in terms of which a given theory is formulated be well defined. He then reminds the reader that all physical theory seems to make use of both *kinematical* and *mechanical* concepts such as "place," "path," "velocity," and "energy". He also reminds the reader that these concepts have to be associated with variables in the Hamiltonian sense of it being possible to formulate a specific Hamiltonian set of functions concerning both observable and unobservable variables. Hence, the problem addressed by the paper is that these two requirements do not seem to be met by any elaborated "quantum theory," Heisenberg's own Matrix Mechanics included. However – and this is what the paper argues – there is a way to "understand" that mechanics so that the associated theory becomes "intuitive"; in short, Matrix Mechanics *does* meet the two requirements after all. Heisenberg points out that all forms of quantum mechanics involve a critique of classical *kinematical* concepts, a critique that is supplemented by tracking "Beziehungen zwischen experimentell gegebenen Zahlen," i. e., by establishing relations between experimentally given numbers. The classical kinematical concepts are associated with various ideas (*Vorstellungen*) concerning continuous paths of motion, distinct places as to the exchange of forms of energy a. m. o. Mentioning the special theory of relativity as an example, Heisenberg claims that such ideas always have certain "experimental consequences." *That* is the sense in which certain theories can be said to be, and thus also required to be, "intuitively understood." Thus, the special theory of relativity does not merely substitute classical concepts with abstract notions corresponding to special algebraic relations between the variables involved in the formulation of the theory; the rules associated with the Lorentz Transformation have definite experimental consequences in the sense that a well-demarcated range of observable, kinematical phenomena makes definite physical sense according to the theory. However, it seems that this is not the case for quantum mechanics, because the renunciation of the classical kinematical ideas (*Vorstellungen*) has as yet no "experimental consequence." For example, Bohr's idea of stationary states may make physical sense both as part of a theoretical model of various atoms and as part of an interpretation of certain (macroscopic) phenomena such as spectral lines; however, it says nothing about what might be the characteristic kinematical and dynamic features of any distinct atomic physical process. Shall we then simply ignore any questions regarding such features? No, because that would mean giving up the very idea of a "mechanics" in the *Hamiltonian sense* that the development and change of the energy states of a given physical system are represented by means of Hamiltonian functions, i. e., by certain algebraic rules that express the lawful relations between variables.

Within Matrix Mechanics, however, we do have these Hamiltonian elements of any quantum theory ready at hand. The formal, mathematical aspect of the theory is in place, as it were. The question that remains to be answered is rather what *practical*, *observational* consequences the introduction of a non-commutable algebra has in respect to canonically conjugate variables. As far as this is concerned, Heisenberg soon points out that we should recognize the (practical) *impossibility* of *simultaneously measuring* the value of a given pair of canonically conjugate variables.

As explained in detail above, because of the Hamiltonian method of representing constants of motion, within classical mechanics one could associate a mechanical model formulated in terms of tensors and matrices with a definite spatio-temporal configuration of the system of objects upon which we measure, such as angular momentum. Thus, in a sense, the phase-space of the process under scrutiny was associated with a spatio-temporal *Vorstellung* of *how* the objects involved in the process "enter into motion" in space and time, say by an impact or encounter of some sort. The theoretical representation of the process does not directly describe that "entering"; but it has to make sense to claim that "*this* is the impact corresponding to this phase-space". Still, what gives rise to a certain atomic physical process can only be depicted in some abstract theoretical manner and is not associated with any definite spatio-temporal picture.

Heisenberg does not claim that we should give up the ambition of relating two observable phenomena by viewing them as end products of certain changes in the physical state of given systems of objects. Any theoretically relevant observable phenomenon should still be related to definite processes involving definite objects. What is questioned is only the issue of *how the objects enter into observed phenomena*. We can no longer say that they do so in a spatio-temporal sense. Formulated more abstractly: the link between kinematics and mechanics has been broken because we have no well-defined, *classical dynamics* concerning the definite forms of change that specific physical objects may undergo.

The non-commutable feature of the variables of the quantum theory implies this because, in short, it is as if any determination of a given variable makes it – temporally – *ungenau* what it would mean for that variable to be associated with its canonical conjugate. Formally we associate variables, but does it for example make sense to say that we pair "places" and "velocities" or pair "work" with (temporal) moments in time? Objectively speaking, what is it that becomes associated when we pair a given set of conjugate variables within quantum theory? Now, the aim of Heisenberg's paper is to answer this question positively. There is something we objectively pair. We *seem* only to pair numbers, but since, in practice, and in mathematical fact, these numbers are associated with tensors (matrices), we *thereby have an intuitive, objective idea* as to what is *really* being paired, Heisenberg argues. Important examples that Heisenberg mentions are the Compton effect, the Stern-Gerlach effect, and various other quantum effects, that is, "effects" that can only be represented by mentioning the possible outcome of two different and successive measurements or observations and that still express something characteristic of a definite system, such as an atom.

It is not that we *first* have the theoretical model of such possible atomic events and then might start testing our models experimentally. Having the models and performing experiments in order to establish lawful relations between observations form two sides of the same coin. Theoretically relevant observations require a formal model and formal models do not make sense in abstraction from the *Vorstellung* of possible, relevant

experiments. This seems to be the early Heisenberg's main philosophical thesis.

The most significant implication of the thesis that Heisenberg develops in his paper is the renunciation of a certain conception of *causality*. Heisenberg is very explicit in this respect: it is specifically what should be called the Laplacean, deterministic conception of causality that is renounced. Given knowledge of the physical state of a given system, within quantum mechanics we cannot predict or describe a definite future development of the phase-space, an issue to which I will return below. Here I would merely like to emphasize that Heisenberg's renunciation of Laplacian determinism forms part of an attempt to make *ontological sense* of quantum physical processes and is not based on epistemic considerations. One might see his attempt as an effort to advance criteria of identity in respect to microphysical objects and processes given the *methodological* constraint, in given experimental cases, that any such microphysical item must be associated with a range of definite, possible observable variations of a subset of the variables according to the physical theory at issue.

As is well-known, Heisenberg composed and finished his early paper of 1927 in Copenhagen, where he was working at the Institute of Theoretical Physics, which was led by Bohr – at a time, however, when Bohr was on holiday in Norway. On his return, Bohr launched such a serious and deeply felt critique of Heisenberg's paper that Heisenberg felt obliged to mention this critique, as well as to acknowledge its adequacy, in a postscript to the paper when it was published. Heisenberg concentrates on two of Bohr's points of critique. First, Bohr found that Heisenberg's account of the relation between microphysical and macrophysical determinations had failed to consider how the notion of an object, within atomic physics, in a sense has to be *generalized* – for instance by introducing a distinction between "bound" and "free" objects. We shall see in subsequent chapters what Bohr might have had in mind concerning this point. Second, Bohr observed that Heisenberg had not considered how the association of formal mathematical notions, such as "continuity", with definite physical objects had to involve a characterization of the *kind of dynamics* of the physical objects in question. The prime example would be the different way in which the respective notions of "particles" and "waves" are associated with an understanding of the causal features of definite observable phenomena. "Motion" and "prolongation," "impact" and "interference" obviously refer to different kinds of physical change. Yet, within quantum theory, all such forms of change may enter into one and the same atomic physical process. The point seems to be that there is no one overall generalization of all these notions of change – for instance, "superposition of wave functions". This would simply be an empty, formal expression. As Bohr would later put it, we face the task of recognizing as well as of combining *different generalizations* of the concept of energy.

Heisenberg's concessions in the *Nachtrag zur Korrektur* leave the reader in the dark. However, within two years, and after having heard and read some of Bohr's early accounts of the idea of complementarity between different kinds of physical phenomena, Heisenberg would re-formulate the thesis and the arguments of his early paper in his very elaborate, instructive, and significant *Chicago Lectures* of 1929. We will now turn to these while bearing in mind the background and agenda originally presented in his early paper of 1927.

3.2 Heisenberg's *The Physical Principles of The Quantum Theory*

Why these Lectures?

There are several reasons why I find it important to discuss the content and structure of this particular work that was published in 1929. In the preface to the book Heisenberg twice makes the claim that it contains nothing but the principles for the interpretation of the quantum theory that Niels Bohr had already suggested:

> "The lectures which I gave at the University of Chicago in the spring of 1929 afforded me the opportunity of reviewing the fundamental principles of quantum theory. Since the conclusive studies of Bohr in 1927 there have been no essential changes in these principles and many new experiments have confirmed important consequences of the theory ...
>
> On the whole the book contains nothing that is not to be found in previous publications, particularly in the investigations of Bohr. The purpose of the book seems to me to be fulfilled if it contributes somewhat to the diffusion of that *Kopenhagener Geist der Quantumtheorie*, if I may so express myself, which has directed the entire development of modern atomic physics". *(Heisenberg 1929, preface)*

True, there are some important differences between the views that Heisenberg puts forward in the book and those actually held by Bohr. Yet, the Chicago Lectures of Heisenberg's are in many ways the best and most detailed account of the early Quantum Theory. It is the first major work of the quantum theory that tries to analyze the concepts and methods around which the research and discussions of the late twenties were turning. Thus one might read the Lectures as presenting the theoretical physical background of Bohr's various philosophical considerations. Heisenberg explicitly deals only with the *physical* principles of the quantum theory. However, it is not these that Bohr wanted to challenge by his continuing effort to elaborate what Bohr later called "the framework of Complementarity". Certainly, the ability to understand and discuss this framework presupposes the ability to make sense of the various sections of Bohr's series of Como-Solvay papers where Bohr discusses the physical principles of the quantum theory in almost complete accordance with Heisenberg's account of these principles in the Chicago Lectures.[80] So I believe that there is no better and clear-cut presentation of the physical theory that Bohr commented upon than these lectures of Heisenberg.

Thus I would claim that one makes a crucial mistake if, in order to grasp Bohr's approach to the fundamental problems of quantum physics, one takes, say, Dirac's way of defining the theory as the starting point. Surely, within the community of physicists, the Dirac Theory soon became the canonical form of quantum theory, and almost every textbook on quantum theory has adopted Dirac's concepts and methods ever since. Consequently, if one wants to make sense of the philosophical questions posed and discussed by Bohr, the right way to begin that effort involves reviewing central aspects of Heisenberg's early account of *The Physical Principles of the Quantum Theory*.

My own special reasons for reviewing the Chicago Lectures are twofold. First, the Lectures exemplify an excellent example of, what is in my view, a Kantian account of the foundations of a mechanics. Indeed, the two prominent inheritors of Helmholtz's

[80] I know of course that these were written and published nearly two years after the Como-papers.

program for renewing the Kantian understanding of physics, Max Planck and Ernst Cassirer, whose views I have presented in the former chapter, both regarded Heisenberg's Lectures as a sort of canon for the quantum theory". Second, the Lectures are important because they to a large extent became the canon for followers of the so-called "Copenhagen Interpretation" of the quantum theory. Although I find it very questionable to ascribe the views that are usually associated with that "interpretation" to either Heisenberg or Bohr, the possibility of misunderstandings only adds to the importance of comprehending the content and structure of The Chicago Lectures.

In the accounts of both Planck and Heisenberg it is clear that it is *not* right to say that quantum physics implies a break with the principle of causality, in the sense of Helmholtz. At first glance, Heisenberg appears to say otherwise. But as both Planck and Cassirer stress, what Heisenberg in fact wants to show in his Lectures is how the Kantian principle of causality is still at the heart of quantum physics. True, there are some things to consider in respect to Heisenberg's precise formulation of the issue; and the failure to produce such considerations, I would say, has been one of the reasons why a number of commentators have been too quick to associate Bohr's framework of complementarity with what turns out to be a very problematic part of Heisenberg's account. So this is another reason why it is necessary to know this account when trying to make sense of Bohr's framework.

The Kantian roots of Heisenberg's account

Both Heisenberg's early paper of 1927 and the Chicago Lectures mark a turning point in the philosophy of physics. It is one of the first essays on the subject to adopt the linguistic turn that came to shape the analysis of scientific thought for many years to come. The primary question posed in the Lectures is how to elucidate the physical principles associated with any given mathematical apparatus. One must be cautious in understanding the question correctly. Heisenberg certainly would not say that it makes sense to isolate the latter from the former: There is no mathematical apparatus whose use is relevant within the context of physics without associated physical principles. To Heisenberg, it would be a mistake to regard a set of formula as neutral in respect to either physics or to some sort of ontology. True, in respect to ontology, Heisenberg is very moderate. In a sense, the only general implication of the quantum theory is that it indicates a general method for the critical analysis of the possible applications of empirical concepts under certain experimental conditions. This view certainly leaves no room for a strictly formal conception of the use of mathematical concepts and theorems within the context of physical theory.

The starting point of Heisenberg's account is the historical fact that there is a range of concepts that constrain what a physical theory might be, namely the set of theoretical concepts associated with the two notions of a material point (a particle) and a (continuous) wave. It is clear from Heisenberg's account that he believes (1) that there is a certain a priori framework relative to which the range of concepts in question make sense, and that the possibility of making sense of these concepts is conditioned by their association with certain *forms of visualization*. In short, there is what in Kantian terms would be called a necessary kind of *Schematization* – a necessary kind of *Darstellung* – of the concepts within visual experience.

It is important to stress what it is, according to Heisenberg, that physicists must necessarily visualize in order to make sense of theoretical concepts; namely physical

processes. This is what points to the concepts associated with definite forms of physical processes such as motion along well defined spatio-temporal paths or radiation in the form of a harmonic prolongation of a field-intensity.

However, Heisenberg's aim was to *criticize* the set of concepts involved in visualizing physical processes. There are three sides to this story. First, Heisenberg wants to follow Bohr in "obtaining the *limitations* of the concept of a particle by considering the concept of a wave" (and vice versa).[81] Interestingly, the critical analysis of either of the concepts of "particles" and "waves" will, in a sense, be formulated *in terms of the other* concept. As we shall see, it is part of this strategy that we can no longer understand either of the concepts as ontological notions. Instead, they should be seen as methodological concepts helping us to interpret observations. We will also learn that the way in which there is a certain condition concerning the mutual use of these concepts (i. e. the Indeterminacy Relations) helps us define, in a non-classical way, what might be a constant of motion – that is, a constant of physical action in a general Hamiltonian sense.

Second, according to Heisenberg, there is a range of "philosophical" concepts that require a "thorough revision", like the concepts of "space-time coincidence", "observation", and "dynamical quantity".[82] Third, Heisenberg finds it necessary to introduce new concepts into physical theory – especially the concept of a "wave-packet". It is worth noting how Heisenberg suggests doing this. He wants to associate the term with a certain kind of *intuitiveness* (i. e., in the form of a superposition of sinusoidal waves).[83]

So, what does it mean to elucidate the limitations of a given concept in the context of the quantum theory, according to Heisenberg? The fundamental part of Heisenberg's thoughts on this issue is evident in the following remark about the general Theory of Relativity:

> "According to this theory, ordinary language (i. e., classical concepts) is applicable only to the description of experiments in which both the gravitational constant and the reciprocal of the velocity of light may be regarded as negligibly small". *(Heisenberg 1929, p. 2)*

Again, the crucial thing is that a physical theory restricts the options for describing *experiments*. Given this view, a clear way to define the term "quantum theory" is suggested: It is a theory (1) that embodies the Quantum Postulate concerning discontinuous shifts of energy, and (2) is formulated in accordance with a special requirement concerning the description of experiments. As such, the Indeterminacy Relations express only a certain rule about how to formulate descriptions of specific experimental arrangements.

Heisenberg and Kant's Metaphysics of Nature

In a sense, Heisenberg follows the Kantian program presented in his *Metaphysische Anfangsgründe der Naturwissenschaften*, because the primary theme of Heisenberg's Lectures is what it takes to construct a new kind of mechanics – a quantum mechanics.

[81] (Heisenberg 1929, p. 11)

[82] (Heisenberg 1929, p. 3). In contrast to Bohr Heisenberg does *not* think that the concepts of "clock" and "yardstick" needs revision. According to Bohr the concept of *independent* tools of measurement must take on a new sense in Quantum Theory.

[83] (Heisenberg 1929, p. 14)

As was the case for all philosophers belonging to Helmholtz's tradition, the answer to this question is based on a particular claim: To construct a mechanics one must demonstrate a physically possible link between a *kinematics* and a *dynamics*.[84]

As mentioned earlier, the Indeterminacy Relations are meant to function as rules; namely rules utilized in the construction of a *dynamics*.[85] So the right way to view the Indeterminacy Relations is this: They do not express a particular limit of human knowledge. Instead, they express the condition for the possibility of a *new* kind of knowledge; knowledge of a new kind of causal relation between natural phenomena characterizing atomic systems.

Thus, establishing such a possibility requires that we define the notion of a "causal connection" anew. Here, it is important to note how much Heisenberg adopted the mathematical apparatus developed by his colleagues in Göttingen, especially Herman Weyl. As we have seen, Heisenberg made much use of this apparatus, in 1925, when constructing his original Matrix Mechanics. Similarly, in the Chicago Lectures, Heisenberg declares right away that the quantum theory is supposed to involve an "application of the theory of linear algebra" (in the same sense in which the theory of relativity involved such an application). Thus, the quantum theory makes use of the notion of tensors – a generalized notion of vectors – together with the associated algebra in respect to both scalar and matrix products.

Heisenberg assigns himself the task of associating such tensors with "kinetic elements" that are different in kind from the space-time "displacements" of classical theory. This much is different if we compare the quantum theory with classical physical theory, but the following similarity between the two kinds of theory must be recognized.

To produce an algebra in respect to kinetic elements within the quantum theory means exactly what it meant for Kant. It means that we have established a calculus, revealing how to view combinations of possible elements as constituting further possible kinetic elements within the range of theory. Thus any possible motion might be seen as a product of a number of elements. In this way one might claim to have established an adequate concept of the *magnitude* of a motion (adequate in respect to the analytical principles of any "extensive" magnitude, which is a magnitude whose parts will always be of the same kind as itself).

The appropriate mathematical apparatus for connecting the theory of linear algebra with the analysis of the new kinetic elements turns out to be the well-known Fourier analysis of harmonic mathematical functions. So this forms the background for the further question of how we establish a dynamics in association with that particular mathematical apparatus. To answer this question, one needs to introduce two new principles of physical thought: (1) a new definition of "causal connections", the need for which I mentioned above and (2) Bohr's so-called Principle of Correspondence. I shall present these principles in turn.

The Definition of Causality: In respect to this definition Heisenberg states:

> "This assumption is one of the formal postulates of quantum theory

[84] (Heisenberg 1929, p. 108, 119)

[85] The usual way to state the Relations is that the product of the *indeterminacy* related to each of two "conjugate", "generalized," variables will necessarily have a magnitude which equals or is greater than the physical magnitude of the quantum of action h. This is expressed in the formula $[(dq * dp) \geq h]$.

> and cannot be derived from any other considerations. It follows from this axiom that the values of two dynamical quantities are causally related if, and only if, the tensors corresponding to them have parallel principal axes. In all other cases there is no causal relationship".
>
> *(Heisenberg 1929, p. 57)*

In other words there is a physical principle associated with the way in which the tensor-product of different variables may be seen as symbolizing a physical relation. For Heisenberg, this is part of defining what he calls the law of causality in quantum theory. Heisenberg tries to argue that the only way to "express causal relationships is by mathematical laws".[86] Thus, Heisenberg tries to show how it is possible to regard the laws of linear algebra as a means for expressing causal connections between interrelated variables. This is how and why he tries to explain the possibility of establishing a new kind of dynamics. The point is that the causal laws thus introduced, reflect (what Heisenberg calls) the same *principle* of causality as did the classical law of causality; the principle that "natural phenomena obey exact laws".[87]

Yet, Heisenberg thinks this is a paradox. On the one hand we do have causal laws in the quantum theory. On the other hand the type of physical being that obeys such laws is indeterminate. Formally, the laws are well defined in respect to wave-packets, i. e. in respect to the algebraic products of harmonic functions. Yet, such abstract items cannot immediately be associated with definite observable phenomena. Heisenberg expresses this paradox by invoking Bohr's framework of complementarity to the effect that "causality" and "space-time description" are complementary parts of our "conceptual scheme" – each part "represent[ing] complementary and mutually exclusive aspects of atomic phenomena".[88]

On the face of it, this is quite confusing. Cassirer is right to claim that the principle of causality that Heisenberg refers to ought not to bear that name. This principle of Heisenberg is a kind of Laplacean one, connected with some form of (ontic) determinism. To be sure, this ontic conception of a "principle of causality" is clearly renounced in the context of the quantum theory. However, Heisenberg is still consistent with the classical Kantian principle of causality that was also invoked by Helmholtz. I agree with Cassirer in thinking that nothing of what Heisenberg wants to say about causal laws in the context of the quantum theory requires a break with that Kantian principle[89]. The causal laws of Heisenberg's quantum mechanics fully exemplify the kind of causal thinking that was advocated by Helmholtz and his followers, including Planck and Cassirer.

But why does Heisenberg choose his particular way of expression? Especially, why focus on "features of phenomena"? And how does he make use of Bohr's framework of Complementarity?[90] To answer these questions, let us recall once again that Heisenberg, first of all, wanted to focus on the limitations of the application of concepts in the

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[86] (Heisenberg 1929, p. 63-5)

[87] (Heisenberg 1929, p. 62)

[88] (Heisenberg 1929, p. 64-5)

[89] (Cassirer 1936, p. 127-8)

[90] To Bohr it is rather the use of conservation laws and the "space-time co-ordination" of dynamical variables that are complementary to one another. This, as we shall see, makes the framework of Complementarity a generalized form of *causality* (in the sense of a method within physical thought, or in the Kantian sense of a Postulate of Empirical Thought).

description of experiments.[91] So, after having proposed the definition of causal connections between variables in quantum theory mentioned above, Heisenberg importantly adds:

> "the influence of the measuring device is treated in a different manner than the interaction of the various parts of the system on one another."
>
> *(Heisenberg 1929, p. 58)*

This has to do with the requirement of making a clear separation (in thought) between the observed "object" and the observing "subject". It is at this point that Heisenberg invokes the Indeterminacy Relations. He postulates them in order to imply that there is no way in which we can visualize a partition of particular experiments into object and subject in causal terms. There is no way in which we can visualize the causal interaction between individual objects, such as a particle or a wave, itshape as forming a separate part of the total system, consisting of the object and the apparatus.

Here, we are not yet referring to an *epistemic* impossibility. We are instead trying to express a peculiar *causal* aspect of what Bohr would call "the observational situation" in quantum physics. As mentioned earlier, the Indeterminacy Relations are rules for the description of experimental arrangements. We have now learned that these rules shall include an account of the subject-object division in given experimental arrangements, in accordance with a description formulated in terms of the physical principles of a particular kind of physical theory – the quantum theory.

So, the Indeterminacy Relations do not simply describe a measure of indeterminateness in respect to some joint determination of conjugate variables, like position and momentum. As we shall see, such a joint determination should always be related to some theoretical notions each referring to a specific constant of physical change. Indeed, the very issue at stake in the construction of a new kind of dynamics is the question of what such constants might be. Of course, one may say that the Indeterminacy Relations express what the constants of atomic physical change cannot be, but that is an irrelevant claim.

What is of interest is not what the Relations rule out, but what they permit. Accordingly, we shall say, instead, that the Relations state something about the possibility of using concepts; namely, using particle-concepts in the description of *wave*like *phenomena*, and vice versa. In this way, the Relations also express what would be a certain division between subject and object within a given experimental application of the conceptual scheme of quantum theory. So this is the issue that led Heisenberg to renounce a classical, objectivistic understanding of the law of cause and effect. He says,

> "The partition of the world into observing and observed system prevents a sharp formulation of the law of cause and effect".
>
> *(Heisenberg 1929, p. 59)*

In conclusion; we are now in a position to explain why Heisenberg chooses to articulate his position as he did: To him, there are indeed laws of causation associated with the quantum theory; only, these laws cannot be formulated in terms of the notions "cause" and "effect". What wrongly might be seen as a causal connection between causes and the phenomena they produce should instead be seen as a connection between visualizable *features* of given atomic physical phenomena. As Cassirer says, Heisenberg does

[91] This is in fact a clarification of one of the fundamental issues of Bohr's, concerning the use of concepts in the description of phenomena produced within given experimental arrangements.

not intend to renounce the principle of causality, in the sense of Kant's or Helmholtz's; because Heisenberg wants to renounce only the possibility of analyzing causal relationships by means of certain forms of intuitive understanding of particular relations of cause and effect. In other words, the forms of intuitive representation of particular physical processes that characterizes classical mechanics and geometrical optics can no longer be seen as proto-examples of any kind of causal connection associated with the functioning of experiments.

As we shall see, Bohr managed to express this issue more clearly; because, the importance of the renunciation of that particular classical understanding is the fact that it tacitly embodies the following claim: There is a "direct" causal connection between individual physical objects and the phenomena that the causal interactions between such objects give rise to. Thus, according to Bohr, it is the assumption of there being a determinate and visualizable causal connection between objects (considered as causes) and phenomena (considered as effects) that we renounce.

The Principle of Correspondence: We now turn to the second principle introduced by Heisenberg in his explanation of an adequate dynamics, the principle of correspondence. Bohr had suggested this principle ten years earlier, before the emergence of matrix mechanics and wave mechanics. The principle of correspondence originally involved two claims:

(a) There is a certain formal analogy between the classical theories and the theories proposed in quantum physics.[92]

(b) at the classical limit there is a numerical identity between the values of certain dynamical variables of the quantum theory and the values of the formally analogous variables of classical theory.

It should be noted that the principle of correspondence, for Heisenberg, concerns only the former claim (a). Also, it should be noted how the notion of a formal analogy had acquired a specific meaning in the light of Heisenberg's matrix mechanics. Heisenberg intends to draw an analogy between the form of the mathematical apparatus characterizing matrix mechanics and classical mechanics. That is the sense in which the principle of correspondence embodies the formal requirement that the mathematical form of the new quantum theoretical dynamics shall be analogous to the Hamiltonian form characterizing older physical theories.

Heisenberg gives no direct justification for his making use of the principle of correspondence, except by making clear the *way* he uses it. The point of introducing formal analogies, he thinks, is to give meaning to non-traditional forms of intuition; which we must in order to grasp how the various parts of an atom may enter into dynamical states and relationships. Here, recognizing certain formal aspects of what is required of an adequate dynamical description of atomic states and their possible transitions is helpful. The mathematical apparatus thus helps us make sense of new generalized concepts of dynamical magnitudes, like "force", "momentum", and "energy".

[92] See Chevalley (1995, p. 15) where she describes the gradual change from the perspective of *formal analogies* to the later perspective of *symbolic analogies* that became part of The framework of Complementarity.

However, Heisenberg makes it perfectly clear that the adequate understanding and use of such formal analogies requires a strict physical meaning.[93] This is where recognition of principles like the principle of least action is important. Because it is only by associating the generalized mathematical scheme with such a physical principle that it makes physical sense to understand the equations of motion, formulated in new mathematical terms, as referring to those kinds of physical systems that are characterized by certain forms of configurations in respect to dynamical relations and potential energy-transformations.

Heisenberg and the framework of complementarity

We saw above that Heisenberg both spoke of the complementary relationship between aspects of phenomena, and spoke of complementary parts of our conceptual scheme as well. Again, this is quite confusing. There is *one* distinction, though that Heisenberg does make perfectly clear – the distinction between descriptions of experimental arrangements implying a space-time description of phenomena (on the one hand), and causality, in the sense of a lawful connection between the physical states of a given system (on the other).

Accordingly, when using either a particle concept or a wave concept, it should be perfectly clear to which of these two aspects of the traditional dynamics one is referring: Sometimes such concepts are used in the account of experimental evidence, other times in the account of objective processes within given systems. Heisenberg's mention of "the complementary character of various part of our conceptual scheme", then, probably refers back to the two different kinds of dynamics associated (1) with the intended observational use and function of given measuring devices, and (2) with the lawful interplay between parts of the observed system.

But why use the troublesome concepts of particles and waves at all, if such restrictions should be imposed on their range of application? To answer this we must remember our agenda, which was to formulate a form of *dynamics* with the intent to lay a foundation for a new form of *mechanics*. This task requires, first, that we associate the dynamics of quantum processes with some form of well-defined *kinematics*. This first task involves making use of pictures – namely intuitive space-time descriptions of phenomena, which is to say that we must make use of the classical notions of "particles" and "waves".

What is at stake is the Kantian requirement that a kinematics should be associated with a form of intuitive reference to dynamical magnitudes the causal structure of the forces of which constitutes an adequate dynamics. Thus we maintain a requirement concerning *Anschaulichkeit* in the link between a kinematics and a dynamics. The simple point is that this requirement need not also be related to the link between a dynamics and a mechanics. Consequently, the possible lawful relations between objective states of affairs need not, and in fact *cannot*, be apprehended visually. But in another sense, Heisenberg would say our account of objective causal relations between physical states is still "intuitive" in the sense of involving a clear application of a certain mathematical apparatus, in the account of the possible energy-transformations between physical states; namely between the states of the *joint* system of apparatus and the object being measured.

[93] (Heisenberg 1929, p.142)

The question of what Heisenberg precisely meant by the phrase "complementary aspects of atomic phenomena" remains. My conjecture is as follows: "Atomic phenomena" means phenomena relating to atomic *parts*, e. g., how an electron or a photon is emitted from an atom involving a definite transition of energy-states. So the issue is this: It is one thing to distinguish between particle-like and wave-like phenomena in the account of experimental evidence. It is quite another to distinguish between two different forms of "physical process" – two forms of physical change – taking place, as it were, *within* given atomic systems.

The logic involved in speaking about "aspects of phenomena" should be noted. Such a formulation of course implies that a whole phenomenon has more to it than any of it is aspects. Now, add to this remark the view that it is only in the context of a given empirical, experimental arrangement that we can speak of either a particle-like or a wave-like *whole* phenomenon. So this explains the point of stressing that, in both the case of particle-like and wave-like phenomena, one should refer to *atomic* phenomena, in order to make clear that one is referring to the same kind of real physical system in any case and in order to recall that each atomic aspect can manifest itself sometimes in wave-like fashion, sometimes in particle-like.

As we shall see, Bohr gradually began to distinguish between these two dimensions of physical phenomena, between the character of our contemplation of physical phenomena as atomic phenomena and the comprehension involved in observing any "whole phenomenon", as either apprehended in terms of wave-like or particle-like effects. In any event, this means that there is a form of physical experience that is not as immediate as our grasp of emerging results of given types of measurement. To reiterate, it takes, what Bohr would call "the comprehension of quantum effects" to establish an adequate form of theoretical understanding of the *appearance* of quantum physical phenomena.

To conclude: In order to be able to detect and record any result of measurement at all, we have to make use of the concepts of "particles" and "waves", for given the historical and conceptual situation, we could not make sense of the experimental arrangement. Otherwise we would not have a clear idea of how the apparatus functions or about how we are able to use the apparatus to realize clear experimental goals.

I believe these are the kinds of considerations that lie behind Heisenberg's talk about "complementary aspects of atomic phenomena". The thread of these considerations is the recognition that there are different and, it seems, mutually exclusive, ways in which to generate phenomena within a given form of experimental arrangement. The aim of any kind of experimentation, within the context of some physical theory, is to inquire how can we comprehend emerging phenomena as giving some relevant information about definite *objective states of given physical systems*. This basic question has acquired a new sense in the context of the quantum theory. Before we can even ask the question, it must be clear what it means to "comprehend" phenomena as containing information about objective physical states of atomic systems.[94] It shows:

(a) We must make use of the concepts of particles and waves in order to account for the comprehension of effects within the context of the quantum theory. We must be able to reflect how we can make use of such concepts in the description of phenomena.

[94] Heisenberg does not use this exact expression. It was introduced by Bohr around 1937.

(b) We also want to characterize various states of atomic systems, as well as their possible transitions, by invoking the concepts of electrons and photons. The point now is that the use of these latter concepts in the description of phenomena cannot, as such, be a depiction of physical states. To achieve this, a further theoretical comprehension is needed (that Bohr would call the 'synthesis of phenomena').

This explains Heisenberg's view that the concepts of particles and waves should be *criticized in terms of one another*. It also explains his discussion of "complementary aspects of phenomena", referring to the complementary ways in which one might regard given phenomena as informative of objective states.

The formal basis of the new Quantum Mechanics

In order to characterize the mathematical apparatus of the quantum theory in more detail, the following should be noted. Heisenberg believed that a new generalized kinematics is possible, because "we are now in possession of the elements of a quantum algebra"; namely the tensor calculus established within the mathematical discipline of linear algebra. Concerning the prospects for establishing a new generalized dynamics Heisenberg declares:[95]

> "So far the Planck constant h, which must play a fundamental role, has not been introduced into the theory. Its appearance proves to be closely related to the non-commutativity of the variables ... In fact it has been found by Dirac that in the quantum theory the expression $(\frac{2\pi}{h})(xy - yx)$ is the analogue of the Poisson Bracket ... in classical mechanics. The invariance of this [classical Poisson Bracket] with respect to canonical transformations of [the conjugate variables] ... is well known".
>
> *(Heisenberg 1929, p. 114-5)*

Recall from the presentation in Part Two, Chapter One, that the notion of a "canonical transformation" has two aspects. First, there is the idea that physical regularities shall be invariant in respect to change of co-ordinate system. Whether physical displacements are represented by Cartesian or by polar coordinates should not be a decisive factor in determining what is and what is not a physical regularity. Second, it is possible to maintain that the basic laws of physics may be interpreted as conservation laws by formulating the requirement that the laws must be co-variant with a certain *kind* of coordinate-transformation. In classical mechanics, this led to the importance of the so-called Galileo-transformation, and in the Special Theory of Relativity led to the importance of the so-called Lorentz-transformation. So, one way to understand Heisenberg's agenda is to regard it as related to the effort of establishing a new kind of transformation that will fulfill certain requirements regarding the invariance and co-variance of physical laws.

As we saw in Part Two, Chapter One, in the Lagrangean-Hamiltonian scheme, one makes use of the notion of "generalized" variables p and q that may represent position and linear momentum. But a generalized variable may also relate to different observable magnitudes. Now, if the equations governing the development of physical processes within a certain physical system are formulated in terms of two variables such

[95] (Heisenberg 1929, p. 114)

that there is a certain *set* of coordinate-transformations relative to which the equations prove invariant, then such transformations are called "conjugate", and the two variables in question are called "canonically conjugate" to each other. Additionally, there is a certain mathematical expression, namely the so-called Poisson bracket which, in classical physics, was regarded as the canonical way of expressing a certain physical requirement in respect to the physical magnitudes that are functions of a pair of conjugate variables. By using Poisson brackets one can express which physical magnitudes (among those enjoying a functional relationship to the conjugate variables) may be regarded as the *constants of motion* characterizing given physical systems.[96]

One might say that the Poisson brackets express a certain structural principle governing the interplay of the conjugate variables of a system. This principle governs a kind of stability within the potential temporal developments of the states of the system, in so far as this development is lawful. In classical physics all of this was precisely what was regarded as constituting a mechanics. The mathematically simple answer to the question of how the unification of a kinematics and a dynamics constitutes a mechanics was as follows: One may use Poisson brackets to characterize the configuration (the phase space) of given physical systems. Consequently, what one needs in quantum physics is to introduce a new generalized form of Poisson bracket, in terms of which one can express the structural (formal) character of the principle that governs the possible interplay of conjugate variables.

Thus, if we see the issue of formulating a new dynamics as part of the effort of developing a form of mechanics by means of Poisson brackets, we first have to confront another question: Given that the dynamical variables must be associated exactly with the kinetic elements of the already establish algebra; what can the mathematical form of the new generalized brackets be, and which kinds of dynamical variable are possible candidates for entering into this new set of mathematical expressions?

So this is the mathematical side to the story of establishing a dynamics, and this is where the notion of a *formal analogy* comes to the fore. The establishment of Heisenberg's matrix mechanics, as pointed out by Dirac, Born, and Weyl, was in principle nothing but an elaboration of a mathematical scheme analogous to the one associated with the classical formula of Poisson brackets. As Heisenberg summarizes the issue,

> "In the classical theory the Poisson brackets of canonically conjugate variables p_k and q_k satisfy the relations ... [that the product within the bracket is zero except when it concerns the variables p_k and q_l, where the indices k and l must not be identical] ... The analogous relations will therefore be assumed for conjugate variables in the quantum theory".
>
> *(Heisenberg 1929, p. 118)*

It is important to note how Heisenberg, given the analogy between the classical and the new generalized Poisson brackets, wants to associate the *introduction* of the *symbol "h"* into the quantum theory with a *generalized conception of motion*:[97] Commenting on the generalized Poisson brackets as satisfying the "analogous" rules of calculation just mentioned, Heisenberg remarks,

[96] The mathematical product associated with the Poisson bracket of such a dynamical variable with the Hamiltonian H will be zero, in case the variable is not an explicit function of time.

[97] The symbol for the Elementary Quantum of Action

> "These 'exchange relations', by means of which *h* is introduced into the equations, are of fundamental importance for quantum mechanics. They correspond to the quantum conditions of theory of stationary classical motions, but whereas these conditions could be applied only to a multiply periodic system, the present exchange relations must be regarded as generally valid for any motion." *(Heisenberg 1929, p. 118)*

So this is why the use of Poisson brackets secures an easy way to express what should be regarded as a constant of motion.[98] In using the generalized Poisson brackets, it appears that no magnitude expressed in terms of only *one* function of the conjugate variables can be regarded as a constant of motion. In classical theory, a way to describe, say, the motions of the Planets, would be to state that the angular momentum is a constant or that the area transversed by the radius-vector, between any Planet and the Sun, is a constant. What now can be a "constant of motion" in the quantum theory?

Well, it is a requirement of the quantum theory that the classical notion of the *path* of motions be given up. Consequently, the temporal development of a magnitude like angular momentum cannot be regarded as constant within a definite space. So the very idea of a "constant" does not seem to make sense! But the idea *does* make sense if we make use of formula analogous to the classical Poisson brackets.

As mentioned before, these formulas in a sense express certain rules governing the lawful interplay of two conjugate variables in accordance with which one can characterize a kind of physical stability. That is a requirement that shall be maintained in the case of the generalized brackets. Instead, the crucial contrast with the classical brackets is this: The kind of physical stability characterizing atomic physical systems must be expressed in terms of *two* magnitudes (in terms of two functions of the set of conjugate variables); because it is the transformation between two different energy states of given atomic constituents that characterizes the kind of stability in question. Also, the numerical expression associated with any two different states must be separated in the configuration space by a certain measure.

To reiterate: There is a well-known instructive geometrical representation of the Hamiltonian characterizing given physical systems; namely the phase-space representation. The dimension of any cell in that space, determined by the dimension of the product of two canonical conjugate variables, is the dimension of physical *action* (the product of energy and time, or the product of distance, velocity, and mass). So a way to make the "quantum requirement" intuitive is to claim that the various cells of the phase-space, the succession of which may correspond to the lawful development of the states of a given system, have a minimum of size. The minimum size of any cell in the phase space associated with any atomic physical system is precisely the magnitude expressed by the elementary quantum of action. This is how the quantum of action forms a necessary part of the mathematical apparatus of the quantum theory: The introduction of the symbol h into quantum theory is associated with the introduction a new concept of *a form of physical change*, i. e. the introduction of a new kind of dynamics in respect to what we can call atomic processes. So, after having established this generalized dynamics, Heisenberg is finally ready to face his primary issue. He states:

[98] Of course, here a generalized and also metaphysical concept of "motion" is in question – a general kind of well-structured physical change, since it is precisely a point to make within quantum physics that one can not maintain any classical concept of motion – any classical concept of space-time displacement.

> "The formal basis of the new mechanics is now completed; for any physical application ... the form of the Hamiltonian corresponding to the special dynamical problem must be known". *(Heisenberg 1929, p. 119)*

The physical principles of the quantum theory

The last remark says in so many words that the generalized equations of motion defining the new field of physical theory are still in need of certain *physical* principles. These physical principles shall not only establish the physical-theoretical framework that shall be associated with the mere formal apparatus, but they should also introduce rules for the construction of various theoretical models covering specific kinds of systems (such as a "many-particle-system in an electromagnetic field"). Regardless of the kind of system, there are *two* physical requirements for the construction of an adequate Hamiltonian function (H). There is the Bohr Postulate of stationary energy states, and there is the principle of energy conservation.[99]

How does Heisenberg meet these requirements, and why is it that doing so counts as establishing a mechanics? First – and this is where Heisenberg's famous use of a "diagonal method" comes into play – it must be clear how any function of the conjugate variables may be seen as a measure of energy. Second, a mathematical method is given for transforming any function of conjugate variables into a *diagonal* matrix.[100] As famously revealed by Max Born, this makes it possible to associate such matrices with the mathematical theory of unitary transformations such that matrices are associated with probability-functions. As Heisenberg puts the matter:

> "The completed scheme for the interpretation of the mathematics of the quantum theory depends on certain assumptions as to the physical meaning of the transformation functions." *(Heisenberg 1929, p. 142)*

The physical principles introduced to meet this last requirement are threefold.

> "1. ... for a non-degenerated system, the diagonal elements of the matrix representing any variable give the time averages corresponding to the various stationary states.
>
> 2. The radiation process, when the particle picture is used, may be regarded as the emission of photons with the spectral frequencies ν_{nm} accompanied by a simultaneous transition of the atom from the initial state with energy W_n to the final state with the energy $W_m (W_n > W_m)$."
>
> *(Heisenberg 1929, p. 122)*

The third principle is the well-known association of the *complex-square* of either a unitary matrix or a wavefunction with the (relative) probability-measure of ...

> "... finding [a] value of [one particular] variable when it is known that [another] value must be ascribed to [another particular variable] ... we must add the express condition that the experiment under consideration actually

[99] (Heisenberg 1929, p. 120)

[100] This is accomplished by showing that the mathematical scheme constructed so far is mathematically equivalent to a principal axis transformation of a Hermitian matrix in a Hilbert space.

affords a determination of [the former value]."

(Heisenberg 1929, p. 148)[101]

It is clear that these three principles have to embody the two primary principles regarding stationary states and energy conservation. In other words, the requirement regarding these primary principles is met by *re*-formulating the three conditions concerning the physical significance of operating with a certain mathematical form. The requirements are imposed so as to ensure that the physical principles of the quantum theory can be associated with the mathematical scheme of transformation theory, and that some use can be made of the principle of correspondence (of the fact of there being a *formal analogy* between the Hamiltonian Scheme of classical physics and the new Scheme of physical thought).

That the introduction of the two first principles meets the requirement of energy-conservation is revealed indirectly. Heisenberg shows that a Hamiltonian function H, that is formed in accordance with the generalized equations of motion in the new quantum dynamics, will "commute" with any function representing the energy of stationary states as expressed by principles 1 and 2. So the Hamiltonian of the new dynamics may be treated as analogous to the Hamiltonian of classical mechanics. But why is this an acceptable argument for having established the principle of energy conservation?

Well, in the classical case the answer was that the law of the conservation of energy could be seen as derived from the principle of least action. But if this derivation of the law of energy conservation is also relevant in the generalized case of the quantum theory, we must formulate a *generalized* form of the principle of least action. Heisenberg, however, does not formulate a quantum mechanical equivalent to the generalized Hamiltonian principle formulated by Helmholtz and Planck. What he does is to show, for a number of important kinds of atomic physical systems, that the generalized Hamiltonian governing each of these specific kinds of systems, can be derived in accordance with "a variation principle".[102]

So Heisenberg does not perform any strict derivation of a physical Conservation law. Instead, he tries to demonstrate how the use of minimum-principles (that each have a form analogous to the classical case) has in all important cases played a crucial role in the construction of adequate Hamiltonians governing the description of physical systems within the quantum theory. Thus, Heisenberg does in fact regard the principle of least action as fundamental in the manner proposed by Helmholtz, Planck, and Cassirer. The principle functions as a Postulate of Empirical Thought, in the Kantian sense of a regulative principle for the shaping of theoretical research, and as the methodological "source out of which all physical Laws must spring", as Cassirer put it.[103]

All in all, Heisenberg understands himself to have demonstrated the possibility of a new form of mechanics, quantum mechanics; because he has revealed how a union between a (new) kinematics and a (new) dynamics grounds the possibility of our demonstrating what in principle is required for regarding the physical laws governing a new domain of physical systems as conservation laws.

[101] Notice how the meaningful application of the third principle presupposes a description of a certain experiment, including an account of how to determine a value for a particular variable.

[102] There is also a generalization of the mathemathical conception of "variation". But as already pointed out above, in reference to the analysis of Jourdain, such mathematical generalization has been involved in most of the crucial reformulations of the principle of least action.

[103] (Cassirer 1936, p. 53)

3.3 Niels Bohr's original understanding of the Principles of The Quantum Theory

Preliminary remarks

My presentation of Niels Bohr's philosophy of physics will be colored by my view that most interpreters of this philosophy seem to misunderstand him in a very fundamental sense, in that they fail to even see *which were the problems* that Bohr found it most important to address. I will even claim that most interpreters turn the essential things upside down. Whereas the interpreters I criticize think that Bohr addressed the issue of how certain well-earned principles of classical physics might play a crucial part in the development of quantum physics. I will argue that Bohr regarded the quantum theory, in any sense of the term, as the best so far. *Everything* we should still say with acclaim about classical physics must be stated in the light of the principles of *quantum* physics.

This first of all concerns the view that classical physics rest on certain forms of *idealization* of experimental conditions. On my interpretation of Bohr, for the first time in the history of physics, perhaps in science in general, we have been set free from such idealizations in the sense that we have become free to conceive of various forms of *abstractions* that are not (as were the classical notions of "particles" and "waves") dependent on specific forms of experimental idealization.

According to Bohr, what has been idealized within classical physics is the use of theoretical concepts in the description of physical phenomena. Following Heisenberg, Bohr thinks one must restrict the use of theoretical concepts in the description of physical phenomena. This restriction does not follow from the internal features of the physical theory, as such, but follows instead from what would count as an adequate description of a certain experimental arrangement.[104]

In relation to this, I will argue that Bohr introduced a new theme in the philosophy of physics, namely *the question of what might possibly be the experimental form of evidence* concerning a given kind of theory. A new understanding of observability leads to a new understanding of objectively posited items within physical theory, and not the other way around. Especially, one should no longer see certain forms of classical *motion* as essential in respect to experimental observations. For instance, spectral lines should not be regarded as causally connected with definite "motions" that takes place within a certain experimental arrangement.

In line with the view of Heisenberg, this implies a new account of the way in which kinematics and dynamics form the conditions for the possibility of mechanics and means that an important feature of the Helmholtzian tradition of classical physics is maintained within the framework of the quantum theory.

My discussion will include a quite detailed account of the following view: The observable succession of experimentally produced phenomena should no longer be seen as forming a certain kind of causal development. Instead, one shall learn to see how the "synthesis" or combination of different phenomena – each of which are in principle produced within *different* experimental arrangements – constitute an objective experience in respect to a really existent, causal feature of given atomic systems.

A simple illustration can help to explain my understanding of Bohr: Consider the atom as a small part of the whole of a macroscopic physical system, the whole of a given experimental arrangement. Consider an experiment not as a sophisticated way to

[104] Here, I omit a small superfluous section of the revised version of my dissertation.

"read" the state of a pre-given object, but as a deliberate attempt to *change, influence, and disturb* the atomic object so as to give rise to certain "effects", a click here and a blip there. In short, we produce certain phenomena by certain means, but because of our theoretical understanding of how *parts* of the atom investigated have observable features within the arrangement, we thereby know how to associate the given phenomena (first with one another, and then finally) with the atom.

Consequently, I consider Bohr a *realist* in most senses of the term. I see the framework of complementarity as implying a sophisticated experimental methodology that enable us to acquire objective knowledge about pre-existing, features of the real world; even if the magnitude of the physical changes of atomic energy that we seek to describe and explain is minor than, or of comparable size to, the minimum of energy that any experimental activity, by necessity, will infuse into the system investigated. To be sure, the advent of *nuclear physics* is but one long confirmation of this.

Part of my interpretation of Bohr is very simple although non-philosophers may find it hard to understand. The view is simply that the development of new kinds of theory in science requires us to adopt *new forms of intuition*. This has to do with the age old Kantian point about the interrelation between the possibilities of *Gesetzmäßigkeit* and *Gegenständlichkeit*. On this view, if you ask what might be a concept of an object within the quantum theory, the answer will have to consider the possibility of *positing* objects in our understanding, and this again concerns the possibility of an intuitive form of empirical presentation of the kinds of objects in question (of the possible *Darstellungen*). It should not really be controversial that such empirical presentations cannot always be given classically by means of pictures in "space-time" relating to certain kinds of motion.

Bohr would sometimes summarize his view on the aim of the empirical sciences by saying that we should never separate "what we have learnt" from "what we have done". This is to some still a radical thesis to the effect that the objective content of theoretical thought is somehow relative to the structure and character of human action. The objective and the subjective features of scientific experience form two sides of the same coin. There are Kantian, Berkelian, phenomenological, constructivist, and pragmatist versions of the view, and I shall argue that Bohr formulated it in a quite original way that is perhaps closer to some views put forward by the later Wittgenstein than to any of the versions I mentioned. According to the Wittgensteinian view, *observations* must be understood as human activities, certain language games that are characterized by the utilization of certain tools (i. e. measuring devices). Now, the possibility of making observational reports *within* the game is conditioned by the very possibility of the game –, by the "fact" that the game is possible. This is a fact that is given only in so far as it makes sense to *talk* about how to play the game. A full description and characterization of the game is not required, but *some* descriptions of possible moves within the game must make sense. In that way, descriptions of "what we do" and a mentioning of "what we can learn", by playing the game, are internally related. You cannot have the one without the other.

The language game in question is the *Hamiltonian* method of theoretical physics. It is a game that, as explained by Helmholtz, is given not merely by the use of certain mathematical schemes in the description of Nature, but instead by the adoption of certain (meta)physical *principles* concerning such a use. Two things, together, make Hamiltonian physics a language game, the fact that there are *rules for the use of mathematical symbols*, and the fact that this use must answer to a *certain practice concerning*

the use of clocks, rulers, ampere-meters, and a pair of scales.

On this view, it is not the mathematical formulas, as such, that form a "model of the world", it is the whole of the practice (the whole of the language game), including the "products" of playing the game – including the theoretical statements and reports (all of which are summed up in various "configurations of possible energy-levels" of the various elementary particles bound within atomic systems).

As we play the game of Hamiltonian quantum physics, we "map" the atomic world; not in the sense that we produce a map, but in the sense that we "draw" features of the atomic world "on to" a symbolic design – just as one might say of a painter that by painting a certain objectively existing states of affairs he "dragged" this part of Reality on to his canvas. Its like building a concrete, miniature, model of something where it does not matter *how* much the model is a copy of the original, but matters how the original could be modelled; namely because of there being certain causal dispositions in the atomic realm that affords there being certain kinds of observable manifestations.[105] I shall elaborate this kind of realism in a subsequent chapter that discusses, and mildly criticizes, Rom Harré's recent formulation of the view.

These are primary features of what I see as Niels Bohr's philosophy of physics. Below, I will further present what I will call "the general framework of complementarity". This broader frame concerns the implications for our understanding and assessment of other fields of inquiry, as well as concerns their mutual interrelation within, what Bohr called, "The Unity of Knowledge". The final chapter of this book presents and characterizes this general framework. So, all in all, in the following I will

i) Give a somewhat exegetic account of the early essays of Bohr (from 1925 – 29) with the primary focus on the notion of forms of intuition; and second, provide an account of Einstein's critique of the so-called Copenhagen interpretation of quantum mechanics.
ii) Give a systematic presentation of Bohr's mature analysis of quantum physics, primarily based on his Warsaw Lecture of 1938, where the primary focus is on two major problems, the Interaction Problem and the Observation Problem.
iii) Give a thematic discussion of "the framework of complementarity" as a generalization of the ideal of causality.
iv) Discuss the question of realism within the quantum theory.
v) Discuss the semantics of the framework of complementarity.
vi) Give a critique of recent versions of a certain orthodoxy concerning the relation between classical and quantum physics.
vii) Present and discus the general framework of complementarity.

My ambition is to present the methodological and philosophical views of Bohr as establishing a framework for the assessment of physical theory, especially in respect to the general implications of physics within *all* fields of inquiry. I consider the interrelation between Bohr and his fellow quantum theorists similar to that between Kant and Newton, since Bohr (in our context) did not really add to the content of physical theory but explained, instead, the possibility of, and rationality in, pursuing a scientific research

[105] My formulations here are inspired by Stephen Toulmin's early masterpiece *The Philosophy of Science* and by Rom Harré's works from 1986 and on that I discuss below.

program based on certain principles of thought. This is not to say that Bohr systematically extended or modified the views of Kant, but I *will* argue that Kantian ideas and problems to a large extent colored and pushed Bohr's philosophical considerations forward. As I will explain in further detail, this is the reason why I consider Bohr to have adopted the Helmholtzian approach to theoretical physics even if Helmholtz may not have been a direct influence on Bohr.

Problems raised in the early essays

> "Bohr's position seems quite strange to us today. However, it turns out to be deeply consistent with a major trend in German philosophical thought ... Bohr's suggestion of substituting symbols for concepts in quantum mechanics ... would be just heresy from a strictly Kantian point of view. But they make sense if we look at the tradition in which we found Goethe, Humboldt, Helmholtz, Hertz, Husserl and others unexpectedly at work together. Indeed, whatever differences existed between these writers, they all thought that the word '*Symbol*' could serve to describe the special kind of knowledge which is not grounded in intuition (ordinary space and time)." *(Chevalley 1994, p. 49)*

In respect the question of how much Bohr inherited the program of Helmholtz, I think that there are two points that we shall acknowledge. First, following the development of the Bohr,Kramers, and Slater hypothesis (see below) Bohr had come to lay much stress on the question concerning the nature and status of conservation laws. But, second, Bohr acknowledged that to grant to the quantum theory that it maintained the possibility of conservation laws would still not be enough to constitute a full philosophical assessment of that new kind of theory. What shall be the criteria that justify our assessment of a new kind of theory? I shall argue in what follows that *that* was the primary issue in Bohr's epistemological considerations in respect to the quantum theory.

One gets a first impression of this issue in the essay from 1925 on "Atomic Theory and Mechanics", that Bohr chose to include in his first collection of philosophical essays, *Atomic Theory and The description of Nature*, first published in Denmark in 1929. The early essay of 1925 was written shortly after Bohr had given up the suggestion made in the ill-fated paper of Bohr, Kramers, and Slater one year earlier, in which the hypothesis was entertained that there might only be a "statistical" sort of energy conservation associated with individual atomic processes. The lesson Bohr learnt on that occasion was not so much an empirical confirmation of a physical law; instead, it was the necessity of regarding the conservation laws as forming part of the whole explanatory account of atomic physical processes. This underscores the view that some principles of physical thought are regarded as more basic than the conservation laws. Examples include the quantum postulates introduced in the formulation of early atomic models, as well as a number of formal principles connected with these models [say, associating the Rydberg-Ritz formula of spectral lines with certain mathematical principles known in electrodynamics], and of course the principle of least action.

So, from early on Bohr might be said to have concentrated on the following issue: How is it that the introduction of basic principles partially determines the epistemological background for the possibility of conceiving a *kind of* lawfulness? The Bohr-Kramer-Slater hypothesis involved making a radical proposal regarding what might be

the new kinds of laws constituting the domain of atomic theory. In the light of the failure of this hypothesis Bohr learnt to accept a constraint on the kinds of physical lawfulness in terms of which any new significant theory in physics should be expressed. That was the topic of the early essay, as its title indicates; "Atomic *Theory* and Mechanics".

A "mechanics" in the sense of the Helmholtzian tradition, was characterized by a special kind of *intuitive representation of physical processes involving a conservation of some dynamic quantity*. This is the essential feature of the kind of theory called "classical theory". So the problem was that if Heisenberg's newly proposed matrix mechanics was to correspond to a new kind of *theory*, the quantum theory, then what would be the representation of physical processes involving a conservation of some physical property? What may this representation be that "completes" the matrix formalism as a significantly applicable physical theory?[106]

Bohr and The Principle of Least Action

Although Bohr did not explicitly discuss the prospects of generalizing the principle of least action, there is no reason to doubt that he recognized the fundamental importance of such a principle. First, Bohr was surely conscious of the mathematical character of the Hamilton Principle. Second, Bohr chose the following way to express what he saw as the significance of the development of the quantum theory:

> "The epistemological lesson we have received from the new development in physical science, where the problems enable a comparatively concise formulation of *principles*, may also suggest lines of approach in other domains of knowledge". *(Bohr 1948, p. 317-8, italics mine)*

> "From the very beginning the main point under debate has been the attitude to take to the departure from customary *principles* of natural philosophy characteristic of the novel development of physics"
>
> *(APHK, p. 32-3, italics mine)*

Third, Bohr would time and again stress how both Heisenberg's Matrix Mechanics and Schrödinger's Wave Mechanics embodied a generalized version of the canonical equations of motion – of the Hamilton formalism – such that the generalized version helped to establish a "suitable formal representation of kinematical and dynamical variables".[107] It is true that until 1938 Bohr would still associate the generalization of the canonical equations of motion with his "Correspondence Argument".[108] However, as I will argue, Bohr always related the issue of *this* generalization with an issue that he called the Interaction Problem. Indeed, this is one of the cornerstones of Bohr's philosophy of physics. As stated in the following, both Matrix Mechanics and Wave Mechanics may be seen as two different solutions to the Interaction Problem. I want to stress how Bohr associates this Interaction Problem with a series of considerations. Take for instance the following remark of Bohr's:

> "In fact, wave mechanics, just as matrix theory, on this view represents a symbolic transcription of the problem of motion of classical mechanics

[106] See especially the last section of the essay.
[107] (Bohr 1938, p. 14)
[108] (ibid., p. 13)

> adapted to the requirements of quantum theory ... Indeed, the two formulations of the interaction problem might be said to be complementary in the same sense as the wave and particle idea in the description of the free individuals. The apparent contrast in the utilization of the energy concept in the two theories is just connected with this difference in starting point."
>
> *(ATDN, p. 75-6)*

I shall explain the details of this below. But first let me underscore the point I am making. It is the *combination* of the effort to generalize the canonical equations of motion and the considerations in respect to the Interaction Problem, taken together, that I understand as involving a generalized version of the principle of least action.

As we shall see, the Interaction Problem is part of an ingenious point of attack made by Bohr on what he called the Observation Problem. In a later chapter, I shall devote two sections to a discussion of the Interaction Problem and of the Observation Problem. Bohr's line of attack on these two problems bears on a certain notion of "abstractions". For now, a single example may illustrate the issue:

The radiation emitted when an atom undergoes a state-transition may be regarded both as a process taking place within an atomic system and as a distinguishable element of the experimental arrangement. One might say that any process of radiation has two aspects of observation. In one sense it forms part of the total set of interactions constituting the atomic system investigated; in another sense it forms part of an observational interaction – part of an interaction with a certain apparatus so as to give rise to specific observable phenomena.[109] The point is that any atomic model, any method of representing the atom as a composite system, implies ideas (*Vorstellungen*) about how the atomic parts become available to direct observation. As Bohr says in one of the extensive Como-drafts:

> "... in all direct experiences about atomic properties we are concerned with the behavior of atoms in interaction with radiation or free material particles. We must even admit that the definition of all concepts entering in the description of observational results presupposes these abstractions".
>
> *(Works VI, p. [98])*

In that sense, the concepts of "elementary *particles*" and "transition *processes*" are methodological concepts; they are "abstractions" in a double sense: They are symbolic representations, not pictures of true states of affairs, and they symbolize "abstracts" from the composite system, "the atom". This is what makes Bohr claim in the Como-Lecture that,

> "... the main stress has to be laid on the formulation of the laws governing the interaction between the objects which we symbolize by the abstractions of isolated particles and radiation. Points of attack for this formulation are presented in the first place by the problem of atomic constitution".
>
> *(Bohr 1934, p. 69)*

[109] "It is scarcely neccessary to mention that for a more detailed description of the interaction between individuals we ... must resort to a procedure which allows us to take into account the coupling of the individuals, characterizing the interaction in question ... such a procedure necessitates a further departure from visualisation in the usual sense". (ATDN, p.62)

As stated, I will return to discuss the details of this view later. It is enough here to observe the "main stress" Bohr wants to place on principles concerning the formulation of laws. So to conclude, Bohr points to the necessity in the formulation of conservation laws of formulating laws that may be said to govern the interaction of abstractions. This again refers to an idealized form of interaction – namely, the interaction between "free" objects (particles or waves). This implies, as Bohr stated in the former quote, a utilization of the energy-concept, for the idea of "free" objects – free to move, free to be propagated in space – is closely connected with the idea of certain distinct forms of energy, say "kinetic energy" or "field-intensity".

Now, in an atom, there are precisely no "free" parts, but only parts *bound* together within a manifold of energy-states. However, this implies something very basic for the establishment of the quantum theory: The various elements entering into the Hamiltonian canonical equations of motion are seen to symbolize ideal forms of energy, such that the modeling of observational interactions, in such terms, is interpreted as forming part of a symbolic representation of a new and complex kind of *Energie-Zusammenhang*. The form of the laws that govern the physically possible transitions between different states within such a manifold (a) are in accordance with the Quantum Postulate and (b) can be formulated in terms of a *selection principle* in respect to the stationary (or stable) character of any possible energy-state. Such selection principles, so to speak, stand proxy for an integration principle proper, but exemplify in any case a kind of symmetry-principle concerning the invariance of a mathematical relation under certain mathematical operations (i. e. Heisenberg's diagonal-method, or Schrödinger's use of standing vibrations within an electrodynamic field).[110]

When any such formal selection principle is interpreted as helping to define the physically possible stable configurations of a composite energy-system, then we have a generalized version of the principle of least action. This is true in so far as the point of the selection principles, or quantification rules, so introduced, are supposed to express restrictions on the formulation of any physically possible conservation law.

All in all, these are my primary reasons for finding it proper to regard Bohr as a follower of the tradition of theoretical physics initiated by Helmholtz. However, there is also good reason to claim that Bohr made important additions to that tradition. These additions – including those regarding the early Heisenberg's conception of the principles of the Quantum Theory that were presented in the former chapter – are reviewed next.

Atomic Theory and Mechanics, 1925

In the following I shall try to give a survey of a range of Bohr's early philosophical essays. To some extent the agenda of Bohr's philosophical considerations was expressed in his early paper from 1925, "Atomic Theory and Mechanics". As already mentioned, Bohr chose to include that essay in his first collection of epistemological papers, *Atomic Theory and the Description of Nature* where it is presented explicitly as forming the best introduction to the epistemological considerations concerning the quantum theory.

[110] "... Heisenberg succeeded in taking a decisive step in this direction by showing how in the equations of motion of classical mechanics the ordinary kinematical and mechanical quantities could be replaced by symbols, which refer directly to the individual processes required by the quantum postulate".(Works VI, p. [95])

The essay lays particular emphasis on the connection between mechanics and mathematics. Accordingly, Bohr begins the essay by reminding us of the importance of the calculus of variation and the general transformation theory for mechanics. The connection between these formal mathematical methods and the Hamiltonian tradition in mechanics is explicitly pointed out. Furthermore, the final section of the essay is concerned explicitly with the question of how the quantum theory does embody conservation laws, and how it does so precisely because the theory is formulated in terms of the kinds of mathematical method just mentioned.

At this time Bohr still made substantial use of his principle of correspondence. Yet, as Catherine Chevalley has pointed out, whereas the principle was previously associated with the notion of pictorial analogy, it now becomes dissociated from such a notion. The primary case exemplifying such a combination is of course the pictorial analogy characterizing Bohr's model of the hydrogen atom, where the atom was depicted as a sort of planetary or orbital system. It is the latter notion that must be replaced by a formal notion of "stationary states".

In order to characterize the situation Bohr makes use of various metaphors. He especially advocates recognizing that Heisenberg's Matrix Mechanics involves a reinterpretation (*Umdeutung*) of all the essential features of classical mechanics. Bohr would later renounce this particular metaphor. In the series of Como drafts, from the autumn of 1927 and on, Bohr would refer to a "transcription" (*Umschreibung*) of the fundamental equations of physical theory. This change of metaphor plays a crucial role in Bohr's turning the principle of correspondence into a form of *argument*. Still, a notion of a form of correspondence between the formal structures of the classical Hamiltonian equations and the canonical equations of the quantum theory plays a certain role in the justification and elucidation of the new approach.

In the essay of 1925 the principle of correspondence in a sense stands proxy for *all* the principles governing an adequately formulated quantum mechanics. This is so because the point of establishing the principle is to bring the Quantum Postulate into harmony with the various theoretical expressions entering into the constitution of the quantum theory.[111] According to the view that I have already attributed to Bohr, the considerations above all go to say that the principle of correspondence, in it's second form of 1925, relates to the claim that there must be some way to recognize the laws of the quantum theory as being formulated in accordance with some generalized version of the Hamilton principle, and thus also in accordance with some generalized version of the principle of least action.

Now, in the essay, Bohr refers to kinds of "pictures" that cannot have the (classical) role they used to have in the understanding of physical theories. For instance, Bohr refers to "mechanical pictures" – a notion he would continue to use, although he never cared to explain it adequately.[112] Certainly, Bohr's primary concern in the paper is the notion of a representation (*Vorstellung*), especially in the classical sense of the *Vorstellung eines Zu-Stand*, be it the representation of a state of motion or the representation of a stationary state associated with an electron bound within an atom. It is important to note the attributes that Bohr ascribes to such representations: the quantum theoretical state-representations are considered "symbolic" inasmuch as

[111] (ATDN , p. 48)

[112] Such an explanation might have made reference to pictures of motions created by drawing orbits in accordance with a space-time representation of the states of motion; that is, a space-time representation of the vectors associated with any dynamical variable.

there is a formal analogy between the state-representations of the quantum theory and those of classical theories. However, there is a sense in which Bohr later modified his early notion of a symbolic form of state-representation. This modification came about when Bohr acknowledged Schrödinger's Wave-Mechanics. This generalized mechanics is not only formally equivalent to Heisenberg's, but from Bohr's perspective, it was recognized as embodying a new kind of intuitive representation of the stationary states of atomic systems; namely, in the form of the famous *Eigenschwingungen*, the standing vibrations of matter waves.[113] Importantly, Bohr would still criticize Schrödinger's own understanding of this. Bohr would time and again remind us that the intuitiveness in question does not refer to a space-time representation of physical states, and thus does not involve any geometrical depiction of the lawful propagation of physical action (of *Wirkung*). Instead, the new kind of intuitive representation represents a theoretical configuration, such as the configuration of standing vibrations in the probability space, associated with the electron-configuration of bound particles within an atomic system. These kinds of representation therefore symbolize a peculiar *non*-intuitive kind of physical stability, but do so in accordance with certain intuitive principles of theory.

In his interesting and very informative book, *Imagery in Scientific Thought: Creating 20th Century Physics*, A. Miller has argued that Bohr and Heisenberg, more or less in collaboration, advanced a distinction between "forms of intuition" and "intuitiveness" (*Anschaulichkeit*). Miller rightly claims that whereas Heisenberg would point more and more to the latter in order to finally renounce the notion of "intuitive" Vorstellungen in any traditional sense, Bohr would maintain the former notion. As Miller presents his case, it seems to be the distinction, often made in neo-Kantian writings, between *Vorstellungen* and *Darstellungen*, that is at issue. According to this distinction, intuitive *Vorstellungen* are associated with the classical Kantian forms of intuition, space and time, characterizing human sensibility. So this is the sense in which intuitive representations are characterized as intuitive pictures in order to stress the pictorial character of space-time representations. In contrast, intuitive *Darstellungen* are "exhibits" of states of affairs in a more formal sense, *exhibiting a possible use of concepts in the description of some range of phenomena*. It is obvious that this neo-Kantian notion of *Darstellungen* is closely related to a Kantian schematization of theoretical concepts, differing in kind from the original schematization of "sensible" concepts.

Now, in the early essay Bohr argues that the stationary states of an atomic system cannot be visualized or pictured by means of the *Vorstellungen* given within classical mechanics or within classical electrodynamics. But the stationary states can be exhibited by means of certain rules of quantification that govern the distribution of states within a manifold of energy-states in terms of selection rules for the coordination of the so-called quantum numbers (n, l, m, s).

This is how both A. Miller and C. Chevalley present the views of Bohr as well. In contrast to Miller, and perhaps to Chevalley, I would want to stress the importance of the fact that Bohr preserved some notion of *Anschauliche Vorstellung*, namely in respect to the readings of measuring instruments. In fact, the essay of 1925 is important precisely because of Bohr's insistence that one has to be able to make sense of the

[113] This is true in the sense that both Matrix Mechanics and Wave Mechanics could be generalized so as to formulate the *same* generalization, and *not* in the sense that the two forms of mechanics, as they originally were formulated, were in any sense "equivalent". It is the generalized version of both forms of mechanics which is discussed througout this book; thus also in the previous account of Heisenberg's Chigaco Lectures.

Vorstellung of a photon that again relates to the *Vorstellung* of an atomic process.

Most importantly Bohr never turned his back on the question of what might be an adequate notion of a *representation of an atomic process*. In my view, since Bohr considered the quantum postulate of Planck an expression of the essential contrast between a continuous and discontinuous form of physical change, Bohr kept posing this question. This, however, is not to renounce any possibility of representing possible quantum processes in thought, and doing so *intuitively*. If this could not be done, we would have to renounce the observability of atomic processes. That is why we must have an intuitive representation of such items as photons and electrons. Thus, as we shall see, we must associate the Observation Problem with the Interaction Problem. We must "weigh the possibilities of (state)definitions with the possibilities of observation", as Bohr put it in his Como Lecture.[114]

It is not the necessary link between the forms of intuition and the forms of physical change, such as "causality", as originally pointed out by Kant, that must be renounced in quantum mechanics. It is instead – what might be called – the Kantian principle of continuity – that must fall. We shall realize that it was never essential that physical change, in the Kantian sense of *Wechsel der Zustände*, be represented by continuous curves in space-time. That was of course already the point of introducing the Hamiltonian phase-space representation. Even within classical mechanics, it had already been established that the change of states of motion can be fully represented as a *Wechsel* of energy states, associated with a variation of kinetic energy. Such *Darstellung*, however, requires a *Vorstellung* in respect to the observables in terms of which the *Darstellung* can be given. Now, the difference between classical mechanics and quantum mechanics concerns the character of such *Darstellungen*. In classical physics the defining demonstration of a phenomenon corresponded to pointing to a definite "point" on a certain continuous time-line within the phase-space. Within quantum mechanics it corresponds to pointing to a distinct cell forming part of a discrete distribution (projecting a probability distribution on to a configuration space).

The reason for this difference has to do with Bohr's definition of a "phenomenon". As we shall see, within quantum physics, to be an observable object means to be an item that enters a variety of atomic processes – that are conceived in theoretical thought – so as to give rise to a phenomenal manifestation. Thus, there can be no *Darstellung* of atomic physical processes without there being *Vorstellungen* in respect to the way in which parts of the system observed are involved in phenomenal manifestations. This was the view that Bohr and the early Heisenberg, both advocated and that – I will argue below in the chapter on the principles of quantum theory – Bohr importantly, by contrast to the later Heisenberg, never gave up.

The Como-preliminaries and afterglows, 1927-8

Around 1926 there was an ongoing discussion between Schrödinger and Bohr. The crucial point of these discussions was the question of whether the new kind of intuitive representation (i. e. Schrödinger's notion of *Eigen-Schwingungen* as representing individual stationary states) implied restrictions on the use of given concepts, or instead, implied the need to introduce new theoretical concepts. Bohr opted for the former traditionalist suggestion whereas Schrödinger opted for the latter. Bohr explained his position in a letter to Schrödinger as follows:

[114] (ATDN , p. 55)

> "[Ich bin] mit Ihrer Betonung der Notwendigkeit der Entwicklung von 'neuen' Begriffen kaum ganz einverstanden. Nicht nur haben wir, soweit ich sehe, bis jetzt keinerlei Anhaltspunkte für eine solche Neugestaltung, sondern die 'alten' Erfahrungsbegriffe scheinen mir untrennbar mit der Grundlage des menschliches Anschauungsvermögens verknüpft ... meiner Ansicht nach ist auch keine Rede von einer mehr oder weniger willkürlichen Begrenzung der Anwendbarkeit der klassischen Begriffe, sondern um [von] der Erkenntnis eines unvermeidbaren Zugs von Komplementarität, der in einer Analyse des Beobachtungsbegriffs zum Vorschein kommt ... In dieser Verbindung möchte ich ... bemerken: Wie ich in meinem Artikel versucht habe, sind [die Unsicherheits-] Relationen als eine unvermeidbare Begrenzung der Definitionsmöglichkeiten des Raum-Zeit-Vektors und des Impuls-Energievektors der einzelnen Individuen anzusehen, indem sie einer Eigenschaft von Wellengruppen Rechnung tragen, die eine unmittelbare Folgerung des Superpositionsprinzips ausdrückt".
>
> *(Works VI, p. [465])*[115]

What comes to the fore in the letter is the issue of how *Erfahrungs-Begriffe* are associated with our ability to produce intuitive representations. This is certainly a Kantian theme. It should be noted how Bohr regards the concept of observation as interrelated with the two notions of intuitiveness and *Erfahrungs-Begriff*. For this is how the issue defining the agenda of the series of Como-papers emerges – that of "weighing the possibilities of definition and the possibilities of observation".

What is a "concept of experience"? To Bohr it means a concept used in the description of physical experience – and this again means, used in the description of phenomena that one can possibly observe. Now, there are the two things I should like to stress in my comments on Bohr's letter to Schrödinger: First, the possibility of observing phenomena involves the possible use concepts in the description of phenomena. Second, this relates to an issue that was already mentioned in the essay of 1925, and that will be discussed extensively below; namely, the issue that certain *Vorstellungen* of photons and electrons constrain the possible use of concepts in the description of phenomena. In sum, the character of these restricting *Vorstellungen* says something interesting about the very concept of observation.

If one reads the English versions of Bohr's various papers, one will see that Bohr seems to use the term "idea" in two different senses. The term is used partly as a translation of *Vorstellung*, but it is also used in order to characterize certain *modes of thought*. For instance, Bohr refers to the "classical ideas" of point-particles and harmonic wave trains. In the German/Danish versions, when Bohr refers to such "ideas", he most often speaks about *Die Begriffe* of particles and waves.[116]

One the one hand Bohr, like all the physicists in the Helmholtzian tradition, maintains the Kantian notion of forms of intuition referring to the necessity in physical thought of producing representations of objects in space and time. Like Kant, Bohr associates the notion of a form of intuition with how such *Vorstellungen* come about.

[115] True, this letter express the view of Bohr's after Bohr had both learnt from Heisenberg's Indeterminacy Relations and Bohr had consequently written his Como/Solvay-paper(s), and thus also after having introduced the "framework of Complementarity". But the letter displays the original disagreement between Bohr and Schrödinger nicely.

[116] Here I omit a small paragraph, which did not do any work, of the officially reviewed version of my dissertation.

But of course these "considerations" of Bohr's are different from those of Kant's. On the other hand, Bohr, in line with the mentioned tradition, wants to analyze how the invocation of spatial and temporal features in the description of phenomena gives rise to, and circumscribes, a certain mode of experience. In particular, Bohr wants to analyze how certain kinds of measurement condition the possibility of applying certain kinds of laws, and thus of applying theoretical *Begriffe* in the description of observable phenomena. By putting these two themes together one can see how the two notions of *Erfahrungsbegriff* and *Vorstellung*, both translated as "idea", hang together according to Bohr.[117]

The Como / Solvay essays, 1927-8

I believe that no one can claim to understand the philosophical views of Bohr, early or late, if they cannot explain the structure and content of this crucial series of essays. It is of course true that Bohr, as he himself put it, "improved the terminology" as he came to write more and more papers on philosophical issues. It is also true that Bohr's various discussions with Einstein and others triggered much of Bohr's philosophical thought. But I find that there is no reason to claim that the philosophical views of Bohr's changed significantly after the Como-period.

A few weeks after the Como Conference that was held late September 1927, and a few weeks before the Solvay Meeting took place in late October, Bohr produced an extensive draft ("the October Paper"), the content of which is presumably closer to the content of the addresses actually delivered by Bohr (in Como and at the Solvay Meeting, respectively) than is the published version, the so-called "A-version" that nevertheless was printed in the *Proceedings* from the Como Conference.[118] The A-version, again, differs in many ways from the longer, revised version, published nine months later in English in *Nature* and in German in *Die Naturwissenschaften*.[119] The latter two versions, the two B-versions, between which there are minor deviations too, are divided into seven paragraphs each of which is supplied with informative subheadings. Below, I shall refer only to the B-versions.

Let me point to some of the views first mentioned in the October Paper that are crucial, but less visible in the various versions published later. In some notes written in September, 1927, before the Como Address, Bohr had already suggested to renounce the "idea of independent tools of measurement".[120] In the October Paper, Bohr also suggests to renounce the "idea of independent *phenomena*".[121] Neither the tools of measurement, nor the phenomena they help make observable, can be seen independently of one another. What comes first is the entire "experimental material", as Bohr calls it, the interpretation of which "rests on classical ideas" (*Vorstellungen*).[122]

[117] In her impressive and very informative *Glossaire* , included as an Addendum to the French translation of APHK , Chevalley has a very helpful explanation of how Bohr makes use of these and other crucial notions. (Chevaley 1991)

[118] Printed in *Works* VI, p. [113-36].

[119] Two years later, a Danish version appeared which is close to being a translation of the German version. That is the general pattern: The terminology used in the German and the Danish versions of Bohr's philosophical essays is almost always the same, whereas the terminology of the English versions is sometimes rather awkward or puzzling if the meanings of the German / Danish terms are supposed to be maintained.

[120] Works VI, p. [75]

[121] Works VI, p. [91].

[122] Later, in my account of what I shall call Bohr's general framework of Complementarity, in respect to

This brings us to the issue mentioned already in the early essay of 1925 that a tension has arisen within atomic physics between the postulates (of experimental thinking) and the *ideas* (Vorstellungen) that accompany our description of phenomena. Two implications of this tension are worth mentioning:

(a) Regardless which kind of lawfulness is adequate for the quantum theory, it must be acknowledged that there are limitations on the potential uses of *Vorstellungen*. There will consequently be restrictions governing the use of concepts in the description of phenomena.

(b) The *Vorstellungen* on which a limitation is imposed are first of all the ideas of *point particles, harmonic waves*, but also that of a *matter waves*.

In sum, the limitation on ideas concerns the range of items that, as we shall see, Bohr calls "abstractions", including a number of prototypical ideas of constituent features of atomic systems, such as "photons" (corresponding to potential transition processes) and "elementary particles" (corresponding to potential stationary states). The importance of such prototypical ideas, as we shall see, is that they help us make sense of forms of experimentation.[123]

In the September Notes Bohr had introduced the concept of an *abstraction*. However, it is in the October Paper that Bohr first tries to connect the concept systematically with the analysis of both the Interaction Problem and the Observation Problem, respectively. To Bohr, there were two paradigmatic kinds of abstractions, namely the notions of free particles and freely propagated harmonic waves. Both are abstractions in the *double sense* that (1) their being "free" can never be seen in abstraction or apart from the possibility of their being bound within composite systems, and also in the sense that (2) their manner of being bound relates to a form of interaction the inclusion of which characterizes certain such systems.

In an atom the various elementary particles interact, as do the individual particles with the radiation fields within which they act. Regardless of the kind of interaction, the very idea of a physical experiment requires that a kind of interaction takes place that conditions the emergence and behavior of various observable entities. But that kind of interaction will, in an important sense, be no different in principle from the kinds of interaction taking place within composite systems.

This is the sense in which whatever one observes may always be related to possible abstractions from certain physical systems. Such abstractions are, as Bohr put it in the September Notes, agencies forming part of the system measured upon that are available for observation. The manifestation of abstractions in observable phenomena display how it is they form part of a composite whole. This is what Bohr has in mind, I think, when he states that atomic constituents like the abstractions of photons and electrons are "observed in terms of their interactions".[124]

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all fields of experience, I shall make frequent use of this conception of "the interpretation of experimental material".

[123] At this point one might add two further notions which would later complete this early part of Bohr's philosophical programme: (c) It is possible to investigate *how* there are limitations on the application of *Vorstellungen*. One may "inquire into the nature of the presuppositions" that frames such application. (d) There is a way in which to assess that the use of concepts in the context of the quantum theory may be said to be in accordance with *a generalized ideal of causality* – namely "complementarity".

[124] *Works VI* , p. 79)

This is also the view that Bohr elaborates in the second paragraph of the Como paper on kinematics. It is very instructive to note Bohr's reference to the tradition of geometrical optics. That tradition is characterized by the utilization of a particular mode of intuition; namely, the use of straight lines in order to exhibit (*darstellen*) the propagation of light rays; or in other words, exhibit the spatio-temporal distribution of spectral intensities. So the method of light rays can be regarded as a way to exhibit *not* a particular subject matter, but the very possibility of observing a range of phenomena in optical physics. In analogy to this, Bohr now suggests that one might regard the constraints imposed on the quantum theory, not the least by Heisenberg's Indeterminacy Relations, as forming part of a method of observation.[125]

The upshot of these considerations is the introduction of a new conception of physical *individuals*, such as "matter waves", the individuality of which is well-defined in terms of the principle of superposition of harmonic waves and the related concepts of "group-velocity" and "phase-velocity". Thus, it is possible to trace the space-time development of such "abstract individuals" without relating to earlier (classical) methods of tracing items in space and time. In this way we can define those energy states of atomic systems that shall be associated with its constituent parts. In short, we shall have "weighed the possibilities of observation and definition against each other", as Bohr defined the agenda of the Como Lecture.[126]

In the series of Como papers, Bohr tries to explain the necessity of renouncing the union between what he calls the "space-time coordination" between observables and what he calls, "the claim of causality", the claim of a causal connection between successive physical states of a given system. This renunciation forms the background of the introduction of the framework of complementarity. In order to see how the framework relates to what has been discussed above, let me make the following distinctions:

(a) the kinematics of the measuring devices
(b) the dynamics of the measuring devices
(c) the kinematics of the various parts of the system investigated
(d) the dynamics of these same parts

(a) amounts to the "tracing of observables" that in classical mechanics contributed both to (b) and (c). That is, (a) contributed both to the understanding of the functioning of the apparatus making up the experimental arrangement and (b) to the tracing in space and time of the values of dynamic variables (c), the joint determination of which define a physical state of the system being measured. Consequently, these states are represented as possible configurations of a system within a lawful physical development (and *not* just a temporal one) of the given system (d).

The third paragraph of the Como paper deals with point (b), the dynamics of possible measurements. The essence of the paragraph is the critique and analysis of the concept of observation – a critique that centers on revealing how any such concept is related to some form of description of natural phenomena. Bohr intends to stress that, in the quantum theory, *the link between (b) and (c) is broken*, which again means that it takes a new concept of observation to settle what may be regarded as the kinematics of the system measured upon, answering point (c) above.

[125] On these relations, see the account of the possibility of performing and describing measurements in quantum physics in later paragraphs.
[126] (ATDN 1934, p. 55)

Now, let us see how these considerations are associated with those of the first paragraph of the Como paper on causality. It must be noted that the basic characteristic of a dynamical relation is not that it is causal, but that it is lawful. Similarly, the depiction of a definite chain of events is not a characteristic of causality as such. It must be associated with a depiction of a unique form of causality. The determination – the defining of physically possible states for given systems – does not in itself involve characterizing any determinate courses of action. So, to say that the emergence of a succession of physical states within a given system is lawful, in terms of a conservation principle, is to say that there is a constancy for some value of a dynamical variable that may be systematically derived from given observables.

Nothing in the quantum theory is supposed to change this. On the contrary, it just shows how the theory embodies the canonical Hamiltonian approach. But one difference comes to the fore, a difference pointed out by Bohr: There is no way in which we can claim that *tracing observables implies keeping account of the magnitudes of dynamic variables "defining" the possible state descriptions of atomic systems*.

Summing up, the framework of complementarity is introduced in the Como paper(s) as an attempt to distinguish what Bohr calls "the claim of causality" and the description of phenomena in terms of spatio-temporal *Vorstellungen*, each of which must be seen as "complementary, mutually exclusive features of the *content* of experience".[127] I shall discuss this in several paragraphs below dealing with the different aspects of the framework of Complementarity. Here, I shall stress only what "the claim of causality" means to Bohr: It means that the possible state-definitions for given atomic systems be related in lawful fashion – even if "tracing" the succession of states, in the theoretical configuration space – in the Hamiltonian phase-space – need not be seen as tracing observables in ordinary space-time co-ordination.

The primary implication of this is crucial. There is no way in which to analyze or scrutinize the very process of observation itself. There is a sense in which "to observe" is a method whose structure and function must be fixed in advance (and fixed differently for different kinds of phenomena). As we shall see, it was the importance and content of this claim that Einstein, for one, never grasped. The claim is at the core of the Interaction Problem that I discuss below. Here, I shall only mention how the claim, relates to Heisenberg's Indeterminacy Relations, according to Bohr. Precisely because these relations impose constraints on the analysis of observations, they clarify the possibility of *defining* quantum-theoretical physical states, disregarding a certain latitude in the determination of some dynamic variables (in the sense of (d) above). In short,

> *the Relations form part of a method of observation re-establishing a link between point (a) and point (c) above (between the kinematics of the experimental set up and kinematics of the system investigated). The method is based on a sharp distinction between points (b) and (c) [between the dynamics of the set-up and the kinematics of the system]; and thus also between points (b) and (d) [between the respective dynamics].*

The fourth and fifth paragraphs of the Como paper try to establish that Heisenberg's Matrix Mechanics and Schrödinger's Wave-Mechanics are but two solutions to the Interaction Problem. This implies that the mathematically formal equivalence of the two theories must not be associated with an equivalence between descriptions of phenomena in terms of individuals. Even if one might claim that each of the theories deals with

[127] (Bohr 1985, p. 135), in my translation from Danish. Compare the vague expression of (ATDN , p. 54.5)

the same kinds of observables (say, photons and electrons) one would have to note that the observations of such individuals refer to different, though interrelated, forms of individuality – namely, refer to individual transition processes represented by Heisenberg's diagonal method and to the stationary states represented by Schrödinger's *Eigen-Schwingungen* (the *standing vibrations* solution to Schrödinger's differential equation).

The sixth and the seventh paragraph of the Como paper give many important clues to the kind of connectedness (*Zusammenhang*) there may still be between these different kinds of individuals, insofar as their connectedness is regarded as characterizing the peculiar stability of atomic systems. Also, it is important in the understanding of this stability to recognize the connection between the possibility of being a "free" agency and the possibility of being "bound" within atomic systems. There is no way, Bohr says, in which the interpretation of observations (based on the abstractions of interacting free individuals) can be separated from an understanding of the possibilities for defining physical states within given systems. *That* is indeed the the primary topic of the Como paper(s), the issue of "weighing the possibilities of observation with the possibilities of definition".[128]

The Como Lecture has a definite conclusion. Bohr clearly states that what he has argued in the Lecture was an attempt to show the necessity and possibility of *adapting our forms of intuition to new forms of theoretical thought*. As I have stated several times, Bohr's primary issue was the question of which principles of thought corresponded to a certain new kind of theoretical thought. The primary answer to this query now seems to relate to the principles governing the interplay between *Vorstellungen* (of a certain intuitive form) and the *Darstellungen* (associated with a new kind of theory). As I will discuss in detail in the chapter on Rom Harré below, this is to the effect that a new kind of schematism becomes associated with classically given *Vorstellungen*. In this sense, the classical forms of space-time intuition are adapted "on to", as Bohr put it, the quantum theory. This is one way to summarize the Como Lecture; another is to say that it systematically translates and relates the early forms of quantum mechanics to specific epistemological issues. As such, it parallels Kant's reconstruction of Newtonian physics in accordance with general principles of thought. The Como Lecture elaborates a connection between a physical theory and the metaphysics of experience. In the following, we shall try to follow Bohr's consideration on the particular notion of experience in question.

The essays of 1929

When Bohr was invited to contribute to a *Festschrifft* of the University of Copenhagen by writing a longer essay Bohr instead chose for practical reasons to collect a number of previously written papers and supply them with an "Introductory Survey". The result was the early collection of philosophical essays, published first in Denmark in 1929, in Germany in 1931, and finally in England in 1934 under the title *Atomic Theory and the Description of Nature* (ATDN). Apart from the essay of 1925 on "Atomic Theory and Mechanics" and the B-version of the Como Lecture, the collection contains the Introductory Survey and two papers delivered in 1929, one in Germany ("The Quantum of Action and the Description of Nature"), and one in Copenhagen ("The Atomic Theory and the Fundamental Principles Underlying the Description of Nature").

[128] (ATDN , p. 55)

I have made the claim above that the philosophical views expressed in the Como Lecture remained at the heart of Bohr's philosophical considerations. It is often suggested that Bohr modified his views in the late 1930's. The modification comes about, it is claimed, either because of the impact on Bohr of the Einstein-Podolsky-Rosen encounter or because of some sort of "linguistic" turn in Bohr's thoughts. Both of these suggestions are, in my view, too strong. But I will not deny the fact that Bohr continually elaborated and clarified his philosophical thought. I see this as an effort to broaden the philosophical outlook, such that Bohr's analysis of physical concepts and methods was systematically related to the analysis of other forms of intellectual understanding. Given this view, if one had to identify a decisive modification of Bohr's philosophy after Como at all, one should say that the change came as early as 1929. *There* is the "linguistic turn", if any, in Bohr's philosophy. This interpretation is consonant with the following point made by Chevalley that the "linguistic turn" of post-Fregean philosophy was somehow prepared by a "symbolic turn" in post-Kantian philosophy:

> "If the 'linguistic turn' in philosophy was prepared by a 'symbolic turn' throughout the nineteenth Century, it is no wonder that Bohr's own symbolic turn in physics was so closely linked to his description of the epistemological paradox in the use of language." *(Chevalley 1994, p. 49)*

Both in the Introductory Survey and in the paper read in Copenhagen, Bohr points to a fundamental "complementary relationship" between the analysis of a concept and the immediate application of the concept.[129] He advocates a general "caution in the use of our means of expression", and reminds us that there are limits to the meaning of our concepts in their various applications.[130] He also states that, when it comes to learning how to express ourselves adequately within new fields of experience, there will be a period when we shall have to express ourselves with a "painting of words", instead of using concepts in our descriptions that can be analyzed according to clear cut principles.[131] Chevalley has argued that all of this is due to an influence on Bohr by Humboldt. Chevalley reminds us that within a Humboldtian conception of language there is a basic distinction between the *analysis* of words and the *synthesis* of words – a distinction so to speak between a rule-governed grammar in terms of which any well-formed sentence can be analyzed, and a more plastic putting together of words, both in order (a) to express the peculiarities of individual states of affairs and (b) to express something for which we may not yet have words. In short we require a distinction between a "scientific" use of words and a "poetic". I think Chevalley's position goes in the right direction but fails to elucidate a further distinction between the "poetic" use of words and the "synthesis" of human thoughts.

Let me try to show how these linguistic considerations arise in the context of the quantum theory. Following post-Kantian thought, one should recognize an essential link between the use of any word and the forms of intuition that characterize our ordinary sensible experience. The link exists because both the use of words in describing

[129] (ATDN , p. 20)

[130] (ATDN , p. 116)

[131] (ATDN , p. 20). The english term "word-picture" does not fully capture the Danish / German "Gemälde von Wörter". There is here an interesting parallel to Planck's original use of the term "Gemälde": "Sehen wir nähmlich genauer zu, so glich das alte System der Physik gar nicht einem einzigen Bild, sondern vielmehr eher eine Gemälde-Sammlung; denn für jede Klasse von Naturerscheinungen hatte man ein besonderes Bild."(Planck 1908, p. 23-4)

phenomena and the formation of intuitive representations of objects is part of our effort to *organize experiences*. However, with the advent of the quantum theory, one can no longer equate the following two issues:

(a) The (theoretic-conceptual) description of the *content* of possible experiences
(b) The (epistemic) interrelation of *phenomena*

The point is that the understanding of the determinate content of any experience can never be accomplished independently of some conceptual ability to "place" any possible experience within the totality of such. Within the context of the quantum theory, this means that we must consider in a new way what it is to have knowledge according to objective physical laws, such that this knowledge grounds the possibility of surveying phenomena. In particular, there is one form of surveying phenomena that we must renounce. There is no way in which we can observe a causal relation between various phenomena. The *succession of phenomena* drops out of our causal understanding of objective atomic structures. This view is at the very heart of the essays of 1929.

So we have to resist the temptation to associate the succession of phenomena within given experiments as forming a direct *picture* of the objective succession of physical states of the system, being measured, in the configuration space. Thus, Bohr goes on to underscore the importance of an investigation into *Das Wesen unserer Anschauungsformen*. By this he means an investigation into the issue (a); an investigation into the limitations imposed on the possibility of using concepts – not the least the concept "cause" – in the description of phenomena.

The Introductory Survey is a summary of the other essays of the early publication, but it contains some very precise formulations lending good support to the considerations of these essays. For instance, Bohr makes clear that reflecting on the limitations of classical mechanical *Vorstellungen*, we have to look for possible limitations in the application of the concepts of the theories, especially the concepts of "cause" and "observation".[132] Since the interrelation (*Zusammenhang*) of the results of physical measurements might in principle be related to a statistical kind of lawfulness, the inter-connectedness between what is observed can no longer be seen as a picture of the lawful connections that give rise to the measurements.

This is why we must reflect on the use of the concepts of the quantum theory in the description of phenomena. We face the task of reflecting what "connection", "succession", "interaction", "measurement", and "observation" are supposed to mean, given that what they used to mean a Planckian World of Sense can no longer frame the intelligible theoretical use of the concepts within the quantum theory. And this is why Bohr, in the Introductory Survey, famously states that there is a limit to the meaning of the results of measurements in the quantum theory, and not because Bohr had become a positivist, as is often stated. In the essay "The Quantum of Action and the Description of Nature" that was written in honor of Planck, Bohr associated all the considerations just mentioned with an account of the objectivity of phenomena. The objectivity of phenomena does not consist in their forming part of a causal succession, as seen from a classical perspective. Instead, there is a way in which we can access a physical kind of lawfulness such that with this assessment follows a way to identify various phenomena and bring them into relation with one another. Indeed, as Bohr states in the Introductory Survey, this is the very aim of the physical sciences:

[132] (ATDN , p. 22)

> "We meet here in a new light the old truth that in our description of nature the purpose is not to disclose the real essence of phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience". *(ATDN, p. 18)*

In the Faraday Lecture of 1932, Bohr began referring to "ordinary causality" characterizing classical physics. It was this ideal that the framework of complementarity was meant to "generalize".[133] I shall elaborate on this notion of an ideal of causality below in my presentation of the various aspects of the framework of complementarity. Here I shall only elaborate on the notion of Unity and it's relation to that of causality: What is at stake is the possible union between two claims: the claim of a causal connection between objective physical states and the claim of operating with intuitive representations of physical states. Consequently, putting the two together, one should relate the possibility of this union to a requirement concerning the unity of state descriptions. By this I mean the unity between (a) the *uniformity* of state descriptions and (b) their status as dynamical.

Taken together, these two claims constitute an account of a definite *form* of change, so as to characterize the potential state transitions of given physical systems. In the context of atomic theory this is what grounds the possibility of characterizing all transition processes as changes in the binding-energy of bound elementary particles within a particular atomic configuration. Thus, we have introduced a new and generalized Hamiltonian energy-concept, and have done so as part of explaining how the Quantum Postulate of discrete transitions processes can be associated with the possibility of our conceiving a new, but *uniform kind of physical change*.

That is the sense in which the requirement of Unity is met in the quantum theory. The requirement is met in so far as we have succeeded in weighing the possibilities of state definition and observation of physically significant, non-visualizable, kinematical elements. According to Bohr, the issue of the possibility of generalizing the classical ideal concerning state ascriptions cannot be separated from the issue of Unity in the description of Nature. Consequently, there is reason to claim that Bohr followed Planck in combining the two issues of *Verallgemeinerung* and *Einheit* in the development of our conceptual understanding of Nature.

Recall: It is not the idea of mechanical connections, of determinate chains of events, that defines classical mechanics in particular. What defines classical mechanics for Bohr and all members of "the great German school in theoretical physics" as Bohr called it in his Faraday Lecture, is the same as what characterized a "dynamical mechanics" according to Kant: a special union of *kinematics* with *dynamics*. Now, the special union between kinematics and dynamics that characterizes classical mechanics is expressed by the classical physical concept of a *motion*. This again is essentially connected with the idea that the representation of the distribution of dynamic qualities can be depicted as a distribution in space and time, and as having a definite intuitive geometrical form.

Within the quantum theory the adequate kinetic elements have no such intuitive form. This is how the framework of classical mechanics breaks down: Any systematic logical representation of the relations between phenomena, like those experienced in the form of the various quantum effects, can in no way consist in a visualizable or

[133] (Works VI, p. [400])

pictorial tracing of dynamic variables in space-time.[134]

Yet, there is another sense in which the quantum theory constitutes an advance in the intuitive nature of our understanding. Bohr always associated Heisenberg's Indeterminacy Relations with a recognition of the limitations of previous forms of intuition. Bohr not only saw this as a "liberation" on behalf of our experience. He also characterized the quantum theory as a "great advance" in our understanding of natural phenomena, and even went so far as to claim that a new era had begun in Natural Philosophy where all ideas ever applied in research were applicable in mutual harmony:

> "... it has been my desire to emphasize as strongly as possible how profoundly the new knowledge [of QT] has shaken the foundations underlying the building up of concepts, on which not only the classical description of physics rests *but also all our ordinary modes of thinking*. It is above all to this *emancipation* that we owe the wonderful *progress* in our insight into the phenomena of nature which has been made during the last generation ... Perhaps the most distinguishing characteristic of the present situation in physics is that almost all the ideas which have ever proved to be fruitful in the investigation of nature have found their right place in a common harmony without thereby having diminished their fruitfulness."
>
> *(ATDN, p. 101, italics mine)*

How can the recognition of limitations on given forms of intuition and the consequent insight into nonintuitive forms of relation be associated with an advance in the intuitive character of physical understanding? To answer this, Bohr's invocation of the *Vorstellung* of photons and matter-waves should be noted. These *Vorstellungen*, Bohr claims, have been supplied with a *handgreiflichen Inhalt* in so far as these representations are systematically related to our keeping stock of dynamic variables.[135] The content of the representations cannot be seen in abstraction from the kind of *Rechenschaft* in respect to dynamic variables that characterizes our effort to relate phenomena to one another. True, there is no simple visual-geometric way to regard phenomena as causally related, as emerging from the various interactions of one and the same objective atomic system. Yet, by performing a logical calculus on various quantum effects, each associated with some abstract *Vorstellung*, we then manage to "synthesize" phenomena, constructing a causal account of the development of physical states, and doing so via intuitive representations – the abstract *Vorstellungen* of photons, electrons, and matter-waves.

As Bohr reminds us, in making use of conservation laws in the account of physical experience, one has to involve some ideas concerning the stable and unchangeable character of atomic constituents. The use of these *Vorstellungen* is part and parcel of the very attempt to establish a particular set of physical laws, the application of which enables us to take account of dynamic variables in the description of emerging phenomena. That is a primary point of the fourth essay of the early collection of philosophical essays.

Following from all of this, Bohr combines two views. The first, as pointed out by A. Miller, is Heisenberg's belief that there is room within the quantum theory for a notion of *Anschaulichkeit*.[136] The second is Planck's idea that the sciences may be said

[134] The Bristol, Wills memorial lecture, (Works VI, p. [61])
[135] And this is yet another phrase Bohr adapts from Planck.
[136] (Miller 1984, p.151, 160)

to develop ever more abstract forms of intuition. Bohr even claims, contrary to what some have considered him believing, that this process might continue. In respect to intuition, the quantum theory is in no way regarded as the end of the line. One must never forget that Bohr himself played a part in the development of nuclear physics contributing to that further abstraction of intuition relative to the quantum theory, the possibility of which he acknowledged already in the last essay of 1929.

Abstraction and idealization

Recently, both Nancy Cartwright and Rom Harré have indicated the importance of the two notions of abstraction and idealization and the need to distinguish between the two. In order to elucidate Bohr's use of the two notions, I want to discuss some parallels and differences between the different ways in which Harré and Cartwright, and Bohr explains the distinction. First, Harré defines the two notions like this (making use of the generic term "strata" that stands for real features of real objects):

> abstraction: not every detail in a stratum need be reproduced in a model
> idealization: not every kink and break in the boundaries of a given strata need be reproduced in a model.

We see that both notions are defined in a methodological sense. "Abstraction" is understood in a Lockean way (leaving out every detail) and has to do with our trying to achieve a more general understanding of the particular instances of which we have some experience. The notion of idealization has to do with a more conventionalistic and strategic aspect of experimental methods, in contrast to the realistic overtone of the notion of abstraction. By introducing abstractions we somehow keep track of the true courses of Nature, whereas idealizations are primaryly *our* ways of selecting and arranging things. The point is not that idealizations are *not* real; instead, it is that something real is represented in an ideal "simple" or formal manner. Also, it is not Locke's account of the *process* of generating general ideas by means of abstraction that Harré endorses; instead, it is the idea of what it is you have achieved once you have established a general concept. In fact, Harré points to Berkeley's insight that general ideas are but particular exemplars that are given a particular, general *role* in the organization of experience. But still, abstractions are considered to correspond to abstract "strata" within a whole range of concrete objects.

In fact, it is not Harré's idea of "abstractions" but, instead, his concept of *affordances* – that I discuss in Part Four, Chapter Five – that comes close to Bohr's concept of abstractions. An "abstraction" for Bohr was an objective feature of reality that could only be conceived in relation to the human possibility of observation of it. In a handwritten note, dated september 9th 1927, we find Bohr making this statement:

> "The complementary features of the apparent contrary claims of individuality and superposition finds it explanation thereby that such agencies as free material particles and radiation in empty space are abstractions according to the quantum theory. They can only be observed through their interactions". *(Works VI, p. [79])*

Bohrian "abstraction" is something whose reality is relative to it's possibility of being observed. As we have seen above, Bohr uses the term "abstraction" especially to cover a non-vizualizable realm of reference. For instance, the stationary states of atoms count as abstractions. However, as I have argued at length, Bohrian abstractions are not only abstracts (in that they form only a part of an objectively existing physical system), they are still intuitive posits in relation to observational interactions (such as line spectra or the photo-electric effect). They are so to speak posits in two different language games. First, they enter our modeling, say, of an atom. Second, they enter our arranging an experimental setup. That implies that idealization has to do with the way in which we can intuit certain abstracts (atomic parts) within a given observational interaction.

A Bohrian idealization, then, is not like the Harréan counterpart a matter of selecting relevant features, a matter of concentrating our attention; it is instead a matter of modeling a physical interaction in the light of a theoretical model (what Bohr called the "weighing of the possibilities of observation with the possibilities of definition"). Bohrian idealization weighs phenomenal displays and objective manifestations in the sense of Harré.[137] It is a matter of weighing the possibility of apprehending phenomena with the possibility of observing posits within the quantum theory.

I conclude that Harré, on my view, is one of the few to have understood the Bohrian notions of abstraction and idealization. However, the *terms* that Harré uses in this regard differ radically from those of Bohr to the effect that the distinction (in Harre's sense of the terms) between abstractions and idealization become close to irrelevant. I find that Harré has rightly pointed out that the *formal* features of a given physical theory and of the models associated with it cannot, and need not, represent the real causal structures of things. But I find it without warrent to relate this to the Lockean and Berkelean issue of how the structure of our experience can be said to have a *systematic* connection to whatever forms the grounds for the possibility of experience. Thus I also find it without warrant to make use of the notions of abstraction and idealization respectively, to express a formal limit to any adequate ontology (i. e. to justify the view that Nature, however complex its causal structures may be, must be so constituted, that it allows or "affords" the intelligible – or well-formed – shape that our experience is known to have). Indeed, I shall explicitly criticize this kind of transcendental argument in a later chapter on Harré.

Now, in one of her recent books, Nancy Cartwright interestingly argued why it is important to distinguish, in her understanding of the terms, abstraction and idealization. According to Cartwright, one ought to distinguish between two senses of the former term, each of which is of relevance to modern physics. First there is a *mathematical* sense, expressed in particular by Duhem. Some physical objects are "abstract", in the sense of not being real and concrete, like (say) points-of-gravity and refraction indices. Second, there is an *aristotelian-metaphysical* sense, in which some existencies are seen as more "abstract" than others because of the number of features needed in order to characterize the existencies. Thus quark-structures are more abstract than molecular ones. Similarly, objects specified in purely functional terms are more abstract than those whose identity presuppose a specification of the "stuff" out of which they are made. In this Aristotelian sense, according to Cartwright, abstraction does carry the Lockean feature of subtraction.

None of Cartwright's notions of abstraction corresponds to Bohr's. Cartwright invokes the distinction between idealization and abstraction in order to argue that "abstract laws" – describing, say, the reality of a "laser" in functional terms – doesn't express a (Humean) regularity, but instead one of Natures *capacities*.[138] Cartwright's reason for adopting this ontology is the important insight, that Bohr would have endorsed, that one should not express the causal structure of objects by reference to some *ceteris paribus clause*. Indeed, this is the reason why both Cartwright and Bohr make a distinction between "abstractions" and idealizations".

The paradigm of idealization is, according to Cartwright, the Galilean idea of "ideal" circumstances such as the frictionless plane. By idealizing, we point to a counter-

[137] See Part Four, Chapter Five.

[138] In Cartwright's ontology capacities must be ascribed to *properties*. Such are not individuals, but "factors" whose operation is complex and contingent with respect to boundary conditions.

factual situation where the laws of physics are true descriptions of what *would* happen under such ideal conditions (knowing that the laws of physics always "lie" about what happens in any real, complex physical situation). Cartwright distinguishes between abstraction and idealization in the following manner: On the one hand, the practice of Galilean idealization (i. e., the frictionless plane) forms a necessary part of any mathematically formulated model in theoretical physics. On the other hand, the intelligibility of that practice presupposes an ontology. For instance, the laws of kinematics are counterfactual – they are ceteris paribus laws. As such, they are idealizations. Still, they form the condition for the possibility that we, within mechanics, are able to express a *real* causal interconnection between objects.

Cartwright wants to inquire how that is possible. Her answer centers on the view that the (repeated) display of regularities within certain experiments make it manifest how a natural property – say of a given atom – has the capacity to tend to cause various regular connections in a range of specific circumstances. So the heart of the matter is the necessity of transcending the level of the counter-factual in our attempt to understand causal structures. In that respect Cartwright's aim is to attack the Humean "linear" conception of causality. Causal structures are, so to speak, multi-dimensional – their complexity transcends any "form" that any kind of logical reasoning may be able construct out of a range of experimental facts.

I want to point out that the Aristotelean concept of abstraction, although Cartwright tries to modify and widen it in a Lockean direction, is strictly *formal*. The determinations or characteristics of a given "abstract" object correspond, at best, to certain, relevant, forms of simplicity corresponding to a specific model of the material conditions for our design of experimental arrangements in respect to a given theory. Consequently, Cartwright's "abstractions" are constrained by the (formal) kinds of idealization that governs a certain form of experimental observation. For example, the formal features of the kinematical elements within the Galilean tradition constrain the *form* of the possible causal structures of the objects of mechanics (even if the *content* of the mechanical laws – the set of possible properties that each tend to cause, in an observable manner, a certain manifest regularity – transcends the ontology of ideal, kinematical relations and conditions).

As to the example of quantum mechanics, as well as in respect to other examples within the modern sciences, Cartwright will certainly have more complicated, mathematical, things to say about, for instance, the statistical character of a given form of idealization, and thus also abstraction. However, that does not change our point. For Cartwright, within quantum mechanics, the range of possible atomic-physical processes that can be analyzed within that field of inquiry will be constrained by the possible formal models of certain experimentally observable phenomena. For Bohr, the necessary idealizations of a given experimental arrangement, instead, condition the possibility of our conceiving of *non-ideal* forms of abstractions. The formal features of any set of possible determinations do not, as Cartwright implicitly has it, characterize atomic structures. Instead, atomic structures are relative to a (non-formal) series of *part-whole* structures (say, a series of transition processes and a series of energy-levels, i. e. an electron-configuration). Each of these part-whole structures thus represents an "elementary" feature of a given atom. They each ground the possibility of our making certain experimental observations, but there is no *systematic*, or *formal*, connection between these "possibilities of observation" and the corresponding "possibilities of definition". As Bohr put it, we have to "weigh" these two sets of possibility against

each other.

In other words, the two sets condition each other within our *development* of our knowledge of atomic structures. A case in point, that I examine in Part Four, Chapter Five, is the discovery of the (Stern-Gerlach) spin-effect and thus the doubling of the previously known atomic structures. According to Cartwright, atoms are characterized by capacities that embody properties to tend to cause certain causal regularities. But let us ask if Bohr would agree that a given atom embodies the tendency to cause a certain statistical behavior of elementary particles in given magnetic fields? On my account he would not. It is not the *behavior* of the elementary particle as such that is a causal product of the constitution of the atom. As will be clear from the discussion of both the concept and the principle of causality in a later chapter, we shall say something more complex. We shall say instead that the atom causally grounds the possibility – not only for different kinds of elementary atomic parts (i. e. electrons and photons) having certain observable manifestations – but also for the different forms of manifestation being "synthesized" (as Bohr put it); namely synthesized within a theoretical analysis of the various experimentally produced phenomena. This dialectic relation between possible forms of analysis and possible forms of synthesis is, as I will explain in detail below, the later Bohr's precise formulation of the somewhat more loose notion of "weighing" the possibilities of observation with the possibilities of definition.

Chevalley on the Kantian inheritance

I find it instructive to quote an excerpt from Catherine Chevalley's work that summarizes the huge impact of Kantian epistemology on the development of theoretical physics in the 19th Century. However, as the closing words of the paragraph say, the quoted lines should remind us how the original Kantian position was modified and challenged as it was applied to the developing field of physics. Chevalley states that,

> "When confronted with Bohr's vocabulary one should maybe take one step more and identify the philosophical language in which quantum theory was born and formulated as the general *erkenntnistheoretisch* language which pervaded philosophy and physics during the 19th Century, especially in the German tradition. This language disappeared. One feature of post-war translations of Bohr's ideas in the literature was that words and concepts tended to be disconnected from their original widely accepted meaning. To make this plausible one can give a few simple examples of 'words of ordinary language' that are used to hide specific philosophical concepts in Bohr's (or Pauli's, Heisenberg's, Born's or Schrödingers's) papers" *(Chevalley 1995, p. 23)*

Before I continue this quote, I will draw attention to the implicit critique of the so-called "Ordinary Language Philosophy" that is sometimes attributed to Bohr. Is is true that Bohr would often make the point that ordinary modes of discourse can never be dispensed within the description of the functioning of measuring instruments, even within the specialized contexts of a theoretically based experimental science. But this does not make ordinary language, as it were, neutral or innocent in respect to philosophical reflection and understanding. Thus, as Chevalley reminds us, the "ordinary" language available for a theoretical physicist working in the 19th Century was a language soaked

in epistemological notions of a general Kantian kind. Examples of these include the following notions that are listed by Chevalley:

> " 'Intuition' (*Anschauung*), for instance, always referred to Kant's concept of the mode through which thought immediately refers to an object, while *Anschauungsformen* referred to space and time as the general forms of sensibility through which we grasp all phenomena. 'Presentation' (*Darstellung*) referred to the operation through which a concept is presented in pure intuition (as in mathematics) or in empirical intuition (as in physics), and therefore was different from 'representation' (*Vorstellung*), which was the generic term for all the different kinds of knowledge. 'Analogy' (*Analogie*) referred to either of two Kantian concepts. It could refer to the 'analogies of experience' which served to describe Kant's epistemology of physics in the *Critique of Pure Reason*. But when 'analogy' and 'symbol' were used together, they referred to the very different concept of analogy which Kant qualified in the *Critique of Judgement*, as a second kind of act that made a concept sensible ... 'Phenomenon-object' (*Erscheinung-Phänomen/Gegenstand-Objekt*) referred, sometimes very precisely, to the different stages of objectivation as described by Kant. Behind the word *Erklärung* and its contrast (many times reassessed by Bohr) with *Beschreibung*, there was a discussion which had been crucial to the development of the *Geisteswissenschaften* during the second half of the 19th Century. Words like 'non ambiguity' (*Eindeutigkeit*), 'coordination' (*Zuordnung*), 'causality' (*Kausalität, Gesetzlichkeit, Ursache und Wirkung*), 'symbol' (*Symbol*), 'image' (*Bild*), 'acceptability' (*Zulässigkeit*), 'exactness' (*Richtigkeit*), 'appropriateness' (*Zweckmäßigkeit*) were all widely discussed in the epistemological works of H. von Helmholtz, H. Hertz, E. Mach, J. Petzholdt and many others. The physicists who created quantum mechanics thus inherited from the widespread influence of Kant's work a general language the conceptual sharpness of which had already been tested and modified by their predecessors. In this sense ordinary language did provide philosophical concepts, and we have an explanation of Bohr's strange emphasis on innocent-looking words."
>
> *(Chevalley 1995, p. 23-4)*

Like Chevalley, I do not mean to regard Bohr simply as a follower of the German School. Although it is true, as Chevalley has argued convincingly, that there is no acceptable way to assess the philosophy of Bohr if one does not acknowledge that Bohr was "born into" the tradition of theoretical physics initiated by Helmholtz; this does not mean that the views of Bohr can simply be thus characterized. One might even say that Bohr, as Chevalley puts it, was "twisting the language [of the tradition] to use it against itself", and that Bohr wanted to "criticize the language, both the ordinary and epistemological, from within".[139]

Still, as Chevalley also stresses, there is a sense in which the critical assessment of Kantian epistemology was guided by a philosophical program that was designed by Kant himself, although this critical assessment was first fully elaborated through successive steps taken by Goethe, Humboldt, and other post-Kantian philosophers. One

[139] (ibid., p. 32)

might describe that program as that of "rewriting the *First Critique* with the *Third* in mind".[140] This view comes to the fore in Chevalley's remark that "authors such as Goethe, Humboldt, Helmholtz, and Hertz appeared in the 1920's as belonging to the same line of thought [that] is clearly evidenced by Cassirer's books".[141] Acknowledging this, I suggest to characterize this "line of thought" as did Cassirer: The program in question was that of re-thinking the interrelation, indicated in the *First Critique*, between a Transcendental Aesthetics and a Transcendental Analytic.

In fact this is precisely the program that Chevalley wants to ascribe to Bohr. Chevalley has indicated an important shift in Bohr's understanding of the notion of "correspondence" between classical physical and quantum theoretical conceptions – a shift that occurred sometime in 1925. Before then, Bohr had for some years spoken about there being "formal analogies" between the two kinds of concepts (and between the respective theories formulated in terms of them). From 1925 on, Bohr began talking about symbolic analogies and began to associate these with a notion of the unintuitive (*un-anschauliches*) character of such analogies. Chevalley importantly links this shift in Bohr's view of the notion of "analogy" with the shift Kant made from the *First* to the *Third Critique*.

As quoted above, the formal analogy was associated with the so-called "analogies of experience", which again were part of the *schematization* of the rule-governed forms of the Understanding – the *Darstellung* of the categories within *Sinnlichkeit*.

The latter sense of the term "analogy", introduced by Kant in the *Third Critique*, relates to the possibility of making sense of concepts when *no rules* are ready at hand for their application. Thus in respect to individual appearances it may be possible to sense a certain wholeness that as such cannot be analyzed in terms of a rule-governed application of a definite set of concepts. Yet one might associate the given appearance with the idea that it is a well-formed product of Nature as such; and consequently, that the appearance is "well-formed" in certain respects. Therefore it may make sense to describe the appearance by analogy to the kind of construct to which we can apply concepts in a rule-governed fashion.

In my view, Chevalley is absolutely right in ascribing this line of thought to Bohr. In relation to this there is something else that should be noted that I am not sure Chevalley would acknowledge: The introduction of the notion of "symbolic analogies" into physical thought had implications for understanding the notion of "analogy" as such, and thus also for the understanding of classical physics. So, as I shall argue, from 1925 onward, Bohr recognized that there is a sense in which even classical physics is a kind of "construct". Within the quantum theory, the expositions of principles and basic concepts are symbolic in a double sense: They are regarded as symbolic in respect, not to certain forms of construction, as such; but instead to the *idealizing character* of the schematization of classical physical concepts. The symbolism of the quantum theory does not, in my understanding of Bohr, substitute the schematism of classical physical concepts; instead, *it put into perspective the point, the meaning, and the practice of schematizing concepts*. This view of Bohr, as I shall explain in detail, comes to the fore in Bohr's analysis of both the distinction and the interrelation between the different kinds of "idealization" characterizing forms of measurement on the one hand and the description of the physical systems measured in terms of "abstractions" on the other.

[140] (Chevalley 1991, p. 45)
[141] (Chevalley 1995, p. 29)

Consequently, one might be warranted in making the claim that the ultimate philosophical question that Bohr undertook, given the considerations just mentioned, was this: *What does it mean to explicate the principles of a new kind of theory if that explication cannot take the form of the (idealized) schematic presentation [in the sense of Kant's First Critique], but may at best be "symbolic"* [in the sense of his *Third Critique*]?

If I understand Chevalley correctly, she wants to say that Bohr did pursue precisely this question from 1925 and on, but that he gradually felt the need to articulate a new philosophical scheme. She comes close to saying that the best idea one can have of Bohr's mature philosophical agenda is that it was an effort to achieve a Hegelian *Aufhebung* of the aforementioned question. I do not agree with this. I would say instead that Bohr engaged in a constant effort to elaborate a coherent program – a program that was always based on an adequate answer to the question presented above. Regardless of what "the philosophy of symbolism" is supposed to be, it will in some sense have to contain a semantic interpretation of the character and limits of the schematization of concepts.[142]

[142] I come back to this, time and again, in what follows, but see especially Part Four, Chapter Five, the paragraph called "apparata as schemata"

4 The Principles of the Quantum Theory: Einstein and Bohr

4.1 Einstein's critique of Quantum Physics

The Einstein, Podolsky, Rosen essay of 1935

As is well known, Einstein never fully accepted quantum physics although he was in a sense its father, since it was he was the first to formulate a physical theory incorporating Planck's quantum of action, namely, the theory of the photo-electric effect of 1905. Now there are a wide range of accounts of Bohr's "discussions with Einstein," to use Bohr's own term. According to Bohr's account, there was a certain continuity within these discussions in that they all had to do with Bohr's – unsuccessful – attempt to have Einstein accept, and even grasp, the framework of complementarity. However, looking at the so-called discussions between Bohr and Einstein from Einstein's perspective, they seem instead to be a series of perhaps very different attempts to raise some critical questions regarding the quantum theory; in other words, in Einstein's view one should not, as Popper has put it, think of the quantum theory, as "the end of the road." Accordingly, although Einstein saw this theory as an important and to some extent successful theory within the development of non-classical forms of physical theory, he always wanted to argue that the quantum theory was *in principle* not an acceptable successor to the classical theories of Newton and Maxwell, respectively. Again, in my view, Popper got Einstein's quarrels right. His concern was that *given* the character and content of the classical theories, the quantum theory did not meet certain normative requirements.

Einstein's philosophical views changed somewhat over the years and were successively influenced by a range of different philosophers. Einstein was always a kind of neo-Kantian. In his intellectual autobiography, Einstein describes how he as a young man, inspired by Euclidean geometry, became fascinated by the idea of there being certain axioms of thought. Einstein points out that all similar ideas concerning necessary and fixed features of Human Thought are in principle rooted in some kind of synthetic character of this thought.[143] He argues that this is because by definition what distinguishes thinking from sense experience, as Kant has it, is the ability of the former first to perform a synthesis resulting in a particular element (e. g., propositions,

[143] (Einstein 1949, p. 11)

possible judgments), and second to expose and clarify a *totality* of propositions. However, through the influence of Kirchoff, Helmholtz, and Hertz, Einstein became a neo-Kantian rather than remaining Kantian in a strict sense.[144] Einstein had always been puzzled by the idea of there being a priori elements of human thought. Now he learned that this should only be understood to express the mathematical character of Human Thought, its ability to establish, fix, and follow rules that could be explained and taught among scholars. This brought Einstein to clearly see the distinction between the application of concepts within experience and thought, respectively. In effect, this is yet another Kantian distinction – between judgments of perception and judgments of experience. However, Einstein associated this distinction with a distinction between "free creations" and "logical features" of our use of concepts, which means that the development of language in general, and of mathematics in particular, opens up new horizons of sense. New forms of experience and thus new forms of questions can be put to Nature. To Einstein this initially meant only that scientific conceptions were not to be seen as a priori but rather as a free response to some pre-given experience, the primary example, of which would be erecting Gallilean mechanics as a means to more clearly express experiences that were already at hand – for instance, by introducing notions like "relative movement" and "frame of reference." Second, the development of new concepts could be seen as forming the first step toward formulating a logical system of *thoughts* proper, the primary example of which would be Newtonian mechanics.

As a result, one might expect that Einstein thoroughly inquired about what precisely constitutes such a "logical system." He did not, and we shall soon find out why. Pointing to the development of electrodynamics, hydrodynamics, and statistical mechanics in the nineteenth century, the main question for Einstein became not so much the character of logico-theoretical systems *as such*, but rather the way in which any such system could be said to create progress within human experience (and not within Human *Thought* as such). Maxwell's and Boltzmann's theories do not, on a formal level, embody higher forms of thought than do Newton's. Rather, they cover a broader field of phenomena, in that the representation of, say, electromagnetic fields and their elements – such as charges, displacement currents, magnetic inductions and so forth – have distinct mechanical features as well. Maxwell's theory is not an extension or elaboration of Newtons's theories, but is in a sense *at one* with these. This is important to notice since the main question that Einstein was to raise in relation to assessing the quantum theory was, similarly, how the quantum theory could be said to be at one with Maxwell's theory (and also the general theory of relativity considered as a general field theory).

Einstein also mentions Hume and Ernst Mach as sources of influence. Einstein adopted their skeptical attitudes towards any established scientific theory.[145] Thus, all in all, the epistemological position of Einstein can be crystallized into two poles: a pole as regards a certain set of normative requirements concerning the development of human experience and another pole concerning his critical, skeptical attitude towards any given (system of) experience(s). To Einstein, Niels Bohr represented a scientist who ignored both these poles, both these criteria. To Einstein, Bohr saw the quantum theory as in some sense necessary, but not because Bohr associated the theory with certain principles of *experience*, it was rather because he dismissed any such principles. To Einstein, Bohr ignored the very manner in which experience can challenge thought. In

[144] (Einstein 1949, p. 15)
[145] (Einstein 1949, p. 21)

the following I argue that instead Bohr indicated the *variety* of ways in which *experience can challenge thought*. The notion of "complementarity" (to be discussed in later chapters) does express certain conditions for the development of new forms of thought. It expresses the *material unity*, so to speak, between what were the given conditions of thought and what has, in certain cases, become the new kind of thought. New forms of thought are, strictly speaking, *elaborated* on a certain background.

However, I think that Einstein's original contribution to the philosophy of physics consists in his formulating a version of the network (or coherence) theory formulated in succession by Poincaré, Otto Neurath, and W. v. O. Quine. I will come to this shortly, but first it should be noted how the views presented above were condensed into a clearly formulated and simple conception of the natural sciences that is very close to that of Planck in that it hinges on a distinction between a pre-theoretical "world of sense experience" and a theoretically posited "real world," the latter being constructed in order to meet a requirement concerning the *unity* of scientific concepts.

I will adhere to Einstein's paper entitled "Physical Reality" from 1936 for two reasons.[146] It is by far the most elaborate account of Einstein's methodological and epistemological conception of the natural sciences in general and the physical sciences in particular. It also contains the most elaborate and strong argument against – what Einstein saw as – the Copenhagen Interpretation of quantum mechanics, that is, the views held by Bohr and Heisenberg, respectively. I will first concentrate on general matters. In the paper, Einstein starts out by making two claims: (1) "The whole of science is but a refinement of everyday thinking," and (2) "experience (often) forces us to seek a newer and more solid foundation."[147] In other words, in a sense science does not differ from experience, in the Kantian sense. In any case, by developing a certain kind of conceptual thought, "experience" is a synthesis, a reconstruction, of a certain body of sense expressions. However, the very *system* of such concepts can be more or less "founded." The crucial issue is what Einstein means by this. My suggestion is that Einstein is not merely talking about a logical unity in a formal sense. He is not merely addressing the issue of how a series of different concepts can form a unified, consistent deductive system. This is evident in two ways. First, Einstein is clearly critical about the idea that one can take an isolated look, as it were, at the axiomatic and deductive character of a system of concepts, ignoring the relation of the system as such to our experience. Einstein had learnt the lesson of Gödel:

> "The fatal error that the necessity of thinking, preceding all experience, was at the basis of Euclidean geometry and the concept of space belonging to it, this fatal error arose from the fact that the empirical basis, on which the axiomatic construction of Euclidean geometry rests, had fallen into oblivion." *(Einstein 1936, p. 68)*

Second, we get a clue concerning the way in which the foundation of a system of theoretical concepts is generated by experience by noticing the following:

> "... since the time of Newton, we have not yet arrived at a new foundation of physics concerning which we may be certain that the whole complexity of investigated phenomena, and of partial theoretical systems of a successful kind, could be deduced logically from it." *(Einstein 1936, p. 71)*

[146] (Einstein 1936)
[147] (Einstein 1936, p. 59)

This refers to Einstein's distinction between "primary concepts" – "such concepts as are directly and intuitively connected with typical complexes of sense experiences" – and "propositions" which connect a given concept to some primary concepts. Such propositions, Einstein says, can be divided into two classes, a class of definitions and propositions that "express at least indirect relations between primary concepts." It is the latter kind of proposition that we can rightly call either "statements about reality" or "laws of nature." In short, Newtonian mechanics provides physical theory with a "foundation" in the sense that it generates a set of possible "statements about reality" to be investigated; a certain manifold of postulated phenomena that – because of the connection to definite sense experiences as expressed by certain primary concepts – can be investigated *empirically*. Einstein mentions two basic examples. He describes how, given the pre-theoretical notions of "rigid" bodies and "periodic movements," Newtonian physics is able to construct the respective concepts of *position* and *temporal difference*. These are the primary concepts that secure the empirical meaning of the Newtonian Laws of inertia, action-reaction, and gravitational force. These three laws make up the *system* of Newtonian physics according to Einstein. However, it is the fourth law, the Newtonian law of force, which characterizes classical *mechanics*. As we shall see, Einstein's critique of the quantum theory is that the systems of Heisenberg, Dirac, Schrödinger, and Born, respectively, are not associated with a consistent and universal *law of force*, however consistent the quantum theory may be said to be.

Since the electrodynamic field theories of Faraday and Maxwell also embody a law of force, Einstein regards these field theories as "transforming the foundation of physical theory":

> "For the theoretical conception of electric and magnetic phenomena one introduced, again, masses of a special kind, and between these masses one assumed the existence of forces acting at a distance, similar to Newton's gravitational force ... the electric field theory of Faraday and Maxwell represents probably the most profound transformation which has been experienced by the foundations of physics since Newton's time. Again, it has been a step in the direction of constructive speculation which has increased the distance between the foundation of the theory and sense experiences."
>
> *(Einstein 1936, 75-6)*

Thus, according to Einstein, with the advent of the electric field theory, a tension gradually emerged between the empirical content of physical theory and the foundation of these theories. Again, the tension does not concern the connection between reality and the theoretical system of concepts as such. It concerns the empirical content of *the theoretical concepts* insofar as these both have to be connected with "primary concepts" and correspond to a logically consistent deductive system of concepts. The problem is how the *propositions* that constitute the formal features of a given theory also qualify as *statements of reality*. In the case of field theory, the specific problem becomes this: How does a field of force embody material particulars? How is it that the (formally posited) "positions" and "displacements" within the field correspond to the real physical motion of "point-masses," to the carriers of inertial, gravitational, and electric mass (i. e., charge)? This was the problem that the field theory of H. A. Lorentz brought to the fore:

> "(Lorentz conjectured that) the participation of matter in electromagnetic phenomena has its origin only in the fact that the elementary particles

> of matter carry unalterable electric charges ... (also) the elementary particles obey Newton's law of motion for the material point.
>
> This is the basis on which H. A. Lorentz obtained his synthesis of Newton's mechanics and Maxwell's field theory. The weakness of this theory lies in the fact that it tried to determine the phenomena by a combination of partial differential equations (Maxwell's field equations for empty space) and total differential equations (equations of motion of points)."
>
> *(Einstein 1936, p. 77)*

I take this to mean that following the advent of field theory, *the mathematics of physical theory lacks unity*. The formal apparatus required in order to ascribe an empirical meaning to the concept of a "point mass" (in the mechanical sense) is equivalent to the formal apparatus required for ascribing an empirical meaning to the concept of a charge positioned within a given field. So here we glimpse the concern which Einstein was to have with quantum theory, because his own theories of relativity – even if they did not generate the ultimate unified field theory – still provided a first and crucial step towards such a theory, in the sense that the transformation of classical theory was made in the light of a very precise diagnosis concerning the formal shortcomings of classical theories. To Einstein, however, the quantum theory was a kind of leap in the dark. It was not a critical transformation of the given theories but, as Popper puts it, an *ad hoc hypothesis*. Consequently, as we shall see, Einstein did not try to prove the quantum theory *wrong* in respect to any specific problem. Instead, Einstein, for general philosophical reasons, tried to rule the quantum theory out. Given the constitutive principles of the theory, it simply couldn't qualify as an adequate successor to the classical field theories. As we shall see, this was the criterion: The quantum theory should never merely be regarded as a theory of matter. It had to include electromagnetic phenomena and effects according to both the general and specific theory of relativity. A theory of matter had to incorporate a field theory. Here is Einstein's general formulation of the issue, a formulation that also portrays what Einstein considers to be the achievement of his own theories of relativity:

> "What appears certain to me ... is that in the foundation of any consistent field theory, there shall not be in addition to the concept of field any concept concerning particles. The whole theory must be based solely on partial differential equations and their singularity-free solutions."
>
> *(Einstein 1936, p. 78)*

This was the goal of the attempt to formulate a new "unified field theory." In Einstein's view, the general theory of relativity helped specify and clarify that goal whereas the quantum theory blocked the possibility of ever reaching it.

Now, to sum up this section, Einstein defends some kind of *wholism* in respect to semantics, epistemology, and the interpretation of scientific theories. Einstein adopts the neo-Kantian distinction we have also ascribed to Planck between a world of sense and a real world, but in contrast to Planck, Einstein requires a *deductive unity* to exist between the two "worlds." Planck saw the development of physical theory as transforming and developing human Reason as such. Epistemic progress also means the self-realization of human Reason. There is no such idea in Einstein's philosophical thought. The ambition is not for Reason to become spiritual, but rather for Reason to be put to work. We must require of human Reason that it finish and complete the job it

has itself begun by means of developing theoretical concepts. The idea of constructing a "real world," the idea of formulating statements of reality by means of *propositions* must be driven to its logical completion.

In effect, Einstein turns his back on Helmholtz. Einstein ignores the latter's distinction between a theoretical physics and a mathematical description of Nature. Einstein ignores the idea of there being certain *metaphysical principles* of science such as the principle of least action. There are no principles of thought in the Kantian sense; there are principles such as the constant velocity of light. Such principles are but a means to give empirical content to, say, the concept of an inertial system and the concept of relative motion. There must be a certain fixation of rules in order to formulate the method and point of the practice of experimental physics. Here mathematics is the paradigm. To Einstein physical theory is – among other things – applied mathematics. But there is no *one* form of mathematics which constitutes the heart of physics. According to Einstein, this is the error of the Lagrangean and Hamiltonian understanding of physics.

As I understand Einstein, what lies at the heart of his philosophy is the idea that *mathematics is (already) physical experience*. Or rather, what distinguishes physical thought from a formal calculus as such is the way in which the former preserves a given set of experiences. There is no guarantee that our experience will be systematic or can be systematized. But there is one thing we must require of our theoretical thought. This thought must not by itself – because of the speculative constructions it has made – prevent our experience from ever becoming more systematic. The ambition of a system of experiences must be kept open and alive. We must remain open to the "suggestions" of nature, as Einstein put it. That is the challenge and the sense in which the rationality of the empirical sciences consists in learning to regard Nature as a *puzzle*.[148] By contrast, Niels Bohr would rather say that we should scrutinize *the ways in which* our experience cannot become systematic according to a certain kind of logic. The very idea of a "system of experiences" may come to mean something new and unexpected. Mathematics as such does not form a paradigm of conceptual unity and clarity.

[148] (Einstein 1936, p. 64)

Einstein's dispute with Bohr and the Copenhagen School

Two papers stand out in connection with Einstein's understanding of the quantum theory: the famous "Einstein, Podolsky, and Rosen" (**EPR**) paper of 1935, and the essay I have presented and which was published one year later. In both papers, Einstein argues that the quantum theory, as it has been formulated and used within physical experiments, *fails to deliver a coherent body of physical experience*, which is why we should still try to formulate a *different* theory that would "more completely" cover the *totality* of physical experience. It is only in the latter paper that Einstein demands that the quantum theory (of the late 1920s) should become a kind of *quantum field theory* instead of being (as Einstein thought Bohr and Heisenberg believed) merely a theory of "atomic structures."

Allow me to reiterate: the physical theory of matter incorporate the physical theory of fields. That was Einstein's agenda, an agenda concerning the uniformity of all physical theory. Importantly, "unity" means two things. It means that we have a frame of reference within which to describe and observe *all* of the possible phenomena that are describable according to the system of laws in question, and it means that the frame is wide enough so as to cover *all kinds of physical systems*, the causal developments of which are objectively describable within the system of laws. The quantum theory meets the former requirement: it covers a wider range of phenomena than does any other physical theory, but this does not mean that the theory meets the latter requirement. It does not. Insofar as the theory, with some explanatory success, can be seen as a theory of the structural properties of matter (as an atomic theory), it does not provide a complete description of atomic systems. We have reason to believe that particular physical processes exist into which individual atomic constituents may enter and which the quantum theory, in principle, is blocked from being able to describe. Einstein gives some reasons for his belief that only a new form of field theory will be able to cover individual atomic processes completely, but he admits that, according to his criteria, physics has as yet no "foundation," and that in a sense classical mechanics is still "at the center" – it is the only elaborate model we have of a complete physical theory, something that, strictly speaking, hasn't existed since the rise of electrodynamics and the development of Maxwell's field theory.

As has come to the fore through the works of both A. Fine and D. Howard in the 1980s, Einstein was not particularly happy about the arguments of the original EPR paper. Einstein mentioned his misgivings in a letter to Schrödinger and presented a new line of attack in a letter to Popper; finally he spelled out his attack in full in his paper *Physics and Reality*. The main difference is this: In the EPR paper the focus is on the "reality" associated with *every* variable of a given theory. The paper of 1936 specifies this rather vague notion of "all" the variables belonging to a given domain by invoking the (neo-)Kantian idea of a real world, in contrast to the more directly given world of sense experience.

Indeed, the EPR paper is short and vague. Its main question arises in the title: "Can quantum-mechanical description of physical reality be considered complete?" Initially, Einstein agrees with Heisenberg in maintaining that the conditions for the possibility of physical theory are essentially relative to the character and "results" of a certain kind of physical experimentation. Consequently, the EPR paper centers on the issue of how the conditions for describing and interpreting quantum physical experiments imply certain constraints as regards the *possible content of verifiable propositions* in accordance with

the quantum theory. First, a criterion for the completeness of a given physical theory is advanced:

> "Every element of the physical reality must have a counterpart in the physical theory." *(EPR, p. 138)*

Second, what is called "physical reality" here is seen as divided into "elements," any of which can be said to be "real" insofar as the following condition is met. This is the famous criterion of reality:

> "If, without in any way disturbing a system, we can predict with certainty (i. e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." *(Ibid)*

As formulated, the criterion expresses a certain ontological implication in respect to a certain kind of epistemic ideal. Obviously, the rationality of adopting the criterion hinges on some notion of determinism: If we can claim to have acquired a kind of experience of some features of a "local" group of phenomena, then, given the deterministic clause, we have thereby already established an understanding of the future developments of those features, non-locally as it were. Thus, the character of the experience of local states of affairs becomes the measure of the "reality" of the universal physical features in question.[149] This is not epistemic idealism – a version of *esse est percipi* – it is rather, Kantian-wise, to associate the notion of "reality" with the notion of objectivity (*Gegenständlichkeit*). The criterion of reality concerns the possibility of *tracking the individual features* of our experience. The criterion of completeness can be seen as semantic: it says, "provide your concepts with an objective reference." The criterion of reality, however, does not say "to be is to be the value of a bound variable," rather it says, "given that your concepts have an objective reference, if in addition there is a certain kind of experimental, empirical application of these concepts (i. e., if you can track a variable) then we can claim that the variable corresponds to a "real element of Nature".

In the thought experiment that the EPR paper famously presents, it should be clear that the knowledge of local phenomena concerns the conditions of certain *objects*. The link between the knowledge of future non-local states of affairs is however of a different kind, as it concerns *a connection between states within a quantum physical system*. In his paper of 1936, Einstein criticizes the conception of the EPR paper by referring instead to a statistic *ensemble* of physical systems. In the EPR paper he states bluntly that the quantum theory is above all a theory about "states." To this Bohr would respond that it is rather a theory about certain kinds of *objects* (i. e., atoms). Einstein agrees with this, that is, when seen as a goal for developing a new physical theory. He claims however that the quantum theory fails to meet this goal.

Consequently, such as the EPR paper's criterion of reality is formulated, the quantum theory – inasmuch as one sees it as a theory of possible quantum physical *states* – poses a problem, that of *how* various individual features of physical reality enter into, or constitute, the reality of certain physical states. In fact, the EPR paper's argument

[149] Here "local" and "universal" mean more than merely the position within space-time; they also indicate the particularity of any one observer versus the universality of all possible observers. Consequently, Harré and others would prefer to use the phrase "absolute" rather than the phrase "universal."

aims at revealing a paradox that follows from the claim that two such features cannot have a "simultaneous reality." Considered as an argument, the thought experiment famously put forward in the EPR paper has a certain premise. It is claimed that **either** the quantum theory is incomplete **or** two non-commuting variables (variables where $p * q$ does not equal $q * p$) cannot have "simultaneous reality."

Einstein considers this premise to follow from the conjunction of the quantum theoretical formalism as such and Heisenberg's Indeterminacy Relations. The consideration is first of all as follows: **If** the quantum theory is complete **then** (on the criterion of completeness) there really do exist individual features of reality corresponding to a given pair of conjugate variables. But these cannot, according to the Indeterminacy Relations, be measured simultaneously. **Consequently**, the two features do not (following the criterion of reality) have "simultaneous reality". There can be no such thing to track.

Second, **if** non-commuting variables do not have simultaneous reality **then** (following the criterion of reality) there is no tracking this simultaneity. **Since**, furthermore, according to the quantum theory, two canonically conjugated variables do not commute **and** such a pair of variables does correspond to an objective physical state of the combined system of an atomic object and an experimental set-up, it **follows** that the temporal character of *this* state by definition cannot be represented within the quantum theoretical formalism. **Consequently**, this theory is (according to the completeness condition) incomplete.

In other words, the premise on which the EPR argument rests hinges on a certain model concerning how the quantum theory embodies *descriptions of individual physical states*. The phase space of the quantum theoretical Hamiltonian is taken *outright* to constitute the description of a state. The paper of 1936 no longer subscribes to this; in this paper, the phase space is associated with a *statistical ensemble of objects*, and the individual cells with a probability distribution as regards this ensemble.

Now, the thought experiment of the EPR paper pictures the impact of two different systems, A and B, and a subsequent measurement on *one* of these systems to the effect that we have a choice as to *which* feature of the state of the system we actually measure. On the condition that the combined system conserves energy, the possible states of the two subsystems after the impact are constrained and interconnected. The argument now runs like this: We cannot consider the quantum theory to be complete, because if we did then, first of all, due to the criterion of completeness, there would be an element of reality corresponding to any of the members of a canonically conjugate pair of variables. Second, given Heisenberg's Indeterminacy Relations, once we measure the value of one of the variables on object A, there will be a limit to the exactness with which we can measure the value of the other variable on either A or B. Thus, following the criterion of reality, it does not make sense to say there is a real state corresponding to the simultaneous reality of the states associated with the respective conjugate variables, since there can be no simultaneous measurement determining the exact value of these quantities.

This however contradicts the fact that once we imagine a case – like the one depicted in the thought experiment – the quantum theory, according to our criterion of completeness, *can* be considered a complete theory. Since we can indeed, for any of the two variables determine the value of the given variable by measuring the similar value on A without disturbing the system B, then following our criterion of reality, we can consider the respective elements of reality to be real. There may not be a "si-

multaneous representation" (a state description) of the combined state of the two real states; but that is not to deny that the two respective elements of physical reality *do have* "simultaneous reality" , following our criterion. Consequently, our contradiction is as follows:

> "Previously we proved that either (1) the quantum-mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality. Starting then with the assumption that the wave function does give a complete description of the physical reality, we arrived at the conclusion that two physical quantities, with non-commuting operators, can have simultaneous reality. Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum- mechanical description of reality given by wave functions is not complete." *(EPR, p. 141)*

Physics and Reality, 1936

Thanks to A. Fine and D. Howard, this essay is now regarded as significantly modifying and clarifying the argumentation of the EPR paper. However, the essay of 1936 offers much more than a modification of the considerations of the EPR paper. As I have already discussed, the paper provides an elaborate account of "the foundation of physics." Understood as such, one might well claim that the EPR paper cannot, and should not, be read separately without taking the whole of the framework, as presented in the essay of 1936, into account.

In relation to the EPR paper's thought experiment, Einstein makes clear why he thought that only a new and general field theory would form a complete foundation for physics. The ontology of the general theory of relativity is restricted, but the mathematical grammar of that theory is paradigmatic, because a tensor calculus associated with a general metric, as it were, makes it explicit how the individual features of the kind of physical reality in question are functionally related. The individual states of the individual systems are explicitly states of the *whole* of the metric spaces in question, so to speak. Consequently, *by virtue of its very position within the general metric* a physical object can be ascribed a definite physical state corresponding to a definite cell in the respective configuration space. This is, I believe, the new criterion of completeness of the essay. The section of the paper referring to the quantum theory in general and to the EPR paper's considerations in particular aims at showing that the quantum theory does not meet the (new) criterion of completeness if one associates the Schrödinger equation with descriptions of the probability-current density of specific variables associated with – or characterizing – *individual* objects. The probabilistic expressions of the formalism should not be seen as providing *state descriptions*. As Einstein puts it:

> "The [Schrödinger] function does not in any way describe a condition which could be that of a single system; it relates rather to many systems, to 'an ensemble of systems' in the sense of statistical mechanics ... The Schrödinger equation determines the time variations which are experienced by the ensemble of systems which may exist with or without external action on the single system.

> Such an interpretation eliminates also the paradox recently demonstrated by myself and two collaborators ..." *(Einstein 1936, pp. 89-90)*

Hence, the argument of the essay of 1936 is no longer based on the "criterion of reality" and the specific condition of completeness of the original EPR paper. The essay points directly to the mathematical character of the Schrödinger equation – i. e., to the sense in which the wave function can be associated with descriptions of states. The argument is that the Schrödinger equation cannot be said to form the basis of a proper theoretical *representation* of individual physical realities. Considered as a basis for a theory, the equation is simply incomplete in the sense that there must be something more to say about the *very* objects that the quantum theory itself posits. According to Einstein, this is what distinguishes classical statistical mechanics and the quantum theory. The former was associated with a complete account of the dynamic features of a certain range of individual features of reality (i. e., the kinetic theory of gases). The formalism corresponded to a certain *model* of a range of physical systems and thus extended the framework of the field of application of mechanics. As I have said above, Einstein thinks that only a quantum field theory would meet a similar criterion, whereas the Schrödinger formalism is blocked from ever being interpreted – or applied – accordingly.

In other words, Einstein thinks there must be a limit to the way in which the experimental phenomenology, or empirical meaning, of a certain physical theory differs from the ontological structure of the posits of the theory in question. Only if the quantum theory is viewed as statistical, as referring to statistical ensembles within the configuration space, is this requirement met. However, once the theory is associated with a classical experimental phenomenology (empirical meaning) with the intention of analyzing the behavior of distinct mechanical parts of the systems to be measured, it becomes necessary to pursue the matter to its logical end in a way which, by definition, is unacceptable due to the Indeterminacy Relations.

Consequently, the argument of the new version of the EPR paper's paradox considers more directly the relation between the formal and the experimental-empirical aspects of the quantum theory. The upshot of the EPR paper's thought experiment is that a choice exists after the interaction of the two systems A and B as to the measurement performed on any one of these systems. Regardless of the variable one chooses to measure, the measurement forms the basis of ascribing a state function to *the very state* of the other system. There is thus a choice, and so in principle we can ascribe two *different* state functions to *the same* state, which is to say that two different *formula* correspond to the reality of the very same *physical* state. This cannot but raise the issue of what the connection is between the two different features that the respective formula *represents* concerning the same state of affairs.

> "This coordination of several [Schrödinger] functions with the same physical condition of system B shows ... that the [Schrödinger] function cannot be interpreted as a (complete) description of a physical condition of a single system." *(Einstein 1936, p. 90)*[150]

Thus, in my view, Einstein indicates that **if** there are certain (methodo)logical principles associated with a certain formalism – such as Heisenberg's Indeterminacy Relations

[150] I have a CD-Rom, containing an alternative translation of the present text; here the term "condition" is translated as "state"; I think Einstein's original word is "Zustand", but I have not checked this!

or Bohr's principle of complementarity – **then** the ontological implications of these principles must be made explicit, similarly to the way in which the respective *theories of force* made explicit the implications of the principles of mechanics. It is not enough to claim – as did Heisenberg and Bohr – that objects of the atomic realm are "non-classical" or have "individualities" (i. e., features that in principle cannot be described by classical means). Put in Fregean semantic terms: if one can make sense of a definite object in different ways, the criterion of identity of that kind of object must be clearly established.

Here one might challenge or defend Einstein's claim by analyzing the premises of the new argument. One might point to the following:

(a) *A separability principle*, concerning the independent existence of the states of the systems measured and the *states* of the measuring devices
(b) *An objectivity principle*, concerning the distinction between the states of the systems to be measured and the *action* of the measuring devices
(c) *A principle of locality*, in the sense of prohibiting any action at a distance
(d) *The principle of the maximum speed of signals*
(e) The *conservation principle* of energy

Subsequently, one might discuss any of these in turn as well as their interconnections. However, I think it is important to realize that these are the principles that Einstein associates with the *quantum theory*; they are not *his* absolute principles. They are the principles that everyone has to accept in order to acknowledge the principles associated with the (by then current) theories of relativity and quantum mechanics, respectively. They express the *logic of the situation*, historically, in theoretical physics: the current construction of a real world in association with a total world of experience. This logic, Einstein thinks, *constrains* our outlook. However, the quantum theoreticians want to have their cake and eat it too, in that they want both to stick to the (methodo)logical requirements of the theory and not to be constrained by its ontological implications.

Einstein is, in my opinion, open to any deviation from the principles listed *insofar as* it is a matter of developing the theoretically posited real world in accordance with the gradual development of the totality of all experience (as explained above). This is what distinguishes a quantum field theory from a quantum theory of matter. The former can be (interpreted to be) *constructed* in light of the historical development of physical theory; the latter is at best a successful leap in the dark.

As we shall see below, Bohr saw the disagreement between him and Einstein to lie at a different level of philosophical reflection. The principles listed seem on the face of it to express *what it is* we have the choice to do within given forms of physical experimentation. Bohr, however, wanted to inquire into which *kind of choice* is in question. The quantum theory does not at all extend the *physical* principles of physical theory; instead it re-interprets the transcendental principles associated with objective and rational observation.

Bohr's response to the EPR paper's challenge

Bohr's response to the EPR paper is less an attempt to argue against the views of Einstein, Podolsky, and Rosen than an attempt to explain himself, to better explain the idea behind the framework of complementarity. As I see it, the bulk of his response has to

do with the notion of rationality in relation to the cut between apparata and the object to be measured. The heart of the matter is that the distinct *parts* of various experimental set-ups may have *different* functions within different kinds of experiments. What functions as part of a ruler in one act of measurement may function as part of a spring in another. Consequently, the kind of *choice* to which Einstein, Podolsky, and Rosen were referring – the choice between which variables to measure – exemplifies a gross simplification and reduction of the real issue of choice: the choice that enters into the *intentional design* of a certain experimental set-up.

Bohr summerized his response to the EPR paper with the following declaration:

> "My main purpose in repeating these simple, and in substance well-known considerations, is to emphasize that in the phenomena concerned we are not dealing with an incomplete description characterized by the arbitrary picking out of different elements of physical reality at the cost of sacrifying other such elements, but with a rational discrimination between essentially different experimental arrangements and procedures which are suited either for an unambiguous use of the idea of space location or for a legitimate application of the conservation theorem of momentum. Any remaining appearance of arbitrariness concerns merely our freedom of handling the measuring instruments, characteristic of the very idea of experiment." *(Bohr 1935, p. 149)*

In this quote it is important to notice the invocation of the concept of *rationality* in respect to the point of recognizing discriminations between various kinds of experimental arrangements. The issue of rationality arises because physicists had to adopt a new attitude towards the very idea of an explanatory experimental natural science. This led to "the necessity of discriminating" (as Bohr puts it in the quote below) between how the various parts of an experimental arrangement might function. To Bohr, this required discrimination may even be regarded as the main characteristic of the new kind of physical-theoretical practice that must accompany the quantum theory:

> "This necessity of discriminating in each experimental arrangement between those parts of the physical system considered which are to be treated as measuring instruments and those which constitute the objects under investigation may indeed be said to form a *principal distinction between classical and quantum-mechanical description of physical phenomena*." *(Bohr 1935, p. 150)*

Moreover, the rational discrimination of parts within a whole experimental arrangement is the cornerstone of what the new situation implies in respect to theoretical observation. This is precisely the attitude that the framework of complementarity is meant to express toward our endeavor to develop new laws in physics in accordance with basic principles of physical thought, such as the conservation principles and the action principle:

> "In fact, it is only the mutual exclusion of any two experimental procedures, permitting the unambiguous definition of complementary physical quantities, which provides room for new physical laws, the coexistence of which might at first appear irreconcilable with the basic principles of

science. It is just this entirely new situation as regards the description of physical phenomena, that the notion of *complementarity* aims at characterizing." *(Bohr 1935, p. 148)*

Einstein (Podolsky and Rosen), like so many others, failed to acknowledge these practical aspects of the framework of complementarity. There is a certain irony in the EPR encounter in that it certainly involved an effort to settle how we are free to choose between different utilizations of the same set of equipment.

I will illustrate the matter by commenting on some remarks made by Bohr in an essay from 1955. In this essay Bohr makes it clear that we need not totally renounce the use of space-time pictures within the context of the quantum theory, because we still need to make use of such pictures in accounting for the structure and function of the experimental arrangement, i. e., in accounting for both the kinematics and the dynamics of these arrangements. Furthermore, there is even a sense in which quantum physics and classical physics rest on the same foundation. Bohr makes the following statement:

"The quantum-mechanical formalism, the sole aim of which is the comprehension of observations obtained under experimental conditions described by simple physical concepts gives ... an exhaustive complementary account of a very large domain of experience. *The renunciation of pictorial representation involves only the state of atomic objects*, while the foundation of the description of the experimental conditions, as well as our freedom to choose them, is fully retained."

(APHK, p. 90; italics mine)

Thus, we have freedom of choice as regards the *spatio-temporal design* of an experimental set-up. Consequently, there are two kinds of choices that must be sharply distinguished. It is one thing to determine certain values of a range of bound variables given the fixation of the unbound; it is quite another to decide to regard a certain item, or one of its dynamic features, as either belonging or not belonging to the fixation of the experimental arrangement. Einstein, Podolsky, and Rosen confuse these two senses of our having a choice. This is why Bohr was anxious to stress that in the context of the quantum theory we are as free as can be to measure whatever *can* be measured. But any measurement, whatever the context, has to comply with certain presuppositions informing the intention to use certain tools of measurement in determinate ways.

Of course, one has to keep in mind the other side of the story: the conditions for the description of atomic states are radically different, inasmuch as the definition of such states cannot be made by means of space-time pictures, which Bohr would often stress, not the least in his essay of 1955:

"While, within the frame of classical physics, there is no difference in principle between the description of the measuring instruments and the objects under investigation, the situation is essentially different when we study quantum phenomena, since the quantum of action imposes restrictions on the description of the state of the systems *by means* of space-time coordinates and momentum-energy quantities." *(APHK, p. 89, italics mine)*

However, as the quote makes clear, concerning the possibilities of describing the spatio-temporal features of an experimental design, there are no special constraints imposed upon quantum physics – except, of course, that there is a theoretico-physical point in performing a given experiment.

Finally, often when it is said that Bohr pointed out the mutually exclusive character of two experimental arrangements, this implicitly refers to the measuring of the same physical features. Here we must be cautious: Bohr would surely say that different kinds of arrangements giving rise to the appearance of different kinds of phenomena may relate to the *same* objects, to the atomic composite systems that the quantum theory models. But this is not to say that we *measure* the same object as if, when loosening a bolt or closing a shutter, we then see the same thing differently. When we do so, what we choose to change is whether to measure, say, the impact of an electron or the interference of a photon. Thus, we choose between observing some different atomic *constituents*, each of which is emitted within the processes defining the experimental arrangement.

There is a very deep philosophical point to make in relation to all this. *The intelligibility of trying to do something and the intelligibility of choosing, at will, to do something are intimately connected*. This is a well-taken Wittgensteinian point.[151] So the following must be regarded as a "grammatical" remark, in the sense of Wittgenstein, about our possible language games: the facts that can possibly constrain or further my action and the intentions which can possibly trigger or limit my doings form two sides of the same coin. Now, let us follow Wittgenstein in associating these considerations with the notion of "observation." In his *Remarks on Color* we find an important remark concerning "the dawning of an aspect":

> "One observes in order to see what one did not see, when one did not observe." *(RC III, § 326)*

In Bohrian terms: One observes in order to comprehend what one did not comprehend when one did not observe. Accordingly, to *try* to observe is thus to try to comprehend phenomena in a certain fashion. "To observe" then becomes an effort whose success is marked by a certain comprehension of an arrangement of things. One may certainly choose *how* to try to comprehend phenomena – choose how to observe, but one can never be said to choose *what* objective features to observe. There is no choosing what to observe, only choosing how. According to Bohr, not realizing this was Einstein's mistake.

4.2 The Interaction Problem in The Quantum Theory

An outline of The Interaction Problem in The Quantum Theory

In previous sections I have presented the primary requirements that should be included in the construction of a new kind of physical theory, according to Bohr. I now proceed to discuss how these requirements can be met. I shall refer extensively to the so-called "Warsaw Lecture" delivered by Bohr at a conference on *New Theories in Physics*, May 30th to June 3rd, 1938. This is the lecture where Bohr made public his effort to improve terminology. One such improvement is the stress that (a) the quantum theory is

[151] It cannot be said that I choose to reach the house, or that I try to reach it, if there is no difficulty about it. What I cannot be said to be *trying* I cannot be said *to will*, and vice versa. (PU II, p. 208).

in particular concerned with the atomic constitution of matter, and (b) that the application of the quantum theory must involve specific rules regarding the description and intended uses of measuring devices:[152]

> "It must in fact be realized that the whole present attack on quantum theory is based on the presupposition that it is possible without regard to the atomic constitution of all matter, to have recourse at least in principle to measuring instruments of arbitrary fineness of construction, which can be manipulated without restriction". *(Bohr 1938, p. 28)*

To make this more precise, I shall now give an outline of five points that together make up Bohr's ingenious invocation of the Interaction Problem in his dealing with the Observation Problem in the quantum theory. As we have seen, the invocation of the Interaction Problem already comes to the fore in the content and structure of the Como Lecture. But the details of the invocation have been explained by Bohr no better than in the Warsaw Lecture. Here are the five points I shall examine successively, and for each of which I have selected a quote, from The Warsaw Lecture, in order to supply each of the points with a suitable superscript:

i) "The Analysis of Experiments" *(Bohr 1938, p. 11)*
ii) "processes open to observation" *(Bohr 1938, p. 13)*
iii) "analogies with classical ideas of interaction" *(Bohr 1938, p. 14)*
iv) the "auxiliary agencies", described by such analogies, by means of "pictures" *(Bohr 1938, p. 18)*
v) Measurements, meaning "... nothing else than the unambiguous comparison of some property of the object under investigation with a corresponding property of another system, serving as a measuring instrument, and for which this property is directly determinable according to its definition in everyday language or in the terminology of classical physics." *(Bohr 1938, p. 19)*

Ad i): The Analysis of Experiments A basic part of Bohr's understanding of the concept of an "experiment" concerns the idea of a *control of initial conditions*. Thus Bohr must be said to maintain an essential part of the traditional view of experiments as involving a method of observation – namely the method of arranging certain initial conditions in order to observe possible physical effects in specific physical systems, given the actualization of certain initial conditions.

In this regard it is helpful to introduce a distinction Bohr did not make – that between an *epistemic* kind of control and a *methodological* kind. The former has to do with the question of whether various instruments are used as was intended, and the latter has to do with tracing observable dynamic variables in the *configuration space* of the system under investigation. Now, in respect to the former kind of control, there is no difference between the quantum theory and other physical theories. It is the latter kind of control that is different. It is this kind of control that (a) suffers "a certain latitude in the account of evidence", and (b) relative to which there is no determinate quantitative

[152] This is a point which Bohr had previously made, particularly in his Faraday Lecture from 1932; see (*Works VI*, p. [392][399])

expression representing determinate physical states of affairs, although there is a quantitative expression of the *lack of* determinateness; namely Heisenberg's Indeterminacy Relations.

Later Bohr refers to point i) above by saying that the very idea of performing an experiment can mean nothing but being able to communicate "what you have done" (i. e. the methodological aspect) and "what we have learnt" (i. e. the epistemic aspect).[153] So, the idea of an experiment forms part of a general notion of scientific experience, implying that no matter how special the *domain* of experience may be; still it must catch on to what characterizes scientific experimental experience in all fields.

Ad ii): About processes open to observation Of special interest here is the notion of "transition processes" associated with the Quantum Postulate. It should be noted first how Einstein's equation $E = h * \nu$, as pointed out by Planck, forms the quantitative expression of a hitherto unrecognized union of the concepts of *energy* and *time*. So the equation provides a background , for example, for interpreting the energy shift of the radiation that is detected *after* an atomic system has interacted with some other physical system. Thus, the postulated correspondence between the definite frequency of the radiation and the shift of energy-condition makes the transition process in question open to "direct observation", as Bohr put it above.

It is important that such transition processes are processes that can first of all be seen as taking place within the system under investigation, hence the phrase "direct observation". It is also important that the system under investigation – as a *closed* system – due to Heisenberg's Indeterminacy Relations, cannot be subject to a direct observation. The atomic system in itself is not a possible object of observation, but *parts of it*, – the individual processes (and with these, also the elements that enter into such processes, like photons and electrons) comprising the configuration of the system – are open to direct observation in the sense just described.

Ad iii): The Analogies with classical ideas of interaction At this point we must recall Bohr's use of the term *Vorstellung* in order to express how certain Vorstellungen of individual physical objects may guide the use of concepts in the description of phenomena. The prime example of such a *Vorstellung* is perhaps the idea of an *elastic collision*; but there is also the idea of an interference of two harmonic waves associated with the superposition principle of free radiation. The possibility of observing transition processes draws on the *Vorstellung* of the photon that, according to Bohr, "embody a conservation law". These are all examples of classical *Vorstellungen* of certain prototypical interactions between physical individuals.

Now, as is especially clear in the Como Lecture, Bohr wanted to draw what shall be regarded as a very ingenious analogy to such "interaction-ideas"; to ideas of how to account for the distribution of energy to individuals. Bohr finds that his drawing of this special analogy can help us explain what it is in the context of the quantum theory that constitutes the inter-action between individuals.[154] This, and only this, justifies the use of the abstract notions of point-particles and harmonic, free wave trains

[153] (APHK, p. 39)(*Essays*, p. 3)

[154] Here I have substantially improved a couple of muddled sentences in the reviewed version of my dissertation. In the following, I move a small paragrahp up by placing it before the qoute.

in the account of quantum physical experience. Given this extremely important part of Bohr's philosophy of physics, it is also important to point out what is at the heart of the usually misread Como-Lecture – the attempt to explain how both Heisenberg's diagonal matrices and Schrödinger's standing vibrations exemplify two similar "auxiliary ideas" of physical interaction, similar to those of a material point-particle and a plane harmonic wave.[155] So this is the sense in which the concept of a matter-wave may be seen as a generalized notion of a kind of individuality pointing to a harmony between the possibilities of definition and observation. But what is the core of the Interaction Problem? In the Como Lecture Bohr sums it all up in the following paragraph:

> "On the whole, it would scarcely seem justifiable, in the case of the interaction problem, to demand a visualization by means of ordinary space-time pictures. In fact, all our knowledge concerning the internal properties of atoms is derived from experiments on their radiation or collision reactions, such that the interpretation of experimental facts ultimately depends on the abstractions of radiation in free space and free material particles. Hence, our whole space-time view of physical phenomena, as well as the definition of energy and momentum, depends ultimately upon these abstractions. In judging the applications of these auxiliary ideas, we should only demand inner consistency, in which connection special regard has to be paid to the possibilities of definition and observation." *(ATDN, p. 77)*

Thus, on the one hand, the quantum postulate represents the idea of the individuality of particles (such as photons and electrons) that transcends the space-time coordination of observables.[156] On the other hand, the idea of individual atomic parts "meets the requirement of causality", since they are theoretically posited in thought in association with conservation laws.[157] Consequently it is still possible to combine space-time coordination with a notion of individual dynamical agencies in the description of phenomena, if we bear in mind that

> "from the point of view [advanced by Bohr] the foundation of space-time co-ordination is offered by the abstraction of free individuals"
> *(ATDN, p. 82)*

This is the sense in which we can describe the phenomena into which both electrons and photons, or any other atomic constituent, may enter. Although such description can be part of the definition of the states of atomic objects, no description of a single phenomenon constitutes such a definition. It follows that one may regard both Heisenberg's Matrix Mechanics and Schrödingers Wave-Mechanics as formal expressions of the possibility of bringing into harmony the two concepts of individual agencies and space-time co-ordination; and so, as expressions of the possibility of ascribing observable dynamic properties to *individual* atomic agencies. But the dynamic properties of the composite atomic systems that are characterized by the *totality of the possible interactions between such individualities* cannot be traced and exhibited in space and time.

[155] In my view, Mara Bellar's reading of the Como Lecture comes close to what Bohr had in mind. See (Bellar 1992).
[156] (ATDN , p. 61)
[157] (ibid.)

Ad iv): Auxiliary agencies described by pictures We are about to introduce the requirement that the description of quantum physical phenomena has to involve the use of classical concepts. However, the context must first be pointed out in which to state this requirement. This context concerns the description of phenomena by making use of certain "space-time pictures" in the fixing of given experimental arrangements. In the Warsaw Lecture Bohr stated that we have to deal with the

> "... complementary character of the pictures employed in the description of every such *auxiliary agency* used in the measuring process"
> *(Bohr 1938, p. 18, italics mine).*

Certainly Bohr refers to the picturing of exactly those "auxiliary agencies" we were discussing above. The focus now is on the role of such auxiliary items in measuring processes. Thus, the context for the assessment of the necessary use of classical concepts concerns the description of experimentally controlled phenomena, the description of which has to involve *the whole of the quantum theoretical formalism* in order to be in the clear about how the experimental arrangement may give rise to the appearance of the phenomena in question.[158]

One must therefore stress that there is no "classical" or "ordinary" mode of description, in the sense of Planck, that is in any way preserved within the practice of the quantum theory. As we have seen with reference to Bohr's letter to Schrödinger, Bohr wanted to argue that we should preserve certain classical *Erfahrungs-Begriffe*, but we shall do so because we try to associate these with a new kind of representation of discontinuous physical processes in the description of phenomena. The use of concepts in the description of atomic phenomena shall be given in terms of ideas (*Vorstellungen*) about individual agencies; namely the individual agencies that – although we must consider these as abstracted from real composite systems – may nevertheless be said to enter objectively into observable phenomena.

In respect to the issue of the necessary use of classical concepts in the description of all kinds of physical experiments, I find that the account of the concepts of space and time given by Bohr in his Bristol Lecture that was delivered October 5th 1931 is very instructive. In the lecture Bohr begins by asking the significant question "how do we introduce the *Vorstellung* of space at all?".[159] In other words, how do we introduce this *Vorstellung* at all in the context of experimental physics? The lecture is an attempt to answer this question, given the validity of Heisenberg's Indeterminacy Relations.

The general point of the lecture is that there is no a priori concept of either "space" or "time" that will always make immediate physical sense in the description of measuring devices. In other words, how a rod may count as a yardstick, or how a system involving a periodic movement may function as a clock, is an open question until the intent of the experiment in question has been settled. After having introduced such considerations, Bohr observes:

> "The general result is that the idea of space and time involves the use of measuring rods which can be considered to be outside the system under investigation so that the interaction with these rods is not traceable in the experiment." *(Works VI, p. [364])*

[158] The notion of "the appearance of phenomena" is another example of Bohr's improved terminology.
[159] Here I translate "idea" as *Vorstellung*, (Works VI, p. [363])

It is important to note that "considering the rods outside the system under investigation" involves characterizing the system. Doing this, we have to make use of the whole of the quantum theoretical formalism, in order not just to represent the very system, but also to represent it as a system embedded in the entire experimental setup, including an account of how the macroscopic devices make room for this embedding. The quote above must therefore be said to imply that the only meaningful application of the concepts of space and time, in the context of performing experiments in accordance with the quantum theory, involves *the use of the whole of the quantum theoretical formalism*. Concerning all this I would like to quote and express my agreement with the following view of Don Howard's:

> "... Bohr's doctrine of classical concepts is ... at first reading, so very puzzling ... Interpretations of the doctrine and the larger philosophy of physics to which it is central run the gamut from a 'positivism of a higher order' (Feyerabend 1958), through Kantianism (von Weizsäcker, 1963), 'neo-Kantianism' (Murdoch, 1987), or 'transcendental philosophy' (Honner, 1987), to critical realism (Folse, 1985) and 'objective anti-realism' (Faye, 1991). Some commentators see in Bohr's doctrine of classical concepts the assertion that we are trapped inside a linguistic framework that imposes its structure upon our description of the world (Aage Petersen [and Favrholdt], 1963 [and 1994, respectively], others take it to be a vindication of Oxford ordinary language philosophy (Bergstein, 1972); and still others see it as having an 'affinity' with P. F. Strawson's argument for the indispensability of the common-sense conceptual scheme (MacKinnon, 1982; Murdoch, 1987) [and Favrholdt, 1994]. In the end, however, all of these interpretations are equally unconvincing, and often for the same reason. They assume uncritically, that we know exactly what Bohr intended regarding (i) what a classical description is, and (ii) where a classical description is to be employed: the only question is where the doctrine of classical concepts places Bohr in the philosophical tradition. But both assumptions turn out to be wrong." *(Howard 1994, p. 202-3)*

Howard has certainly identified the weakness in most of the philosophical interpretations of Bohr. The implicit, but wrong, assumption in all these questionable interpretations has been this: Everything about using concepts within the ordinary domain of classical physics is regarded as being in order. So Bohr's strategy, it is said, is that of trying to connect in systematic fashion the more troublesome use of concepts in the context of the quantum theory with the preexisting well-ordered and coherent conceptual practice known from classical contexts.

But as I shall argue; no use of a given fragment of any language, however classical, can have such paradigmatic status. Nor is it in any sense necessary to relate the linguistic practice associated with the quantum theory to another "classical", linguistic practice. On the contrary, one must re-consider everything that enters into the linguistic practice associated with the quantum theory including those aspects of the linguistic practice of classical physics that can be said be to have been maintained, in some way, within the new practice.

We have now to combine the considerations that were launched in the Bristol Lecture concerning the concepts of space and time to both the Interaction Problem and to

Heisenberg's Indeterminacy Relations. First, the use of any device, as either a yardstick or as a clockwork, has an inescapable dynamic aspect; because, the issue is how to fix either the "place" or the "moment" of a dynamic occurrence of, say, the passage through a line, the moment of the passage through a line, the time of impact on a plate, the point of the impact on a plate, and so on. Then – insofar as we recognize the dynamic character of the events we wish to fix – the introduction of Heisenberg's Indeterminacy Relations implies the impossibility of a *joint* fixation of, say, the time of the impact on a plate and the place of the impact on that plate.

We see that is there is no pre-given way in which a certain plate or a certain line can be said to form a part of an experimental arrangement. Interestingly, points, lines, or plates might form part of *both* (a) a complex system of things constituting a clock, and (b) a complex system of things defining the frame of reference in respect to some spatial determination. But they cannot be said to form part of the same experimental *arrangement* in both ways. Indeed, the point is that there is no such arrangement in abstraction from the mutual functioning of any of the parts in respect to the intended use of one particular such "part-whole arrangement".

What this comes to is nothing less than the establishment of a rule for a new language game to play, called "measurement in the quantum theory".[160] The classical idea of a co-ordinate system silently embodied the idea that the same system of rods could function both as a reference frame for positions and as a reference frame for time-points. Thus, when a ball hits a wall, the latter functions both as a yardstick and as a clock, such that it makes sense to say "I looked at the place on the wall at just the moment the ball hit it". Or imagine something hanging down from the wall, and that the sun is shining from above so that there is a shadow on the wall that stems from the thing hanging down. Imagine also that this item is moving because of certain strokes of wind. Then it would make sense to say, "The ball hit this spot on the wall precisely when the shadow of the thing reached up to that spot".

In contrast to this, within quantum-theoretical experimentation, no definite system of dynamic features can jointly form part of a yardstick and a clock. Or, to use the precise concept of a machine: no one machine can function jointly as both a yardstick and as a clock. In short we can say that a clock is not a piece of machinery whose parts might also constitute a characteristic feature of any yardstick. Still, a clock (qua being just that, a clock-work) is as a whole a piece of machinery. As Bohr puts it;

> "... a clock is a piece of machinery the working of which can completely be accounted for by ordinary mechanics and will be affected neither by reading of the position of its hands nor by the interaction between its accessories and an atomic particle". *(APHK, p. 49-50)*

This must be seen as a definition of a clock; a definition by means of associating a such with a transformation of a free dynamical system into a "frozen", functionally defined system; turning it into a "machine". One might call this the *cut between dynamics and machinery*.[161] Now, it is important to see that the cut between dynamics

[160] Superscript of the third paragraph in the Como Lecture.

[161] The "fixation of the ruler" is no different, since it takes a dynamic effort to freeze the rod into a definite geometrical shape. If you say that some rods have a varying length that is simply disregarded in actual uses of these rods as yardsticks, and that this takes no dynamic effort, I reply: The very concept of *a varying length* presuppose an ability on our behalf to have some idea about how it is exactly a *dynamic property* of some sort which makes certain items better suited for being used as measuring rods. You must f. ex. be able

and machinery involves making use of the *whole* of the quantum theoretical formalism in the description of the intended application of various devices and features within a given observation.

As I understand Bohr, the "machinery" associated with certain dynamical features of an experimental arrangement must be ideally conceived in accordance with the general idea of either a clock or a yardstick. Consequently, it is such ideally posited, but objectively functioning, pieces of experimental machinery that must be described in classical terms. Note, it is not the use or the function of the clocks or rods that should be described in classical terms. It is only the very *readings* of whatever indicators they involve in their workings or construction that must be reported in terms of "classical" or "ordinary" uses of concepts.

We have learned a lesson concerning the necessity of discriminating between the clocks and rods constituting particular experimental arrangements. We shall now learn another concerning the necessity, within the quantum theory, to discriminate between different such arrangements. This we shall do by invoking the substance of what Bohr put into his response to the EPR-challenge. So we now turn to the question of how certain features (such as points, lines, and planes) *successively* might form part of different and distinct measuring devices. Here, it might be helpful to recount an example that Bohr gave in his Planck Lecture of 1929. Talking about the "reciprocal character of the perception of touch" Bohr states:

> "One need only remember here the sensation, often cited by psychologists, which everyone has experienced when attempting to orientate himself in a dark room by feeling with a stick. When the stick is held loosely, it appears to the sense of touch to be an object. When, however, it is held firmly, we loose the sensation that it is a foreign body, and the impression of touch becomes immediately localized at the point where the stick is touching the body under investigation. It would scarcely be an exaggeration to maintain, purely from psychological experiences, that the concepts of space and time by their very nature acquire a meaning only because of the possibility of neglecting the interaction with the means of measurement." *(ATDN, p. 99)*

The first part of this quote brings to the fore a very crucial consideration. Some items, even when their overall place within given surroundings is quite stable, may function in separate ways. The stick is held by the hand and touches the same things all the time. Yet, either the stick must be regarded as an object investigated, or it must be regarded as a part of the means of investigation. But it can never be regarded as both within the same activity; because that would require an impossible form of observation on our part. The impossibility relates to us. The stick is allowed by Nature to be as Nature allows sticks to be, no matter what we observe or do. That is not the issue. The issue is that observation involves much more than *registration*. To observe is to structure a way of consciously relating to some things. As Wittgenstein later put it, to observe is to arrange or prepare for something to be *seen*.[162] Thus, observation involves observing what one has no chance of seeing unless one has managed to "organize" the given

to place them, hold them, or move them in some fashion. For all this, see Wittgenstein's interesting remarks *Philosophical Investigations*, II, p. 225

[162] See my previous discussion of this point at the end of the former chapter!

surroundings in a certain manner.[163] In other words, it is not that perception requires some sort of *Gestalt*; but instead, that observation involves recognizing the kind of practical context to which any given perceptual *Gestalt* belongs.

The second part of the quote above reminds us that such considerations are of relevance also when it comes to the observation of physical variables, including spatial and temporal determinations. One observes in order to arrange that "positions", "moments", "velocities", or "impacts" become visible. This implies that it makes no sense to claim that the arrangement itself is visible. The experimental arrangement itself is not to be seen; instead, the arrangement allows there to be something to be seen (i. e., allowing phenomena to appear for us to see).

As mentioned above, Bohr went into such considerations concerning the possible and intended uses of tools of measurement several times, including not the least the Bristol Lecture from 1931. Again, these ideas might be seen as an elaboration of the kinds of considerations on the basis of which Bohr had been able to meet the challenge put to him by Einstein, already, at the Solvay Conference in 1930. One might conjecture that it was on that occasion that Bohr became fully aware of the necessity and importance of articulating in painful detail how any measuring device is *a composite, dynamical physical system*. In theoretical physics, all rulers and all clocks must be part of a complex experimental setup. And the reading of such clocks and rulers is only possible and can only be significant on the condition of formulating a theoretical explication of the particular physical features that might be observed.

In his EPR paper Bohr, having summarized some of the primary views of Einstein, Podolsky, and Rosen, goes on to introduce his own position by reminding us of the following:

> "Indeed, the *finite interaction between object and measuring agencies* conditioned by the very existence of the quantum of action entails – because of the impossibility of controlling the reaction of the object on the measuring instruments if these are to serve their purpose – the necessity of a final renunciation of the classical ideal of causality and a radical revision of our attitude towards the problem of physical reality." *(Bohr 1935, p. 146)*

As I have discussed earlier, there is no dynamical physical system that can function jointly as a yardstick and as a clock. Now, consider this fact in the following way: *Nature allows us to introduce a discrimination between two kinds of apparatus*. The distinction between rulers and clocks should thus be regarded as no mere practical issue. Any description of natural phenomena in terms of concepts has a clear and significant content only insofar as the observations – that the description pertains to – can be comprehended by reference to a fixed functioning of certain devices.

Of course, the fundamental distinction in respect to apparatus, that between rulers and clocks, must be supplemented with a set of distinctions between rulers and "springs", and between clocks and "springs".[164] But there is no basic distinction between such springs and clocks and rulers. True, Bohr would often refer to a basic, complementary relationship between space-time co-ordination and the application of conservation laws. But, as Heisenberg also pointed out, this is a characteristic duality, only, *within* the description of apparatus. Take for example the following quote:

[163] (RC, Part III, § 326)

[164] Where a "spring" means a device intended to detect the momentum or energy transferred on impact or by pressure.

> "Indeed, it is *excluded in principle to control the energy which goes into the clocks without interfering essentially with their use as time indicators*. This use in fact entirely relies on the assumed possibility of accounting for the function of each clock as well as for its eventual comparison with other clocks on the basis of the methods of classical physics."
>
> *(Bohr 1935, p. 150)*

"Space-time coordination" amounts to fixing a "where/when", to fixing a pair of the form (r, t). But that does not yet count as having spotted *anything*. It is simply to specify that whatever may be spotted – say, the passage of the electron through the slit – may only be spotted on the background of some determinate arrangement. The same applies to the application of conservation laws. Such an application is a way to characterize some item as a spring; such that if there is an impact on the spring the subsequent vibration of the spring tells you something. So my point is that regardless of the way in which these vibrations or other indications may come about, there must be a temporal and/or spatial determination of these *indications*. Now, these determinations must be indicated by *some* rulers and *some* clocks. And *these* devices cannot be both kinds of rigid apparatus at the same time.

The description of apparatuses already involves dynamic accounts. The description of a ruler or clock is not something that comes first, before the invocation of dynamical features in terms of theory. But of course, whatever is involved in the description of the measuring devices is involved also in the description of the possible phenomena that may appear during the use of the apparatus. So the insistence that we make the description of apparatuses the focal point in fact implies no restriction. That is the sense in which the description of a certain class of phenomena involves the application of conservation laws, whereas there may be another class of phenomena whose description involves only space-time coordination. The former presupposes the description of the possible use of a spring; the latter presupposes the description of the possible use of a ruler and/or a clock. All of this will always involve *both* the application of the *whole* of the physical theory currently under scrutiny, as well as the application of the concepts of space and time in the account of the functioning of the various parts and features of the devices forming part of the *entire* experimental set up.

Here "involves" refers to there having to be certain aspects of the emerging displays of blips, blinks, and spots, all of which should be comprehended in the account of the emergence of single phenomena. But that is far from saying that the ascription to objective physical states is characterized by a mutually excluding relationship between dynamical and spatio-temporal attributes, which they are not. None of these attributes are ascribed to the objective atomic physical states at all. The "kinematic" and "dynamical" elements of the states of atomic systems are quite complex elements; elements of a quite non-intuitively structured kind.

Ad v): Measurements meaning "standardized comparison of properties" In The Warsaw Lecture, Bohr characterizes a measurement as being constituted by,

> "nothing else than the unambiguous comparison of some property of the object under investigation with a corresponding property of another system, serving as a measuring instrument, and for which this property is directly determinable according to its definition in everyday language or in the terminology of classical physics." *(Bohr 1938, p. 19)*

Now, as mentioned, following his lack of success in explaining the adequacy of the quantum theory to a number of leading physicists, including Einstein and Schrödinger, Bohr came to feel the need for an improved terminology. Accordingly, the concept of measurement was one of the crucial concepts that Bohr tried to clarify. I shall not comment further on the proposed clarification here, except by noting how Bohr would later refer to the clarified conception of measurement simply as implying *standardized comparison*.[165]

But at this point I mainly want to stress that the issue of the clarification of the concept of measurement must be seen as part of a further agenda – that of clarifying the *connectedness* of a series of methodological concepts in the field of experimental physics. Especially, we shall have to consider the connectedness between the concepts of *measurement, comprehension, phenomenon*, and *synthesis*. I shall argue that it was the identification of this very connection between methodological concepts that formed the bulk of the solution that Bohr gave to what he called the Observation Problem in the quantum theory, the problem discussed in the second paragraph of the Warsaw Lecture and to which we now turn:

4.3 The Observation Problem in The Quantum Theory

An outline of the Observation Problem in The Quantum Theory

In the Warsaw Lecture Bohr associates the requirements concerning the descriptions of both the construction and the manipulation of measuring devices with a philosophical problem that he calls the Observation Problem. He refers to this problem at the beginning of the third paragraph of the lecture. This paragraph centers on an attempt to compare the way in which the quantum theory and the theory of relativity both highlight certain aspects of what Bohr sees as the Observation Problem:

> "In both cases we are confronted with novel aspects of the observational problem, involving a revision of customary ideas of physical reality, and originating in the recognition of general laws of nature which do not directly affect practical experience". *(Bohr 1938, p. 25)*

It should be noted what is the problem in the Observation Problem, namely "the recognition of general laws of nature" that imply restrictions on the meaningful use of concepts in the description of phenomena. In other words, to establish a new kind of physical theory implies establishing a framework for the expression of specific kinds of physical regularity. This, again, will involve giving an analysis of the possibilities of observation within the new domain of experience that we investigate. This is the problem about which Bohr will teach us a lesson:

[165] (*Essays*, p. 6). I can not help seeing a parallel between Bohr's idea of measurement and the later Wittgensteins characterization of a number of language games; about which *Alles kommt auf die Vergleichsmethode an*! (RC, III, § 259). One might say, the fixation of the ruler is a presupposition of the language game of measurement; and that is why there is one thing about which it does not make sense to say it is or it is not 1m long. That is the standard meter in Paris (PU, I, § 50). The description of that rod as a standard, in terms of the concept of length, has no *physical* sense. According to the rules of the language game of measuring, the use of the rod as a standard, in a way rigidly prescribed, is a presupposition for the siginificant use of the physical concept of "length".

> "The main lesson of the whole discussion is ... the necessity of describing entirely on classical lines all ultimate measuring instruments which define the external conditions of the phenomenon, and therefore of keeping them outside the system for the treatment of which the quantum of action is to be taken essentially into account." *(Bohr 1938, p. 28)*

The important thing here is first of all how Bohr underlines the idea of *ultimate* measuring instruments. Also, the fundamental distinction required between these ultimate devices and the physical system, whose properties are being measured, should be noted. This is the background upon which Bohr introduces the most noticeable example of his new improved terminology, to the effect that one ought to,

> "... reserve the word 'phenomenon' for the comprehension of the effects observed under given experimental conditions". *(Bohr 1938, p. 24)*

Bohr would later shorten this restricted definition of the term "phenomenon", but I find it important to quote the original, full explanation of the term.[166] So, I have divided that first introduction into two – the core statement quoted above, and the elucidation of that core in the following:

> "These conditions, which include the account of the properties and the manipulation of all measuring instruments essentially concerned, constitute in fact the only basis for the definition of the concepts by which the phenomenon is described". *(ibid.)*

One might state the core definition of the term "phenomenon" in Fregean fashion. To refer to a phenomenon, according to Bohr, involves acknowledging the possibility of there being a definite way in which the phenomenon is given (answering a Fregean "sense"). Namely, that a phenomenon must be given by means of some comprehension of effects on the part of certain observers. The special meaning within physics of the notion of an "effect" should be noted: Such effects are far from being Humean events. Instead, they are a very complex set of circumstances. For example, one talks about the Doppler effect, the Zeeman effect, and the Hall effect, all of which were known within classical electrodynamics. In the context of the quantum theory one refers to various physical effects like the Compton Effect, the Stern-Gerlach Effect, the anomalous Zeeman Effect, etc.

This means that a phenomenon, in the new improved Bohrian sense of the term, is far from being an event or an appearance (in an empiricist sense of that term).[167] It is of utmost importance to note how Bohr characterizes a phenomenon as a combination of measurements. I have to quote in full:

[166] That it "refer to observations obtained under specified conditions, including an account of the whole experimental arrangement" (APHK, p. 64), or "reserving the word 'phenomenon' solely for the reference to unambigously communicable information in the account of which the word 'measurement' is used in its plain meaning of standardized comparison" (*Essays*, p. 6).

[167] As mentioned in a former footnote, part of Bohr's improved terminology included his beginning to refer to the "appearance of phenomena". This turn of phrase, which is rather important for understanding the new concept of "phenomenon", was actually introduced by Bohr in the essay on causality which he wrote in 1937. In his second paper on causality, Bohr again made heavy use of the expression "appearance of phenomena". See for example the summary of (Bohr 1948).

> "The essential lesson of the analysis of measurements in quantum theory is thus the emphasis on the necessity, in the account of the phenomena, of taking the whole experimental arrangement into consideration, in complete conformity with the fact that all unambiguous interpretation of the quantum mechanical formalism involves the fixation of the external conditions, defining the initial state of the atomic system concerned and the character of the possible predictions as regards subsequent observable properties of that system. Any measurement in quantum theory can in fact only refer either to a fixation of the initial state or to the test of such predictions, and it is first the combination of measurements of both kinds which constitutes a well-defined phenomenon." *(Bohr 1938, p. 20)*

So a phenomenon is a combination of two kinds of measurement – one directed towards the fixation of an initial state, a fixation that involves the "cut between system and measuring machines", that I spoke about earlier, and another directed towards the character of possible predictions. The latter phrase explains the use of the term "effect". Say, it is an "effect" that a certain beam splits in two, or that the frequency of some radiation changes on impact on material items. The *character* of the possible predictions will refer to concrete manifestations such as "the angle of the beams relative to a certain plane" or "the spectral characteristic of the radiation before and after the impact".

Thus, to comprehend a physical effect, like the Compton effect, will require some sort of combination between two measurements – one relating to the spectral distribution of the radiation before the impact of the radiation, the other relating to the spectral distribution after the impact. Now the comprehension of the two measurements involves more than the mere comparison of a quantity. So it is not the very change in the frequency of the radiation that makes up the phenomenon. Instead, the comprehension of effects involves making use of the whole of the formalism. In respect to the Compton effect, this means that both the Quantum Postulate of discrete stationary energy states and the Einstein formula $E = h * \nu$ must be invoked.

What is more, the necessary application of the whole of the quantum theoretical formalism presupposes making a distinction between what it takes to fix an initial state and what it means to characterize possible predictions. The former relates to the kind of system investigated under a specified circumstance, whereas the latter relates to the set of possible processes characterized as being "open to direct observation". This, I suggest, explains why Bohr says that it takes the combination of two kinds of measurement to constitute a well-formed phenomenon.

Here, one must distinguish between *the comprehension of effects* (that Bohr would later also refer to as "the comprehension of phenomena") and *the synthesis of phenomena* that forms the backdrop for the comprehension of phenomena. Now, the third paragraph of the Warsaw Lecture ends with a crucial explication of the quantum theory by describing it as "a generalization of the very ideal of causality"; and the explication of this important feature of the theory is given precisely by explaining that the aim of the viewpoint is establishing a framework for the synthesis of phenomena.

The distinction between the comprehension of effects and the synthesis of phenomena seems straightforward. The former refers especially to the possibility and necessity of applying two different kinds of concepts in the description of a *single* phenomenon, such as the use of concepts in accordance with mechanical and optical theories respectively. The synthesis of phenomena, however, is a matter of *combining* different kinds

of phenomena so as to represent the possible physical states of one definite system of objects under investigation.

Here, I want to recall – as the following quote shows – that one and the same object can be elucidated from mutually exclusive viewpoints and recall that the notion of the synthesis of phenomena is associated with a new *concept of an object*, for the basic consideration we are pointing out in relation to the set of possible state transitions is that to any coherent concept of an object there must be an associated account of how to combine mutually excluding uses of certain other concepts forming part of any description of such objects.[168] So our distinction between the comprehension of effects into a single phenomenon and the synthesis of phenomena as part of a state description of certain objects is, implicitly, contained, for instance in the following statement; for that is what is involved in making a distinction between (a) information about a single phenomenon and (b) the experience of the behavior of the *objects* entering into such phenomena:[169]

> "Information [ad a)] regarding the behavior of an atomic object obtained under definite experimental conditions may, however ... [ad b)] be adequately characterized as *complementary* to any information about the same object obtained by some other experimental arrangement excluding the fulfillment of the first conditions."
>
> *(APHK, p. 26, square brackets mine)*

Bohr's actual use of the expressions "comprehension" and "synthesis", however, is not quite consistent in the sense in which I have suggested. Especially in respect to the former expression, Bohr would extend its use, talking even about "the comprehension of laws".[170] The distinction that one might claim to have been drawn consistently by Bohr concerns instead the question of what is the focal point when using the respective expressions of "comprehension" and "synthesis". The comprehension of whatever is comprehended concerns what Kant originally called the *apprehension* of *Erscheinungen* in accordance with the transcendental principles of Understanding. The issue concerns the structure of conceptual thought and points to a condition for the possibility of such structure; namely the condition that these structures inhere in intuitive representations of the objects entering into *Erscheinungen*.

In contrast, the issue of the synthesis of phenomena refers to the combination of something whose different character seems to make the combination problematic. This is what motivates the following claim by Bohr:

> "... the extension of our knowledge may lead to the recognition of relations between formerly unconnected groups of phenomena, the harmonious synthesis of which demands a renewed revision of the presuppositions for the unambiguous application of even our most elementary concepts." *(Bohr 1936, p. 28)*[171]

[168] See also (*Essays*, p. 4)

[169] The last paragraph is an extensive clarification of a confusing footnote in the reviewed version of my dissertation

[170] (APHK, p. 86-7)

[171] This formulation has to be compared with Bohr's definition of a "conceptual framework" as "an unambiguous logical representation of *relations* between experiences". (APHK, p. 68, italics mine)

The use of concepts in the description of phenomena was never supposed to be a goal in itself. The description or apprehension of *Erscheinungen* was always just a step within the process of learning to observe a *system* of phenomenal appearances, the reality of which it is our goal to elucidate. As we shall see in the following chapter, Bohr's framework of Complementarity is part of an attempt to consider the essential association between the comprehension of quantum effects and the synthesis of phenomena.

In conclusion, this is what the Observation Problem in the quantum theory comes to: It was never a question of whether it is somehow impossible or difficult to make adequate observations in quantum physics, given what it means to observe atomic states. The problem lies deeper. We have inquired into what it means "to observe" in the context of the quantum theory. The observation of atomic objects, of those peculiar composite systems, has to involve a systematic, conceptual combination of various phenomenal appearances, each of which must already be comprehended in accordance with some conceptual grasp. *To observe is to prepare for making judgments of objects. To comprehend is to prepare for observation*, and to do so by grasping what is displayed as possibly counting as evidence for or against certain judgments of objects.

Thus, we have constructed a way of "weighing" certain possibilities of observation of objects with certain possibilities of state definition. I suggest that one sees this as characterizing all methods of observation. Take a pair of scales. If one scale goes up the other goes down. To be puzzled that the scales cannot jointly go up only shows you do not know the practice of using the pair of scales in order to observe. Similarly, the mutually exclusive uses of concepts of space-time coordination and of causal concepts in describing empirical effects is part of a single method of observation.

So how do we know that different individual phenomena, the observation of which is at issue, can be said to relate to the same atomic structures whose lawfulness we wish to elucidate? The problem of establishing that presupposition was the problem solved by our examination of the Interaction Problem. With that in place we can now say, as did Bohr:

> "As all measurements thus concern bodies sufficiently heavy to permit the quantum to be neglected in their description, there is, strictly speaking, no new observational problem in atomic physics." *(APHK, p. 89)*

Precisely: the character of the Observation Problem is as it has always been. Only the presuppositions for examining and solving the problem may vary in respect to different contexts of experience. That is why we have to inquire about any such context what it will mean to observe, what the practice of "observing" comes to in the particular fields.

The framework of complementarity is supposed to help us see all such considerations in the right light. As we shall see, this viewpoint shall help us in many respects:

(1) We shall learn to consider the structure of theoretical thought in a new light, and the account of the Interaction Problem is part of this.

(2) We shall learn to see the methods of conceptual thought in a new light, and the account of the Observation Problem is part of this.

(3) We shall learn to see human observational practices in a new light, and the response to the EPR-challenge is part of this.

(4) Finally, we shall learn to see cultural aspects of scientific practices in a new metaphysical light.

In the following chapter I shall discuss the first three of these aspects, using for all three the same label – the *strict* framework of complementarity – whereas I shall reserve the term "the *general* framework of complementarity" for the latter aspect that I shall discuss in the final chapter of the present book.

4.4 Causality and Complementarity

The strict notion of complementarity

What Bohr no doubt saw as the main "lesson" of the advent of the quantum theory was that it somehow modified the classical-physical notion of "causality". As I have argued above, this is not to say that the problem of causality as such was the first and major philosophical concern of Bohr. To both Heisenberg and Bohr, the problem of causality came to the fore within the quantum theory as a consequence of dismissing the classical understanding of tracing a given succession of phenomena in space and time. Within the quantum theory there is no point in adopting a *uniform* spatio-temporal description of the succession of phenomena. What is it that we achieve, then, when we, in some non-uniform manner, point to a certain combination of phenomena? How is it that such an *observation* of a given combination of phenomena figures in our determination of certain objective, physical states of affairs? In short, how do we "weigh the possibilities of observation with the possibilities of definition, of possible states?" As repested several times, this was the question that, in the Como Lecture, first led Bohr to introduce the notion of "complementarity":

> "... in the description of atomic phenomena, the quantum postulate presents us with the task of developing a "complementarity" theory, the consistency of which can be judged only by weighing the possibilities of definition and observation." *(ATDN, p. 55)*

The required "complementarity theory" involves our renouncing any attempt to give a *causal account of the succession of phenomena*. This is not an epistemological remark (about what we might recognize, given certain kinds of circumstances), but rather a methodological remark concerning which phenomena we might have *reason to pursue*. Consequently, regardless of how the experimental conditions are fixed, any given series of phenomena in no way determines the possible phenomena to be observed in the future. This is the view behind the so-called "viewpoint of complementarity," or "framework of complementarity," as stated in the Warsaw Lecture:

> "... the View-point of Complementarity allows us indeed to avoid any futile discussion about an ultimate determinism or indeterminism of physical events, by offering a straightforward generalization of the very ideal of causality, which can aim only at the synthesis of phenomena describable in terms of a behavior of objects independent of the means of observation." *(Bohr 1938, p. 25)*

This "ideal of causality" must thus go by the board. I shall argue below that not only must we renounce a causal account of the succession of phenomena, we must also renounce the idea that *objects are causes of phenomena*. For we observe phenomena *qua* their being phenomena, and not qua their being caused by certain objects. Hence,

we must introduce a non-classical account of the way in which different phenomena can be said to be causally related, as well as of the sense in which an object "forms part of" or "enters into" the generation of certain phenomena. In short, we need to modify or generalize certain classical physical notions of causality. Consequently, recalling the Como Lecture, Bohr consistently presented the framework of complementarity as an attempt to "generalize the very ideal of causality":

> "... the trend of the whole argumentation presented in the Como lecture was to show that the viewpoint of complementarity may be regarded as a rational generalization of the very ideal of causality." *(APHK, p. 41)*

We get a hint of what precisely Bohr means by this idea of a "generalization" if we consider the following, early formulation of the idea from the Faraday Lecture of 1932:

> "The use of energy conservation in connection with the idea of stationary states ... means an upholding of causality particularly striking when we realize that the very idea of motion, on which the classical definition of kinetic energy rests, has become ambiguous in the field of atomic constitution. As I have stressed by the argumentation mentioned, space time co-ordination and dynamical conservation laws may be considered as *two complementary aspects of ordinary causality*." *(Works VI, p. 375-6)*

The point thus seems to be that what was considered (the) one (and only) form of causality within classical theory – namely, a coupling between, on the one hand, the states of motion of individual objects (kinetic energy) and, on the other, the physical states of objects as such – has proved to embody two quite different forms of causality: a) the kind of causality that characterizes *bound energy* and b) the kind of causality that characterizes the energy of "*free*" particles. The change in the *kind of energy* that is involved in, say, the emission of a photon from an atom (corresponding to a shift in the energy state of given electrons) is radically different from the interchange between various forms of potential and kinetic energy within the context of ordinary mechanics. I conclude the following:

(1) "complementarity" is a kind of relation between space-time coordination and dynamical conservation laws ...

(2) corresponding to a relation between the possibilities of observation and the possibilities of definition,

(3) and answering to a relation between various (bound and unbound) forms of energy,

(4) which in turn corresponds to a relation between different forms of causality.

(5) And this, in its turn, indicates a relation of complementarity between different experimental set-ups, as well as between the respective kinds of phenomena that these set-ups allow:

> "... it is only the mutual exclusion of any two experimental procedures, permitting the unambiguous definition of complementary physical quantities, which provides room for new physical laws, the coexistence of which might at first appear irreconcilable with the basic principles of science.

> It is just this entirely new situation as regards the description of physical phenomena, that the notion of *complementarity* aims at characterizing."
> *(Bohr 1935 [the EPR paper], p. 148)*

In sum, one should consider points (1) through (5) as forming a unified whole in the sense that it would be pointless to try to characterize any one of them as the main point or to try to reduce any one point to any one of the others.

In stating points (1) through (5) I have made use of the term "relation," which is to be understood in the Kantian sense that "complementarity" is a concept of relation as opposed to being a concept of quantity, quality, or modality, respectively. Thus "complementarity" is a concept of relation in the same sense in which "causality," according to Kant, is such a concept. For Kant, causality means a set of possible relations between distinct appearances, such as the appearance that the Sun is shining and the appearance that a stone is hot. Thus, the concept of causality implicitly concerns a form of interaction between two objects. What are we to say about the notion of complementarity? First, as indicated in (1), the kind of interaction in question is no longer conditioned by the possibility of motion (in space-time). Second, according to (2), the dynamics of the experimental set-up has to be taken into account. This corresponds to Heisenberg's idea that the possible descriptions of given experiments condition the use of concepts in the description of causally relevant phenomena. And this is in fact also stated in (3) through the notion of "free" particles (free to move in observable manners).

It seems then that the notion of complementarity generalizes the concept of causality in the following sense. Within the classical context, two "freely moving" objects, like the Sun and a particular stone, might in principle interact because they each belong to one and the same field of objects (i. e., the possible objects of classical mechanics, corresponding to the Newtonian laws). Within the context of the quantum theory, freely moving and observable objects can be said to be causally connected only to the extent that a) the description of the causally relevant phenomena is relative to the description of a certain experimental set-up, and b) it makes sense to consider different set-ups like this as "embodying" *the same atomic system*. Consequently, spatio-temporally speaking, in "ordinary" causality we have two mutually exclusive objects engaging in one kind of (mechanical) interaction. In "complementarity" we have one and the same atomic system that – by being embedded within two different forms of experimental arrangements – gives rise to two mutually exclusive phenomena. Does it really make sense, then, to regard the notion of complementarity as a generalization of the concept of causality? To answer this question we must first direct our attention to a distinction between the (Kantian) *concept* of causality and the (Kantian) *principle* of causality. The former is the concept of relation between different substances, like the Sun and a stone, in the sense explained above; the latter is formulated by E. Cassirer as follows:

> "What the causal principle signifies ... is not a new insight concerning content, but solely one concerning method ... With regard to content it does not go beyond what has already been observed; it only confirms it and confers upon it as it were the epistemological *imprimatur*. In this sense it belongs, using the language of Kant, to the modal principles; it is a postulate of empirical thought ... It does not maintain that the process of translating data of observation into exact statements of the results of measurement ... is ever complete. What it demands and what it axiomatically presupposes, is only this: that the completion can and must be sought,

> that the phenomena of nature are not such as to elude or to withstand in principle the possibility of being ordered by the process [of translating data] ... the causal principle belongs to a new kind of physical statement about measurements, laws, and principles. It says that all these can be so related and combined with one another that from this combination there results a system of physical knowledge and not a mere aggregate of isolated observations." *(Cassirer 1936, p. 60)*

As was the case with Heisenberg, Bohr certainly subscribes to this Kantian principle of causality as "a statement about measurements, laws and principles that says that all these can be so related that from this combination follows a system of knowledge and not a mere aggregate of observations." In this sense the term "complementarity" underscores the (paradoxical) situation that it is precisely the mutually *exclusive* character of certain kinds of experimentally produced phenomena that makes them fit for adoption into a systematic unity in accordance with certain physical laws.

This explanation corresponds well with Bohr's general definition of a "framework" as providing a logical representation of the possible *relations* between various phenomena.[172] Thus, a framework of complementarity is a means to a certain end, namely, that of maintaining the Kantian principle of causality within the context of the quantum theory. On the other hand, however, the framework of complementarity involves not only a "generalization" but a strict *denial* of what Bohr would sometimes call "*the ideal* of causality," which, in my view, should have been called "the idealization of the *concept* of causality." Bohr's use of such expressions has caused some confusion among even the most able interpreters. Jan Faye is a case in point. He thinks that the renunciation of the "ideal" of causality means the denial of a basic *principle* of causality as well. Let us take a look at which principle that might be.

Faye's view on the issue of causality seems to be just the opposite of Cassirer's and mine.[173] According to Faye, Bohr believed that quantum physics had given up the *principle* of causality, whereas the concept of causality necessarily had to be maintained. Faye even supports his interpretation by quoting Bohr:

> "the view has been expressed from various sides that some future more radical departure in our mode of description from concepts adapted to our daily experience would perhaps make it possible to preserve the ideal of causality also in the field of atomic physics. Such an opinion would, however, seem to be due to a misapprehension of the situation. For the requirement of communicability of the circumstances and results of experiments implies that we can speak of well defined experiences only within the framework of ordinary concepts. In particular it should not be forgotten that the concept of causality underlies the very interpretation of each result of experiment, and that even in the coordination of experience one can never, in the nature of things, have to do with well-defined breaks in the causal chain." *(Bohr 1937, p. 293) [quoted from Faye 1991, p. 132]*

Can there be any doubt, then, that Faye interprets Bohr in the right way, whereas Cassirer and I misread him? Well, to begin with, let us see what Faye takes the principle, and the concept, of causality to be:

[172] (APHK, p. 68)
[173] (Cassirer 1936, pp. 124-5)

> "The *ideal of causality*, on the one hand, consists of the idea that a causal representation of physical phenomena in space and time is always a feasible task. It is assumed that every phenomenon is caused by some other phenomenon so that any physical object can be described in terms of it's causal connections with other physical objects. This ideal is one which cannot be realized in quantum mechanics ... On the other hand ... the *concept of causality* is necessary for the order and structure of our experience in the sense that only by imposing it on the phenomena we perceive in space and time are we able to obtain knowledge of objects independently of subjective experience ... the concept of causality underlies the understanding of every experimental result as being an effect of an interaction between the instrument and the atomic system." *(Faye 1991, pp. 132-3)*

Faye's understanding of the "ideal of causality" is obviously a version of the Leibnizian principle of "grounding," the idea that everything that exists has *its own* "ground." Reformulated within the context of classical physics, the principle becomes the view that since the *state-descriptions* of certain physical systems answer to the principle of grounding, so too must the manifest states of measuring instruments, so that any two observable phenomena can, in principle, be causally connected. According to Faye, the problem of causality that Bohr wanted to address is thus:

> "... the finite magnitude of the quantum of action constitutes the reason why the quantum mechanical system interacts with the experimental instrument in such a way that one cannot fully determine or control this interaction, and owing to which it is no longer possible to describe a causal connection between the system under observation and instrument used for the observation. Bohr therefore concludes that 'independent reality' in the ordinary physical sense can neither be ascribed to the phenomena nor the agencies of observation." *(Faye 1991, p. 137)*

In my view, this is not a problem considered by Bohr because, as I understand his position, it hardly makes sense to talk about "the interaction" between the measuring devices and the objects under investigation. It is true that Bohr renounced the idea of there being "independent phenomena," but whatever counts as an *object* of investigation must in some sense be embedded within the experimental arrangement.

Faye and I agree that the lesson to be learned, the point of adopting the framework of complementarity, is that it is necessary to impose a *restriction* on the use of the *concept* of causality (in accounts of wave-like and particle-like phenomena) and to avoid postulating a causal connection between the two kinds of phenomena. However, as is clear in the above quote, according to Faye the point of making use of the concept of causality in this restricted fashion will be to make sense of the results of experiments as causal effects of the (otherwise unanalyzable) interaction between objects of measurement and the instruments that are used to perform the measurement. This is achieved in two steps: First, we must account for the "unfolding" of phenomena. According to Faye, this corresponds to the issue of *subsuming* a *series* of events under concepts. The recognition of a particular *kind* of order within the series of observations has to be expressed by applying the concept of causality. For example, in order to describe a phenomenon as "wave-like" we acknowledge a certain kind of lawfulness in the way that observations follow one another, qua events. This is said to constitute

the *criterion of reality* for the observed quantum physical objects. Second, apart from recognizing the existence of non-classical quantum objects – through the assessment of a distinct causal ground for observing certain phenomenal regularities in the manner just accounted for – there is *nothing else* we shall ever be able to say about the *nature* of such objects. The logical character of the system of phenomenal combinations allowed by the formalism itself constitutes the *criterion of objectivity* concerning the new realm of reference. In this sense, according to Faye's account, the description of the quantum world cannot transcend the realm of phenomena. Thus, only a rationally restricted causality, adopted merely in order to assess certain kinds of phenomenal regularity, constitutes an objective account of the (new) realm of reference.

In my opinion, this is not how Bohr suggested that we face the problem of causality (i. e., the problem of how to restrict the use of any concept of causality according to a new framework concerning the *principle* of causality). Before discussing Bohr's position further, let us consider the essay from 1937 that Faye specifically mentioned above.[174] Bohr begins the essay by making the following claim:

> "On several occasions I have pointed out that the lesson taught by recent developments in physics regarding the necessity of a constant extension of the frame of concepts appropriate for the *classification* of new experiences leads us to a general epistemological attitude which might help us to avoid apparent conceptual difficulties in other fields of science as well." *(Bohr 1937, p. 289; italics mine)*

Now, what does the issue of the classification of experiences have to do with the issue of causality? First of all, one should note the following remark of Bohr:

> "Before entering into the problems to be discussed, I need recall only briefly how often the development of physics has taught us that a consistent application even of the most elementary concepts indispensable for the description of our daily experience, is based on assumptions initially unnoticed, the explicit consideration of which is, however, essential if we wish to obtain a classification of more extended *domains* of experience as clear and free from arbitrariness as possible."
>
> *(Bohr 1937, p. 289-90, italics mine)*

Surely this means that the classification of domains is a major concern in relation to the issue of the reasons for restricting the use of some concepts, like the concept of causality, in the description of experiences. The point seems to be that this restriction shall not only, as Faye would have it, concern the manner and range of application of those concepts, but instead the *context* in which to employ them. My disagreement with Faye's account of this issue thus has to do with what I see as an unwarranted empiricist reading of Bohr, in which the issue of an "analysis and synthesis of experiences" is reduced to a matter of "ordering" a series of observations. Faye views the concept of causality simply as a kind of ordering principle (which for some reason is embedded in our ordinary practices). I however associate causal concepts with certain *criteria of identity*, and thus with the classificatory function of referring to distinct objects within

[174] The talk Bohr gave at a physics conference preceding the Second International Congress for the Unity of Science in Copenhagen in 1936 (Bohr 1937).

a well-defined field of objects. A causal concept, according to my reading of Bohr, expresses an objective kind of *causal structure* (e. g., the possible energy states of electrons bound within a given atomic system as expressed in an electron configuration diagram).

When Bohr refers to "a new situation in physics" he is suggesting a new experimental framework for relating different kinds of phenomena in order that they, in combination, symbolize a distinct kind of objective states of affairs. Thus, in his paper of 1937, after having introduced the "discovery of the universal quantum of action," Bohr declares:

> "Indeed this circumstance presents us with a situation concerning the analysis and synthesis of experience, which is entirely new in physics and forces us to replace the ideal of causality by a more general viewpoint usually termed 'complementarity'." *(Bohr 1937, p. 291)*

We can now see the basic flaw in Faye's reading of Bohr. Bohr's renunciation of the "ideal of causality" is a renunciation of the universal applicability of the classical-mechanical, Kantian, *concept* of causality as regards a balanced account of the analysis and synthesis of phenomena. Bohr simply made the point that this classical concept of causality was associated with a limited domain. Faye and I agree that in relation to the quantum theory Bohr indicated the possibility of a restricted use of the classical Kantian concept of causality, but whereas Faye assumes that Bohr argued that we must avoid invoking a special quantum physical causal understanding of phenomena, in my view Bohr argued against the possibility of an unrestricted use of certain forms of causal *representation* – such as "space-time pictures." The framework of complementarity is not a *substitute* for the previous classical understanding of causality but is a *generalization* of it, and this means that we can indeed continue, within the context of quantum physics, to regard phenomena as causally produced; though produced neither by the objects investigated nor by the "interaction" of these objects with the given measuring devices, but rather by the very manner in which the objects are embedded within *the whole of the experimental arrangement*, corresponding to – and thus also relative to – a certain description of the experimental set-up.

It takes the whole of the quantum theoretical formalism to describe "the manner in which the objects are embedded in the experimental arrangement," but – in Bohr's view – we can and must keep to ordinary language, including that of classical physics, in order to account for the possible *observations* of quantum physical phenomena. This forms part of the task of "weighing the possibilities of definition with the possibilities of observation" (i. e., the task of finding a balance between the analysis and synthesis of phenomena).

By saying that phenomena are causally produced, however, we are not obliged to characterize the physical process of production itself. We are not claiming that phenomena have certain *efficient causes* in the Aristotelian and Humean sense. Faye is right in seeing Bohr as renouncing this, but is wrong in taking only this kind of causality into account. Quantum physical phenomena "arise" or "emerge" from within certain observational situations. *That* from which they arise objectively exists. Quantum physics deals with a kind of reality. However, even if we objectively know *that* the kind of reality in question (i. e., atomic physical systems) gives rise to certain phenomena under certain observational situations, we shall never be able – within physics – to answer the question of *how and why* this is possible. Compare the following: to be

colored is a way in which an object can be visible, but to ask how and why an object is visible in this way is futile, because it is one thing to say *what happens* when we see a certain object (e. g., it reflects light at a certain wavelength), and another to say that this constitutes a kind of visibility of a certain *object* and does not merely say something about something else (e. g., about the properties of light).

Faye's Bohr pursues the strategy of viewing *atomic objects as logical constructs of the properties exhibited in phenomena*. It follows that the reality of atomic objects is constituted by their possibilities for interacting with the kinds of things that we can deal with in an ordinary manner. All we shall ever know about atomic objects is how they interact with material particulars that are associated with criteria of identity, the introduction of which is based on certain recognizable features of familiar things – be it slabs of meat, flakes of snow or familiar, mechanical, spatio-temporal phenomena. It is only possible to ascribe definite kinetic and dynamical properties to atomic objects in respect to physical interactions insofar as one conceives of these in the manner Faye's Bohr does.

Consequently, the causal properties that can meaningfully be ascribed to atomic objects have to correspond to forms of physical change that are already known within a familiar physical context.[175] All references to atomic objects will, ultimately, have to be based on the sense of predicates used to describe manifest experiences. Only in this way will the use of theoretical predicates in experimental statements have determinate – albeit recognition-dependent – truth conditions.

My dispute with Faye is this: I take Bohr to ascribe a sense to individual experimental statements only in terms of their derivability from the *whole* quantum theoretical formalism. This, in turn, involves *some* empirical observations in terms of classical concepts (one cannot make sense of the phenomenon – the fact – that an electron gives rise to an interference pattern if one cannot observe whether a certain diaphragm is rigidly fixed). Thus, in my view, a Bohrian kind of "experimental statement" that describes a quantum phenomenon might be as follows: "there is an electron interference pattern on the screen" – and only a quantum theorist would be able to understand this. Faye, however, requires that we observe and report the interference pattern *itself*, directly, as well as the original state of the electrons, indirectly, so as to describe how they are "prepared" by, say, being energetically excited within an accelerator or the like. Faye is right in denying a causal explanation of the "route" of the electrons *from* the canon ejecting them over the diaphragm they pass to the screen they hit, since we are dealing with with a "closed" phenomenon. But in my opinion Faye's account of the description of a quantum phenomenon becomes too closely tied to a series of state-descriptions.

I think that what confuses Faye is the standard notation of the Dirac wavefunction, in which the function for the combined system is written as a product of wavefunctions representing each component. Concerning many-body systems, the wavefunction is written as a linear combination of such products so as to express possible *symmetry properties* within the possible permutations of elements. Now, if each such function is expanded as a Fourier series in order to secure a mathematical expression of some special physical properties of the system under consideration, mathematically speaking we have a sum of sums; physically we have a shorthand for the division of the combined system into different kinds of physical stability, each associated with

[175] This is in direct contrast to the principle thesis of the present book.

certain forms of energy, and each corresponding to possible constants of interaction (generalized constants of motion). This is how an application of the whole of Dirac's formalism both expresses a physical understanding of how to split up the Hamiltonian that governs the combined system and informs the experimenter how possible *observables* are to be accounted for. As I see it, Faye is wrong in believing that the use of the quantum theoretical formalism is primarily a means for surveying how individual *state* descriptions might relate to one another, in order to ground the possibility of closed phenomena. Thus, I think Bohr would have denied the view that Faye ascribes to him in the following:[176]

> "... Bohr looked at the reality of the atomic object in the following way: what we observe is the atomic object in a certain state; we do not observe a phenomenal object which is caused by the atomic object. Atomic objects do not cause their own states which we then perceive; they are in these states whenever we observe them. Such observation is accordingly interpreted on the assumption that the atomic object interacts with the measuring instrument in such a way as to make it the case that the state of the atomic object is made manifest by the state of the measuring apparatus." *(Faye 1991, p. 228)*

It must be clear by now that the basic issue for Faye's Bohr is to learn how to come up with *state* – descriptions of atomic objects. Since Faye's Bohr is a non-realist, and given Heisenberg's Indeterminacy Relations, there can be no possibility of trying to construct a type of statement describing the *inherent* properties of atomic objects. We must renounce that aim, and restrict our efforts to describing quantum phenomena only, as constituted by (or, in the form of) a special kind of observational encounter. Consequently, we must learn to see how objective states of a special kind may be present under specified, experimental conditions. To "see" this involves drawing deductive links expressed by a set of formula.

Consequently, Faye has, on Dummettian semantic lines, elaborated a mode of objective *description* (in the sense that the reference to the experimental set-up has been specified, so as to be clearly separated from the reference to the interaction). But here we must be cautious: It is one thing to give an account of a new kind of property for objects to have, but it is quite another thing to give a new account of *what it means* to "ascribe a property to an object." Clearly, it is the latter that Faye's Bohr aims to do. Because, it is first *in terms of such a new account* that a new "concept of object" (i. e., the "concept of atomic object") is supposed to be introduced.

Faye's answer to these queries is ultimately that the emergence of quantum phenomena is *lawful*, though not in the sense that it is the process through which the phenomena come into being that is lawful, but rather in the sense that quantum phenomena emerge as "suited for" a lawful kind of connectedness to other such phenomena. Accordingly, the reality of the atomic *object* is solely the fact that manifest quantum phenomena exhibit a certain logical structure. Which now makes me re-state my criticism of Faye. I can see it no other way than this: the kind of logical structure that quantum phenomena have must in some way be analogous to the kind of structures which *classically recognized* items are supposed to have. This is not a view that I would ascribe to Bohr.

[176] Cp. Don Howard's similar critique in (Faye and Folse [ed.] 1994)

Atomic objects, as I conceive of them, jump, spin, annihilate, group and regroup in all sorts of non-classical ways. Their causal powers do not just have different, unvisualizable shapes; they *manifestly* entertain all sorts of different *kinds* of causality. They are, as Rom Harré has put it, more like sunsets than billiard balls, and more like a fast growing wood than a water wave. It is quite clear that Faye's Bohr would not be allowed to speak in such realistic and metaphysical terms. Of course, for a conceptualist, there are no real independent structures to be ascribed to the objects that we are epistemically justified in viewing ourselves as being able to recognize.[177] The conceptualist therefore only has a *formal* notion of something's being an object (being a posit), and all the talk about different "concepts of objects" relates to different conditions of *observability*, and is thus an epistemological issue and does *not* relate to the real, objectively existing differences there are between, say, atoms and water waves. Thus, it comes as no surprise that Faye claims the following:

> "The atomic object does have several possible phenomenal manifestations in the sense that it can only meaningfully be ascribed several relational properties with respect to certain experimental conditions which exclude each another. But this does not entail that the nature of the atomic object is something over and above its various possible manifestations. A phenomenon, in Bohr's terminology, is not an object but the property with which it becomes visible with respect to a certain experimental situation. So the phenomenal object is the atomic object exhibiting a particular property." *(Faye 1991, p. 229)*

Is the reality of these objects therefore *just* the reality of their "relative properties" (secondary properties?) as they are manifested in observational encounters? I take it that Faye would gladly say that the atomic objects are "more" than the sum of their relative properties. They are, if you like, the *logical* sum thereof. But Faye is anxious to deny that atomic objects have the "*inherent* primary property," the causal power, to manifest themselves in different, recognizable ways.

Faye's notion of 'atomic object' comes to this: Faye quotes with approval a correspondence between Bohr and Max Born, where Bohr explained his views about atomic objects as being *invariants* in the Hamiltonian sense. Faye comments on the letters, stating the principle that atomic objects are but invariants between *phenomena*. Born first wrote to Bohr:

> "What I meant by 'behind the phenomena' is in mathematical language just 'invariants' in the most general sense of the word. The various aspects of phenomena which we consider in quantum mechanics have also a theory of 'invariants', or in less learned language, common features which do not depend on the aspect, and it is this I would like to preserve as something beyond our direct experience" *(quote from Faye 1991, p. 210)*

Bohr then replied by declaring that he could indeed endorse this account of Born:

> "I owe you, of course, an apology for my remarks [in an earlier letter] as to the question of what is behind the phenomena ... As you express your views in the letter, I agree entirely and had myself the same attitude

[177] I will discuss Faye's semantic version of conceptualism below.

> when in my letter I spoke of a consistent abstract generalization of classical mechanics and electrodynamics interpretable only on correspondence lines." *(quote from Faye 1991, p. 210)*

Here Bohr is referring to the Hamiltonian practice of viewing the possibility of establishing an *algebra* in respect to conjugate variables as an expression of a *kind of physical stability*: any conservation law should only be formulated on the background of such an algebraic approach. Faye, for his part, speaks all along, and very vaguely, about the conservation laws of energy and momentum. Such laws supposedly govern most of our ordinary understanding of things. Faye states:

> "As I understand his [Bohr's] reply [to Born], Bohr was saying that 'a consistent abstract generalization of classical mechanics and electrodynamics', which quantum theory is, gives us the lawful connections, or if you like invariance, between the phenomena we can observe. This is all there is about the reality behind phenomena. The quantum phenomena are given empirically, and they are objectively real in the sense that they are manifested to us in the context of lawful connections. The lawful connection between the atomic phenomena is our grounds for believing that these phenomena are connected by what is not observed, i. e., by atomic objects existing between preparation and detection. Consequently, atomic objects are real in so far as they contribute to the creation of such lawful connections." *(Faye 1991, p. 210-1)*

Therefore, Faye would add, we are not allowed to say anything about the powers of atomic objects to "contribute to the creation" of lawful connections between phenomena. Remember what "lawful" *means* for Faye: it means that we are fortunate in our attempt to follow explicit rules for the use of theoretical terms. Faye has thus made his Bohr pay a heavy price in order to escape – as we should – the notion of objects as causes of phenomena. We are to be silent about *any physical* link between a physical object and the phenomena into which it may enter. We should not, as I think Bohr insisted, merely keep silent about a "classical causal" link.

4.5 Apparata as Schemata; a Discussion of Rom Harré

Realism and Novelty

To me, Bohr is surely a realist. He is an epistemic, as well as a metaphysical realist since he claims that the atomic systems that are referred to in atomic physics exist independently of our means of recognition:

> "We know now, it is true, that the often expressed scepticism with regard to the reality of atoms was exaggerated; for, indeed, the wonderful development of the art of experimentation has enabled us to study the effects of individual atoms". *(ATDN, p. 93)*

Bohr is also a semantic realist since he claims that what we can meaningfully say about atoms is objectively right or wrong without our being able to know it. None of this need be, and in fact is not, ruled out because of the undeniably relative character of every result of measurement, or because our subsequent verbal accounts of such results will have to relate to certain experimental procedures. For instance, Bohr expresses,

> "The fact that in atomic physics, where we are concerned with regularities of unsurpassed exactness, objective description can be achieved only by including in the account of the phenomena explicit reference to the experimental conditions, emphasizes in a novel manner the inseparability of knowledge and our possibilities of inquiry. We are here concerned with a general epistemological lesson illuminating our position in many other fields of human interest." *(Essays, p. 12)*

It should be noted how Bohr considers the relativity of observations in respect to experimental procedures, not as a hindrance but as a cognitive resource for obtaining exactness within our objective description of natural phenomena, and thus also as a resource for our theoretical insight into real physical structures. So the epistemological lesson that should be learned is that experimental procedures are not something that blur, disturb, or cover whatever we talk about. They form no "veil of experience". There is no such veil.

According to the less robust form of realism I consider Bohr to advocate, the experimental procedures in a sense form part of what we talk about. But what is more, they arrange the ontological space for what we talk about. We have procedures that contain among other things, atoms. By establishing procedures *we arrange a way for atoms to be*. We not only prepare the states of atoms, we prepare for them to be, at all.

All such metaphors may, taken literally, lead to misconceived problems. For example one might maintain that an atom is only a sort of "phenomenal object" – a shaped up reality that is fully given in the form of some phenomenon, whereas Reality as such should be regarded as the amorphous "substance" behind all phenomena. In other words, the reality of things might, at best, be inherent in every single distinct object. None of this needs to be addressed in our account of the strict framework of complementarity. Instead, the objective reality of things is inherent in our procedures and arrangements. We manage to "take" the atom into account, both in theory and in practice. We play around with atoms. The experimental arrangement is like the stick in our previous example. The atom is a system whose parts get kicked around by the stick. We play with photons, electrons, and other atomic constituents. But our doing so may still bring to light the peculiar kinds of lawfulness according to which atomic processes occur.

It is not just that we "trigger" some underlying, latent process. That realistic conception is too robust. Neither shall we say that the existence of laws conditions the possibility of our being able to perform experiments with the results we get. Such transcendental argumentation is also too robust. It is an overly robust form of idealism. The point is not to distinguish between "what is there already" and "what we do". What we do is there in the fullest sense of the term. Of course you can press the point that the world must be so, that what we might do is possible, but that provides no elucidation at all.

There have recently been several attempts to alter or modify the various forms of realism. I personally agree with M. Dummett and C. Wright in believing that, in principle, there can be numerous forms of realism, and that this is all a matter of specifying *what is the point* – in given contexts of discourse – of distinguishing between (a form) of realism and the opposing position (be it a form of idealism, phenomenalism, instrumentalism, verificationism a. o.).

Consequently, I think that the critical assessment of the received, logicist tradition in the philosophy of science should not concentrate on finding flaws in some of the *specific* aspects of that tradition. I mean, if you argue that one must introduce a "new" conception of theories, of models, of theoretical terms, of scientific progress etc., your reasons for arguing this should concentrate, purely, on the *full* account of your own position. There is, as it were, no point in considering the development and change of the *philosophy* of science. Here, we have not to do with a process of trial and error. The positivists, the instrumentalists, the naturalists, the neo-Kantians, and the pragmatists within the philosophy of science have not made any "mistakes". You should not argue they have been "wrong". Instead, you shall assess, justify, or criticize *the adequacy of their respective accounts relative to certain problems within the sciences themselves*.

This is not to set aside the legitimacy of a strict normative account of science. Maybe one can a priorily characterize what rationality consist in and consequently how one should conduct scientific thinking and experimentation. But then, the task is to argue that there can possibly be certain forms of knowledge-seeking enterprises corresponding to your normative claims. You have to show that something called "science" (or better, specific fields and forms of science) is *possible*. Also, you cannot take for granted that physics or any other developed tradition meets your normative criteria. Of course, like Laudan, Popper, and Kuhn you can a priorily consider physics to exemplify the essential features of science and then try to reconstruct or elucidate what it is within physics, as you find it, that shall cast a light on the normative assessment of any other kind of science, as well as provide a critical horizon also for physics itself.

It is for reasons like these that I favor the philosophy of science of Nancy Cartwright. She manages to present her agenda, so to speak, in abstraction from the tradition of the philosophy of science. However, she is *then* willing and able to (try to) account for the way in which her account differs from, and involves a critique of, certain parts of a series of established forms of philosophy of science.[178]

Now, I will briefly present Cartwright's position because I want to express where my disagreement with that position lies. This critique will then bring me to present and discuss in some detail the recent position of Rom Harré, a position that in many ways is informed by his realistic interpretation of Niels Bohr's philosohy of physics.

I consider Cartwright (from 1989 and on) first of all a neo-Aristotelean. I think she has fully adopted an Aristotelean ontology in respect to *causality*. However, she is not a true and strict Aristotelean in respect to the metaphysics of Nature, as such. She tries to elaborate a new idea of dispositions, of "tendencies to cause", and she has all sorts of original things to say on how it is that such dispositions can be actualized and shaped within various forms of physical reality and activity.[179] However, the upshot of her philosophy of science is, on my view, the claim that the (metaphysically given) causal dispositions of Nature

(a) cannot be individuated as distinct, existing "powers". The four Aristotelean kinds of cause do not, as it were, *act as one* real agency. "Causation", as such, is not a real, physical process. Nature has, on her account, a tendency to cause, and thus a tendency to produce powers.

[178] I have a similar praise concerning two of the philosophers of science whom I will discuss critically in detail below, Rom Harré and Jan Faye.

[179] (Cartwright 1989)

(b) This is to the effect that there is no such thing as a fundamental *causal structure*. Such structures are generated relatively to the formation of certain kinds of physical system.

(c) So for instance, with the formation of the solar system, Nature, qua its underlying tendency to cause, generated (brought into being) a certain *form* of causation (i. e. gravitational pull and push). But still, it is not yet given precisely *how* this kind of causation "acts". There is as yet no distinct causal structure, no distinct physical causes.

(d) These distinct causal structures can however be ascribed to, say, the solar system, even *before* that particular system in reality possesses them. That is, we can *model* the solar system as a kind of "nomological machine". We can associate the solar system with a certain kind of physical regularity and lawfulness.

(e) In the laboratory we can then construct other but "similar" nomological machines. Then we will know that Nature does have the capacity to generate such regular forms of system, i. e. that the basic dispositions of Nature should be seen as *capacities* because they embody the causal tendency to generate objects and systems with recurrent, regular properties. The tendencies of Nature are like an embryo. Nature – of and from itself – not only generates whatever exists. Nature has the capacity to *give birth* to what exists. The very process and generation – as well as the form and character of – the products are pre-established. Nature is pregnant with certain *forms* of objective existence and with *specific* causal structures embodied by these forms.

According to Cartwright, Men have a standing possibility of intuition by means of which we can express basic ideas corresponding to certain general, abstract features of Reality. Cartwright says almost nothing about this capacity of intuition. However, she has much to say on the various ways in which these abstract ideas and forms can be made more and more concrete corresponding to the ways in which Nature's tendencies to cause unfold; first through the formation of definite systems of objects and finally through the production and preservation of certain stabilities and regularities.

Her account is shaped by two philosophical strategies. First, she wants to "place" the various conceptual features of science at their respective positions within the generative processes of both Nature and Thought. For instance, "theories" have various features, some of which are "principles" associated with the basic abstract features of reality. Other features are specifically related to certain artificially constructed and produced systems, like the laser or an electric network. In between these two poles we have the features of theory associated with certain kinds of *models*. The process of concretion, as such, by means of which the abstract features become more and more causally structured and concrete, is seen as a kind of *modeling the world*. This is both an ontic process of differentiation, integration, and production and an epistemological process of clarifying, making manifest, and shaping our vision of things. In short, modeling is a way for Nature to display her capacities. It is something that orders and prepares the reality of things for *our* outlook, but also a way in which Nature realizes *itself*.

Second, on this philosophical basis she can formulate a precise question: How is it possible to account for the *explanatory features* of our scientific concepts and practices? Or better; *inasmuch as* we consider these as explanatory, are we then not committed to accepting an ontology like the one depicted above? If first we have accepted science

as a rational, explanatory practice have we then not already committed ourselves to the neo-Aristotelean framework?

Anyway, this approach raises the issue of why just *this* framework. May there not be a variety of forms of neo-Aristotelianism and may there not be *other* alternatives. This is why, knowing the alternative put forward by Rom Harré, Cartwright's approach becomes questionable. As a critical position, her's is a very fruitful basis for challenging various forms of empiricism, pragmatism, and robust forms of realism. As a kind of transcendental position aiming at making clear what the given understanding of certain kinds of science *commit* us to think, her position is not convincing.

At least, one must scrutinize thoroughly what it might mean for there to be "tendencies", "dispositions", "capacities", "causal connections", "objects", "systems", "regularities" etc. On this, Cartwright is simply not clear and does not provide a detailed, justifiable account. Yes, she gives a lot of examples mainly from economics and physics. And yes, she does stress that she is no fundamentalist and consequently does *not* adhere to a basic ontology but instead to "a dappled world".[180] But that does not set her free from the charge of accounting properly for those features of change and development *in terms of which* the world may be characterized as "dappled". A "dappled" world is by definition not chaotic or amorphous. It is a world that embodies capacities for shaping, differentiating, and integrating things. The world may not be an intelligible order, a such, but it must be pregnant with such orders if the characterization "dappled" shall be adequate – or else "dappled" simply means "too complex to grasp".

Four reminders concerning Bohr's philosophy of physics

On my view, noone has better discussed and elaborated the kind of realism that one should associate with Bohr's understanding of quantum physics than Rom Harré. In a series of works he has developed a very significant and instructive interpretation of the philosophy of Niels Bohr. At the core of this interpretation there is the idea that we associate various measuring devices – that are constructed and utilized within certain disciplines of physics – with Kantian schemata. According to Harré, we have here an important neo-Kantian and Bohrian account of what it means for concepts to be realized. Just as Kant proposed that the application of the categories to objects can only be realized through the mediation of a schematism similarly, Harré argues, the application of the theoretical concepts of quantum physics to atomic objects can only be realized through the mediation of certain measuring apparatus. Now, in order to initiate my presentation and discussion of these issues, let me remind the reader of four points that I have defended and explained in more detail above.

(a) Bohr did not associate the quantum theory with a new ontology. He primarily regarded the assessment of the quantum theory as a recognition of a new kind of theory – a theory in respect to which one might endorse a new understanding of what it means for there to be evidence in support for any adequate application of the theory. Thus, Bohr's direct critical target was not classical notions of physical Reality but instead classical conceptions of the *subjective* features involved in the assessment and application of given theories.

(b) Accordingly, Bohr challenged not only the a priori status of our forms of intuition but challenged also the classical (Kantian) conception of the *uniformity* of these

[180] See the title and introduction of (Cartwright 1999)

forms. For Bohr, space and time were methodological notions the use of which is necessary, only, in association with the application of certain forms of physical theory. Thus, there is no fundamental uniform link between the forms of intuition and the categorical causal structures of physical reality. In other words, there can be no universal or basic form of *demonstration* of the objects posited within physical theory. What it means for there to be atoms, electric currents, or plasma flows may raise quite different issues – in the sense that the *practice* of assessing and applying the corresponding theories may differ significantly. The conceptual practice of theoretical physics is – as a matter of historical fact – not uniform in any adequate semantic sense. In short, there is no one uniform, principal kind of *schematism*, no one Canon expressing how to employ and understand the rules of physical theoretical thought. Under the spell of Kant, physicists were led to the illusion of there being a uniform, basic dimension of all theoretical thought. The advent of the quantum theory, however, put an end to that illusion.

(c) In semantic terms, this means that there is a variety of *criteria of identity* associated with the various kinds of physical theory. There is no uniform way by means of which the *criteria of application* of theoretical terms and the criteria of identity, that are associated with them, are inter-related. The connection between criteria of application and criteria of identity is complex and may vary from context to context.

(d) In methodological terms, this means that there is no a priori conception concerning the possible use of any kind of measuring device, including clocks and yardsticks. There is no universal sense of what it means to "tell the time" or to "determine the length" of something, neither is there an a priori conception of what it is to measure determinate physical objective regularities. The quantitative distribution in space-time of physical qualities is a complex matter that may correspond to a variety of different (mathematical) shapes. Thus, what it means to 'trace' or to 'detect' something may differ significantly. In his early notes on the issue of complementarity, Bohr formulated this in a radical way: It doesn't make sense to talk about independent measuring instruments nor about independent phenomena, at all. The *given* in physical experience is neither the character of the measuring devices nor the occurrence of some range of phenomena. The given is – solely – the *use* of a series of instruments in order to further the generation of certain physical "effects". Also, it is first the theoretico-logical combination of such observed effects that constitutes any one definite phenomena. Phenomena are very complex and dependent items. In fact, the objects posited within physical theory are in a sense less complex, which is due to the fact that physical theory – when it comes to it – can only refer to and explain certain abstract features of reality – explain formal features whose articulation depend on human imagination and reasoning. Bohr never denied that part of Kantian constructivism.

Harré on the concepts of "affordance" and "Umwelt"

As mentioned, Rom Harré has suggested an interesting and – I believe – convincing way to compare the philosophical views of Niels Bohr with certain features of Kant's philosophy of Nature. Further, Harré has proposed a convincing interpretation of Bohr's philosophy of complementarity – an interpretation that involves a new and

valuable way to associate the views of Bohr with a new form of scientific realism. In the following number of paragraphs, I intend to present these suggestions of Harré in order to inquire how they may be of value in relation to the interpretation of both Bohr and Kant that I have myself presented.

Inspired by Marjorie Grene's exposition of J. J. Gibson's ecological psychology of perception, Harré associates Bohr's epistemology of experimental physics with two key concepts. The first of these is the concept of a *Human Umwelt*, introduced by von Uexküll, the second is that of an *affordance* introduced by Gibson. A "Human Umwelt" is characterized by Harré in the following threefold manner:

i) The "living space" for human beings that are able to make use of certain pieces of apparatus – the latter being viewed as extended bodily organs.
ii) The "object study" of the sciences. Harré coins the phrase, "the limits of my world is the limitations of my apparatus".
iii) The space that the (noumenal) world affords to our perceptual systems and experimental techniques.

As Harré reminds us, both Kant and Vico originally introduced a similar concept already:

> "In the Gibson- von Uexküll framework I have been putting together there is an enlarging human Umwelt which is that aspect of the 'total' world that our perceptual systems and the apparatus by which we have extended and enlarged them, makes available to us. In one version or another this is an old idea. For Vico and for Kant it was the root of the intelligibility of society and of empirical experience respectively." *(Harré 1990, p. 302)*

In order to revise former conceptions of realism Harré, however, adds certain new features to this vision concerning our ability to continuously enlarge the world of human experience. He writes,

> "The old vulnerable form of convergent realism could be expressed in the image of scientists as miners digging deeper in search of the gold that was there independently of their nature and activities. Our new robuster ... realism[s] can be expressed in another image, that of engineerers reclaiming the polders. The result is indeed more land, but it comes into being through human efforts to drain the estuaries." *(Harré 1990, p. 324)*

Thus, Harré wants to underscore the role that technology in specific, and human practice in general, plays both in the constitution and enlargement of our knowledge. Accordingly – in allusion to a well-known phrase in Wittgenstein's *Tractatus* – Harré coins the phrase "the limits of my world is the limitations of my apparatus".

Now, before I go on, I will say a few words on Harré's philosophy of science in general. As is well known he has for long defended scientific realism. The thoughts on Bohr, von Uexküll, and Gibson are dominant in (Harré 1990) and (Harré 1988) but were elaborated already in Harré's greatest work *Varieties of Realism* from 1986 in which he defended a position called "policy realism" (the best argument for which is found in [Harré 1993]). However, since then he has more and more consistently supplemented his position of 1986 with a certain account of the interrelation between theories and models, as presented most thouroughly in (Harré 1997). This has led to a

defense of a (new) kind of realism, as exposed in (Harré, Aronson, and Way 1995). The interrelation of all these thoughts is evident in the significant paper (Harré 1998). This bring me to the following introduction: You can say that the critical target of Harré's philosophy of science is twofold, first the logicist understanding of theories, second the actualist understanding of physical experiments. As to the former, the primary thing is to make clear that the basic feature of a theory has nothing to do with the possibility of generating various *propositions* that can then form part of some sort of deductive reasoning. Instead, a theory is a certain kind of rule; namely a set of instructions for constructing and utilizing a certain model (in the sense of a concrete miniature version of some aspects of real capacities and causal powers). This view embodies a critique of both traditional syntactic and semantic conceptions of theories since, according to Harré, a theory is not a means for producing *representations of Reality*. A theory is neither a set of propositions nor a set of models. A theory is *about* a model; but it does not merely describe the model, or (as the Sneed-Stegmüller version has it) expose and install a certain kind of formal structure on whatever corresponds to the theory. This has to do with Harré's non-Fregean, and I think Strawsonian, notion of reference. Theoretical terms have referential *uses* by means of our constructing certain models (exemplars, prototypes, standards, or "icons"). I come back to this notion of models below.

In respect to the second critical target, Harré formulates two principles of which he is critical:

> "THE PRINCIPLE OF TRANSPARENCY: Experiments reveal some aspect of the natural World, as it is, *ceteris paribus*. It follows that the analysis of experimental procedure itself can be omitted from the epistemology of natural science.
>
> "THE PRINCIPLE OF ACTUALISM: Experiments reveal occurrent aspects of the natural World. It follows that the results of experiments can be described in indicative propositions." *(Harré 1998, p. 355)*

The primary thing for Harré is to criticize what he sees as "the metaphysical principle implicit in the principle of actualism".[181] Once this is achieved, one can formulate an *alternative* and acceptable principle of transparency:

> "... the performances of experimental apparatus are open to another non-actualist interpretation. They display what Nature is capable of in conjunction with apparatus. In so far as the apparatus is a bench-top model of some Natural state of affairs, it displays real possibilities. The argument [of the paper] shows that despite the falsity of the Principle of Transparency a proper understanding of the status of experimental apparatus and so of the process of experimenting, coupled with a non-actualist ontology, scientists do have access to Nature. The crucial step is the abandonment of the Principle of Actualism. In consequence the Principle of Transparency can be rewritten. Apparatus is not transparent to the actual states of the World, but to its powers and tendencies". *(Harré 1998, p. 369)*

[181] (Harré 1998, p. 358)

The last sentence expresses how the two targets of criticism connect by means of a Bohrian account of experimentally produced *phenomena*. The conjunction of apparatus and object of inquiry, together, possesses the capacity to engage in such physical forms of change as are displayed in certain ways in accordance with the manner in which we have arranged the conditions for the possibility of those very forms of display. This is a non-actualist account of experimentation. The experimentally produced phenomena are not occurring events; they are not caused by definite actual states of the object investigated, or by the "interaction" between this object and the apparatus in question. One may wonder why Harré still thinks that an experiment is transparent in respect to its displays. According to him, what is displayed is not some actual state but some underlying capacity or tendency. We shall see below that this means that the *very* capacity is put on display. The experiment is thus seen as an eye opener and not as part of an explanatory task. This is the view originally formulated by Stephen Toulmin in his *Philosophy of Science*, and later elaborated by J. Aronson in the 1980s, to the effect that any explanation of physical relationships presupposes that we have exposed (*Darstellen*) what is at issue (Toulmin's primary example was the public demonstration of light rays) and have exposed how such items have certain *definite* manifestations (say, light rays can be reflected and refracted. You can only discover a regularity such as Snell's law; that is discover the stable index of refraction for specific media if you have the *Darstellungsweise* in place. And any explanation you can provide within geometric optics will be relative to this means of exposure).

Following this general introduction of Harré, I will first concentrate on his inspiration from Niels Bohr and then make some further general remarks about Harré's own position. So let us first see how he associates (what he sees as) the neo-Kantian concept of a Human Umwelt with (what he considers to lie at the core of) the Gibsonian concept of an affordance. Harré explains this concept in a number of ways,

> (1) "An affordance is the disposition of an unspecified substrate to manifest *a definite interaction* with a highly specified interactant."
> *(Harré 1986, p. 292, italics mine)*

> (2) "Affordances are a special kind of tendency, one for which the typical manifestation must be related to something specifically *human*."
> *(Harré 1986, p. 283, italics mine)*

> (3) "... affordances [are] dispositions whose *content* is derived from the kinds of response they bring about in man-made apparatus"
> *(Harré 1988, p. 60, italics mine)*

We see that affordances – especially in the context of experimental physics – are those (dispositional) properties that we can ascribe to the objects investigated, however, only ascribe with reference to the emergence of phenomena – in the Bohrian sense – within experimental set-ups. Harré uses both the phrase "Urstoff" and the term "Glub" to denote physical Reality as such. Thus, according to Harré, a phenomenon in the Bohrian sense corresponds to the actualization of a way to "shape up the glub". He writes,

> "Phenomena, observable states of affairs, occur when pieces of material apparatus are physically applied to the ur-stoff of the world ... The way an apparatus is built leads to the shaping up of the glub into this or that displayed phenomenon" *(Harré 1986, p. 303)*

> "Particles and waves are created out of the glub by the use of pieces of apparatus ... All we can say of it [the glub] is that it has certain dispositions to permit shaping in this or that way ..." *(Harré 1986, p. 304)*

> "One could look on physical apparatus as devices for forcing the ur-stoff to display itself in a certain shape ... phenomena are displays of joint affordances of apparatus and world." *(Harré 1986, p. 306)*

Complementarity and the comprehension of phenomena

For reasons that follow below, I think the following distinction of Harré should be noted. A phenomenon is the *display* of a certain "shape", for instance the emergence of observable space-time effects that are associated with either particles or waves (as indicated by "tracks", "blips", or "spots"). This should be contrasted with a *manifestation*. Phenomena put the Ur-stuff (shaped and "thrown up" by the use of the devices) on display. The emergence of such phenomena is an indication and actualization of the dispositional properties of the Ur-stoff. Phenomena are what the Ur-stoff affords. Such affordances, however, can become *manifest* in and through the emergence of phenomena. Harré writes,

> "An affordance is a dispositional property of some generic substrate which manifests itself in some particular form of human manipulation". *(Harré 1990, p. 339)*

As I have described above, Bohr drew a similar distinction as that which is drawn by Harré between the manifestation of affordances and the display of phenomena.[182] Bohr distinguished between the comprehension of quantum effects and the synthesis of phenomena. Since quantum effects are objective manifestations of real atomic properties – according to the quantum theory – they constitute affordances in the sense of Harré. Similarly, according to Bohr, the systematic contemplation of various effects and manifestations that constitute the observation of any whole phenomenon corresponds to Harré's notion of the display of phenomena. Observations/displays of phenomena involve a wholeness the possibility of which is constituted by the comprehension and recurrence of the physical effects/manifestations that are afforded by the physical systems under investigation.

The framework of complementarity was for Bohr an expression of the mutual exclusive possibility of applying two different kinds of intuitive pictures – or representations – of quantum effects. So the issue concerns the possibility of utilizing two exclusive kinds of *comprehension* in the systematic effort to synthesis phenomena into a coherent theoretical conception of those atomic systems that are causally responsible for the emergence of the quantum effects in question, through the interaction with the experimental set up.

As I have explained in a former chapter, the comprehension of such effects involves the *joint* use of the concepts of space and time in order that we can ascribe a definite spatio-temporal shape to the given physical manifestations.[183] Now, it is such shapes that stand in a mutually exclusive relationship to one another and do so, only, relative

[182] See the section on "The Oberservation Problem", in Vol. II, part 2.
[183] (Ibid.)

to the possibility of applying their corresponding spatio-temporal *Vorstellungen* in the account of how observed phenomena may count as evidence for the occurrence of particular, definite quantum physical processes. Let us see whether the considerations of Harré are in line with this Bohrian view. Once we have endorsed the Gibsonian understanding of objective affordances, there is only, according to Harré,

> "... a short step to complementarity. We humans can build, so far, only two main kinds of apparatus, each kind shaping up the glub in different ways, particulate ways and undulatory ways. It is phenomena – the glub as shaped by apparatus – that present themselves within the constraints of complementarity. But this move is not enough. A new kind of concept [i. e. 'affordances'] is needed to express what has turned up in phenomena as dependent in some causal way on the unknowable properties of the glub." *(Harré 1988, p. 66-7)*

> "What a physical system *affords* is relative to the nature of the being which interacts with it, in particular what states it is capable of taking up. Affordances are dispositions of physical things relativized to that with which they interact ... Complementarity expressed in affordance terms, goes like this: the glub affords particulate phenomena for one species of apparatus and undulatory for another, and human beings cannot make this equipment so that one of each kind can occupy the same place at the same time." *(Harré 1988, p. 67)*

In accordance with this, Harré suggests that we regard the concepts of space and time as involving two different *grammars* each of which governs the use of demonstratives like "here" and "now", or "there" and "when".[184] This view implies that we shall not consider the two concepts as representing real, objective structures of Reality. There *is* no space-time in the sense of an ontic structure that would constitute all events and processes occurring in the Universe. As Harré put it,

> "Global space-time is a fiction, a mode of discourse. And each world-line is ontologically a human *story*, not a pan-temporal being ... On this score it seems to me that Niels Bohr was absolutely right in insisting that the results we get *must* be expressed in the vocabulary of classical physics. In that dialect the grammar of the expressions like 'track', 'place', 'event' and so on is just what was once misleadingly set out as traditional meta-physics. There is no conceivable way in which a dialect with expressions that obey the grammar of the key terms of relativity theory could be used to any effect in laboratories or for the reporting of results."
> *(Harré 1990, p. 331)*

The application of the grammars of space and time give shape to various language games, such as those of our "tracing", "tracking", "placing", "pointing", "indicating",

[184] "Space is a conjunctive totality of places. 'Here'and 'exist' are not tied together conceptually. The quantifier by which a totality expression is created is an 'all'. All xs exist and all pairs of xs coexist. Time is a disjunctive totality of moments. 'Now' is conceptually tied to 'exist'. 'An event can only happen *now*' is a grammatical remark. Hence its apodeictic character. No advance in physics could make us give it up." (Harré 1990, p. 331)

or "picking" certain things in certain situations. No underlying ontology grounds or defines such practices. There is no *uniform* manner in which things present themselves within human experience. Still, we know of a series of linguistic practices that involve the use of clocks and yardsticks. In the unfolding of these practices we have to acknowledge there being definite constraints and conditions involved in the application of clocks and rulers.

Let us ask which kind of necessity we have to do with in these cases? One gets the answer to this question wrong – one gets Wittgenstein wrong – if one first look at a selection of authorized clocks or yardsticks and then asks, "what if the temperature rises and the length of the ruler is enlarged?", or, say, if one asks; "if we use clocks as part of a religious ritual, is it still a 'clock-work'?" Such questions wrongly suggest that we could analyze the necessary condition for anything's truly being or functioning as either a yardstick or as a clock. Any such stipulation, however, will only go to authorize a *special* kind of yardstick or clock within a special kind of physical practice. Sometimes we may well have good reasons for such authorized stipulations and standardization of our measures of spatio-temporal extension and physical magnitude. But regardless of which such reason is at issue, it will point not to a fixation of the ultimate structure of Reality, the stipulation will instead express a significant way to acquire a comprehensive and justified insight into the systematic inter-connection of a large number of causal relationships that we have experienced as part of our effort to acquire the most comprehensive view on the inter-relatedness of all the particular causal relations that are associated with different spheres of reality.

A central claim involved in this is the following: a pair of apparatus, where one is intended to function as a clock and the other to function as a yardstick, cannot occupy the same spatial or temporal region. *Where* the pointer of the clock moves, there cannot be a yardstick, and – similarly – where such a stick is placed, no dynamical alternation, constituting a clock, can "take place". In making this claim, we are not suggesting any particular ontology. We are merely reminding participants within the tradition of theoretical physics – given an intended use of particular measuring devices – that they must be able to report "what they have done and what you have learnt", as Bohr put it. Here, the participants are supposed to report how they skillfully managed to "place", "trace", "indicate", or "point to" various physical manifestations. Especially, in giving such an operational report they are not supposed to *describe* the design of the clocks and the yardsticks that are involved in the performance of given experiments. "Telling the time" is not to describe a clock, but is to report on the use of a material design in some intelligible way. As Harré formulates it, the grammars of space and time – as well as the theoretical concepts of a particular experimental science – are *realized*, only, within the use of a certain set of apparata.

> "It turns out that classical physics permits the realization in physical apparatus of two classes of *concepts*, particulate and distributed, particle concepts and wave concepts. The glub is such that the two classes of apparatus cannot be used together, and therefore a description of phenomena in which instances of *concepts* of each class are paired is unacceptable. Particles and waves are created out of the glub by the use of pieces of apparatus. We should not think of the glub as being either particulate or wave-like in the absence of such an interaction."
>
> *(Harré 1986, p. 304, italics mine)*

In what follows I will explain what I consider significant in respect to this semantic approach to the interpretation of experimental physics. I will do so by comparing (a) the way in which Harré associates the considerations at issue with the Kantian idea of a schematism with (b) my understanding of this feature of Kant's natural philosophy.

Eva Shaper on Kantian schemata

The Kantian idea of a schematism concerns the issue of what it is, and what it means, for concepts to be realized in particular objects – be it the abstract objects of geometry or be it concrete substances. As I have discussed in detail in this volume, the idea of a schematism – in the sense of an a priori time-determination of possible experiences – was supposed to fulfill several semantic functions in the application of the categories of thought. First, schematisms had to make sense of the idea that these categories can be applied to something not belonging to or constituted by human thought. Second, the idea that there are particular objects that can be subsumed under given categories must be demonstrated so as to entail operative features, i. e. it must be demonstrated that it makes sense to try to recognize a specific kind of individual objects in a particular manner. Thus, the schematism must provide the criteria of application for the general terms through the application of which the various categories can be expressed, such that these criteria corresponds systematically to a series of criteria of individuation, in space and time, of any possible object of thought. Third, since the application of any category must by definition be rule-governed and since the table of categories is the canonical *expression* of the rules of thought, we need an account of *wherein* the rule-governed application of category-words consist. That account is what the schematism provides. The schematism demonstrates the sense in which a certain kind of application of the category-terms can be associated with a possible objective and determinate experience of a particular kind of objects. In short, the existence of the schematism explains the sense in which a given application of the category-words is associated with certain *criteria of identity* in respect to the objects at issue.

One can characterize a schematism as a rule of construction concerning what it is to constitute the intuitive *Vorstellungen* of a range of objects. That is the sense in which the schemata are time-determinations a priori, and the sense in which the concepts of space and time corresponds to a priori *forms* of intuition. In a classic essay, Eva Shaper pointed out that the primary issue that led Kant to introduce the idea of a schematism is the fact that human experience in itself – and not just the phenomena experienced – unfolds *in* time (by contrast to merely unfolding temporally, that is, unfolding as a temporal order).[185] She rightly reminded an Anglo-American audience how the idea of a schematism had functioned as a springboard for a variety of (so-called) continental philosophical programs, including not the least the hermeneutic phenomenology of Heidegger, the structual-semiotic phenomenology of Cassirer, and the perceptual phenomenology of Merleau-Ponty. Accordingly, Shaper argued that an adequate understanding of Kant's account of the schematism should imply a critique of both a subjectivist and a constructivist interpretation of Kant. She wrote,

> "The basic Kantian insight which lurks in Schematism seems to me this: though it is true that we construct, we construct not as minds, or

[185] (Shaper 1962)

intellects, not by being mind, but by being in time."

(Shaper 1962, p. 313)

Further on, she explains,

> "Reference cannot be wholly outside the particular structure which is disclosed in understanding, cognition – or in language generally and in art. Rather, in the various attempts to articulate, the 'real' ... is constantly 'under construction' ... [thus] whatever we mean by 'mind' or 'human mentality', it constitutes itself into what it is only in encounter".
>
> *(Shaper 1962, p. 319)*

So the basic line of thought that Shaper wants to underscore is this: Human constructions and articulations can never by mere re-presentations of an already given, real order. There is no "given" for our experience to conform to in the representational sense. We should say instead that the fact that we may construct or articulate something that makes sense, and which involves an advance in our epistemic capacities, show something about the reality of things – that it shows something that can never be captured within the content of any one particular judgment. Such recognition of the possibility of making sense of the world in a certain way should instead be seen as grounding the possibility of formulating a whole *set* of judgments about what we encounter within our experience. Shaper rightly associates this view with the basic theme of Wittgenstein's *Tractatus*, to the effect that the structural possibilities of our thought cannot themselves be thought. Thus they cannot be constituted by our thought. The possible structures of thought only exist, and can only be recognized, within the (temporal, active) unfolding of our linguistic constructions. Since this is indeed at the heart of the Kantian idea of a schematism, we may begin to acknowledge the point of Harré's suggestion that we consider physical apparatus as schemata. Let me explain all this in more detail. Shaper's precise account of the Kantian idea of a schematism is as follows:

> "Schematism in general is the application of general concepts to particulars via schematic representation which specifies the rules for constructive repetition of each particular instance". *(Shaper 1962, p. 307)*

I find this formulation a little inadequate since it wrongly suggests that the schemata are prior to their application within a schematism. Shaper explicitly describes the schematism as "the act of operating the schemata". She rightly, in my view, characterizes transcendental schemata as "exhibitions of the grounds for application of second order rules (of categories) to the given".[186] But the schematism is not simply the very act that satisfies or actualizes the possibility of such an exhibition. The schematism is instead an *Inbegriff* of the rationality and intelligibility of conceiving certain things in certain ways. The schemata may be seen as models for a series of ways in which to subsume particulars under general concepts; but it is the schematism – meaning, the *idea* of an operative feature embodied within such forms of subsumption – that is crucial. Accordingly, the schematism helps explain the point, the possibility, and the intelligibility of a series of criteria of individuation and recognition. As such, they do not just actualize a set of criteria of application for a given set of general terms; instead, *they involve a demonstration of a sense in which certain criteria of application of given*

[186] (Shaper 1962, p. 307). Notice the distinction between "phenomena" and "the given" (p. 315).

categories ground the possibility of introducing a new set of criteria of identity. I shall give a more Fregean account of this issue of criteria of identity below.

Shaper's otherwise excellent account of the idea of a schematism suffers from the weakness that she believes that the relation between particular objects and general terms is uniform. There is however no one such fundamental kind of relation. There is no general form of "subsumption", nor of "predication", nor of "reference", for that matter. Similarly, there is no one way in which to understand the possibility of demonstrating the occurrence of something, to recognize something, or to otherwise encounter it. That is precisely why we have to introduce and make use of criteria of identity, knowing that there can be a *variety* of such, and that this variety has to do with the *different* way in which the introduction of criteria of identity is based on a utilization of a possible operation associated with already given criteria of application.

Instruments of observation as schemata

Returning to the notions of physical theory, it should be noted that the necessity of applying the concepts of space and time – according to the Kantian approach – refers to the *subjective* feature of the possible application of given categories. I am here referring to the necessary form of certain, significant kinds of *Vorstellungen*, and thus to a necessary pre-positing, a pre-*Setzung*, of possible objects of experience. Consequently, it is a cardinal error to believe that the application of the concepts of space and time refers to the noumenal realm, instead of a certain range of phenomena. The spatio-temporal *description* of things only points to the realm of phenomena. However, within the unfolding of our experience, the systematic application of the categories may well be said to embody a *characterization* of the objective features of the world of Reason. Now, following these considerations it certainly seems possible to justify the claim of Harré, that we associate measuring apparatus with the idea of a schematism. Harré writes,

> "I believe we should interpret Bohr's philosophy of physics along the following lines. Phenomena, observable states of affairs, occur when pieces of material apparatus are physically applied to the ur-stuff of the world (I prefer to nickname this stuff 'glub', to avoid any metaphysical temptation that arise from the connotations of the word 'stuff'). The way an apparatus is build leads to the shaping up of the glub into this or that displayed phenomenon ... Apparatus, like the Kantian schematisms, is itself constrained by the Newtonian (classical) properties of humanly manipulable and observable matter. All phenomena, then, must be describable in classical concepts. Though the concepts must be classical it may be that there are certain combinations of such concepts that are forbidden. The 'glub' does constrain phenomena in a general way, since there are only certain ways that it can be 'shaped up'. It is a cardinal error to attempt a noumenal application of the classical concepts, that is to try to describe the state of the glub by their use." *(Harré 1986, p. 303-4)*

We see that Harré associates the Bohrian account of the unity of phenomena and apparatus with the Kantian idea of a schematism, not just because we focus on a way for general theoretical concepts "to be realized", but also because the respective accounts of what constitutes a physical phenomenon, both in the case of Kant and that of Bohr, involve two claims, (a) That the *objects* disclosed within phenomena cannot

be described by any finite set of general terms. However (b) the *joint* and systematic use of a range of fundamental concepts grounds the possibility that we can initiate a rational empirical search for a certain objective order the character of which we could not have recognized before. So the Kantian and Bohrian account of phenomena is part of an account of the possibility of epistemic advance. The insight that all possible phenomena must be recognized within a certain form of conceptual framework is precisely what should make us realize how theoretical thought may plunge into new fields of experience. And that is why the suggestion to associate measuring instruments with a schematism becomes important.

Harré, however, fails to mention one of the features of Kant's philosophy of physics. The idea of a schematism – the idea of transcendental principles of the Understanding – helps explain and ground the possibility of constructing a *mechanics*. But the full account of this possibility has to include an analysis of what Kant called the *metaphysical* principles that constitute an adequate metaphysics of Nature. Accordingly, the idea of apparata as a kind of schematism has to include this second feature. However, Harré makes no explicit use of the distinction between transcendental and metaphysical principles. Shaper implicitly does so when she reminds us that Kant associated the transcendental schemata with "schematized categories"; in other words, with proto types of objects represented in terms of their falling under the categories, something like a set of *Sachverhalten* in the sense of the *Tractatus*. Accordingly, metaphysical principles help transform such "logical posits" into whole and concrete objects – into objects in respect to which we have introduced a specific kind of criteria of identity. In this sense, as I see it, measuring apparatus functions as metaphysical principles and not as schemata. The Bohrian suggestion that any phenomena form part of the whole of a given experimental set up forms part of an account of how we should introduce specific criteria of identity for atomic objects. Bohr's definition of phenomena entered the scene of theoretical physics (a) at a time when there was an established theoretical practice (b) that was prolonged despite its seeming differentiation into different new forms of physical theory. That is the point of mentioning apparatus. The variety and richness of these, as Harré will have it, point to the possibility of enlarging the Human Umwelt. So the rationality involved in our being reminded of all these Kantian issues, then, has to do with the insight that however differentiated the enlargement of our world may be, we have still to do with *one* world within our rational, intellectual endeavors.

Butts on schemata as semantic rules

I find it instructive to compare Harré's invitation to associate apparatus with schemata with the widely recognized view of R. E. Butts. Butts' primary thesis is that Kantian schemata are "meaning-rules". I think that the idea is this: Kant demonstrated that any "observation-language" – in principle – has the same "categorical structure". There is a fundamental form that constitutes any language by means of which we can describe what is given to us in experience. There is an a priori manner of "organizing content". Butts explains that,

> "Categorical subsumption, or the application of a category, involves the *production of*, or the *systematic demand for*, observations of a certain kind. It is precisely in this sense that Kant's claim that the categories specify what it means to be an object of experience is to be understood. But

> the categories cannot do the job alone; the schemata as semantic rules inject the empirical sense into the observation language. It is only thus that the categorical framework can come to be correctly regarded as the set of conceptual presuppositions of all possible empirical knowledge claims".
>
> *(Butts 1984, p. 76)*

We see that Butts understands Kant to have argued that the conjunction of the categories and the schemata constitute a definite set of "conceptual presuppositions". My problem with this is that it points to some sort of *ontological* presupposition and not to the realm of phenomena. In my understanding of Kant, we have no such presuppositions in the sense of a priori *judgments*. Certainly, the form of all possible judgments is determined a priorily, but in my interpretation of Kant there is no way in which we are allowed to presuppose anything about particular and specific kinds of substances. That is precisely why the schematism, the transcendental principles of the Understanding, must be supplemented by *metaphysical* principles of Reason in order to infuse an empirical sense into the theoretical application of the categories.[187]

Thanks to the schemata we have criteria of individuation within a given logical space. As explained above, we have what corresponds to the empirical meaning of a set of *Sachverhalten* in the sense of Wittgenstein's *Tractatus*, but have as yet no determinate *Tatsache*. We have demonstrated the possibility of objects of experience within a general framework, but as yet no determinate real objects (i. e., we have kinds of apparatus, but as yet no experience that is mediated by the means of these apparatuses. We have the *form* of the possibility – the logical structure – of possible objects of experience, but as yet no specific experience to match that form. Consequently, the schemata should not be regarded as semantic rules in terms of which to associate categories and empirical terms. That sounds too much like Carnap's correspondence rules, and it involves the illusory notion of semantic rules according to which they are essentially associated with some sort of correspondence between more or less "empirical" terms and their empirical uses. We shall say instead that the introduction of a schematism is part of explaining what it means for there to *be* semantic rules – in the sense of criteria of application. As I explained, the schematism expresses the way in which the demonstration of a (canonical) way to apply a category to certain objects embodies criteria of individuation concerning these objects (say, a cloud chamber affords "tracks"). Consequently, Butts is also wrong when he claims that,

> "Thus the schemata as semantic rules give the general form of observation predicates *within* the conceptual system of the categories and the principles, within the most general epistemological system that is possible. This system, of course, will in turn make possible the introduction of any number of particular scientific systems with their own (more narrowly conceived) categories, law forms, semantic rules, and observation predicates. The *specific* observables to be permitted in these lower-order scientific systems will result from *choices* of ranges of entities germane to those particular sciences. But the general form of *any* observation predicate allowable in *any* science will be given by the schemata as the semantic rules operating in the epistemological formalism". *(Butts 1984, p. 74)*

[187] Kr. d. U. AXXVII / BXXIX, p. 90

As I see it, there is no such thing as the "general form of any observation predicate". This view wrongly associates the idea of a schematism with the issue of how to demonstrate a certain kind of uniformity – as expressed by the general phrase of "an observable" – the form of which is supposed to be universal. In his endorsement of such a view, Butts interprets the schemata as "rules that link categories and observation predicates".[188] Thus, the schemata – the intuitive interpretation of the operation of the schematism – are supposed to combine two different forms, each specified. The first is a general but specified form of presupposition, the second a general but specified form of predication. So two specified forms are seen as corresponding to one another. Accordingly, the schematism becomes the rule in accordance with which we demonstrate that very uniformity. The scheme itself therefore becomes a specification – namely the specification that *these* two specified forms be linked by *this* rule.

Anyone familiar with Wittgenstein's rule-following considerations will see that such an account raises serious problems. Thus, I find it important to underscore the following points: In Wittgensteinian terminology we should say instead that schemata are *expressions* of rules. Schemata are canonical presentations of significant, criterial uses of certain category words. As such, the schemata are precisely what Kant called *Grundsätze*; they form a scheme for the *possibility* of positing objects of experience. The schemata function like introduction rules of various elements of our logical notation. The various schemata are exposed before the introduction of any actual experience within the phenomenal realm.

But there is no scheme that we can establish about what is universally and uniformly *involved* in any adequate application of a given word. There is no world-word link that can be viewed from the outside of both the world and our language. Instead, the schematism as such is the canonical stipulation and exposition of a rule of application of a given category word – a stipulation and exposition that is performed in order to secure certain semantic criteria. The schemata that express that the schematisms are adequate are not rules for the already rule-governed categories to conform to. Instead, they are expressions of our having recognized the adequacy of applying – not the rules of thought, but – the entire *practice* at issue; the practice of attempting to make objective judgments by means of relating the various categories to one another.

The most important issue to acknowledge in relation to the idea of a schematism is not the one addressed by Butts concerning the empirical sense of certain terms, it is instead the issue of the system and unity of our experience; with special regard to the way in which the assessment of that unity grounds the possibility of *enlarging* the possibilities of thought (and not just to "apply" our concepts to particular features of some empirical reality). Heidegger nicely explains all this as follows,

> "Jetzt handelt es sich nicht – wie bei den vorigen Grundsätzen – um 'Anschauung', um 'Wahrnehmung', sondern um das Ganze der Erkenntnis, worin das Ganze der Gegenstände, die Natur in ihrer Anwesenheit, bestimmt wird, um die Erfahrung". *(Heidegger 1936, p. 175, italics mine)*

As we shall see, the particular schemata that were called "the analogies of experience" are of particular interest, and as was explained above, these schemata – which for Kant alone express the possibility of a *mechanics* – only make sense in conjunction with an idea of Reason concerning the lawfulness and unity of Nature. In the continuation

[188] (Butts 1984, p. 69)

of the quote above, Heidegger explains very well what the logical point at issue is. The stipulation of the analogies is not merely a matter of establishing certain relations, but is instead part of an effort to try to relate a series of relations to *one another*; which in terms of physics means trying to unite all the dynamic features of things into one coherent representation of the lawful interplay between things. In short, that is precisely what is involved in the demonstration of the possibility of a *mechanics*. That is what is achieved by Kant's demonstration of the *whole and unified system* of dynamic *Grundsätze*. Heidegger rightly describes these as "rules of searching and finding" that – as the quote makes clear – points to the *modal* character of what it means to be a possible object of experience. Thus, the point of demonstrating an analogy is not to settle anything (that this is one way to make sense of things), it is instead to express the sense in which a new modal order may be recognized. Reasoning by analogy is not a matter of classifying similarities, but is instead a matter of our making sense of a new way to construct classes of things.

The logical space of electron configurations as realized in apparata

So the following is what it takes to introduce a new domain of objects for theoretical physics. One must advance a canonical way to exhibit a kind of uniformity in terms of which certain analogies of experience may show themselves. It is especially important that we are able to *demonstrate* certain "analogies", or "equivalences". Harre's invitation to associate Bohrian apparatus with Kantian schemata in fact points precisely to these considerations. As I will explain in detail below, the association between schemata and apparatus hinges on the claim that we can only demonstrate certain equivalences, certain formal patterns within a range of possible physical experience, if we refer to specific forms of apparatus that are each associated with (a) definite forms of space-time coordination and (b) definite mathematical functions between the variables of the physical theory at issue. In the context of the quantum theory, point (a) is "realized" in the form of a certain apparatus, like the equipment constructed and utilized by Stern and Gerlach, to the effect – as Harré put it – that electrons and other elementary particles can be recognized as "affordances" of precisely such apparatus. Point (b) mainly refers back to the formal notion of a "constant of motion" and the way in which – for most branches of theoretical physics – that notion became associated with the mathematical conception of a Poisson bracket. As I have explained above, these considerations were especially crucial for Heisenberg in his development of Matrix Mechanics. In the following, I will elaborate on both of these points (a) and (b) in turn.

The Stern-Gerlach experiment was intended to show the wave-properties of matter.[189] The experiment has three parts or features. First, there is the preparation of a beam of electrons, second there must be a stable magnetic field that is graded in accordance with a well-defined path for the passage of electrons, and finally there must be a crystalline stuff – functioning as the target of the beam – in which diffraction can take place. In this way the scene is set for the display of a new kind of phenomenon – the phenomenon of *atomic spin*. The experimental set-up is therefore constructed such that there emerges a special kind of manifestation, namely diffraction patterns, the comprehension of which involves recognizing a special kind of phenomenal appearance. It is

[189] For Harré, the experiment is one of the *twenty great experiments that changed our view of the world*, according to Harré's presentation in his book of that name (Harré 1981).

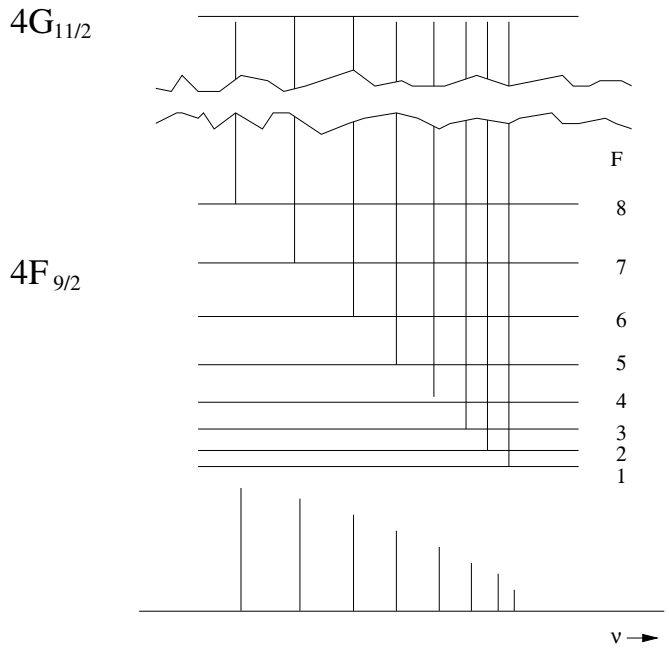
only with reference to the structure of the magnetic field and to the geometry, in particular of the path of the moving items – and in general of the whole of the kinematics of the electron-gun – that this new way to comprehend phenomena makes sense and is possible. We have here, in the Bohrian sense, a prime example of "the comprehension of a *single* quantum physical phenomena" – of what it means to comprehend a "quantum effect".

H. J. Folse and others have suggested that Bohr made use of some idea of "phenomenal objects". On this view, emerging particles, like electrons, or emerging wave-like phenomena, should be recognized as two different, complementary ways in which the same atomic object enters into an observational interaction. In my discussion above I have argued that Bohr should not be interpreted in this way. Following Harré's analysis of the Stern-Gerlach experiment he would agree with my criticism of Folse. In this analysis we should not inquire how certain "investigation-independent" objects become phenomenally shaped up under certain experimental conditions – such that they *only then* emerge as definite physical agencies, i. e. enter into definite forms of causal interaction. Accordingly, it is important to underscore the point that the "electrons", in our story, is *part of the apparatus* – a fact that takes nothing away from whatever kind of reality and objectivity electrons are supposed to have. In respect to a similar case, Harré writes,

> "According to Bohr's point of view ... the track in a cloud chamber is a manifestation of electronhood that is available to human beings only in the context of that cloud chamber. It is the world and the cloud chamber that has a disposition to display itself as electron-tracks. What of the electrons that we picture as causing the tracks? They too are but affordances of the total set-up ... A manifestation (phenomenon) cannot be partitioned into a bit due to the instrument *and* a bit due to the world. Only in the environment of that instrument is that disposition revealed that way ... Thus these dispositions must be attributed to the instrument / world complex."
> *(Harré 1996, p. 132)*

What matters in the Stern-Gerlach experiment is not the splitting of the beam considered as a property of ontologically self-subsisting electrons. What matters – what Stern and Gerlach can be said to have demonstrated – was how certain atomic *constituents* can be "bound" within stable atomic physical systems. Accordingly, the crucial thing is the split in the electron-configuration-*diagram* by means of which we map the possible energy states of atomically bound electrons. Such an electron-configuration diagram was, literally speaking, "written all over" the Stern-Gerlach experiment.

An Electron-configuration diagram for the Isotop ^{139}La [190]



This graphic displays the electron-configuration, at the level of the so-called hyperfine structure of the possible states of energy that each electron, which is bound within a particular atom, can realize.
The hyperfine structure splitting of the transition $5d^2 6s\ ^4F_{9/2} - 5d^2 6p\ ^4G_{11/2}$ with the structure of the $^4G_{11/2}$ level unresolved.

What was discovered through that experiment was that three-dimensional diagrams split into two kinds; the spin ups and the spin downs. The construction of the Stern-Gerlach experimental arrangement thus introduced a new kind of *apparatus* – a kind that affords four-dimensional diagrams of energy states.[191]

I consider this to correspond to Bohr's account – especially in the Wills memorial lecture of 1931 – of the different, complementary ways in which we can experimentally arrange a "space-time coordination" in order to frame the possible emergence of those kinds of phenomena that may be interpreted as providing evidence for, or against, certain physical theories. Neither Stern/Gerlach nor Davisson/Germer can be said to have made an ontological discovery. Instead, what were achieved by the experiments of these pioneers were a demonstration of both the adequacy and the intelligibility of the very framework of atomic physics, namely the very idea of atomic systems describable in terms of stationary energy-states of constituent elements and in terms of the associated transitions processes characterized by definite measures of change of such states. In short, considerations on the construction and use of experimental arrangements became crucial in the account of the *empirical* character of the quantum theory – the account of what it means, in that special context, to justify an application

[190] The illustration is based on *Elementary Atomic Structure* by G. K. Woodgate, McGraw-Hill, London, 1970, p. 172.

[191] Alluding to Wittgenstein's famous remark in the *Tractatus*, Harré acordingly claims, first, that the limits of the world of the physicist is the limitation of his apparata (Harré 1990, p. 302); second, that the historian of physics does not stock a library, but rather stocks a technical museum of apparata (Harré 1990, p. 313).

of a certain theoretical scheme in the light of certain kinds of phenomenal observations.

Theory and identity, the Pauli Principle reconsidered

As Harré has argued convincingly, through the employment of *Feynman diagrams* one finds a similar physical interpretation of the mathematical invariants relative to certain groups of transformation in quantum field theory.[192] Thus, it seems that the association of such invariants with criteria of physical theory – like criteria of existence, stability, and identity of certain features of physical reality – is almost universally accepted within the tradition(s) of the actual physical sciences. It is most likely that the reason for this universal acceptance is pragmatic – based on the belief that such acceptance leads to theoretical success. However, it is difficult not to see the widespread recognition of the importance of mathematical invariants as pointing to an implicit rationality that governs physical research.

Thus, there is every reason to say that physicists, to this day, have maintained the neo-Kantian, theoretical tradition of Helmholtz to the effect that any acceptable physical principle and theory has to conform to a set of canonical mathematical schemata. Indeed, that *is* the rationality behind the physicist's belief in mathematical transformation and group theory. Almost no one considers such schemata to express the ultimate and true structure of physical reality. But still we have to do with more than a mere methodology. The conceptual logic that is embodied within the established tradition is – for Helmholtzian reasons – a symbol for the recognition of a certain *form of theory*. Accordingly, it is important to reconsider this notion of a new form of theory in order to assess our claim that the addition to the Helmholtzian scheme of the Fregean consideratons on identity helps illustrate some crucial features of the quantum theory. Harré writes,

> "Theories ... from a logical point of view, are identity statements ... To accept [any corresponding account of theories like that of J. Aronson] one must subscribe to Frege's notion of identity rather than any version of Leibniz law." *(Harré 1986, p. 199-200)*[193]

Above, we have reflected what it takes to establish a new domain of objects for theoretical physics. We agreed with the statement of Harré in the former quote that any version of Leibniz's law should be supplemented with an account of *how* certain equivalences should be demonstrated, such that the outcome of these demonstrations could be interpreted as constituting the possibility of introducing a new kind of identity-statements. Thus we showed that, first of all, there must be a canonical way to exhibit a kind of uniformity in terms of which analogies of experience may show. *Analogies must be demonstrable*. That is what is achieved – only – by constructing, imaginatively, forms of apparatus, associated with definite theoretical functions and definite forms of space-time coordination. Without such a background we cannot recognize any pattern within the given physical manifestations as corresponding to distinct, objective features of physical stability.

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[192] (Harré 1988)

[193] From a pragmatic point of view, theories are rules for the construction and use of a certain kind of model. This is implicit in the following discussion to the effect that identities must be demonstrable.

Once again, we see the importance of the possibility of recognizing a *formal* property of what may be seen as the outcome of a certain demonstration. The outcome of a canonical demonstration of the conditions of applicability of a range of terms – terms that are already used to report physical manifestations within given experimental setups – thus permits us, further, to advance a term-introducing operation by means of which we introduce such theoretical determinations as "spin" or "quark". If, at this point, we can actually stipulate meaningful conditions of applicability of these theoretical terms we have in effect successfully introduced a range of identity-statements of a new kind and have thus given an explicit sense to the employment of terms in reference to the newly introduced items.

In the tradition of Hamiltonian physics, the use of generalized Poisson-brackets precisely goes to prove a formal property of the functions governing the generalized variables. As revealed above, the algebraic rules that govern the use of Poisson-brackets is associated with the notion of a 'constant of motion'. Thus, within the algebraic tradition in question, the concept of such constants have well-defined conditions of applicability. Consequently, if Frege's method of introducing new criteria of identity shall be useful here, our question becomes: *Can we associate each formally demonstrated "constant of motion" with a term-introducing operation* – for instance, those that are involved in the introduction of quantum numbers – *such that any of these demonstrated constants can be systematically associated with a canonical account of how to apply such numbers in future physical research*. For example, we have atomic models in terms of which we associate the principal quantum number with "binding energy", the second with "angular momentum", the third with "magnetic momentum" (the Zeeman effect) and, finally, the fourth with "magnetic polarization" (spin). We can thus stipulate the *Pauli principle* that any atomic constituent should be "demonstrated" in terms of one, and only one, set of such numbers (n, l, m, s). At that point, we can be said to have established a canonical expression of the statements of identity that governs the reference to atomic constituents. As I see it, this is a good illustration of how to understand the metaphysical principles of quantum physics along general post-Fregean lines.[194]

Harré on the domestication of Nature

I have now explained in detail how I consider apparata as embodying Kantian metaphysical principles to the effect that the use of a certain kind of experimental setup in the demonstration of a range of formal features within a range of constructed phenomena gives license to our advancing objective theoretical claims about a new subject matter, like the atomic realm. It has been part of my argument that I have not been engaged in developing and defending a certain kind of epistemology or methodology concerning that particular realm. I have instead considered the *metaphysical* question of what it means for there to *be* such realms – realms the objective exploration of which requires the Bohrian approach. In considering this, I have paid particular attention to Rom Harré's comparison between Bohr's program and that of Von Uexküll's. I could endorse Harré's invocation of the notion of a *Human Umwelt* – the "living space" that we continuously extend by exploration and construction.

[194] In the first draft of this chapter, I included a longer account of the systematic connection between the Kantian idea of schemata and Frege's notion of criteria of identity, especially in relation to Michael Dummett's account of Frege's use of the latter notion within Arithmetic, see (Brock 1999)

However, I have been critical about Harré's suggestion that apparata, in this respect, are primarily viewed as schemata – and not as metaphysical principles proper, in the Kantian sense as explained above as well as in the chapter on his Metaphysics of Nature.

I now turn to another set of critical remarks that hinges on Harre's claim that there are certain "robust criteria of identity" associated with well entrenched, established form of conception, such as those associated with the (sub)types of "corpuscle", "animal", "physical thing", "occilator", "person" etc. I consider Harré to think that such "robust" concepts have two distinctive features; first that it makes sense to say that there are certain features or traits of the objects corresponding to the concepts that embody, or circumscribe, a series of similarity-relations. Apparently, the idea is that there is a number of ways in which these features can be "inherited" by *other* items.[195] This gives rise to the idea of a so called type hierarchy where any "type" within this system of things can be characterized – not as an instance of some general kind – but as a *natural* kind that is both a "determinable" and something "determinate" relative to its place within a total hierarchial system of types.[196] I come back to this. Second, this all gives rise to the idea of a possible *displacement of concepts*, for example when concepts that were associated with, say, classical physical objects in motion, become associated with non-classical atomic forms of physical change.[197] Quantum physical objects really do not move in space and time; but *qua the models* we have, and because these models may incorporate certain forms of similarity to classical models, we can somehow attribute a *real* existence to atomic systems.

My worry about all this is that Harré implicitly falls victim, as did Einstein, to a kind of ontological conservatism. I want to inquire how *radical* a new kind of conception can be and how *different* – when compared with the old – the new conception of the atomic physical realm can be. On this I am inspired by the semantic idea of a *conservative extention* of a given kind of discourse.[198] This is a notion that points to a, perhaps radically new, kind of discourse with entirely new rules for the language games in question. But still, in some sense, there are "routes" or "areas" within the new discourse where a system of older rules function as they previously did in former kinds of discourses. So you can both say that the new rules are *introduced* into the already established games, and claim that the total system of new and old rules make up an entirely *new kind* of linguistic practice. In short, it really makes no sense to claim that the old rules "constrain" or "block" what any new rules might add to the prospect for developing the practices in question.

Consequently, what I question is the *uniformity of theoretical discourse*. I challenge the idea that there is something paradigmatic in respect to the development of quantum physics. Thus I challenge the idea of Planck that also Einstein adopted: It is one thing to insist that theoretical thought must always correspond to certain basic forms of *unity* (in respect to perception, empirical outlook, the logical structure of language etc.) It is another to claim that the development of such unified forms of thought correspond to a certain kind of *generalization* or universalization inasmuch as this is supposed to mean that there are distinct features of the given systems of thought that have been and

[195] (Harré 1995, p. 37) based on (Shastri 1988)

[196] (Harré 1995, p. 38)

[197] For more on this notion of displacement, see below

[198] To be considered in Part Five, Chapter Four, in a paragraph on the linguistic philosophy of the later Michael Dummett

must be *preserved* within any future development of scientific theories. In short, I think one can and should be a neo-Kantian in respect to the *formal* character of theoretical thought, but not in respect to the *schemata* associated with these. It is true that our concepts must be schematized but there is no *one* necessary form of schematization, and consequently no *one* form of metaphysical model of the world in accordance with certain semantic principles. Analogies of experience must be demonstrable. But there is no Canon for what such a demonstration amounts to. This is what I want to discuss in the following sections:

As I said, I think that Harré claims that even within the seemingly special field(s) of quantum physics, the characteristic ontological presuppositions are similar to ontological presuppositions made within others fields. They have the same (Lockean) "source analogue" even if they express different "type-hierarchies" or "models".[199] Now, in my terminology, quantum physics does *not* have such similarity to the older physics. Quantum physics embodies quite new *metaphysical* principles. These do not correspond to any familiar way of making use of certain logico-theoretical schemes. This has been a primary point from page one of this entire work: It is only in the light of the *new* kinds of theory that one is able to make sense, at all, of certain similarities between older and new forms of thought. In my view, that is where Harré's metaphor of "exploring the *Umwelt*" becomes unlucky, because it fails to express how a new light may be cast on the formerly cultivated land.

In my account of Bohr's philosophy of physics, I have underscored how the fundamental notions of "energy", "stability", "process", "observation", "explanation", and "evidence" changed their meanings with the advent of the quantum theory. With that change our whole understanding of the experimental sciences changed. However, I have also continuously argued that quantum physics was build around the very same Hamiltonian tradition on which classical forms of physical theory relied. How do these two claims fit together? The answer I will suggest below is this: Understood as a method of cognition, the development of the quantum theory was far from revolutionary. Understood as a specific new kind of physical theory, it involved a radical change regarding what we, following Kuhn, might well call the disciplinary matrix of physics. Clocks were no longer clocks in the sense they had been before. Phenomena, like blips and clicks, were considered in quite new fashion. The whole practice of relating formula with data changed. I could put this easily in Wittgensteinian terms. New, but familiar games were developed. But the *pieces* of these games were radically different. I am *not* saying that the *rules* for the use of certain pieces, like clocks and clicks changed much. What changes are the very pieces. In atomic physics, we deal with new *kinds* of experimental setup. As I have explained in my account of Bohr, there was, to him, no sense in which we can still refer to the very apparata and to the very clocks and yardsticks without reference to specific setups in the quantum physical terminology. By contrast to the claim made by Harré, this is to say that we do *not* maintain ageold criteria of identity within quantum physics. Now let us take a closer look:

Harré on models and supertypes

As mentioned, Harré is critical of a formal conception of theories, and tries to see the relation between theories and models in a different non-formal way. He writes,

[199] (Harré 1986, p. 203-9)

> "Theoretical discourse is not an attempt (hazardous and underdetermined) to describe aspects of the natural world that we cannot perceive, such as the dance of the molecules or the interior of black holes, and so on, but instructions for making models of them. The kinetic theory of gases is thus read as a set of instructions for making progressive sequences of models of gases such that the behaviour of samples of gas is simulated by the behaviour of the model. The true relation is one of relevant similarities and differences between models and that which they represent."
>
> *(Harré 1997, p. 4)*

The "relation" betwen a model and what it represents is, according to Harré, not a relation between a *conceptual* understanding and a *concrete* physical system. It is a relation between *two* concrete items, the model and what it represents. Harréan "models" are miniature, toy-like items. The art of experimentation is the art of constructing language games where our toying around with certain pieces can be understood as in itself *exemplifying* what goes on elsewhere, in the vast (not, what goes on in the "real" world, for our game is as real as anything can be). A case in point, Harré thinks, is he way in which Darwin understood farming and breeding animals as exemplifying some of the evolutionary aspects of natural species.

Harré makes use of the notion of the *source* of a model. This enables him to distinguish between those models that have their source in what they represent, and those that do not. Consequently, if a model is introduced by means of analogy, so that the source of the model is not part of what it represents, we see how the establishing and gradual modification of such a model may have a distinct cognitive role; because, we may come to realize that what was to begin with but a formal analogy does, when it comes to it, exemplify an objective, real feature of the system represented by the model. This is because we can discover *real* similarities between, say, a pendulum and an occillating system of molecules in a Van der Waalls gas or the currents within an antenna. This is a crucial remark of Harré:

> "It is not that one type of entity is seen to be analogous to another and then they are seen as exemplifying the same supertype. Rather, it is because they exemplify the same supertype that they are analogous".
>
> *(Harré 1997, p. 5)*

For instance, Bohrian atoms are not planetary systems. However, there is a way to understand elementary particles as entering into state-transitions, although we have no immediate conception of the states involved. There are strictly speaking no orbits, and no states of motion; yet the definite quantitative changes in energy point to precisely *such* states that can be ascribed well known Hamiltonian and Maxwellian qualities; which in this case, I would say, is the supertype.

In my critical assessment of this, I will point to Harré's notion of the *displacement of concepts* from one context to another. I will ask why he does note seem to have elaborated an associated notion of a *displacement of models*. As I have already explained, Harré has analyzed the ways in which models based on analogy can be transformed into models that have their source in what they represent. Such transformation cannot take place concerning the criterial models that are associated with what Harré calls "supertypes" in respect to a certain "type hierarchy" of abstract determinations, such as "physical thing" or "person". In respect to the models that have their source from

items that corresponds to such supertypes, the only transformation we can have is – as Harré has it – the very displacement of *concepts* involved in the understanding of the respective practices of modeling the world according to given such models. This becomes, as it were, a fixed "supermodel".

So, if we cannot accept a view like N. Cartwright's that abstract ideas are simply always already at hand, and that there is no point in trying to inquire how our previous experience makes certain abstract principles plausible, we thus seem to reach a point where all significant language games are elucidated by reference to the fact that there are some "recurrent features" within our form of life. In this way, we are tempted to establish a fusion of a transcendental argument with metaphysical realism to the effect that our understanding the world in certain well entrenched patterns is considered justified. However, I find that there is no need to declare any "supertypes". As not the least Michel Bitbol has recently argued, neither the world nor our practices have a certain, definite "categorical structure".[200] Once, after a lecture in Aarhus 1997, when faced with this criticism, Harré answered as follows:

> "(As) concerns the origins of type-hierarchies, I believe were we to trace the development of any one hierarchy that is of importance in constraining model construction we would find an initially rough and tentative classification system gradually firming up as it is put to use, undergoing all sorts of transformations as new phenomena require a place in the structure. Provided we are not tempted to crystallize the working hierarchy too soon into necessary and sufficient conditions, it will retain its fluidity and dynamic character. Just because the solution to the problem of salience and relevance of similarities and differences in presenting analogical reasoning is solved by attending to 'vertical' relations in the relevant type-hierarchy with the 'horizontal' relations dominated by inheritance from supertypres, does not mean that comparisons by similarity and difference plays no role in the cognitive development of the sciences. Indeed in the early stages of the formation of a type-hierarchy it is only because similarities and differences are noticed relative to some project then being undertaken, that type relations are created in the first place. And indeed even in the most sophisticated uses of such hierarchies the point of the super / subtype relation is to fix which similarities and differences should be attended to in building and assessing models." *(Harré 1997, p. 9)*

So what should we be attending to in our effort to construct new models? By mentioning the notion of a conservative extention of a given linguistic discourse, I have indicated the idea of there being a certain kind of *platform* on which to raise a new kind of construct. The new practice can be "introduced" and demonstrated in a certain way. This was also the idea behind my understanding of the normative features of the notion of new criteria of identity. Given a certain kind of reason by analogy there is some, specific, way in which to demonstrate *these* kinds of analogies as forming a basis for some kind of development. Here, the Fregean and Wittgensteinian kinds of criterion turns on the issue of how *you know what you do* when you introduce and establish the new practice. But knowing this does not have to involve *how it is* we perform, nor *what it is* to perform the old practice. Instead it concerns how certain elements and moves

[200] (Bitbol 1996)

within the former game can be utilized. In this utilization of "old" elements you have already broken with the rules of the former practice *as such* even if you have all along employed strictly familiar kinds of rules.[201] This has to do with the essence of human freedom. Given how you are truly situated you can in a way *toy* with various features of your situation in order to *seriously anew* this situation. That is what Germans and Danes call *Um*-Stellung. Its like turning the tables and as a consequence establishing a new situation.

To consider this, we will do well in discussing a notion that Harré tends to use more and more in his writings, that of "domestication". We have seen that, according to Harré, The *Human Umwelt* is regarded as continuously extended in the sense that people manage to cultivate and shape kinds of beings that already existed in our natural environment. Importantly, such constructs, like for example experimental setups, may ground the possibility for the occurrence of new kinds of phenomena that could not have been actualized had we not made the respective constructs. However, according to the Gibsonian view, we may well claim that the real and natural world affords such dispositions; dispositions that can only be actualized within the contexts of certain human constructions. If we try to follow this line of thought, we may ask how radically new a domesticated item can be in relation to its "wild" or untamed counterpart?

But perhaps the metaphor of domestication is unlucky. Like Popper, I feel like asking if our learning to produce and to deal with tamed versions can truly inform us about the nature and character of *all* the wild ones? We would very much want to say that our ability to shape and control specific objects displays something true and objective about a *broader* range of objects that the domesticated ones exemplify. However, the problem is that domestication presupposes domains. For the concept of domestication only makes sense if it is given what it means to belong to some cultivated land or farm. Now, the formal relation between "tame" and "wild" is like subtype to supertype. But how does the circumscription of a given subtype determine *which* supertype (or which range of such) it is related to? Say, the farm is the geo-sphere and we have to project our understanding of the real stuff of that sphere on to our grasping and manipulating, also, outer space? We may ask whether any farmer before Darwin in fact did have any understanding and experience in respect to the *Darwinian* evolution of their cattle. Did they understand themselves to bread and evolve *populations* or *species*? It's one thing that we can, in retrospect, characterize their practice that way. It's another to claim that our, new and general, understanding (and its domain) forms an "extension" of a former such. Consequently, the question is: How do the ontological constraints that are imposed by a given model become a *resource* for our catching on to a new kind of models?

Harré might counter these remarks by saying that I am now implicitly relating to the *logical* relation between individuals and universals. Whereas matters are different once we recognize that we should instead consider the relation between the *concrete* individual items in question and the naturally extended family of objects to which these items belong. In short, we should consider the relation between a concrete *model* and the kinds of realities that the given models are supposed to exemplify. As mentioned, Harré invokes the neo-Kantian idea of distinguishing between "determinables" and "determinates" instead of distinguishing between classes and instances.

[201] I take this to be a main point of Felix Klein's *Erlanger Program* concerning the generalization of algebraic rules and the demonstration that novelty within arithmetic does not have to imply radical dis-unity.

Making this move is to point to the unity of form and matter in Kantian fashion. It is saying that any given formal analogy between two items corresponds to a similarity in respect to the way they are *real*. To Kant this had to do with the way in which Human Reason could grasp the conditions for the possibility of such items. To Harré, it has to do with the prospects for modeling the way in which one can experience the items by means of a certain kind of empirical investigation. But still, the view hinges on a certain kind of *constraint* in respect to our building models associated with the development of scientific concepts and theories. Put in Harré's own terms; the possible *idealization*

associated with certain established models constrains the possible *abstractions* that correspond to the newly constructed models.[202]

Models are idealization in the sense that they "need not reproduce every kink and break".[203] They are abstractions in the sense that they "do not represent every detail in the respective stratum".[204] Only *some* of the real features of classical particles can be said to be similar to the *defining* features of non-classical particles (such as the feature that the latter affords tracks in a cloud chamber). Consequently, Harré considers the idealizations within previous forms of science as providing a cognitive resource. Its the same with Nancy Cartwright. She considers "Gallilean idealization", such as constructing an almost frictionless plane, as a step in the direction of making crucial and general scientific ideas more concrete. Both Harré and Cartwright stress how, as it were, given forms of reality are *pregnant with structure*. To fix, produce, and identify new causal structures; that is what Harré calls "abstraction" and Cartwright calls "concretion". To both, this is the mark of scientific explanatory progress. They both consider the cognitive progress of science as consisting in its ability to clearly expose and demonstrate the capacities of Nature, and thus of demonstrating how Nature is pregnant with certain kinds of powers and causally structured interactions.

To Bohr, "idealization" was something to overcome. The focus on "abstractions" was precisely a matter of transcending the idealized space-time representations of possible experimental observations. There is no similarity *at all* between the understanding of the Stern-Gerlach apparatus and the understanding of classical yardstick, clocks, and meters. In the latter case, you detect something, you register something, or you "measure" something. You record. In the former case, you *abstract*. You provide a new distinct way for electrons to display themselves *as quantum-features* bound within a certain atomic system. Abstraction is an action with the very aim of disregarding certain ordinary kinds of idealization. Here "to disregard" does not mean "to forget". You are out to *introduce* a new feature of reality, spin. So you deliberately toy and play around with given forms of understanding. But there is nothing about the ordinary kind you wish to keep as exemplifying an established feature of reality. You are out to teach yourself a lesson, learning *not* to associate the reality of things with the notion of "the movable in space and time". You are out to radically change your entire outlook in a sense in which *there is no turning back*.

Now, I do not mean to criticize Harré's idea of domestication by simply claiming that he fails to account for the constitution and individualization of domains. On the contrary, I will instead push his thoughts to their Wittgensteinian basis. Consequently,

[202] Recall, I discussed these notions at the end of Part Three, Chapter Two.
[203] (Harré 1997, p. 3)
[204] (ibid.)

we have to take it very literally that we have been considering what is required for, and involved in, our being able to *regard something as* a "model" of something else. Thus, we must somehow, directly and bluntly, cut through all the intellectual, philosophical worries and state, in Wittgensteinian fashion: "*This* is how we understand *this* as a model of *that*!" The point is (as Wittgenstein in my view often pointed out) not to understand the phrases in italics as proper names. No thing, no item, no specific individual feature of reality is designated by their means. The phrases in italics have an *expressive* character. By making the claim that *this is how we go on* within a certain linguistic practice, we try to express what is considered a salient feature of that practice, *as such*. We do not first have a list of features of the game from which we can then pick out the salient ones. There can be no such lists. Any "description" of the language game is already a way to engage into the game (I mean the game one intends to engage in by making a given description, and not some game described on the background of some previously given circumscription of that particular game; a game that is now, by means of the current description, explicated).

Few things exemplify Harré's idea of "domestication" as well as a *work of art*, and few things can change the world in which we live as much as such objects. A painting may consist of only a mixture of colors, shades, figures, and shapes (including lumps of dry paint etc.), but whole worlds and whole lives can be exposed and challenged by such means. Such exposure is possible because a work of art functions within a cultural setting and expresses the interests and aspirations of culturally situated people. On this cultural level, we have continuity and novelty at the same time. If Harré intended to address this level, the analogy between experimentation and domestication would be right. Here, the criteria really stick deep; because, regardless of the multiplicity and historical development of the various language games they all point back to, and form part of, the human form of life. *However, once we pay attention to the features of the particular language games, there is no real point in our maintaining that they all correspond to a certain "family" of language games*. That is the point I have been trying to make. I conclude from these Wittgensteinian considerations that we have to elaborate a more *metaphysically complex* account of the view that Harré has offered. This is to say that we can indeed maintain both the view that quantum physics involves a quite familiar way in which to domesticate our natural surroundings, in the Gibsonian sense, and maintain that this familiar kind of domestication, nevertheless, provides us with a variety of radical transformations in respect to our ressources for producing, recognizing, and controlling things.

5 Classical Physics as Ideal. A critical assessment of some recent interpretations of Bohr's philosophy of physics

5.1 The two Dogmas of the Copenhagen Interpretation of Quantum Physics

Howard's critique of The Orthodox View

I want to elaborate on Don Howard's claim that most interpretations of Bohr's philosophy of physics hinge on a certain romantic understanding of either classical physics or of our so-called ordinary practices.[205] I want to point out how such interpretations of "Bohr's doctrine on classical concepts" are often based on two unacceptable views. First, there is a set of ideas about the status and character of classical physics. Second, there is a set of ideas about the status and character of ordinary language. Let me introduce these two sets of ideas in somewhat schematic fashion:

First Dogma: Classical physics as an epistemic ideal Even if it might be historically more correct to associate "classical physics" with a clear ontology, it is instead some epistemological ideals that characterize the conception of classical physics that is usually associated with Bohr. The basic view is that scientific theories constitute "exact", mathematical descriptions of natural processes, which again has to do with a certain notion of "objective representation". By means of mathematically formulated scientific theories we manage to "save the phenomena" adequately. Consequently, we manage to represent the objective structure of whatever exists in the natural world. In traditional philosophy of science, one thing that unites the rationalist, the empiricist, the realist, and the idealist is the view that classical physical theory forms a prime example of what it is to entertain determinate concepts in our thought. The conceptual practice of classical physics is anything but ambiguous, confused, tentative, inconsistent, or fluctuating. It is as "exact" as thought can be. It forms, so to speak, the very definition of "cognition".

Most accounts of the philosophy of Bohr thus present the problem posed by the advent of the quantum theory as follows: The exact conceptual practice of classical physics cannot be prolonged in order to cover the quantum realm. Now, given the

[205] See the quote in Part Four, Chapter Two

(misconceived) premise that there is a "realm" where the use of classical concepts is in place, how is it then possible to apply these very concepts in another "realm" – even if a) this application cannot be determinate in the same sense as before, and b) the classical concepts must be applied in conjunction with some "non-classical" concepts.

In my view, this question puts everything upside down. Bohr did not picture classical physics as in any sense *ideal*. Instead, he made the claim that *any* kind of physical theory involves the use of "idealizations". However, this feature of physical theory had to be brought to the fore within the quantum theory, whereas it could be somehow disregarded within the classical context. Accordingly, Bohr pictured classical physics as suffering from illusions that nevertheless have some pragmatic value – a pragmatic value that similar illusions within the quantum theory cannot have. So, in any sense of the term, the quantum theory *is the best so far*. And every value that might still be ascribed to classical theories is ascribed from this perspective; the perspective that gives historic priority to the quantum theory.

Second Dogma: Ordinary language has semantic priority The root of the second set of ideas goes back to the distinction between "appearances" and "reality". This distinction presupposes that human experience, so to speak, has a home ground – the world of appearances – where it knows it way around. However, the distinction has never been formulated without raising serious questions. This has to do with the notion of "subjectivity". One the one hand, it seems as if we know the "subjective" aspects of experiences better than the (more) objective or "independent" features. On the other hand, one might as well view the subjective elements as those that color, distort, or veil the true reality of things experienced.

Anyway, most traditional forms of philosophy operate with some notion of a kind of *familiarity with the world* that is rooted in sense-experience, in causal connections to features of our surroundings, or in common social practices. Regardless of the way it develops, one feature is taken for granted by most traditional philosophers, namely that people have ordinarily acquired a verbal ability to describe *recurring* objects and states of affairs. The practice of re-identification by means of verbal ascriptions lies at the heart of ordinary human activities, it is traditionally claimed.

Now in my understanding, the idea of an ordinary language philosophy – both in the original sense of Austin as well as in the Wittgensteinian sense – were in fact attempts to *break with* the mentioned tradition. The basic idea of both Austin and Wittgenstein was that *there exists no determinate ordinary linguistic practice that forms a necessary framework of philosophical inquiry*. That, precisely, was why philosophers had to pay attention to ordinary language in order to set philosophical thought free from various mythologies of ordinary language the acquisition of which – both Austin and Wittgenstein supposed – characterized traditional philosophy.

The case of Strawson is a bit more complicated. Strawson lays on the one hand more stress, than did Austin and Wittgenstein, on the *constraints* imposed by what Strawson called "the actual structure of thought" (i. e, structure of given linguistic practices). It is on the other hand a point of Strawson that the actual practice does not necessarily conform to a pre-given logic or formal grammar. The aim of theoretical or systematic linguistic reconstructions should only be to establish so called "perspicuous grammars", the function and character of which can never be fully determinate.[206]

[206] I try to present and discuss Strawson's semantics in systematic connection with his reconstruction of

In all these kinds of "ordinary philosophy" there is no denying that ordinary linguistic practices may be quite complex, open, and confused. There is no implication to the effect that "ordinary language" has any privileged status. On the contrary, as Austin put it, the theoreticians aim should primarily be to "torture and distort ordinary language" in order to clarify certain philosophical issues.[207]

Many followers of Wittgensteinian and of ordinary language philosophy turn all this upside down. These philosophers, however, usually fail to distinguish between the following two, entirely different, points:

(1) Any philosophical reflection must be rooted in some ordinary use of words.

(2) Ordinary language – even if it is "in order as it is" – may still be said to lack certain ideal features that can be ascribed to some non-natural language in accordance with semantic reflections that corresponds to point (1).

Now, a number of unacceptable views about the character and status of ordinary language are often ascribed to Niels Bohr. There should of course be no question that Bohr did point to some basic features of "everyday language", but he did so in the sense in which both Austin and Wittgenstein considered ordinary language. Bohr, Austin, and Wittgenstein all criticized the belief that there are some "proto linguistic acts", like "referring", "describing", "naming", "explaining", and "understanding", which are considered the same within any linguistic practice. That is why we should adopt a quite humble view in respect to these prototypical linguistic acts. Thus we have to look at those everyday activities where explanations, descriptions, and denotations etc. are actually performed.

It is part of the *ordinary conceptual* practice of the physical sciences to perform experiments and measure physical quantities in certain ways, and if it is part of such practices to conform to certain standards of, say, "explanation" and "observation", then – pace point (1) above – no adequate reflection on the given practice should be based on entirely *different concepts*. Bohr's considerations on ordinary language amounts to something like this, but they don't imply that we should attribute epistemological or semantic priority to ordinary language over and above other forms of language.

The Ordinary Language Orthodoxy is still alive and well

It might seem that "the ordinary language orthodoxy" is a phenomenon of the past. The more recent interpretations of Bohr seem to be far removed from both positivist and common sense conceptions. No recent interpreter seems to associate Bohr with simple or crude conceptions of ordinary language. These days we find interpreters who examine certain proposed analogies between Bohr and sophisticated philosophers like Strawson and Dummett. However, it turns out that most of the recent interpretations of Bohr suffer from notable shortcomings. First, it seems that one has to modify and simplify the views of, say, both Strawson and Dummett in order to have them match the claimed views of Bohr. Second, the result of the proposed schematic applications of modern semantics to the issues raised within the philosophy of Quantum Physics comes sadly close to reiterateing most of the misconceptions that I pointed out above. Third, this means that despite the fact that there seems to be big differences between

Kant's analytic in (Brock 2002)

[207] See (Austin 1956)

the various recent interpretations of the philosophical thoughts of Bohr, they are all in a sense analogous. The common denominator seems to be a kind of *pragmatism* concerning the issue of how various rational features of the practice of classical physics are maintained within the more "complicated" arena of quantum physics.

Also, there is something important that all the interpretations that I criticize, forget. To inquire into the possibility of practicing quantum physics will have to involve the recognition of features that – even within classical physics – were always crucial, but have so far not been adequately brought to the fore by the advent of the quantum theory. The very aim of the various interpretations I criticize is pointless. If you want to inquire, say, into the possibility of a new form of Art, there is no way in which that inquiry can leave pre-established conceptions of Art untouched. If Quantum Physics shall be compared to classical physics, at all, there is one and only one way to do so – namely, by analyzing the possible *relations* between the two practices, and that, by the logic of the task, requires viewing these relations from a perspective that *includes* the quantum theory, and that again implies transcending the boundaries constituted by classical thought.

5.2 John Honner's interpretation of Bohr

Demonstrable particulars

The most elaborate attempt to associate the philosophy of Bohr with non-Fregean semantics of the 1950s was made by John Honner in his *The Description of Nature, Niels Bohr and the Philosophy of Quantum Physics*, published in 1987. In the following I will be concerned, only, with pointing out how the two dogmas concerning "classical physics" and "ordinary language", respectively, colors even this most sophisticated and sober account of Bohr's philosophy. First, let me mention Honner's view in respect to what constitutes "classical physics",

> "What is essential to the character of a demonstrable particular is that it is evidently public; it is very materiality locates it in space and time. This is not to say that there is such a thing as an absolute space-time framework, but that demonstrable particulars are sensible objects which exist in a relationship in space and time to those who sense them and refer to them. Such particulars have the character of the objects of classical physics, since they are clearly separate from the observers who refer to them. The space-time framework, furthermore, prevents the possibility of duplication of particulars; even if two particulars are identical, they cannot occupy the same position in the space-time framework. That is part of the condition of their sensibility and materiality." *(Honner 1987, p. 206)*

This is on my view plain ontological ideology. Ontologically speaking, there is no such thing as the very "materiality" of things. And there is no such thing as a "basic", "bare", or "demonstrable particular". Also, there is no universal epistemic act such as "locating objects in space and time". That is to say that, *what it means for there to be* these things may differ from context to context (from language game to language game). There is no uniform and a priorily given way in which we "encounter" or "experience" the world.

However, I recognize that Honner associates such ontological claims with a certain metaphysics of experience, or a metaphysics of language to the effect that the apparent crude and unacceptable ontological views emerge as "implications" of certain semantic or epistemological considerations. I want to approach this side of the story in two steps: First, one might associate the ontology of demonstrable particulars with a kind of "transcendental argument" to the effect that some part of what objectively exists *must* be identifiable, given the fact that we have some epistemic success and posses some observational ability concerning these objective features of things. There is, so to speak, a limit to epistemological skepticism. Thus, one might suggest that the nature of things is such that we, in ordinary circumstances, "truly" can exercise an ability to "demonstrate" the presence of things, or to recognize them, in some principal way. As Honner put it,

> "Our participation in events which are re-identifiable is the basis for Bohr's affirmation of the reality of our world ... It is a fact that we can repeatedly and unambiguously refer to particular aspects of our world."
>
> *(Honner 1987, p. 150)*

But on my view, it is not a fact that we can "repeatedly and unambiguously refer to particular aspects of our world", if that is supposed to point to some sort of proto-relation between language and world. Regardless of what "empirical reference" is supposed to mean, it must be conceived in a much more complex manner. Again, any claim to the effect that there is a basic and *uniform* character of our "relatedness to the world" is sheer fantasy – a fantasy from which none of the proponents of the Helmholtzian tradition of theoretical physics, including Bohr, ever suffered.

Honner suffers from that semantic fantasy, because he combines transcendental arguments with an ideology concerning the possibility of any language. In Honner's words,

> "Strawson places a great deal of stress on the existence of material objects in space and time as the key to the ordinary referring powers of individual persons, who are also material bodies in space and time. This is the ordinary, everyday 'classical' framework which Bohr himself acknowledges as primary in any attempts at objective description."
>
> *(Honner 1987, p. 204)*

> "Bohr maintains that language works because it is founded on the regularity of re-identifiable particulars in the sensible world."
>
> *(Honner 1987, p. 218)*

To a Wittgensteinian like me, there is no such thing as *the* "ordinary referring powers of individual persons", nor is there such a thing as *the* "workings" of common language, and there is certainly no such thing as "the regularity of re-identifiable particulars". Of course, seen from within the perspective of a particular language game you may feel able to "go on". You may experience the recurrence of some items and you may feel confident that you have truly caught on to some objectively existing features of things. But that has no definite ontological implication.

As should be well known, Strawson's agenda and views are in fact very different from such semantic philosophical ideologies. He interestingly, but in my view wrongly,

elaborates on both Aristotle's conception of categories (of substance) and on Kant's conception of the necessary link between the forms of intuition and the categorical concepts. By launching his idea of a *descriptive metaphysics* Strawson wanted to argue that (i) even though our "actual structure of thought" shall not be associated a priorily with some determinate formal logic, (ii) one might nevertheless always ascribe a certain kind of grammar to our actual thought; a grammar relative to which one can then try to reconstruct the given language that will thus be supplied with a so-called "perspicuous grammar". In short, there will always be a way to associate the given language with some concepts of substance and re-identifiable features on the basis of which some sort of semantic clarification might be achieved. Now this quite sophisticated synthesis of Aristotle and Kant, proposed by Strawson, did not include making the claim that Honner makes, that:

> "Associated with Bohr's fundamental arguments in his interpretation of the quantum formalism is a provocative hint at *a link between the given character of ordinary language and a deterministic-mechanistic view of the workings of nature*". *(Honner 1987, p. 216)*

This Laplacean, or Hobessian, conception of nature was never entertained by Bohr, nor by any of the proponents of the Helmholtzian tradition of theoretical physics. Indeed, there is no "workings of Nature" in terms of which we may *explain* the character and status of our linguistic practice. We have to ask, why such a view is as widespread as it sadly is.

I would like to point to a very typical line of thought that in my view has distorted the ideas of many philosophers, namely the idea that *to be an object is to embody a power* (which is correct) *to cause a certain series of events* (which is wrong). On my view, one should instead, following Bohr and Kant, say that to be an object is to be a power to *appear* to a human observer in some determinate way. This is not to say that to be is to be observable. It is to say, instead, that *some* of the causal powers of any object must in principle be observable. By contrast, Honner states that,

> "The assumption of strong objectivity in classical physics is critical ... since causality describes connections between objects and events clearly independent of the observer." *(Honner 1987, p. 57)*

This line of thought hinges on the view that there is an objective link between determinate objects and certain, manifest, events. A causal understanding of things implies our describing such links. That is the paradise of everyday causality. Unfortunately, outside of that epistemic paradise, we cannot lay bare the objective link between objects and the events they causally contribute to bring forth because (it is assumed) within quantum physics to observe is itself a physical action of the same order of magnitude as the observable physical effects. Accordingly, within quantum physics we can no longer "demonstrate realities", as Honner puts it. East of Eden we can at best "invoke deeper realities":

> "Complementarity is applied more broadly to those deeper realities which, by virtue of the indivisibility of the quantum of action, are inseparable from our interaction with them." *(ibid.)*

On my interpretation of Bohr, the recognition that observations are human actions that have causal effects, helps us instead to understand why, at all, our experience can acquire an objective content. The fact that part of what conditions the emergence of observable phenomena are circumstances that we can plan and "scrutinize" (as Bohr would sometimes call it) helps us to pursue certain investigations of the objective structure of matter we would otherwise not be able to pursue.

Honner on the framework of complementarity

This is the kernel of what Honner considers as Bohr's framework of complementarity:

> "(b1) Some kind of conceptual framework is a necessary condition of the possibility of ordering experience.
>
> (b2) It is a necessary condition of the possibility of objective description of processes at the boundaries of human experience that concepts related to more normal experience be employed.
>
> (b3) Our position as observers in a domain of experience where unambiguous application of concepts depends essentially on the conditions of observation demands the use of complementarity descriptions if the description is to be exhaustive." *(Honner 1987, p. 105)*

In the final chapter of his book, Honner alludes to Strawson in order to elucidate (b2):

> "(B2) concerns itself with the priority of public reference to definitely identifiable particulars and well-entrenched conceptual frameworks in any attempts to extend the range of our experiences and to shape our description of such experiences". *(Honner 1987, p. 203-4)*

> "The claim of (B2) can be restated as follows: Particulars which can only be identified indirectly must be identified by referring to the demonstrable particulars if the identification is to be unambiguous".
>
> *(Honner 1987, p. 205)*

To summarize: Honner's reading of Bohr hinges on his version of one of the two Dogmas of the Orthodox Interpretation of quantum physics – that which imply that quantum physics had to make use of the *very concepts* that already played a crucial role within classical physics. Given this, it now becomes interesting to ask why, and how, Honner can still ascribe a *realist* position to Bohr? This characterizes the kind of realism that Honner considers Bohr to have adapted:

> "Bohr's advocacy of complementarity was not an abandonment of realism but an attempt to provide a more general framework for the description of nature; maintaining objectivity and realism would be at the cost of reappraising the status of our usual physical concepts. In particular, we would need to learn that such concepts were symbols, pictures, and idealizations, when applied to quantum events." *(Honner1987,p. 153)*

The logic of this realistic interpretation of the framework of complementarity – seen as a framework substituting the classical "causal space-time framework" – is this: In the

classical context, there need not be any gap between the "immediate" use of a pictorial concept and it's "analysis". The dynamical properties of objects may be represented by means of concepts relating to a pictorial account. This has to do with the following:

(a) any phenomenon in quantum physics implies a non-ignorable participation of ours.

(b) a new peculiar kind of synthesis is called for, in order to understand how extra-ordinary kinds of phenomena – that are still in some sense wave-like and particle-like, respectively – are inter-related, and are so thanks to *a new kind of participation* of ours.

Consequently, Honner thinks that,

> "The overall force of Bohr's argument is that we are without absolute foundations in our participation in the world, despite the acceptance that our language works by being anchored in everyday experience of reality. Instead, we are agents operating within a given" *(Honner 1987, p. 222)*

> "Words not only demonstrate obvious realities, but also invoke deeper realities. Even 'reality' was for Bohr merely a human word."
> *(Honner 1987, p. 223)*

So Honner seems to say that we can learn to "operate words" within a given world without our having an anchorage in experience for these operations. This means that we do not *simply* "demonstrate" the reality of things, but invoke some "deeper" realities. The reality "beyond" our experiences is called "deep" because we *do* have empirical truths concerning this reality. These empirical truths, however, are so "deep" that what *seems* to be contradictory ways of characterizing certain aspect of reality in terms of these turns out to be equally objective.[208] Thus, what may well be called "Honner's motto":

> "*... the way things are requires complementary accounts of the way things seem*." *(Honner 1987, p. 173)*

[208] (APHK, p. 66)

The invocation of deeper realities

Now, Honner writes,

> "[Bohr] is aware that the ordinary usage of classical descriptions only applies where reference is unambiguous. He considers that descriptive concepts of this kind, arising as they do in the world of our ordinary experience, are the only terms available to us if objectivity is to be retained in our language. Second, given the limitation, which the quantum discontinuity imposes, we are only able to speak unambigously about quantum events when interaction with macroscopic apparatus occurs. What we are then talking about is the whole process of observer/observed interaction, and reference must therefore be made to the conditions of observation if the communication of what is observed is to be unambiguous and accurate." *(Honner 1987, p. 86)*

In my view, something goes wrong here. The realm of reference is split into two, one having to do with the real processes occurring in Nature, and another with our performances. The latter take place in Nature, all right, but the implication is that *observational* processes are of a particular kind, and that a reference to the conditions of these processes forms a necessary component in any account of human experience. What is wrong with that, in my view, is that it becomes part of the *content* of an observational report how the observation has been established. What we get is a version of the so-called genetic fallacy.

I do not mean to say that a mention of our means of observation is irrelevant. To take a simple case: It may be part of the meaning of "this is a cup" that one might see this by looking. Or take a claim such as "this is a download" that implies a reference to ways of separating officially released records from unauthorized re-productions. Such reference, however, to the *context* of observation/verification is not supposed to be part of a description of the *process* of observation/verification. Similarly, in quantum physics, although to report that one has observed a "Compton scattering" electron recoil resulting from impact of photons must involve a specification of the experimental arrangement (of the "condition" of the source of the photon-beam, of the "fixation" of the target-electrons, and of the condition and fixation of the detecting devices after the scatter). Call this the context of observation the specification of which has to make use of classical space-time pictures, as explained in the former chapter. That is all. There is no further question in respect to *how* we observe specific manifest effects on apparatus so as to make sense of the workings and structure of the experiment.

Recall Bohr's response to the EPR challenge: We must be conscious about how to choose to observe certain phenomena. We must see the experimental design in a certain fashion. But this is not to say that we arrange the *process of observation*, as if we would be able to characterize that by means of some general cognitive functions, like "detect", "register", "note", "perceive", "measure" etc. And there is no way in which what we observe in itself indicates how we observe. True, if we did not observe (arrange) like *this* we would not observe *that*. But the content of our observations just are what they are, say we see the emission of some elementary particles. We may do so by means of a certain manifestation of arranged physical effects. But these means should not be thought of as a kind of "filter" or "configuration" of what is observed. Our motto should be: *Do not ask what goes on and what takes place as we observe*. There are no general

characteristics of the observing process, as such, in terms of which to characterize the content of our theoretical observations. Compare; perhaps if I raise my arms so as to fill my lungs with air I can better sense the richness of the fragrance of a certain forest. But my smelling this should never be seen as a result of my *raising my arms*. In short, there is no such thing as an occurrent "observational process". Observation is deliberate *action*, and what we observe is something we happen to encounter in so far as we approach the world in a specific intellectual manner.

It should be noted that both Honner and I think that what is detected in a quantum physical experiment may not *yet* be an observable phenomenon. For my Bohr, this is to say that the phenomenon is in a sense a sort of construct made in order to *comprehend a possible structure* of what happens to be detected. Whereas Honner's Bohr will say instead that it is the detected *events* that are comprehended in order to *imagine* a quantum phenomenon that is, strictly speaking, beyond the reach of our experience – a view of which my Bohr would be highly critical.[209]

5.3 Henry J. Folse on Bohr and how Science informs Epistemology

How Science informs Epistemology

In his book *The philosophy of Niels Bohr. The Framework of Complementarity*, and in several articles over the years, Henry J. Folse has argued that Bohr's framework of complementarity forms part of a defense of a new kind of realism.[210] I have much sympathy for Folse's able and inspiring analysis of Bohr's philosophical thought. I do also ascribe a new kind of realism to Bohr. What is more, Folse seems to be one of the few interpreters of Bohr's philosophy who put his finger on, what in my view, is the right spot; the notion of criteria of identity. Thus, I can endorse the primary lines in Folse's reading of Bohr. However, I am critical about many of the specific theses proposed in his discussion. I find that most of Folse's arguments and considerations are based on two questionable premises. First, there is a premise concerning *how* the ordinary use of language has a privileged semantic status. Second, there is a premise to the effect that the classical Hamiltonian kind of science corresponds to *pre*-Kantian metaphysical and epistemological considerations. In a recent summary-article, Folse presents the metaphysical and epistemological thesis that he ascribes to Bohr as follows:

> "Ontic Realism (**OR**); it is rational to believe that the entities and processes postulated by our best theories really do exist."
>
> "Epistemic realism (**ER**); these same theories aspire to provide whatever knowledge of these entities and processes it is possible for human beings to attain." *(Folse 1994, p. 125)*

Folse goes on to mention three theses that were rejected by Bohr, and which, according to Folse, characterize classical physical thought:

> "The Epistemic Thesis of Mechanistic Representationalism (**MR**) (or the ideal of visualizability'): to have knowledge of an entity or process

[209] As to Honner's interpretation, see the cryptic claim made by Honner (p. 132) about our not being able to "control effects" since "quantum mechanical object do not exist in determinate states". What then, I ask, has become of the Hamiltonian method?

[210] (Folse 1985)

one must be able to form a spatio-temporal picture in which that entity or process is described (i. e. 'represented') by a range of predicates which hold a one-to-one correspondence with properties inherently possessed by a real entity or process in nature."

"The Doctrine of Primary Properties (**PP**): In order to provide the spatio-temporal picture of entities [required by **MR** above], entities must be characterized as inherently possessing at least those properties which serve to locate them in space at each instant of time, and processes over a finite temporal interval."

"The Ontological Thesis of Mechanistic Materialism (**MM**): The natural world consists exclusively of 'substances', éntities, which inherently possess only those properties accorded to them in their representation in mechanical theory." *(Folse 1994, p. 125)*

According to Folse, the conjunction of the five thesis (**OR**, **ER**, **MR**, **PP**, **MM**) together makes up a philosophical outlook that is adequately called "classical atomistic realism". Folse's claim now is that by rejecting the three latter theses, and by trying to *reformulate **ER***, Bohr wanted to establish a new alliance between **ER** and **OR**, Ontic Realism, so as to *launch a new kind of Atomism*. Folse writes,

"Bohr could not abandon **ER** [Epistemic Realism] with respect to quantum theory, for to do so would leave his commitment to **OR** [Ontic Realism] with respect to that theory undefended. Thus from the engagement over atomism we gain a perspective from which to understand Bohr's philosophy: the problem Bohr's strategy was intended to solve was to find a way of revising the epistemic ideals of the classic atomist alliance (*i. e.* **MR**, **PP**, and **MM**) so as to make secure his right to claim that the quantum theory provides the maximum possible knowledge about the real atomic systems of the micro domain (*i. e.* **OR** and **ER**). Complementarity was his answer; it is the epistemological lesson he tries to teach."
(Folse 1994, p. 127)

The crucial part of Bohr's philosophy of physics, as presented by Folse, then becomes the effort to elaborate a new account of *what it is* to have *knowledge* about physical entities (objects or processes). The answer to this inquiry turns out to be something like this: In a scientific discipline we learn, by putting the right experimental answer to Nature, what "Nature permits us to presuppose". In this way, we hope to make causal sense of the predictive success of our experimental doings. This answer comes to the fore in the light of a critique of the three theses **MR**, **PP** and **MM**, here formulated in my words:

– By giving up the ideal of visualizability (**MR**), and thus acknowledging the inevitable dis-continuous character of all micro-physical interaction, we have provided room for non-classical presuppositions about the causal properties of "phenomenal objects" (such as 'waves' and 'particles'): There might be new ways to understand how *such* objects (the behavior of which we can picture in spatio-temporal terms) give rise to certain empirically manifest phenomena by interacting with macroscopic (observational) systems.

– Those are the only properties of physical things we need *represent*. So, to oppose **MM**, the Ontological View of Mechanistic Materialism, we have better *take Nature to consist only of phenomena* (as all there ever happens, all there can ever be in the physical world).

– However, we must still understand the best of our theories to refer to real, independently existing entities that *ground* the phenomena. In contrast to **PP**, the reality of things *behind* the phenomena shall not be represented in terms of inherent, primary properties of *objects*: The grounds of phenomena should be understood, instead, as powers (properties of physical *activities* or interactions).

Now, before I turn to the issue of critically assessing the claims of Folse's, it should be noted how the claims fit the agenda that Folse ascribes to Bohr – that of introducing a new kind of realism:

> "If we learn the epistemological lesson of complementarity and abandon the ideal of vizualizability, we may still pursue – in a revised form – the realist goal of *understanding* the relationship between atomic systems and the quantum theoretical description of the phenomena adduced in support of that theory. Complementarity leaves open the way from microphysics to a philosophy of nature freed from its classical alliance with the indefensible positions of **MR**, **PP** and **MM**." *(Folse 1994, p. 138)*

I shall argue below (a) that this way of overcoming classical physical thought is based on a wrong conception of the tradition of theoretical physics to which Bohr saw himself as belonging to and (b) that the points, which according to Folse's understanding of Bohr, characterize the quantum theory, are answers to questions that were never asked by Bohr, or by any other proponent of the Helmholtzian tradition of theoretical physics.

Folse is careful not to place Bohr in specific realist camps. The kind of realism that one ought to recognize Bohr as pursuing, Folse rightly claims, is a realism that "keeps open the lines of communication between natural science and natural philosophy", and not a realism defined in terms of a set of axiomatic statements. Accordingly, Folse wants to argue that,

> "(1) Bohr's position on the philosophical map is not easy located using the reference co-ordinates used by the philosophers, and (2) If Bohr is to be placed on the realist side of the frontier separating the opposing philosophical antagonists, then that frontier might be drawn in a way which may would teach philosophers how to make a better map for orienting our discussion of the quantum theoretical description of nature. This may well be considered what Bohr believed the epistemological lesson taught by the quantum revolution to be all about ... My intention is ... to teach a lesson in philosophical map-making." *(Folse 1994, p. 120)*

> "My motivation here is simply to keep open the lines of communication between natural science and the philosophy of nature, to see in the epistemic achievements of empirical science rational grounds for ontological convictions about the nature of the world in which we find ourselves." *(Folse 1994, p. 137)*

Thus, Folse sees Bohr as arguing for a possible, new kind of alliance between *empiricism and objectivity*.[211] Folse describes this as the crucial issue for any epistemology. Thus, we need an account of *how science informs epistemology*:

> "Bohr's method of argument must assume that in describing nature through our theories, we learn empirically from the success or failure of these theories what nature permits the scientist to presuppose about it in order to describe it unambiguously. This is simply another way of saying that science informs epistemology ..." *(Folse 1985, p. 223)*

The point is that such an account may be empirisitic in the sense of corresponding to the latest scientific experiences. However these experiences shall not be seen as occurrent representations. They are not *Vorstellungen*, they are "informations" that make a well-formed content of theoretical claims possible; and *as such* do they provide a standard for objective knowledge. That is how "science informs epistemology", according to Folse. Standards of objectivity, concerning *what it means* to describe states of affairs in nature objectively in theoretical terms, change as part of the scientific enterprise. As is clear, it is not this interdependence between current scientific claims and epistemological standards in *itself* which matters. What matters is *how* this interdependence is recognized and functions. Take the following of Folse's remarks:

> "In order to follow why Bohr believes complementarity removes ... ambiguity, we must remind ourselves that in basing the description of nature on *observation*, science becomes committed to accounting for how that observation reveals information concerning the observed object through interacting with it." *(Folse 1985, p. 208)*

It is the method – "how observation reveals information about objects" – and not an individual observation about some object that shows "how science informs epistemology". It is only by reflecting *how* observation reveals information about – precisely – *objects* within various scientific research traditions that we manage to establish adequate and clear-cut *assertability conditions* that govern the use of theoretical notions within the different contexts. Only when we have established this, are we warranted in our advancing a *realistic* understanding of the theoretical discourse in question.

I have much sympathy for this approach. However, I will argue that Folse's interpretation of Bohr is based on a too narrow conception of the connection between (the) natural sciences and a *metaphysics* of Nature (in the Kantian sense).

Phenomenal objects

We shall try to redescribe experiences as observations in order that they may embody *information about particular objects*. This is not to say that the manifest experience – the results of a measurement – shall be seen as an *effect* of some *occurrence* causally involving the object.[212] In a way, the very object observed is posited within the description of the manifest phenomenon as a so-called *phenomenal object* that must be distinguished from a conception of the object "in itself". Folse writes that,

[211] (Folse 1985, p. 199ff)
[212] As, we saw John Honner also has it.

> "... some phenomena can be treated as 'observations' which are produced by interactions with objects not themselves present in the experienced phenomena. Thus the descriptions of experimental phenomena as physical interactions will require reference to atomic systems as objects 'behind' the phenomena, in the sense of that which produces the phenomena, but the phenomena experienced are not themselves 'representations' of these objects. Although phenomena described as observations provide the foundation for accepting or rejecting theories, 'observations' cannot be 'independent' of such descriptions, as was presupposed in the interpretation of science of traditional empiricism, because in order for a phenomenon to be relevant for the acceptance of a scientific description it has to be described as an observation of some determinate phenomenal object." *(Folse 1985, p. 203-4)*

The importance of the notion of "a phenomenal object" is that the ontological implications of the presuppositions associated with the positing of such objects help us to make sense of there being objective interconnections between mutually exclusive *conditions* for the generation of very different kinds of phenomena. The idea of introducing such "phenomenal objects" is a characteristic, Folse would agree, already of *classical* physics. The two well-known notions of "phenomenal objects" that were introduced in classical physics, of course, are the notions of "waves" and "particles". Thus, particles and waves are *phenomenal* objects. They are posits or "*categories of specific descriptions*", such that given experienced experimental outcomes (say, vibrations, traces, light-blinks, Geiger-blips) can be described as causal phenomenal manifestations of a certain *kind* of real objects, "particles" or "waves".[213] As such, these phenomenal objects are "abstractions" or "idealizations".

Due to the introduction of the notion of phenomenal objects, a given description of the manifest experimental experiences provides an account of the *particularity* of the individual physical objects observed, but does not yet account for the *identity* of such. However, the method in question aims at establishing how individual phenomena can count as evidence for or against the acceptance of specific theoretical formula, as well as aiming at explaining how the posited phenomena may acquire a logical function within further theoretical constructions. That is, the phenomena constructed so as to relate to particular phenomenal objects must be related to one another in such a way that the modalities of this combination of phenomena qualifies as an expression of the *structure of the reality* of those physical objects the phenomenal appearance of which is in question.[214]

Abstractions and idealizations

As stated in former chapters, I find it necessary to distinguish between the two Bohrian notions of "abstraction" and "idealization". Folse's notion of a "phenomenal objects" expresses a failure to make this distinction. I want to underscore that there is no correspondence between the way in which objects *enter into phenomena* (i. e. as "idealizations", such as point particles and plane harmonic waves) and the way in which *objects form part of physical systems* (i. e. as "abstractions", such as elementary particles or

[213] Ibid, p. 203ff.
[214] See Folse 1985, p. 211.

other forms of atomic constituents including transition processes). As I have argued, Bohr maintained the principle that the physical abstractions that are posited within the quantum theory are associated with some form of intuitive representation (*Vorstellung*) – and the primary example here are the various abstractions that relate to the idea of an electron configuration diagram characterizing given atomic systems. Such diagrams must never be seen as merely forming a sort of logical construct in accordance with certain *observables*; say, the spectral lines detected when analyzing various substances. Instead, a "spectral line" is associated with an idealization of the observational, experimental arrangement – namely an idealization of the spatio-temporal distribution of energy concerning the possibility of comprehending individual atomic physical phenomena. However, as I have argued, the comprehension of individual phenomena does not in itself settle the issue of the *synthesis* of phenomena into well-defined state-descriptions. This synthesis calls for a broader perspective – the perspective of the embedding of the physical *system* investigated in the entire system that makes up the whole of the experimental arrangement, such that we are entitled to claim (1) that we have observed an object (say, an electron or a photon) that participates in *both* of the systems (in both the atom and the experimental arrangement), and (2) that the configuration of possible *interactions within the atomic system* can each be thought of as having a form of experimental display (say, a display of some kind of energy-shift). This, then, is what an electron-configuration diagram provides. It provides not only the quantitative measures, but also the *shape* of any significant experimental manifestation, such as a spectral line or an impact on some dynamic-elastic medium.

Some questions about the reference of theoretical terms

First, it should be noted that Folse thinks Bohr inquired how particle-like and wave-like phenomena, when related to one another, may be seen as referring to one and the same definite micro-object. So, according to how Folse considers Bohr to have argued it is necessary to introduce a new perspective on the conditions of reference in the language of physics. I disagree with this because, in my interpretation of Bohr,

(a) there is no way in which one might comprehend certain *phenomena* without understanding which kinds of *objects* one was supposed to deal with. To think otherwise is an illusion that probably stems from the misconceived idea that "particles" or "waves" in some (phenomenal) sense count as perceptible *objects* in the full sense of the latter term to the effect that the ontology of atomic objects that gives rise to either particle-like or wave-like phenomena are thought to differ from their classical counterparts only by being more "complex" constructions out of phenomena.

(b) As I shall argue, Folse bases his interpretation of Bohr on an unacceptable notion of "empirical reference".

Here is a characteristic paragraph of Folse's:

> "To give the classical descriptive terms the empirical reference they must have if the [quantum] theory is to be confirmed by observation requires interacting with the system. But the quantum postulate entails that the interacting whole has an individuality which prohibits unambiguously

> defining the state of the system while it is being observed. Thus the physical conditions necessary for observation (interaction) are complementary to those necessary for defining the state of the system (isolation) ... Quantum theory is empirically confirmed by phenomena which are interpreted as physical interactions between the observing instruments and atomic systems. In representing these interactions, the observing system is described in terms referring to the observable properties of the phenomena i. e. in terms of 'classical concepts'." *(Folse 1985, p. 138)*

It seems as if what Folse calls "empirical reference" shall be secured in any context by means of our being able to *observe some properties of phenomena* in an indisputable manner. Folse further assumes that phenomena must be regarded as some sort of causal effect. He consequently faces the question of how to determine *which kinds of* physical interactions it is that, in given cases, give rise to certain effects. According to Folse, there is a straight answer to that question within classical physics that is due to the possibility of recognizing a kind of "correspondence" between the *states* of whatever interaction is in question (on the one hand) and the states of the *objects involved in the interaction* (on the other). This holds because the latter states can be regarded as being distinct from the states of the *instrument* by the means of which an observational interaction takes place. Consequently one can view the *properties* of the emergent phenomena as a *logical* representation of the states of the system observed. This method of describing phenomena as being associated with logically constructed property-spaces – a method that of course is utilized within the Hamiltonian conception of a phase-space – is an adequate means of representing the physical states that gives rise to the phenomena. The "definition" of such states are at one with the logic of their "observation", which implies that an observed *series* of phenomena can be seen to represent a possible physical change in the system investigated "directly". In line with this, Folse mentions the following two things as crucial for understanding how the knowledge acquired in classical physics was based on experimental evidence:

> "... the classical view that the two ideals of observation and definition could both be attained in a single description ... the goal of observation, a space-time description of the physical system ... [and] ... the goal of defining the state of a system through determining its causal effect on the observing system by means of conservation principles."
>
> *(Folse 1985, p. 258)*

Obviously, Folse's conception of the former ideal "of observation" hinges on the problem of how to *individuate* objects as candidates for a "description". In short, it is the difference between such things as waves and particles as "posits of description" which is in question. Folse wants to remind us how the individual objects referred to within a classical physical theory can be associated with a definite *anschauliches Vorstellung* – that is, with a definite spatio-temporal "form" which constitutes what Folse calls a phenomenal object. So this shall be regarded as a condition for tracing the dynamical properties of individual beings. This becomes the "ideal of definition" to the effect that the definition of the state of a given system, at a given space-time-point, conditions the possibility of calculating specific causal effects (of the behavior of the defined system) on the measuring instruments. Folse summarizes the ideal(s) of "classical" physics as follows:

Folse's conception of classical mechanics

> "In the classical mechanistic view there are
>
> (a) the theoretical representation of the classical mechanical state of the system defined in terms of the parameters of space, time, momentum, and energy,
>
> (b) the phenomenal object or system as observed characterized in terms of those observable properties which give direct empirical reference to some of the terms of the theoretical representation, and
>
> (c) an independent physical reality, characterized as an entity possessing those properties which are held to cause the observable properties of the phenomenal object and which in turn correspond to the terms that define the classical mechanical state in the theoretical representation of that state
>
> The first allows us to predict the characteristics the second, which in turn is regarded as the phenomenal effect the third. It is this reason which justifies describing the object as an independent reality in terms of the properties of the phenomenal object. This way of describing nature allowed one to 'picture' the state of a physical system as it exists isolated from any observation of it." *(Folse 1985, p. 252-3)*

Just as much as this explains the principles of physical, theoretical representation in classical contexts, Folse believes, just as much does it explain the impossibility of basing quantum physical representations on them. However, by the introduction of the concept of a "phenomenal object", Folse thinks, we manage to turn the tables and explain how, in fact, the quantum theory is based on a utilization of these very classical principles. Let me comment on these two points in succession:

As I see it, Folse's reconstruction of classical mechanics hinges on the claim 2) about *direct empirical reference*. Folse seems to explain the rationality of this claim by relating it to an idea of "atomism". As we shall see, Folse pictures the transition from classical mechanics to the quantum theory as a step between two kinds of "atomism", where we go from a classical kind that is based on some quite simple notion of "particulars" within a space-time framework, and then step to a kind of abstract "entity-realism".[215] Concerning this, I find it important to underscore a claim that lies behind the kind of classical "mechanical atomism" in question; namely the claim that the physical interaction between two particulars, between two "mechanical atoms", is in itself a physical *force*: The very interaction is conceived as an *occurrent "event"* that has a physical power attributed to it. The very interaction becomes a "cause" whose phenomenal effects are determined by "causal laws", the *form* of which is externally related to the *kind* of objects in question.

Thus, we have to do with a pre-Kantian notion of objects that a) are seen as "independent" of the *laws* characterizing both the substantiality and the kind of particularity of possible objects (i. e., laws characterizing the extensive and intensive magnitudes of possible objects); and that b) are independent of their possibility of *entering into* causally productive physical encounters with other objects.

[215] See below!

Consequently, this kind of atomism centers on the idea that *objects cause phenomena*; that is, it centers on the idea that the objective causal structure of the object has an essential link to a range of possible (observable) phenomena – in contrast to being only characterized by the *internal* possibilities of change within a physical configuration space. The focus is on the course of events, and not on the *Wechsel of Zustände*. It is as if there is a *physical process* that begins with an event, into which the object enters, and which ends with another event, into which enters a measuring device. Folse rightly says, that this concept of a causally productive object must be given up within the quantum theory.[216] I ask, with Kant, if it should ever have been employed?

Folse associates the notion of "classical objects" with the notion of *inherent properties*, because his concern primarily lies with the Lockean model of "primary properties". Now, the notion of a "primary" property was introduced by Locke as part of a complex issue concerning a possible way to distinguish various forms of human experience. As I understand Locke, there is a certain logic within the way in which some kinds of experience can be seen as independent of the conditions of the observing subject. Thus, it might be suggested that talk about "extension" is objective in a sense that talk about colors is not.

I would say that this, in itself, does not suggest anything in respect to the causal structure of any kind of beings. It only forms part of stipulating a requirement in respect to any adequate ontology. It expresses the principle that any adequate ontology has to correspond to some form of *epistemic realism*. In the days of Locke, the latter was naturally associated with a representational theory of perception, that again gave rise to the distinction between the nominal- and the real essences of things perceived.

So the question remains: Is there any necessary reason to associate a notion of mechanical particulars – characterized by a set of "inherent", causally productive properties – with the objects of classical physicists? I think not, nor does Folse give me any reason to think so. Not only does the Kantian reconstruction of Newtonian physics make such use of Locke quite superfluous; what's more – and as for example some of the works of Rom Harré make clear – there is quite another way to invoke the traditional Lockean Scheme that is far from rehearsing the ideologies of classical Mechanical Atomism.[217] The points 1) – 3), mentioned above that Folse sees as characterizing classical mechanics belong instead to philosophical mythology, and do not come from significant physical thought.

"Entity Realism" and the nature of physical experimentation

Folse rightly claims that his account is not based on a correspondence conception of truth. In fact, Folse is not willing to adopt any *epistemic* notion of truth, and this explains why Folse wants to make use of Ian Hacking's account of "entity realism".[218] Folse writes,

> "On Bohr's concept of reality we individuate the parts of the world not *qua* spatio-temporally 'separable' physical systems possessing properties apart from any interaction, but instead *qua* 'individual' interactions each

[216] (Folse 1985, p. 222).
[217] See, (Harré 1986)
[218] (Hacking 1983)

> of which is a whole phenomenon the description and prediction of which must be the goal of a successful physical theory". *(Folse 1987, p. 174)*

Here I think Folse misunderstands Bohr: The latter wanted to analyze the possible "well-formed" *single* phenomena. Folse talks about the individuation of *interactions* giving rise to phenomena. So Folse's aim in speaking of the "wholeness" of phenomena is to point out how it is possible to relate single phenomenal appearances to specific objects, so as to be able to claim there being an objective connectedness between different such phenomena; namely, by claiming that they are manifestations of the *same* object that appears "wholly" under different conditions. The unity of specific objects within their various physical conditions becomes, so to speak, an aspect of the "whole of the experimental arrangement".

For Folse, this implies that *if* we manage to restrict the use of given classical pictures such that this use aims, solely, at specifying a set of possible *forms of interactions* that involve a definite kind of object with given macroscopic apparata; *then* we shall have stipulated the *criteria of application* for these classical concepts in the given contexts. We can then further interpret the possibility of our having established a regular employment of a set of theoretical terms as constituting *criteria of identity* for the kind of objects in question. That, finally, is what it takes to establish a "complete description" for a range of phenomena.

However, Folse must be said to have misinterpreted Bohr. Bohrian phenomena are not Folsian, occurrent events in possession of causal powers. They are real, existing outcomes of given experiments. As such, they shall be regarded not *simply* as candidates for a possible recurrence of the items with which we are dealing, but regarded instead as repeatable human *actions*. In fact, Folse's quasi-Lockean strategy that takes into account the causal structure of possible *evidence* – and does so in order to reproduce the causal structure of reality as symbolized theoretically – collapses because he fails to consider the causal aspect of *our* manipulations. By contrast, Bohr was always careful to mention this as forming an essential aspect of a given experimental condition. This, in one stroke, challenges the Folsian conception of physical experimentation:

To perform a physical experiment is for Folse a matter of a) observing what happens under specified conditions with the theoretial aim of b) making sense of this observation as a description of the causal effects of the interaction between a physical object and the apparata involved in the experiment. This is in accordance with Folse's aim of regarding the framework of complementarity as implying reconciliation between an empiricist theory of knowledge and a semantic realistic position according to which the objectivity of descriptions of Nature is secured by a theory of reference. For Folse, the invocation of a causal account of b) makes it possible to transform the empirical reference involved in a) into the non-empirical reference of the terms used to denote theoretical entities in b). To me, and I will claim, for Bohr as well, this view corresponds to an untenable understanding of physical experimentation since it involves making a too sharp division between (a) the different aspects of human activity, (b) the "arrangement" of the experimental set up, (c) the "observation" of "what happens", and (d) the "description" of the latter. Instead, one ought to see observation as a structured, continuing *human* activity, involving doings, reports, and sayings.

What is so special about quantum physics?

So my remarks in the preceeding paragraphs add to my discussion in the former section of this chapter. *If* it is part of the epistemological lesson of the quantum theory that one has to reject **MR**, **PP** and **MM**, *then* ought it not be interesting to compare this "lesson" with Kant's?[219] Indeed, I find that there is every reason to claim that *all* of the philosophical lessons that quantum physics, according to Folse, ought to teach us, have already been taught by Kant. In other words, they are already adequately associated with the actual practice of *classical* physics. Consequently, I find it difficult to endorse the notion of independent objects, carrying properties "inherently" that, according to Folse, characterizes classical physical thought, and that – in the implicit sense that I have accounted for above – for Folse, still forms the backbone of quantum physical experimental investigations.

My reconstruction of the argument of his book shows how that argument is faithful to the claim he makes that Bohr launched the framework of complementarity in order to search for a new kind of empirical realism – an empirical realism suited to form an alliance with an atomist, ontic realism.[220] According to Folse, the framework of complementarity formed part of a search for a new framework, a new alliance between **OR**, **ER**.

However, this raises the question in what way quantum physics is something special in this respect? If we cannot account for the apparent radical character of quantum physics without telling the complex story of Folse, about revision of ontology and semantics, *what* then are we licensed to say, according to Folse, about the *rationality of classical* theory in these respects. Neither mechanical atomism, nor Newtonian physics, nor the character of "classical theory" remained in one definite form. It was a long and winding road that led from the Gallileo transformation concerning relative mechanical motions – crossing Newtonian laws as well as Leibnizian forces – and that underwent transformations within the various schemes of D'Alembert, Lagrange, and Hamilton, in order, finally, to blossom once more within the Lorentz formulation of electrodynamics. How can the considerations concerning "complementarity" ignore the characteristic threads and changes of *this* journey? Is there no important way in which the latter idea can be understood as a *generalization* of productive physical-metaphysical thought. As I have argued in detail above, it makes little philosophical sense to conceive of the framework of complementarity in abstraction from the long history of the principles of mechanics.

Relearning the conditions of reference

Turning once again to the decisive point 2) above in Folse's reconstruction of classical mechanics – to the dogma of the possibility of *direct empirical reference* – the following question must come to the fore: *How* are we, according to Folse, to conceive of the objects referred to in classical physics as being *causes* of phenomena? Folse's suggestion was that the referents of theoretical terms cause some *phenomenal* objects to manifest some observable properties whose effects can be described within the traditional causal, spatio-temporal framework of ordinary contexts. The possibility of conceiving the referents of theoretical terms in this fashion follows from the stipulation that we can

[219] Using the abbreviations of Folse as listed above.

[220] As the quote above says, and as Folse had stressed before that, see (Folse 1985, p. 235-6).

ascribe inherent causal properties to the referents. This conception of reference within classical physical theory now brings us to the core of Folse's interpretation Bohr:

If the (new) theoretical notions of the quantum theory shall be ascribed a definite reference (whatever that means), then we will have to *relearn* the conditions of application of a range of (classical) concepts that are used in the description of (classical) phenomena, such that the restricted, or altered, use of those concepts makes it clear how physical phenomena, thus described, "involve" determinate *objects*. Folse explains the possibility of achieving this – the possibility of establishing the *in*direct reference of the theoretical notions within the quantum theory – as follows:

> "Bohr regarded the uncertainty principle as directly expressing the formal consequence of ... [the] ... complementarity between the mode of space-time co-ordination and the mode of description of causality ... [however] Insofar as the formalism does allow predictions of phenomena described in terms of ... classical parameters, these parameters correspond to properties that are just as truly properties of the object described as they were classically. But Bohr does not take this fact as implying that these properties also belong to an object as it exists apart from such observational interactions. Instead, complementarity holds that the classical concepts refer to properties that belong only to a *phenomenal object*, the object as it is observed ... the use of the classical terms to describe atomic systems as 'particles' or 'waves' interacting with the measuring apparatus refers not to a concrete reality but to an abstraction which is necessary for describing the phenomena as interactions between the measuring agencies and the physical systems described by quantum theory."
>
> *(Folse 1985, p. 138-9)*

Folse will have us ask questions like this: "Is it possible, by making use of some well-known forms of *Anschauliches Vorstellungen*, to re-shape our account of the way in which physical interactions may be regarded as 'observations'?" This is like asking; "can we make *new sense* of certain forms of evidence" in respect to various experimental situations, such that we will be able to *describe* whatever is detected *as constituting* a new kind of (Fregean) sense?" How can the well-known forms of evidence be associated with a *new kind of presentation* of objects referred to within physical theoretical thought? The positive answer to such questions supposedly secures the possibility of our referring to new realms of experience. However, I don't think Bohr raised this issue at all!

Folse and I agree that the necessity of a restricted use of classical concepts in quantum physics has to do with stipulating the *causal* character of the objects within a new physical realm. Folse considers this to mean that we shall stipulate "how the atomic object, when encountered in specific observing circumstances, will appear". This is to him what characterizes theoretical knowledge.[221] Consequently, he would say, an important task of a theoretical science is to develop a way of *describing encounters*, such that observable well-known forms of physical effects can be systematically, but not necessarily pictorially, related to properties ascribable to a range of objects observed. It follows that the restriction that the observable properties shall be associated with *causally* interacting properties is not part of a restriction of the possible *content* of

[221] (Folse 1985, p. 244, 259).

applications of the theoretical formalism in question. It only helps stipulate the *criteria* for the description of the *observable features* of the set up, such that one might view the stipulations as specifying criteria for the application of certain classical concepts as part of an account of *how emerging phenomena may count as evidence* in respect to the justification of the theoretical formula in question.

To me this is simply the reverse of what I consider Bohr's position. According to my interpretation, one should ask instead "*what might possibly be* the forms of evidence in respect to certain kinds of statements?" The justification of any statement presupposes our having already taken certain observations and analytical relations for granted. However, this crucial inter-dependence between what is observable and what is a possible content of given statements about non-observable items does *not* hinge on certain a priori and intuitive forms of presentation. There are no pre-given schemata for a Fregean Sense. Different kinds of objects may be presented and "observed" in all sorts of ways. It was here – concerning the feature of observability – that the quantum theory was particularly radical, not concerning the feature of non-observables. The quantum theory does not disclose a strange, hidden realm of things whose manifestations are quite ordinary. Instead, the quantum theory makes an unexpected, real, order visible in the experimental world of a physical laboratory.

Folse's conception of how emerging phenomena may count as evidence is part of an account of how a new kind of epistemic realism lends support to the "entity realism" that, as we have seen, Folse ascribes to Bohr, and thus also to an account of how the concept of causality may still, within quantum physics, function as a link between 'epistemic realism' and 'entity realism'.[222] Folse writes,

> "Bohr's realism is not concerned with arguing the ontological thesis of entity realism; this position is one which he simply *assumes* as established experimentally. His problem is this: given that there really are atomic systems, how can we alter our understanding of the use of concepts in describing nature to justify claiming that the quantum theoretical account provides knowledge of such entities ... In its most general form, Bohr's new version of epistemic realism could be expressed as follows: acceptance of a scientific theory as providing a complete description of a specified range of phenomena warrants holding that theory provides *knowledge* about the unobserved entities which cause these phenomena that form the empirical evidence for the theory." *(Folse 1987, p. 167)*

The premise on which Folse draws these conclusions is, as we have seen, that genuine "scientific" or "theoretical" knowledge *must* assume the form of knowing the causal structure of the kind of *appearances* that cause observable effects on apparatus.

I ask: Although Folse explicitly criticized the classical *representational account of experience* has he not maintained the primary *structural aspects* of that account? Lockean perceptions mediate the causal encounters between external objects and our sense organs, on the one hand, and the conceptualized awareness of experiences. Similarly Folse's "phenomenal objects" mediate the "encounters" between atomic objects and observing instruments (on the one hand) and the understanding of experienced features of physical change on / in apparatus (on the other). So whereas Folse claims Bohr to have established an alternative *model* of human experience that breaks with classical

[222] (Folse 1987, p. 163)

epistemic realism, I would say instead, that he has launched a new version of what is essentially the same model.[223]

5.4 Jan Faye's interpretation of Bohr as a Semantic Conceptualist

Faye on conceptualism

Jan Faye is honest and explicit about how he considers Bohr a proponent of a general philosophical position, that of conceptualism – the third, or middle, position between nominalism and conceptual realism. Faye's modernized version turns out to be a unique mixture between Michael Dummett's idea of semantic anti-realism and views held by the danish philosopher Harald Høffding, whose philosophical position, as Faye himself puts it, already is very eclectic. Høffding blended pragmatism, Kantianism, empiriscism, and naturalism so as to give rise to, what Faye calls, an *objective anti-realism* – a position according to which a) there is no gap between epistemology and its ontological implications – even if b) we can establish objective truth about an independently existing reality. However, we can do so c) only relative to what are the subjective grounds for producing truth-valued claims about that reality. These subjective grounds have on the one hand to do with a priori forms that condition the possible well-defined objective content of any experience. However, these forms are on the other hand a kind of evolutionary product that may have changed in the course of history. In the light of this general conceptualist perspective, Faye formulates a kind of *Manifesto* in which he distinguishes between the following kinds of concepts:

> "First, there are *the ordinary knowledge-determining concepts which are entrenched in the description of our most basic experiences*. To this group belongs concepts like 'space', 'time', 'cause', 'event', 'thing', 'animal', 'Man', 'action' etc. No change in the scientific conceptual system can make the use of these concepts senseless. Then there are *other, more scientific, concepts which form part of a theoretical precision of the ordinary concepts*, and which determines the empirical content of scientific theories. To this group belongs concepts like 'mass', 'force', 'momentum', 'energy', 'charge' etc. Finally, there are *theoretical concepts the meaning of which is fully fixed by the theoretical structure* they belong to, and the use of which therefore stands and falls with the question of whether the description of new scientific discoveries can be fitted into this structure. The use of the concepts belonging to the former two groups determine the conditions under which it is possible to objectively describe both ordinary and scientific experiences. The use of these concepts is a condition for the possibility of distinguishing between subjective and objective experiences, as for the possibility of rational goal-directed action. The important thing concerning these empirically based concepts is that people do possess objective experience if what is given to the knowing subject can be described in terms of these concepts."
>
> *(Faye 1993, p. 45-6, italics mine, my translation from Danish)*

I find that this tripartation of possible concepts is rooted in a particular ontology. As regards the first kind of concepts, I would say, there is no such "pragmatic a priori" set

[223] (Folse 1987, p. 166).

of concepts that both conditions the content of ordinary experience and forms the basis for our distinguishing between subjective and objective experiences. Second, I think, there is no special set of "scientific" concepts corresponding to a basic "precision" that characterizes everyday concepts; as if such features as "mass", "charge", or "power" must be seen as a determinate, or "precise" features of a causal, substantial reality, with which we are acquainted in ordinary life. Certainly, there are no special "theoretical concepts" (as if "fields" and "spin" refer to some more abstract feature of reality than does "chair" or "charge", or as if the structure of fields has a more complex semantic background than the structure of ordinary things and classical substances. In short, I think that there is no reason to turn the history of the development of scientific-conceptual thought into a history concerning a step-wise *ontological* development.

The kind of objectivity with which Faye is concerned relates especially to the issue of the *determinedness of the content of experience*.[224] In this respect, Faye considers himself as following strictly in Frege's footsteps. He seems to think that Frege contributed essentially to a reformulation of the conceptualist program. *Fregean sense* thus become, as it were, the universal form for any objective content of experience to conform to. Consequently, the conceptualist seems to have got a new powerful weapon in his hand; because the *realm of reference* is set free from metaphysical dogma, while we uphold the universal form secured by the determinateness of Fregean sense. The actually possible structure of thought shall no longer be seen as essentially expressing the logically possible structures of thought that we can establish in *new* realms of reference, the existence of which we may not yet be able to grasp.

Such a view must be criticized for two principal reasons. First, there is a problem about viewing the Fregean notion of sense as expressing a *universal* standard of *cognitive* determinateness; although it may be a *semantic* standard in some sense. Second, one may ask how the expansion of the use of certain scientific concepts in order to cover a new realm of reference may be regarded as a involving a "precision" of these concepts.

Faye considers nomological laws as corresponding to semantic rules that guide and instruct our use of theoretical concepts in the "description of experimental observations".[225] To Faye, it is important that we manage to establish more and more adequate semantic rules that both (1) guide the way we, at any actual moment within the development of a kind of theory, describe and relate observations lawfully, and (2) further a kind of scientific progress. Gradually, Faye thinks, a new and more complete *logic* emerges that frames our scientific descriptions more adequately. This "logic" is not a *mirror* of an independent reality, Faye says. However, because the invocation of a scientific language that has a determinate structure and logic is *necessary* in order to obtain certain *determinate* objective experiences of a certain object, we are accordingly entitled to claim that we have discovered, nothing less than, *the language of reality itself*.[226] Faye thus makes the following claim concerning this set of pragmatic a priori concepts:

> "... the concepts which are necessary for the possibility of scientific experience ... have always been with us. They did not just evolve when Man

[224] The notion of 'objectivity', adapted by Faye is the one proposed by Crispin Wright in his book *Wittgenstein on the Foundations of Mathematics*, the notion of 'investigation-independence'.
[225] (Faye 1993, p. 45).
[226] (Faye 1994, p. 46).

began thinking systematically about life and Nature. They were already formed when we began orientating ourselves in the world, long before our predecessors developed any real self-understanding. Those kinds of concepts are a condition for the possibility of distinguishing between subjective and objective experience, and for the possibility of rational action and thought. You might say, that our human abilities as rational and knowing Beings entirely rest on the use of these concepts. Of course, a better understanding of the logic and meaning of those concepts is closely tied up with a logical analysis of the conditions for the possibility of experience, including scientific experience. That is the job of the philosopher."

(Faye 1989, p. 122, my translation)

It is clear that Faye (when it comes to it) defends a form of empiricism. The fundamental concepts in Faye's classification are seen as "pragmatic a priori" – that is, as "entrenched" in our ordinary dealings with Nature – in a way, though, that is to some extent open to historical change. Faye must therefore be said to endorse an empiricist account of the way in which some pre-given concepts – each of which as such expresses a fundamental feature of our Human Nature – constantly acquire new "meanings" within the *one* language used by *any* (ordinary) user of language. This amounts to an empiricist view because the basic line of thought is that human knowledge is something that is gradually build up thanks to the possibilities of cognitive development that are embodied in our Human Nature. Human experiences are triggered and become gradually reshaped through our interaction with other naturally existing things, whose natural causal dispositions accordingly constrain our possible cognitive development.

Thus, there is a certain pre-given "logic" within the possibility of natural development; a logic that may itself be gradually uncovered. This is the "job of the philosopher", while the scientist must stick to the task of developing scientific and theoretical concepts about special realms within Reality. To me, this expresses an ontology as well as an epistemology that should hardly be ascribed to any philosopher within the Helmholtzian tradition of theoretical physics, including Bohr.

Faye's use of Murdoch; The Indefinability Thesis and The Strong Meaning-condition

Faye's book may be read as a series of formulations of one and the same thesis about the indefinability of the states of objects of experience, beginning with Høffding's vague ideas about continuity, followed by the early Bohr's interpretation of Heisenberg's Indeterminacy Relations and finally giving rise to a strict semantic formulation of the thesis. Faye introduces Bohr's early formulation of the thesis as follows:

> "... Bohr believed that the discovery of the quantum of action had brought to an end the sharp separation between object and instrument since it implies that the exact simultaneous position and momentum of an object cannot be measured. But Bohr also held that an object cannot meaningfully be said to possess these exact values simultaneously. I shall, following Murdoch, call the latter claim Bohr's *indefinability thesis*."
>
> *(Faye 1991, p. 168)*

The indefinability thesis – which Faye adopts from (Murdoch 1985) – involves the requirement that the *states* of the subject and the *states* of the objects be specified, although the thesis underscores the *non*-separability of these two kinds of state. According to Faye, the thesis forms part of the early Bohr's interpretation of the quantum theory. However, after the advent of the EPR encounter, Bohr advanced a semantic reformulation of the thesis. Faye believes, that was based on the following background:

> "Quantum mechanics, according to Bohr, radically changed the situation in which it is meaningful to attribute classical state-defining properties. Because of the indivisibility of the quantum of action, and the following non-separability of the state of the quantum object and the state of the

> measuring instrument, the verifiability conditions under which we are justified in ascribing attributes to an atomic system are different from what they would be in classical physics. Owing to the quantum of action and the indeterministic nature of quantum phenomena, it is no longer possible to ascribe simultaneously to a system properties which were both considered necessary for a full description in classical physics." *(Faye 1994, p. 107)*

The core of the claim made here is that the *verifiability* conditions for state-ascriptions within quantum physics differs from those of classical physics. Faye shifts between talking about state-ascriptions and ascriptions of *properties*. In the latter terminology, the indefinability thesis becomes part of an argument for the existence of relative properties. The argument is associated with the so-called "strong meaning condition" that Faye also adopts from Murdoch's reading of Bohr. So the core of Faye's exposition is, what he takes to be, two main ideas of Dummett. Faye explains the strong meaning condition as follows:

> "It is quite obvious that Bohr supports the strong meaning condition, as Murdoch calls it. The mere presence of the measuring instrument is only a necessary condition for the meaningful ascribability of position or momentum to the atomic object. What is also needed for a meaningful application, according to Bohr, is that measurements are made. Indeed if no measurements take place there can be no phenomenon to provide us with experience on the basis of which we may ascribe the determinate value of a selected parameter to a particle. The type of measuring instrument determines only the kind of concept which may be meaningfully applied if acts of measurements are actually performed." *(Faye 1991, p. 194)*

The strong meaning condition is only justified if we presuppose that the meaning of theoretical terms depends on an actual application of various instruments – "the mere presence of measuring instruments is not enough".[227] This points to an account of how the reference to a certain frame grounds the possibility of ascribing a determinate sense to the readings of measuring instruments in given situations. Thus, the strong meaning condition hinges on the requirement that "acts of measurement are performed". This is, Faye thinks, what explains the necessity of specifying atomic objects in terms of "relational properties":

> "Bohr argued, ... incompatible attributes can meaningfully be predicated of the system only when there exists an actual measurement with respect to a certain experimental set-up. In this way incompatible attributes are *relational* properties which manifest themselves in connection with the interaction between the observed system and the observing system."
> *(Faye 1994, p. 107)*

Relational properties are properties that are only manifest *within observational interactions*, to use Folse's phrase. They are properties that are exhibited by quantum objects in observational encounters, and only in such. Now, the previous three quotations, in sum, specify the character of what can be regarded as the "content" of individual phenomena. They specify, as Folse would put it, how observations are informations. For

[227] (Faye 1991, p. 195)

Folse, this corresponds to the question of how observations are informations about objects. In a sense, Faye wants to avoid precisely this reformulation, since Faye thinks that the ability to recognize a certain kind of logical interrelation between individual quantum phenomena is independent of, and prior to, the ability to *refer* to objects of experience. This is one of the primary principles in Faye's semantic discussion.

So, I want to inquire into Faye's notion of the "content" of individual phenomena. Faye claims:

> "Bohr's developed view of complementarity can briefly be put as follows: (a) conditions for application of scientific concepts are determined by the experimental situation; (b) experiments can be unambiguously described only in terms of classical concepts supplemented with ordinary language; (c) the experimental situation in quantum mechanics is different from how it is in classical mechanics because the application of a classical state-defining concept in one context simultaneously precludes the use of another classical state-defining concept which, in a different context, is equally necessary for our understanding of the phenomena."
>
> *(Faye 1994, p. 98)*

Here, note Faye's claim that the assertability-conditions of different concepts can exclude one another when the concepts are invoked simultaneously and contextually. Faye wants to link this possibility to Bohr's view concerning the complementary character of kinematical and dynamical variables. Faye therefore suggests that Heisenberg's notion of indeterminacy refers to an indeterminacy in the *meaning* of ascriptions of position and momentum – and thus also in the description of the experience of quantum phenomena. So Faye continues,

> "Bohr's arguments for these three key elements of his position can also be summarized briefly: (a) is true because scientific concepts can be used descriptively only if their application is connected with recognizable situations. A fixation of their application to what is observable is a precondition for meaningful and unambiguous communication. (b) is true because any meaningful and unambiguous communication requires a distinction between 'subject' and 'object' in such a way that we can refer to objects without referring to our subjective representation of these objects; and the use of classical concepts and ordinary language reflects the subject-object distinction by yielding a causal space-time description of the object. And finally, (c) is true owing to the discovery of the quantum of action and the associated non-separability between the behavior of quantum object and its interaction with measuring devices." *(Faye 1994, p. 98)*

These explanations are supposed to elucidate Bohr's post-EPR, semantic position. Accordingly, the semantic argument of Faye includes the following view: The use of classical concepts that enter into both kinematical and dynamical descriptions of the state of quantum physical systems will have an ambiguous application in such descriptions unless specific conditions are fixed, namely conditions for the possibility for the concepts to have an objective reference. However, such reference can only be to phenomena. First a *logical* combination of phenomena constitutes the basis for meaningfully applying the concept of "an atomic object". The possibility of assessing "the reality" (or

"objective existence") of such objects is thereby secured. In conclusion, Faye has formulated requirements that are part of the *meaning*-conditions for ascriptions of physical properties to atomic objects on the basis of experimental evidence. I have tried to show how the semantic position outlined by Faye is quite complex. Especially, in order to have an overview of his account, one must carefully distinguish the many kinds of linguistic conditions involved this account. These are primarily:

– *conditions for the satisfaction of applicability-conditions of classical concepts:*

> "The conditions for the applicability of classical state concepts change from classical mechanics to quantum mechanics in the sense that in quantum mechanics the satisfaction of these conditions consists of some *actual* verification, owing to the fact that the course of the atomic object in space and time cannot be subdivided, while in classical mechanics the satisfaction is connected to some *possible* verification." *(Faye 1991, p. 227)*

– *conditions of meaning in order to determine the reference of theoretical, singular terms:*

> "the meaning of the term 'atomic object' is not related to the satisfaction of the actual conditions of verification. To understand the term 'atomic object' in a given experimental statement is indeed to know how the occurrence of this term in the sentence contributes to the determination of the truth condition of the sentence ... That is to say, the concept of atomic object is defined by all the possible relations which connect it to the concept of observables within quantum theory." *(Faye 1991, p. 228)*

– *conditions of derivability from theoretical formula as part of the meaning-condition for experimental statements:*

> "part of the meaning of an experimental statement, in which a particular property is predicated of an atomic object as observed or in which the result of one measurement is connected with the result of a consequent measurement, *qua* being described as recordings of one and the same object, consists in its condition of derivability from the formalism. This means that experimental statements attributing properties to the atomic object have to be deduciable from the quantum theory if they are to be counted as having a truth-value. We may understand the meaning of such experimental statements only if we are able to point to a procedure in which they can be derived from a consistent theory. So the correct use of experimental sentences is in part determined by a theory for which we have strong grounds for its empirical adequacy in virtue of its predictive force." *(Faye 1991, p. 228)*

– *conditions for the satisfaction of truth-conditions of descriptive statements:*

> "A particular descriptive statement in physics predicting a certain attribute of an object is claimed to be true if, and only if (1) the satisfaction of the experimental conditions for asserting that sentence, are, or can be, empirically confirmed." *(Faye 1991, p. 226)*

These criteria togetther constitute the semantic core of Faye's reformulation of Bohr's position.[228] Faye must be credited for having successfully made clear two things: First, there are many good reasons for exposing Bohr's framework of complementarity in semantic Fregean terms. Second, an adequate account of Bohrian semantics might well include the themes and distinctions proposed by Michael Dummett. However, I do not think that Faye sees correctly how, and where, Bohr's thought is semantic, nor do I think that Faye faithfully reproduces the Fregean-Dummettian approach.

Objective anti-realism

So I want to give a more detailed outline of the way in which, I believe, Faye has adapted the following features of a Dummettian semantic conception of philosophy. First, there is the general division of all descriptive statements into three classes, those that are effectively decidable, those that are decidable only by indirect means – say, by a derivability procedure, whereby the sentences of this class can be related to sentences of the former class, – and finally "undecidable sentences". Descriptions, in classical terms, of an experimental set-up are effectively decidable, Faye thinks. The framework of complementarity therefore has two aims; to account for the meaning-conditions of experimental statements, first, by accounting for the assertability-conditions of the theoretical terms that enter into the description of individual phenomena, and second by accounting for the derivability-conditions of these experimental statements corresponding to theoretical formula.

To me, this is where Faye isn't faithful to the Dummettian account. Dummett certainly does not regard the division between decidable (effectively or indirectly) and undecidable sentences as universal; because we should always be able to give an account of *how* such a division plays a certain linguistic role within a specific linguistic practice in accordance with a particular elaborate semantic theory. Thus, not only will it depend on the context *what it means* for a sentence to be "effectively decidable" or "indirectly decidable", there may also be different roles in the various linguistic practices for sentences of the two forms to play. That all depends on how these linguistic practices function concerning the way in which we orientate ourselves in respect to the realms of reference involved. This is precisely what Dummett calls "a semantic theory", associated with a canonical logical syntax for the given language, shall make clear. I discuss this further below.

[228] One should note that both a "criterion of reality", in respect to atomic objects, and a "criterion of objectivity" (in respect to quantum physical state-descriptions) is implied by the account. I think that it is clear that each of these criteria are analogous to the original Høffdian ones that Faye presents at the outset of his book (this note was integrated in the main text in the reviewed version of my dissertation).

Dummett against global (objective) anti-realism

In short, Dummet cannot be said to have advocated a *global* form of anti-realism, as ascribed to him by Faye. Dummett is actually very clear on this issue,

> "This global anti-realism appears as a single unitary thesis, to the effect that a justificationist theory of meaning should supplant the generally received truth-conditional theory, on the ground that the obscurity of the general notion of a grasp of the condition for a statement to be true inhibits the received theory from yielding a plausible account of our understanding of language and our mastery of its use. The matter is then to be resolved by a face-to-face combat between this general anti-realist theory of meaning and the truth-conditional theory, based on two-valued classical semantics, espoused by realists ... this way of viewing the matter seems to me seriously mistaken." *(Dummett 1994, p. 472-3)*

Dummett goes on to explain that it doesn't make sense to talk about "applying" a general "anti-realist" outlook. For each different context analyzed, one has to work out a meaning-theory in terms of which, alone, specific questions about the concepts of "truth" and "meaning" can be formulated. Thus, Dummett explains, the general linguistic philosophy ...

> "... remains, for me, a research programme. Justificationist and truth-conditional meaning-theories do not stand opposed to one another as rivals. Neither is a worked-out theory: the justificationist principle is an unavoidable starting point, the truth-conditional one no more than a hoped for goal." *(Dummett 1994, p. 473-4)*

In the light of all this, Faye should recognize that it doesn't make sense to discuss a *global kind of* realism or anti-realism. Now, if Faye were to respond that he never proposed to do this, the serious question to ask him will be this: If meaning-theories are contextually directed to specific realms of reference, say, "atomic objects" and *if* Faye is right in ascribing an anti-realistic meaning-theory to the linguistic practices of quantum physics; then how shall this meaning-theoretical account relate to *what may well require a totally different* meaning-theoretical account of *each* of the so-called "classical" physical domains. For as Dummett says;

> "As long as the disputes over realism concerning different subject-matters are treated as distinct, there is no reason to presume that all are to be resolved in the same sense: a realist about the physical world is under no compulsion to be a realist about mathematics or about mental events and states." *(Dummett 1994, p. 472)*

And this, we add, goes for the many different fields of physical inquiry as well. Now, in order supply my critique of Faye with some substantive claims, I want to explain Dummett's later idea of a linguistic philosophy in some detail:

Dummett's linguistic philosophy, revisited

Dummett has for long tried to present his entire research program as an effort to develop "a theory of meaning". He has gradually elaborated a basic scheme in terms of which this "theory" splits into four components[229]

(a) The Theory of Sense
(b) logical theory
(c) semantic theory
(d) meaning-theories

One may crudely describe the way in which these components enter into Dummett's research program as follows: We look at given linguistic practices and try to associate any such with the implicit application of a logical theory. The primary case – Frege's – is to understand the practice of arithmetic as corresponding to an application of first and second order predicate logic. This understanding is then interpreted as involving a semantic theory, first of all a theory of reference based on a truth-functional theory of meaning (i. e. a "realist semantics"). These two steps together make up a middle level of philosophical analysis; a level that is supposed to form a bridge to both an upper and a lower level set of questions, to a Theory of Sense and meaning-theory, respectively.

The latter two theories are really meant to represent the same linguistic practice, only in different perspectives. A *meaning-theory* is a theoretical representation of the more or less implicit mastery of given fragments of the entire use of language that any competent individual speaker of the language may possess. The Theory of Sense, however, is more the philosopher's attempt to formulate as adequately and systematically as possible how the practice investigated may be recognized as involving special, but coherent and rational forms of *thought*. So one of the crucial ideas of Dummett's is the view that these two models, a Theory of Sense and a meaning-theory, can be established and assessed only if we have first recognized which semantic and logical theories corresponds to the models proposed.

The *compositional* view of the use of language lies at the heart of these considerations. That again leads to a certain semantic conception of human understanding; the idea that the understanding of the content of thought is mediated, if not constituted, by the conscious grasp of syntactic structure. Dummett even calls this "the fundamental thesis of linguistic philosophy" to the effect that there is no gap between what it is to posses a given concept and what it is to be able to use a certain linguistic expression in one's grasp of that concept. In other words the grasp of the concept does not come about before – and isn't externally related to – the ability to use the predicate in question. Consequently, Dummett points to these fundamental questions:[230]

> – what is it to think *in words*?
> – what is the relation between the understanding of words and the meaning of determinate thoughts?
> – what is the relation between the understanding of words and our knowledge of the meaning of thoughts?

[229] Here, I disregard the Fregean tripartaion between a Theory of Meaning, a Theory of Force, and a Theory of Color, and refer only to the first of these three dimensions of, what I would call, the entire Theory of Language.
[230] (Dummett 1986)

One should recognize some of the philosophical positions that are implicitly criticized by advancing precisely these three questions.[231] First, we are about to put aside all those ontological views that cannot be associated with any clear semantic theory, because we are reminded that an ontology, when it comes to it, is not a kind of world-picture. Instead, it is but a coherent perspective that unfolds itself within given conceptual practices. Thus, to mention an important example of this; there is no way in which one can conceive of a segment of reality as composed of "particulars" if one has no adequate semantic account at hand of the meaningful use of proper names, predicates, and relations. The semantic structure corresponding to the way in which the use of linguistic sentences unfolds constitutes the only means in term of which we can claim, at all, that the practice under scrutiny involves our possessing a certain conceptual grasp of things. This explains the need for advancing a semantic theory in terms of the notions of (Fregean) sense and reference.

Second, we can claim to possess this grasp only in so far as we can be said to articulate the significant structures more or less reflectively; thus the need for viewing the concept of sentential *meaning* as basic. This concept plays a role in the *philosophy* of Frege and Dummett that is analogous to the role of *Erscheinungen* in the Kantian epistemological system, or to the *Sachverhalten* in the Tractarian system proposed by the early Wittgenstein. Whereas the notion of reference (or in general, semantic value) embodies the idea of how to catch on to the reality of things by linguistic means, the notion of sense points instead to the cognitive, and thus subjective, possibility that human beings are able to both fix and entertain the thoughts they produce by means of a certain set of uniform linguistic acts.

In sum, the middle level of semantic analysis both aims at criticizing the analysis of conciousness on which many forms of epistemology were based, and aims at functioning within epistemology somehow in analogy to the role of certain mental structures within classical epistemology. Some lingustic philosophers are critical of this. But to Dummett it is not only important to associate an adequate semantics with some epistemological considerations but also important to recognize this epistemological component of the theory as forming part of a critical metaphysical view; say, about the ontological status of numbers, of past events, or of the structures described by theoretical physics.

This is what makes the elaboration of The Theory of *Sense* the basic aim, or agenda, of philosophy. A complete Theory of Sense, like Frege's, shall be sharply distinguished from any of the various meaning-theories with which it might be in accordance. The Theory of Sense is supposed to relate to the *whole* of our linguistic practice, whereas meaning-theories are supposed only to represent the linguistic practice concerning a given fragment of our entire language. Two meaning-theories may differ very much in principle – say, the theory adequately representing the use of quantum physical expressions, and the theory adequately representing the ordinary practice of describing tables and chairs; yet these two meaning-theories may both be in accordance with the same Theory of Sense. This is the reason why we can both elaborate a general Theory of Sense, of a Fregean kind, and still leave open the issue of how to associate any meaning-theory with a realist or anti-realist semantics. Consequently, what we must first set ourselves to do is to try to grasp which kind of uniformity and universality a complete Theory of Sense must have in order that it (a) leaves open the issue of real-

[231] Here I omit a couple of superfluous remarks of the reviewed version of my dissertation.

ism, and (b) also provides us with certain fruitful means in terms of which to formulate such issues in relation to definite contexts.

Importantly, Dummett has adapted a phrase of P. F. Strawson, the notion of "feature-dependence". The idea associated with this notion is that the ongoing use of certain expressions implies that the speaker in a sense can be said to trace a certain feature of reality. Thus emerges the idea that there is something called the objective conditions of application of given expressions that is constituted – not only by a world/word link as seen in a third person perspective – but also by a world/person relation, such as is involved in identifying, recognizing, or individuating something. The idea is old indeed. It is for example very close to Locke's idea of nominal essences as well to Aristotles' idea of a category. As I see it, the Strawsonian notion of feature-dependence is understood by Dummett as characterizing an important kind of *constraint* in respect to the possible ways in which we can establish a regular use of certain expressions.[232]

To Dummett, it is important to point out how we are *not* to conceive of this world/person link. It is important that we cannot a priorily describe it as a matter of tracing "particulars" or of recognising "universals". Dummett wants to rid us of the idea that our application of linguistic expressions is based on a kind of uniform feature-dependence in a way which does not form part of a *semantic* analysis. There is, Dummmet says, neither a uniform kind of "predication", nor of "naming", nor of "individuating". What it means for us to perform these kinds of speach act may differ from context to context. This marks the difference between a Fregean semantics and a semantics of a traditional kind (to which belongs the semantics of Strawson, according to Dummett).

Consequently, we must point to a strict semantic uniformity within the conditions of application of given expressions. This is precisely what the Fregean notions of sense and reference makes possible, Dummett thinks. If we systematically inquire how the use of given expressions contribute to the sentences of which they may form part, we establish a kind of analysis that will be adequate to the word/world link and the world/person link at the same time. Thus, what is missing in most semantic accounts, Dummett thinks, is an effort to represent the *systematic* features our linguistic practices. This may seem odd, given that Strawson and many other philosophers of language have proposed to do just this – to systematically reconstruct or represent given linguistic practices. But these accounts leave something important out of consideration. They forget to inquire what is the *point* of there being certain systematic features of our various linguistic practices.[233]

The lesson of intuitionistic mathematics and logic

On this, Dummett writes;

> "We cannot hope to achieve any illumination by taking the notion of truth as given: we have to *win through* to that notion, if we can, and in

[232] Here I omit an idle sentence of the reviewed version of my dissertation.

[233] This is indeed a Kantian consideration concerning the regulative principle of "the idea of system". The question has to be asked what it is that you have if you have managed to represent a given tradition of thought in a logical, a formal, or a systematic way. Because we have to learn to see that there can never be a determinate and final answer to that question. In Fregean terms, the idea of a certain kind of deductive, analytical feature of some mathematical practice can never fully constitute a model for all forms of deductive or systematic thought.

what form we can.

The notion of truth is not immediately given by the mere existence of a linguistic practice involving utterances of an assortic character. That is sufficiently shown by the possibility, demonstrated by the intuitionist's way of construing mathematical statements in general, of interpreting a large range of statements ... as declarations rather than affirmations, that is, as embodying objective claims but not having independent truth-conditions."

(Dummett 1994, p. 474)

When it comes to analyze a given linguistic practice, we can never a priorily claim to know how, and if at all, there is a certain truth-concept whose application within the practice in question *eo ipso* represents in what sense the use of assertoric statements constitutes an objective description of reality. The world-word link cannot a apriorily be ascribed a certain uniform semantic character. So why is it that there may still be something general to learn from the possibility of an intuitionistic, or proof-theoretic, account of the formal deductive practices of mathematics? The answer to this question has two sides to it, a) the special *epistemic* character of the stipulation of logical symbols according to the intuitionistic account, and b) the relation between a semantics for a formal language and a semantics for a fragment of natural language, respectively. Concerning the first point a), Dummett writes,

"The interest of intuitionistic logic lies in the fact that it is adapted to a family of different interpretations; it is the right logic, not just for Brouwer's specific conception of intuitionistic mathematics, but for a variety of different ways in which the logical constants can be understood in terms of progressing acquisition of information rather than of truth-values determined once for all." *(Dummett 1980, p. 614)*

This is a very important insight, indeed. It concerns the groundbreaking Fregean conception of analyticity, especially in relation to the character of syntactic (or otherwise formal) stipulations. The point is that such stipulations shall never be seen as a way to install an order of some kind within a previous sort of dis-order, nor be seen as a mere stipulation by convention. A "definition", in the semantic sense, will always involve a crucial re-organization of possible sentential content, as well as involve a re-orientation concerning the question of what constitutes an adequate and meaningful justification of certain assertions. That is the sense in which any semantic stipulation by necessity will have an *informative* character. This point of Frege is perhaps best known in relation to his account of the basic distinction between sense and reference – i. e., that statements of identity must be informative in the sense that they can be used to convey a meaningful piece of information to members of the linguistic community in question. Accordingly, the importance of Brouwer's account of the way in which the meanings of the logical constants may be stipulated as part of a proof-theoretical approach lies in the fact that this account embodies an explanation of the apparent paradoxical matter – that fixing the meaning of the basic logical symbols within a given system of language involves learning to recognize unforeseen and previously unthinkable connections between various states of affairs. As Dummett says,

"Deductive reasoning can lead us to where we never expected to get; but we can account for its doing so, only if we acknowledge that a single

> step takes us a definite distance ... The existence of deductive reasoning thus compels us to admit some gap between truth and that which enables us to recognise truth." *(Dummett 1990, p. 176)*

Thus, the important lesson to be learnt from the advent of the intuitionistic interpretation of the logical rules of mathematics is epistemic. The lesson is that the possibility of establishing certain deductive routines within the use of linguistic expressions involves what Dummett calls "an epistemic advance". It is significant to recognize that this is a lesson concerning the character and status of a *semantic* theory; a theory concerning the interconnection of the concepts of truth and meaning within any adequate analysis of a given fragment of our language. Thus, the lesson concerns the issue what is involved in an attempt to systematize or formalize such fragments – of what might be the point of advance thus achieved.

This brings us to the second point b) concerning the relation between a semantics for a formal language and a semantics for a natural language. On this issue, Dummett writes two things that should be noted. First,

> "A semantic theory for a formal language serves as a practical means for laying down the intended interpretation of that language; it may therefore take for granted whatever the reader may be presumed already to know. A theory of meaning for a natural language is, by contrast, a purely hypothetical entity. Noone actually proposes to construct one, or to use one for teaching a foreign language; the only point of considering what form such a theory would in principle take is the philosophical one of throwing light on the concept of meaning and that of a language. A theory of meaning must therefore be conceived of as taking nothing for granted" *(Dummett 1994, p. 131)*

Second,

> "A semantic theory for a formal language is not, however, merely a convenient alternative means of specifying an interpretation for a symbolic system which we wish to handle in a more precise ... manner ...; it is a model for what might in principle be done for all languages". *(Dummett 1994, p. 130)*

To take the latter point first, for any fragment of our language there will always be a point in our trying to systematize some of its formal features. Especially, it will prove significant to inquire in what way the given fragment of natural language may be said to form a so-called conservative extension of the formal system modeled. We will return to that notion shortly. First, we must note the former point concerning the difference between a semantics for a formal language and a semantics for a natural language. In saying that the latter must not take anything for granted, Dummett refers to the link between the semantic theory in question and the Theory of Sense associated with it. This is to say that for any given fragment of our natural language, we can never a priorily claim to know what it means for there *to be* a determinate sense involved in the application of any given series of linguistic expressions. Consequently, there is no way in which it would be possible, a priorily, to adequately reconstruct the fragment in question in accordance with a given type of semantic theory, say a global truth-conditional or verificationist account. Also here, we have to *win through* to the adequate kind of semantic theory.

A case in point would be quantum physics. Dummett is very explicit about this,

> "The only other logic which appears to have any philosophical profundity as a serious rival to classical logic is quantum logic, and that is highly doubtful; it is only intuitionistic logic, developed on the basis of Brouwer's revision of mathematical practice, that has compelled us to take seriously the idea of a coherent logical theory deviating in a fundamental manner from classical logic." *(Dummett 1980, p. 613)*

I quote this in order to underscore, on Dummett's view, the true importance of the Browerian intuitionistic interpretation of the linguistic practice of mathematics, because – as stated by Dummett – this is the *only* case that linguistic philosophy has established so far – the only language game whose possibility serves as a complete and rational guide to any attempt to reconstruct other forms of linguistic practices. Thus I would say, the transformation of Brouwer's intuitionist interpretation into a semantic theory amounts to something close to Kant's reconstruction of Eucledean geometry and Newtonian mechanics as giving rise to the table of schematized categories.

Dummett will not rule out that new and better guides may be constructed, say, in terms of quantum logic. The requirement is only that we keep in mind that some kind of semantic theory concerning the formal features of a given fragment of our language must be formulated, such that it is an open question how this kind of semantic theory may be seen as a guide for examining the characteristic features of *any other* fragment of our language. This is the legacy of Brouwer;

> "... Brouwer's work on the foundation of mathematics represents the one sustained attempt so far made to trace the full consequences of an idealist position ... That is not to say that, in areas other than mathematics, intuistic logic is precisely what is required, nor even to claim that the coherence of intuitionism has been fully vindicated, it is simply to remark that Brouwer was a pioneer in investigating a topic that no-one before him had even perceived as requiring investigation." *(Dummett 1980, p. 613)*

So this explains why we had to go into so much detail about the case of intuitionism. We should want to know in general how the prospect of a possible systematization of a given part of our use of language involves an assessment of certain features of the already established linguistic practice. Accordingly, we should want to both have our cake and eat it. In other words, we should want to be both able to say that our reconstruction corresponds to the defining features of the practice already given, and to say that our reconstruction adds something significantly new to that practice.

Linguistic harmony, stability, and conservative extension

This is what makes the notion af a conservative extension of a given fragment of language so important. That notion in itself gives us some idea of what it means to fulfil the wish that we expressed above. Dummett explains the notion of a conservative extension as follows,

> "Given a formal theory, we may strenghten it by expanding the formal language adding new [expressions and rules governing them] ... In the new

> theory, we can prove much that we could not even express in the old one; but it is a 'conservative extension' of the original theory if we can prove in it no statement expressed in the original restricted vocabulary that we could not already prove in the original theory." *(Dummett 1990, p. 217-8)*

The idea of a logical constant is of course to *add* to our possibilities of proving or recognizing things. Thus it might be the case that a logical constant is made use of within a chain of reasoning, the formulation of neither the premise nor of the conclusion of which contains the constant. If so, to say that the introduction of the constant – as a supplement to the already given instruments of the language at issue – is a conservative extension of the language, means that the conclusion of the chain of reasoning in question (not containing the constant) could have been proved already in terms of the old vocabulary.

Given this definition of the notion of a conservative extension, how can we then be justified in believing than none of the logical constants that are employed within a given linguistic practice have been added to the stock of linguistic expressions in use in a non-conservative fashion; and if we can not be thus justified, what would be the problem? At the bottom line, the idea of a conservative extension of the logical apparatus of a given formal language relates to an account of what it is to have an adequate semantic theory for the language in question. The idea shall help us clarify what it means for there to be *meaning-criteria* governing the construction of well-formed sentences. The idea is especially significant in considering the way in which various different, and different forms, of linguistic principles may, and may not, be in "harmony" with one another; in other words, the way in which the various characteristic functional features of different semantic types of expression – such as names and predicates – may be said to form part of a unified, coherent linguistic practice. All of that, we hope, might point to some sort of uniformity in the way in which the associated linguistic rules can be articulated within a unified semantic framework.[234] As was mentioned by Dummett, the notion of a conservative extension originally belonged to formal logic. Therefore, in adapting the notion to the analysis of natural language, the following must be said,

> "A conservative extension in the logicians' sense is conservative with respect to formal provability. In adapting the concept to natural language, we must take conservatism and non-conservatism as relative to whatever means exist in the language for justifying an assertion or an action consequent upon the acceptance of an assertion." *(Dummett 1990, p. 218)*

Once again it is underscored by Dummett that we understand the logical constants of a given fragment of language as forming part of the entire set of semantic instruments or means for justifying the individual assertions that can possibly be made in the given context. However, the very attempt to justify given forms of deductive reasoning, Dummett thinks, forces us to involve *more* instruments than the justificationist ones. A concept of truth must be introduced, and with it certain principles of the semantic theory. Dummett writes,

> "The practice of deductive reasoning extends the meanings of our statements beyond those which they would bear if we appealed only to the di-

[234] An example of which, I would say, is the Kantian table of schematisms constituting, in Kant's own words, a rational physiology of material substances.

rect means of establishing them. But since we do not first learn one practice, and then enrich it by adding the other, we do not apprehend deductive reasoning as extending the meanings of our statements but as faithful to those meanings. This is why we are not wholly comfortable with a conception of meaning as given solely by reference to the direct verification of our statements, but find it more natural to think in terms of meaning as given by what makes a statement true where the truth of a statement is *not* to be identified with the occurrence of a direct verification"

(Dummett 1990, p. 178)

"Inferential reasoning has the value it does, however, because it is usually indirect ... In forming some conception of a property, weaker than our having a direct warrant, we acquire an implicit grasp of a notion of truth." *(Dummett 1994, p. 476)*

"We have to examine piecemeal which features of our linguistic practice call for a notion of truth, and what notion they call for, which is to say how far that notion goes beyond the simple conception of a direct warrant ... All this is what I meant by saying that we have to *win through* to a notion of truth." *(Dummett 1994 , p. 477)*

This is why we must always ask how the justificationist means are harmoniously used in conjunction with other kinds of semantic principles, especially – as we shall see – those which Dummett calls the principles of consequence. In short, the attempt to advance a *rational* reconstruction of the employment of linguistic rules concerning the basic logical symbols and features of a given language must in some sense be adequate, also, to the *pragmatic* features of the use of the language in question.[235] To say this, in fact, is just to try to formulate, in the most general semantic form possible, how a given practice of recognizing various truths – despite it can never be revealed to conform to any strict formal semantic model – can nevertheless still be said to involve a rational, though contextually defined, linguistic practice.

On the issue concerning the harmony between the two kinds of linguistic features, the cognitive and the pragmatic, Dummett points out that,

"... the most important fact is that practice is not sacrosanct. Justification and commitment ought to be in harmony with one another: that is why, if meaning is taken as given in terms of either, the theory must show how the other can be derived from the meaning as so given. The condition for such harmony to obtain is twofold: first, that whatever serves to justify a statement ought also to justify any simpler statement to which acceptance of the first commits us; and, conversely, that all commitments consequent upon acceptance of a statement should already be consequent upon anything offered in complete justification of it."

(Dummett 1994, p. 162-3)

[235] "We can distinguish two general categories of such principles [embodied in our linguistic practices]. The first category consists of those that have to do with the circumstances that warrant an assertion, the basis on which we may recognize a statement as having been established ... We may permit ourselves to speak of them as principles of *verification*... Clearly however, our use of the language cannot be exhaustively described in terms of our application of principles of verification ... In acquiring language, we learn a variety of principles determining the consequences of possible utterances; these compose the second of our two categories of principles which govern our linguistic practice." (Dummett 1990, p. 211-2)

On the face of it, this may look like a kind of compromise between rival philosophical positions that is suggested for no other reason than to demonstrate that it cannot a priorily be denied. For this would imply that it seems without warrant to accept only one of the positions that the compromise in question concerns. This would however be a misinterpretation of Dummett's point of view. First – as we have seen – Dummett refuses to recognize either a global truth-conditional account or a global verificationist account as significant positions, and thus as rivals, at all. Accordingly, Dummett wants to point only to two *features* of the practice of speaking a language, and to underscore how these two features shall always be interrelated in some way or another; since that is, Dummett thinks, part of what constitutes a linguistic practice.

Second, we do not really speak of a compromise in any logical or abstract sense. We speak of the complex interplay between various kinds of *knowledge* involved in the competent use of linguistic expressions within given linguistic practices.[236] It is not that these forms of knowledge can be regarded as certain proto-types, such that the issue merely is how these forms are differently interrelated in specific contexts. All attempts to refer to well-defined forms of cognition and recognition will be wrong because they are based on unwarranted metaphysical conceptions of cognition.

By contrast, the significant semantic issue we shall face hinges on the possibility that we have *no* clear conception of what cognition comes to within individual linguistic practices, or language games. We have no such general model. On the contrary, we are turning to a linguistic analysis precisely because we are trying to construct what might be the most general account possible, and it is as part of this enterprise that we *begin* to take notice of the complex interplay of the various features of any linguistic practice. What we have at the outset is some idea about the *whole* of the practices in question, and any suggestion in respect to the specific "poles" or "features" thereof shall be seen in relation to a formal representation that is advanced for some theoretical purpose. We are not trying, head on, to reconstruct some *actual* practice.

As Wittgenstein pointed out, we are not trying to explain how something that really takes place or happens can possibly come about. So in a sense, it is only the philosopher who talks about the justification of statements and the commitments thus produced for the participants of certain practices. Indeed, it is only the philosopher who refers to such practices, at all. In introducing this theoretical representation, the philosopher has two basic perspectives, a) that it is an essential feature of the practice of using the language that people try, sometimes, to describe how things really are, and b) that the use of language forms part of a social and practical communion among individual people – that "to imagine a language is to imagine a form of life", as Wittgenstein put it.

This is why, the requirement that there be harmony between the cognitive and the pragmatic features of our linguistic practices must be associated with a further requirement; the requirement that there be a certain economy in respect to the instruments or criteria by means of which the given practice unfolds in its characteristics. This is a requirement that expresses both a constraint and a perspective to which any semantic theory must conform; namely, that an assessment of the theory will have some point for any rational participants within the practices at issue. Associating this latter requirement with the notion of stability, Dummett describes the issue as follows,

> "There is, however, a further requirement, which we may call stabil-

[236] What matters is the interplay between certain forms of know-what, know-that, know-when, and know-how.

> ity. This condition is that we do not demand more, in justification of a statement, than is required for it to carry the commitments we take it to bear; and conversely, we should not understand it as carrying fewer commitments than would be warrented by what we require as a justification for it" *(Dummett 1994, p. 163)*

This shall of course still be considered a pure theoretical requirement, like the requirement of harmony. Consequently, we have still to do with a theoretical model that may very well turn out to be inadequate. Indeed, this is fully in line with the bottom up strategy that frames our entire analysis. Thus, we must remind ourselves that,

> "Linguistic practice is enormously complex, and takes a great deal of time to acquire. Justification and commitment are distinguishable features of that practice. There is no more certainty that there will in fact always exist both harmony and stability between them than there is that a machine will always function as intended. For this reason, we cannot demand of a theory of meaning that it will always yield a description of prevailing linguistic practice accurate in all details: on the contrary, the existence of disharmony and instability is more likely to come to light when a systematic account of the working of the language is undertaken, and so the theory of meaning may prompt a change in our employment of it."
> *(Dummett 1994, p. 163)*

Concluding remarks in relation to Dummettian semantics

Consequently, I want to stress that there is as yet no elaborated semantic model in terms of which one could try to associate the strict framework of complementarity either with a semantic realistic or a semantic anti-realistic position, and there is even no elaborated and clear-cut way to use, say, the Dummettian semantic framework in the context of physics.

If one intends to apply, say, the Dummettian framework, one should be faithful to it. In that case; one should first analyze, for every context discussed, what a semantic dispute over realism will mean in that *particular* context. Still, we have no straightforward method of even asking and answering that preliminary issue. Thus, one has to begin by characterizing particular contexts, trying to associate any such with a paradigmatic case, the examination of which might help us clarify what, in principle, a dispute over linguistic meaning might mean in the respective context considered.

As we have seen, Dummett's suggestion in respect to such a paradigm case happens to be the dispute between conceptual realism and intuitionism in mathematics. He characterizes that dispute as a dispute concerning the possibility of stipulating a determinate meaning of the logical constants and other logico-semantic rules within the deductive practices of classical mathematics and intuitionistic mathematics, respectively.

However, we are still not helped in clarifying the question of what "realism" might be in the context of physics. Both in respect to classical physics and to quantum theory we are as yet not in the clear about *how these respective linguistic practices contain deductive parts, or how deduction or inference are constitutive parts of the respective practices*. Until we know that; we cannot claim to have recognized a Dummettian kind of dispute.

However, by providing my interpretation of Bohr's philosophy of quantum physics, I have in effect contributed to answering the question of how deductions and other analytical forms of inference enter into the linguistic practice associated with the quantum theory. Consequently, I can offer a suggestion in respect to how one might undertake a *semantic* examination of the quantum theory.

First, let me note a few things: I would say that classical mechanics is best associated with a form of *anti*-realism since – given its idealizing features – it leaves no gap between our methods of thought and reality itself. The new situation in physics thus concerns *the development of a form of semantic realism out of a form of semantic anti-realism*. The paradigm case of mathematics, chosen by Dummett, portrays just the opposite. This does not rule out that one may very well use Dummett's advice about how to regard the deductive practice of mathematics as forming a paradigmatic semantic battleground. Only, we have to describe the situation in respect to physics in some fundamental semantic terms, and the terms "realism" and "anti-realism" cannot yet be among these.

Instead, we shall focus on the possibility of a *conservative extension* of a given linguistic practice. We shall do so in respect to the issue of how the various linguistic *principles* of a given linguistic practice may or may not be in *semantic harmony* with each other. And we should inquire how the linguistic devices that enter into the linguistic practice in question are utilized so as to imply a special kind of *semantic stability* characterizing the practice of using linguistic means.

The guiding idea behind all this is that the given practice has a formal aspect the recognition and assessment of which gives, as yet, no sure indication of the constitution

of the complete practice. So, it would be rational to try to elaborate the principles of a new practice that

(a) Embody something like the formal part of the former practice and where
(b) The whole of the new practice can be seen as some sort of extension of that analogous formal part into a completely integrated and clear linguistic practice.

Formulated like this, it will obviously be very fruitful to associate the views of Dummett with the framework of complementarity. Classical physics is the originally given practice that contains a formal part, the coherent analysis of which, however, gives no adequate account of the integrity (harmony and stability) of the complete practice as such. Quantum physics, then, will be the newly introduced practice, the formal part of which will be analogous to the formal parts of the classical theory. Thus, we have now transformed the broad questions about the completeness and interpretation of the quantum theory into a clearly understood *semantic* issue, the issue of how to consider the conceptual practice that shall be associated with quantum physics as forming a conservative extension of the conceptual practice associated with classical physics.

Faye's idea of physics and language

Faye ascribes a coherence concept of truth to Bohr. I do not believe that Dummett endorse such a truth concept, for two reasons. One of his basic semantic aims was precisely to reject the idea that philosophical analysis should be performed in terms of a generally applied truth-concept, Second, in so far as Faye is right in ascribing to Dummett the view that only *cognitive* concepts of truth are philosophically adequate, a coherence concept is not even one of the candidates. I must conclude that Faye has got Dummett wrong in believing that we could elaborate a universal form of objective anti-realism that involves a universal truth-concept.[237] Faye, on my understanding, wrongly links the question concerning an adequate truth-concept, *head on*, to a concept of "reality", and thus also links it head on to a particular dispute between "realism" and "anti-realism". Thus, an *illusion* may arise that there is a general, all-important philosophical problem concerning what is involved in the rejection of classical two-valued logic, i. e. involved in giving up the principle of the bivalence of truth-values for statements made in various context.

Anyway, I agree with Faye that in trying to account for the semantic framework of any part of theoretical physics we must ask why, and how, our ordinary uses of concepts informs the possibility of developing new, theoretical conceptions. However, if there is one thing that certainly does not enter into Dummett's linguistic philosophy, it is the view that is expressed in the very conclusion of Faye's book:

> "Everyday language with its vocabulary of material objects is, on Bohr's view, the language in which we are able to form unambiguous statements about our ordinary experience. The rules and categories which are entrenched in this language, in that they make up the conceptual framework within which it operates, do in part constitute our ordinary experience by determining the forms under which we can speak meaningfully about our experience. Among those concepts that are part of the structure

[237] See (Faye 1993, p. 43)

> of our thoughts and are expressed in everyday language are time, space and causation, and in virtue of being so they acquire a sort of *a priori* status – which may be called pragmatic *a priori* – similar to that Høffding had assigned them. The rules and categories of ordinary language are necessary for us to communicate unambigously about the world in which we are, in Bohr's terms, both actors and spectators. Only by means of this language are we able to describe to ourselves and to our fellow creatures what we experience and how we interact with the environment.
>
> *(Faye 1991, p. 235)*

I all in all think that Faye would do better by not supplementing his more helful views – such as the following – with his general ideas of a semantic version of conceptualism. The meta-semantic framework that Faye tries to associate with Bohr's framework of complementarity is at best superfluous or, at worst, damaging to the rationality of that very framework.[238] So, let us take a more constructive view on some of Faye's more helpful remarks, such as this:

> "... in discovering new areas of experience we may find that the content of some of the categories entrenched in natural language have to be modified if their use in the light of the novel experience proves to be ambiguous and inaccurate. In cases where what has hitherto constituted the conditions whose satisfaction warranted assertions descriptive of our observations fail to guarantee such coherent descriptions, on account of the fact that the epistemic grounds for their justification are lacking, the specification of a fresh set of conditions is required whose satisfaction restores coherence and thereby umambiguous communication" *(Faye 1991, p. 235-6)*

With the risk of being too much down to earth, I want to illustrate my critique of Faye by imagining some students of classical physics that, along the lines suggested by Faye's position, are now in a position to adopt a new linguistic practice associated with quantum physics. Thus, let us grant that classical physics embodies a well-established and well-defined use of observation reports that is based on a certain method of dealing with, and reading, observational instruments. We also grant that any serious student of physics can easily learn to give observational reports that could well be used by the cleverest of theoreticians in their respective efforts to develop further theoretical accounts and to construct further experimental arrangements. So, what Faye's Bohr seems to claim is that such a student should have no special problem in learning a new linguistic practice. We shall be able to provide him with clear semantic rules that instruct and inform his observational practices in the laboratory.

Our students have learned to "describe the arrangements" they have set up in the laboratory. By doing this they have learnt a code for translating these descriptions into stipulations of "where" and "when". In other words, they have learnt to use the terms by means of which the variable features, of both a kinematical and dynamical kind, of the observed atomic systems can be specified. They have learnt such things as not to shout "it has position (xyz)" when a spring is vibrating, or shout "it accelerates" when a certain bolt is fastened. They have learnt to concentrate their visual attention

[238] My own account of the semantics of the framework of complementarity is summarized below, in Part Six, Chapter two, that discusses the unity of semantics and pragmatics.

on certain screens or pointers. In short, they have learnt to read complexly constructed clocks and other "meters". Faye's mature Bohr has in a sense developed a procedure in order to assure that quantum theoretical experts, who do not themselves actually take part in laboratory activities, may continue to communicate unambiguously by e-mail.

Now, can our students ever become experts on their own? Have they also learnt to construct and perform new kinds of quantum theoretical experiments? How are we supposed to think that the ability to do research hinges on the ability to master certain observational practices; and what is it, anyway, to consider quantum physics as forming a field of *research*? These are the kinds of questions that I think Faye's mature Bohr will have some difficulty in answering. Of course, Faye may respond that he never required that Bohr should have accounted for how the various abilities of observing, calculating, constructing etc. actually could be "carried over" from person to person. What we have learnt from his Bohr is a set of conditions and requirements forming, as it were, a logically coherent set of rules. This set of rules is there for the taking. How anyone manages to catch on to them, or how a division of linguistic labor is distributed among the individual members of the quantum theoretical speech community, is not our interest. Its just that if sombody fails to comply with the set of rules; then she is out of the game of theoretical physics!

However, the position of Faye's mature Bohr has a feature that does not come to the fore in this narrative. Faye's account often points to the supposed fact that some of the procedures involved in the practice of experimental physics are "guaranteed" or "certain". Faye explicitly states that the objective, anti-realist position he presents corresponds to an *empiricist* theory of knowledge.[239]

> "... objective anti-realists ... argue that states of affairs are objective. But, they claim that states of affairs confer truth only because statements about them are verifiable or otherwise demonstrable. Thus, in general, objective anti-realists not only subscribe to an empiricist theory of knowledge, according to which experience is the basis for acquiring beliefs about nature, but they also regard experience (partly) as the ground for what can be justifiably asserted as true about the nature, but they also regard experience (partly) as the ground for what can be justifiably asserted as true about nature. For objective anti-realists the world exists but always as a conceptually grasped set of entities, properties and relations which might have been described different from what it is if human's abilities had been different." *(Faye 1994, p. 98)*

I will discuss the semantics involved in this claim below. Here, I will only point out that the two features mentioned by Faye as characterizing objective anti-realism need not correspond to one another. It is not true that the possibility of secondary properties – or of affordances in the sense of Harré's – corresponds to "conceptually grasped sets of entities". According to Harré, the meaning of theoretical concepts is typically associated with certain models such that the reference to objectively existing items hinges on some kind of analogy between the objects described in terms of the model and the posited, real objects. I have myself followed Bohr in calling this feature of physical theory "abstraction" Thus, because of the association between such abstractions and the idealized – modelled – objects whose objective features are relative to our ability to

[239] (Faye 1994, p. 98)

recognize physical manifestations; we have found a way to transcend the rigid ontological scheme of conceptual realism/conceptualism/nominalism. Indeed, this is a point made not only by Harré but also by Dummett who often stresses how the adoption of a Fregean semantics breaks with precisely that rigid scheme. Considering the position presented by Faye, one should also note that the reference to relative properties rests on his empiricism:

> "The significance of calling a property relative with respect to external circumstances is that of pointing out that it can only be predicated of the object if certain experimental conditions are fulfilled. A relational property is not a quality that has been possessed prior to the objects entry into that relation." *(Faye 1991, p. 228-9)*

The phrase of "fulfilling experimental conditions" is not an innocent addition to the previous list of *linguistic* conditions. What is "fulfilled" ("satisfied") is a possibility of answering to a *subjectively given "form"*, which of course is exactly what any conceptualist must claim. Our conceptualist wants to account for the possibility of a form of *objective* description of external beings. His strategy is to restrict the range of such descriptions to cover only our *encounters* with such beings. His suggestion is that the description of these encounters is "objective" if only we can specify the *conditions for their "appearance"* (and so we have another, metaphysically far from innocent, notion of a kind of "condition"). Thus Faye's Bohr:

> "The description of the phenomenon has to take into account the observational conditions under which it appears." *(Faye 1991, p. 194)*

Now, I would require of our students at work in the quantum physical laboratories, simply, to exercise the observational abilities it takes to do their job. Put in Wittgenstein terms, "the kind of certainty is the kind of language-game". Thus, I would not ask, "how do you read a clock?", or "have you really fixed the temperature of the yardstick?", *nor* would I ask "are you sure the electron '*passed*' the slit?". Following Bohr, I will expect my students to know "what they have done" so that I will know what "we have (all) learnt" about quantum systems after the performance of given experiments. If, by accident, I had reason to be skeptical and asked; "Well, did you *fix* the spring to the iron bar?", I would be trying to get a message cross, indicating the context-dependent relevance of carefully having employed a very special technique of "fixing" regardless of which variable is in question. I would certainly not be satisfied with a reply like the following, that expresess confidence about what my students knows about chairs and tables and how they can read their bedroom alarm clocks; for what is in question is not whether this or that student can demonstrate that he is not a fool and has a license to be at large in the laboratory. It is whether anyone can claim to have demonstrated the *emergence of a special phenomenon* by assuring us that they have followed specified rules in respect to observation, construction, and calculation. I would consequently protest against Faye's view that,

> "... the experimental arrangement itself constitutes the conditions for the description of the atomic object; that is, the experimental arrangement determines the conditions for our linguistic behavior in domains where the quantum of action plays a role, in the sense that any successful reference

to it guarantees that the use of concepts such position and momentum be unambiguous, even in this context of experience." *(Faye 1991, p. 192)*

> "... a specification of [what I have called the kinematics and the dynamics of the measuring instruments, respectively, which form part of a whole experimental arrangement] is necessary for the meaningful application of one of a pair of conjugate variables in the *description of what* is observed. *(Faye 1991, p. 193, italics mine)*

I can understand this in no other way than as a repetition of the Høffdianized claims that Faye has stated formerly in his book. These claims imply that we must distinguish between the measuring instruments and the arranged set-ups of which they form part, and that the set-up "in itself" fixes the conditions for an unambiguous reading of the instruments. According to Faye, the only new thing in quantum physics is the need to *maintain* this distinction between set-up and instrument in the account of intelligible *performances* involving various instruments. The quantum theoretical experimenter must include, in his clear separation between the set-up and the instruments, also a view concerning *how that separation* is "present" *within the very performance*. That becomes part of the requirement of being able to account for the "conditions under which phenomena appear". Spelled out in detail, the requirement becomes this:

> "For each time we predicate a certain observable property to an atomic object there exists a definite reproducible procedure which we must follow in order to make a meaningful ascription and which allows us to determine the truth-value of the predicative statement. This is due to the fact that the conditions for a correct application of a dynamical or kinematical concept in quantum mechanics is limited to an appropriate experimental investigation which makes these concepts stand for relational properties." *(Faye 1991, p. 231)*

One should ask: If it is the introduction of repeatable procedures that helps quantum theory "save the phenomena", why was that not already enough in classical physics. Is it because there is an implicit claim in respect to *how* the procedures involved are "repeatable"? Remember, Faye is here dealing with the problem of how to make sure that certain predicates have a well-defined use. He is talking about the possibility of there being recognition-criteria for whatever may count as the ground of applying these predicates. In the classical context, these criteria was provided by the very set-up, the spatial configuration of which was seen as "fixed", and thus as "recognizable".

In quantum physics the momentum of clocks is indeterminate as is the position of elastic constructions suitable for detecting a mechanical impact. In a world where only strange clocks and strange yardsticks are available, how do we then manage to use kinematical and dynamical concepts with a definite sense? Frege's famous distinction between 'sense' and 'reference' certainly enters Faye's account. *One* way to fix the sense of *some* predicates is to "fix their reference". Knowing a Fregean 'sense' is knowing, for a given term, how its referent is associated with an identifying condition. To account for a Fregean 'sense' for a given term is to account for a method by means of which the referent of the term is "given" (as the referent of the term). Such stipulations might help us to determine an objective property because we already know the

sense of other terms that refer to it. It *may* be that learning the sense of a set of expressions in the language consists of grasping – in respect to some well-known items – what counts as a given kind of presence of such items. Thus, I might explain that a "vector" is what you have whenever you have an equivalence class of arrows (defined in terms of length and direction). The canonically stipulated mode of presentation serves as a determination of the *sense* associated with the expression 'vector'.

Somehow, this must be close to what Faye has in mind by claiming that the kinematical and dynamical concepts used in the description of quantum theoretical phenomena must be properly introduced, and that this is secured by the introduction and establishing of a frame of reference if no other means of introduction is available. Thus, formulated as a semantic view, the framework of complementarity explains how a frame of reference that clarifies the introduction of kinematical and dynamical predicates can be had – even in the light of the Heisenberg Indeterminacy Relations.

However, Faye's Bohr wants more than this. He wants this account to imply more than an explanation of how the sense of some special predicates can be properly introduced. He further wants to *hypostasize* such introductions. In accordance with his empiricist attitude he insists on asking – not only for the possibility of making sense in a world of strange clocks and rods – but also for the *grounds* of that possibility. He insists on requiring that there is something that *satisfies* the condition for the possibility of making sense. Concepts are only fulfilled if they are somehow related to actual percepts. As Faye state:

> "... Bohr's anti-realism in its most fully developed version is based partly on a general argument supportive of semantic anti-realism, to the effect that in the domain of quantum physics we can communicate meaningfully only about that of which we are able to obtain empirically based and assured knowledge." *(Faye 1991, p. 234)*

As I explained in Part IV, it is part of the significance of the Gibsonian notion of affordances that we consider this an empiricist fallacy. The display of phenomena does not, eo ipso, qualify as a manifestation of objective affordances. Only the manifestation of *phenomena* – a manifestation that take into account the wholeness and complementary character of such given phenomena – constitutes the appearance of objective affordances; and so constitutes Kantian *Erscheinungen*. So the view stated in the quote above is Faye's addition to Bohr, and should not be regarded as forming part of the framework of complementarity.

6 Unity – of Nature, Knowledge, Practice, and Language

6.1 The general Framework of Complementarity

Between Schiller and Hegel

I find it justified to ascribe a *general* framework of complementarity to Niels Bohr. This framework concerns some critical-metaphysical issues of the kind that are usually related to various idealistic and romantic philosophers of the late eighteenth and early nineteenth Century. One may formulate the general framework of complementarity as follows:

In respect to the conditions for the possibility of different modes of thought, one must always try to articulate how these conditions is regarded as mutually exclusive. As we have seen, the conditions for describing different forms of phenomena may mutually exclude one another. This implies there being mutually excluding conditions for the use of certain concepts in the description of phenomena. So making such conditions explicit must function so as to rouse philosophical reflection.

Formulated as such, the general framework of complementarity comes close to expressing the philosophical attitude expressed by Hegel too; the attitude of an *eternal vigilance*. Given this attitude, human thought is awakened when it is adapting too much to preexisting frames for metaphysical understanding. Human reflection will then be urged to overcome the given frames of thought. However, the aim in this overcoming of preexisting frames should not just be to install a new frame. The aim shall also be to lead our thought back, so as to acquire a more genuine grasp of the states of affairs that gave rise to the modes of thought in question. It is this joint effort of taking a step forward by means of returning our attention to crucial matters within the given situation that characterizes the general framework of complementarity.

As I have mentioned before, I think that Catherine Chevalley has argued convincingly that Bohr was much inspired by a range of romantic philosophical writers. Indeed, to ascribe a romantic philosophical view to Bohr ought not be too surprising. Certainly, to invoke the romantic attitude that there can be no adequate intellectual framework covering the Totality of all Being will only help in our understanding of Quantum Physics along the general lines I have proposed in the former chapters.

According to Bohr, the physical sciences elaborate a conceptual framework. In other words, they try to establish an “unambiguous logical representation of relations

between experiences".[240] However,

> "The main point to realize is that all knowledge presents itself within a conceptual framework adapted to account for previous experience and that any such frame may prove too narrow to comprehend new experiences."
> *(APHK, p. 67)*[241]

I agree with John Honner that Bohr's understanding of physics must be related to some kind of metaphysical approach consistent with a romantic philosophical outlook. Honner stated that, "microphysics has become, in Bohr's work, a kind of metaphysics".[242] This motivates Honner to quote one of Heisenberg's personal recollections of something Bohr once said:

> "Philipp Frank ... gave a lecture in which he used the term 'metaphysics' simply as a swearword, or, at best as a euphemism for unscientific thought. After he had finished, I had to explain my own position, and this I did roughly as follows:
>
> I began by pointing out that I could see no reason why the prefix 'meta' should be reserved for logic and mathematics – Frank had spoken of metalogic and metamathematics – and why it was anathema in physics. The prefix, after all, merely suggest that we are asking further questions, i. e. questions bearing on the fundamental concepts of a particular discipline, and why ever should we not be able to ask such questions in physics? ... In all such discussions what matters most to me is that we do not simply talk the 'deep in which the truth dwells' out of existence. That would mean taking a very superficial view."
> *(Honner 1987, p. 197) quoting (Heisenberg 1971, p. 210)*

Bohr's words above include a reference to the following words of Schiller:

> "Nur die Fülle führt zur Klarheit
> Und im Abgrund wohnt die Wahrheit"[243]

It is tempting and makes good sense to relate this metaphysical attitude of Schiller to Bohr's framework of complementarity. The framework was introduced precisely in order to make philosophical sense of the claim that we are, at best, able to survey a manifold of different aspects of experience. However, the truth itself lies deeper in the bottomless abyss that we shall never reach, but will somehow still be able, in successive stages, to keep in view.

I believe that John Honner is right to say that Bohr may have adapted such a view from Schiller. The view includes an allusion to a romantic philosophical conception of works of art. Such works are seen as having been produced in accordance with a special, superior kind of synthetic experience. However, the works of art are manifestations of this superior synthesis only in so far as the works also symbolize a fundamental

[240] (APHK, p. 68)

[241] Given my interpretation of Bohr, it is important that he here uses the term "comprehension", see Part Four, Chapter Two.

[242] (Honner 1987, p. 6)

[243] From *Die Lehre Konfucius*

groundlessness and fundamental limitation within the synthesis involved in human experience. That is why it must be recognized that human thought may be elaborated to a point where it symbolizes the inevitable *Aufhebung* of itself. However, at such a point the seeds are sown for a new vision; a vision for incorporating, as it were, all previous modes of understanding.

Yet, although such a vision is shadowed, as Bohr once put it, the vision can never be fully or adequately exposed in thought proper (i. e., it cannot be expressed in words).[244] This means that the task of philosophical reflection first and foremost will be that of planting such integrated visions in *concrete* cultural and scientific settings. This is how reflective thought is constantly urged to overcome existing metaphysical frameworks. This process of (1) framing phenomena, (2) viewing frameworks as symbolic in respect to a new vision and (3) re-planting the symbolically announced, is a continuing process or spiral. I shall be more specific and explain the point of many of the metaphors just mentioned in what follows where I shall try to reconstruct what, in allusion to Kant, might be called the *Architectonic* of the viewpoint.

From physics to biology

I think that the importance Bohr saw in our trying to broaden the range of the framework of complementarity is indicated by his selection of essays that was included in his own ultimate collection of philosophical essays, *Atomic Physics and Human Knowledge*, published in 1957. The first essay of the collection is entitled "Light and Life" from 1931. One should take seriously the title of this essay, because it is one of the primary aims of the essay to show how the notion of life may be compared, in principle, to the notion of light. Already in the Como Lecture Bohr had explained that one ought to take the discussion about the nature of light for what it is. In physical theory we need not inquire into the nature of the individual agencies or into the nature of the individual carriers of energy. What matters is not the nature of the photon, but how the photon enters into the experimental material of given experimental arrangements:

> "The two views of the nature of light are rather to be considered as different attempts at an interpretation of experimental evidence in which the limitation of the classical concepts is expressed in complementary ways." *(ATDN, p. 56)*

Comparing this to the Danish/German versions, one can see that what Bohr calls the "interpretation of experimental evidence" translates as "an adoption of experimental facts to our common form of intuition". As we know from the final remarks of the Como Lecture, this is just the opposite of what we ought to do. We should not try to adapt experimental facts to the extent forms of intuition associated with the wave and particle models. We should instead adapt the facts to the kind of intuition associated with the statistical interpretation of the Schrödinger equation in accordance with the mathematical theory of Unitary Transformations. The question about the nature of what can be visualized, the nature of particles and waves, exactly drops out of the picture. There is no question about the nature of light or of matter over and

[244] See the end of what I call Bohr's *Manifesto*, below.

above our inquiries into the possible stable energy-states of a system of interacting individuals.

Similarly, there is no question about the nature of life over and above our inquiries into the stable and purposive functioning of organic beings within their interaction with given surroundings. Just as is the case with the notion of the nature of light, the notion of the nature of life as used in biological research can never be related to the possible outcome of any kind of experimentation. At best, Bohr thought, it might be seen as an expression of "the nature to which human beings belong":

> "... just as the quantum of action appears in the account of atomic phenomena as an element for which an explanation is neither possible nor required, the notion of life is elementary in biological science where, in the existence and evolution of living organisms, we are concerned with manifestations of possibilities in that nature to which we belong rather than with the outcome of experiments which we can ourselves perform ... The main point is that only by renouncing an explanation of life in the ordinary sense do we gain a possibility of taking into account its characteristics".
>
> *(APHK, p. 76)*

The quantum of action symbolizes the character of atomic processes involving discontinuous forms of physical change. That is what the notion of a photon means.[245] The notion points to a peculiar form of distribution of the energy bound within composite atomic systems. However, to mention the discontinuous character of atomic processes must imply an ontological determination. In a sense there is no such thing in the world as discontinuous processes, as such. Regardless of the way in which the re-distribution of energy within physical systems takes place, we shall not try to specify the nature of this redistribution in itself, seen in abstraction from any particular physical system. That is the sense in which there is, strictly speaking, no "light", no "matter", and no "energy". It does not make sense to talk about there being some distinct dimension of physical Reality the existence of which conditions the possibility of certain kinds of physical system. There is no such substratum.

We should say instead that concepts like energy, light and, matter refer to *the possibility that physical change may have definite forms*. This again implies that our ability to contribute to the dynamic interplay of physical things consists in our being able to produce physical changes having such definite forms.[246]

Similarly, Bohr thought, we shall not seek an explanation for the distinct possibility that organic life may exist. Instead, we shall set out to investigate the structural relationships in accordance with which organic forms of life may unfold, and in accordance with which the kinds of biological change that characterizes organic processes take place. The second essay in APHK, "Biology and Atomic Physics", from 1937, elaborates on this issue.[247]

Now, I want to label the concepts "Light" and "Life" *key concepts of complementarity*. I shall argue below that the concept of "culture" was considered by Bohr a

[245] This is symbolized in the basic equation $\frac{E}{h} = \nu$

[246] I could well argue that this is fully in line with Kant's original concept of "substance". The substance of things for Kant meant their being *changable in accordance with forms* – namely in accordance with that *possibility of structure*which could be demonstrated in terms of a "Schematism".

[247] This essay includes the often quoted remark made by Bohr concerning some parallel between the framework of Complementarity and Buddhism.

similar such key concept. Bohr's consideration of the latter key concept was first expressed in the essay "Natural Philosophy and Human Cultures", from 1938, that is the third essay of APHK. Bohr pursues the themes raised within that essay in a fourth, important essay contained in APHK, "The Unity of Knowledge", from 1954. Thus, it is noteworthy that Bohr, in editing this ultimate collection of philosophical essays, chose to include only one summary article of his reflections on the physical aspects of the framework of complementarity – namely the widely read " Discussions with Einstein", from 1949 – and did not choose, say, the Warsaw Lecture nor the essays on causality from 1937 and 1948, respectively.[248]

To outline the general drift of Bohr's thought in these essays in more detail, we must return first to his generalization of the framework of complementarity in the context of biology. Here, the framework turns on the apparent opposition between the physical functions of bodily organs on the one hand, and the ability of living organisms to be self-organizing and even self-preserving on the other. Bohr thought that analyzing this opposition would be part of a critique of the ontological opposition between vitalism and physicalism (or materialism). Moreover, Bohr thought that the analysis in question could profit from the views I mentioned earlier concerning the analogy between the two notions of light and life:

> "... the existence of life itself should be considered, both as regards its definition and observation, as a basic postulate of biology, not susceptible of further analysis, in the same way as the existence of the quantum of action, together with the ultimate atomicity of matter, forms the elementary basis of atomic physics.
>
> It will be seen that such a viewpoint is equally removed from the extreme doctrines of mechanism and vitalism. *(APHK, p. 21)*

As we have seen in respect to physics, Bohr saw himself as performing an *Aufhebung* of the dualism between the two candidates for representing the nature of light, between particles and waves. Similarly, Bohr wanted to perform an *Aufhebung* in relation to the question about the nature of life. Consequently, he began performing an *Aufhebung* of the apparent opposition between vitalism and physicalism by analyzing how such an opposition might arise from certain prejudices.

Bohr's aim in performing this *Aufhebung* was to explain how biology can be a research tradition, at all. He thus discarded both vitalism and physicalism as possible research programs. So, it is crucial to consider how Bohr explained the possibility of a biological science. It should therefore be noted that Bohr in the quote above associates the existence of life with a basic postulate of biology, and does so in much the same sense in which Bohr – along Kantian and Helmholtzian lines – understood the Principle of Causality. Thus, we have to do with a Postulate of Empirical Thought according to the following claim: The existence of life is a rule governing the structure and aim of biological research, and does not in any sense correspond to a hypothetical claim of some theory that may some day turn out to be false. The existence of life is far from being something entering into the content of our thought. It is instead a fundamental part of what enables us to do the kind of research that might lead to our thinking correctly about biological matters.

[248] (Bohr 1937)(Bohr 1938)(Bohr 1949)

It is not a *hypothesis* that the plants and animals investigated in biology are living things. It has not been, and can be never be a discovery, as a result of biological research, that plants and animals live. In short, what Bohr wants to remind us is that the existence of life is a presupposition for the practice of doing biological research. This reminder will make us realize that both vitalism and mechanism are impossible research programs within biology.

Anyway, it should be recognized that the philosophical considerations that Bohr advanced regarding the biological sciences were not just implications of previous, analogous considerations that Bohr had already entertained within the context of physics. One might even say that the opposite is the case. Indeed, it is a fact that the philosophical reflections of Niels Bohr were all along inspired by some views of his father, the physiologist Christian Bohr. In the final essay of APHK, "Atomic Physics and the Problem of Life", he quotes a crucial paragraph included in one of his father?s writings:[249]

> "As far as physiology can be characterized as a special branch of natural sciences, its specific task is to investigate the *phenomena peculiar to the organism as a given empirical object* in order to obtain an understanding of the various parts in the self-regulation and how they are balanced against each other and brought into harmony with variations in external influences and inner processes. It is thus in the very nature of this task to refer the word 'purpose' to the maintenance of the organism and consider as purposive the regulation mechanisms which serve this maintenance. Just in this sense we shall ... *use the notion 'purposiveness' about organic functions*. In order that the application of this concept in each single case should not be empty ... it must, however, be demanded that it be always proceeded by an investigation of *the organic phenomenon under consideration*, sufficiently thorough to illuminate step by step the special way in which it *contributes to the maintenance of the organism*."
>
> *(APHK, p. 96, italics mine)*[250]

The interesting thing about these words of Bohr's father is not just the fact that the paragraph contains several turns of phrases that Bohr would adopt, including the expression "comprehension". Niels Bohr adopted more than that. His framework of complementarity can to some extent be said to formulate *the attitude behind* the views of Christian Bohr. Furthermore, Niels Bohr's understanding and interpretation of the biological sciences follows fully from those of his father's, even in the following details:

To consider the possible aims of the biological sciences, one must first of all ask how a living organism may be subject to an empirical investigation. This again implies asking how one might investigate certain phenomena that come about in connection with the organic functioning of different parts of the whole organism under investigation. This further implies

(i) that one must secure such experimental circumstances that the organism be kept alive, that its organs function according to purpose, and that the essential physiological mechanisms and processes within its body progress as they shall;

[249] I put the things that I wish to note in italics, and I divide the quote into separate paragraphs.

[250] Niels Bohr continues this quote of his fathers: "I have quoted these remarks which express the attitude in the circle in which I grew up and to whose discussions I listened in my youth, because they offer a suitable starting point for the investigation of the place of living organisms in the description of nature". (ibid., p. 96)

(ii) that one must secure circumstances under which the organism is allowed to either grow (in the case of plants) or act (in the case of animals) in the teleological manner characteristic of the given kind of organism.

This implies that the notion of purposiveness takes on a double meaning since it may refer both to the function and role of particular organic parts and to the aims and direction of growth of the whole organism as such. This, again, implies three points:

(a) The apparent opposition between vitalism and mechanism is futile. We must recognize that we must think, not in terms of an opposition between (would be) forms of Nature, but in terms of an opposition between different kinds of *phenomena*. Thus, we should instead consider the opposition as pointing to a wholeness within any organism in respect to different features of the purposive character of its organic activity.
(b) In order to investigate one kind of phenomena associated with one kind of purposiveness, one cannot ignore the other feature of purposiveness. One has to consider the whole of the experimental conditions under which certain kinds of phenomena may appear.
(c) The pre-theoretical notions of purpose that were used hitherto in relation to the two senses of purposiveness mentioned above, must be substituted by a pair of theoretical concepts: organic function and self-organization. As a result, **when** the pre-theoretical and ontologically unwarranted notions of purpose are *transcribed* into the methodological concepts of organic functioning and self-organization **then** an apparent ontological contrast disappears. An understanding should arise implying that the same organic systems, each containing a variety of purposive features, could be investigated as part of the same experimental research tradition, answerable to the same biological laws, however complex.[251]

Here, we must look more closely into how Bohr formulated his critique of the viewpoint of mechanism:

> "On this view, the very existence of life must in biology be considered as an elementary fact, just as in atomic physics the existence of the quantum of action has to be taken as a basic fact that cannot be derived from ordinary mechanical physics. Indeed, the essential non-analyzability of atomic stability in mechanical terms presents a close analogy to the impossibility of a physical or chemical explanation of the peculiar functions characteristic of life." *(APHK, p. 9)*

As Bohr says, there is a limit to the analyzability of biological phenomena, and thus also in respect to the possible aims of physical and chemical forms of explanation. So in a sense, there can be no explanatory point in pursuing the viewpoint of mechanism. A similar point could be made in respect to the viewpoint of vitalism. As Bohr states elsewhere:

[251] In order to stress the analogy between physics and biology that the framework of Complementarity is supposed to consider, I have made use of the term "transcription of concepts", which we have seen that Bohr introduced in his Como Lecture.

> "It will be seen that such a viewpoint is equally removed from the extremes of mechanism and vitalism. On the one hand, it condemns as irrelevant any comparison of living organisms with machines ... On the other hand, it rejects as irrational all such attempts at introducing some kind of special biological laws inconsistent with well-established physical and chemical regularities." *(APHK, p. 21)*

Vitalism is an impossible research program, because it is irrational to claim that there are specific and distinct life-processes. There are no special laws of life. There can be no science of life, as such. But one can establish a biological science that is characterized by the manner in which it investigates various phenomena of life. In order to clarify this, one shall introduce two theoretical notions of purpose. In other words, we must transcribe this notion into the methodological concepts of "organic function" and "self-organization":

> "... the obvious exclusiveness between such typical aspects of life as the self-preservation and the self-generation of individuals, on the one hand, and the subdivision necessary for any physical analysis on the other hand. Owing to this essential feature of complementarity, the concept of purpose, which is foreign to mechanical analysis, finds a certain field of application in biology. Indeed, in this sense teleological argumentation may be regarded as a legitimate feature of physiological description which takes due regard to the characteristics of life in a way analogous to the recognition of the quantum of action in the correspondence argument of atomic physics". *(APHK, p. 10)*

Since we have seen that both mechanism and vitalism are ruled out, we must consider more thoroughly how the different aspects of life can be examined empirically, such that the characteristic organic complementarity between different theoretical concepts of purpose comes to the fore. This implies the following: First, Bohr invites us to realize that biology is a kind of research that deals with a special kind of phenomena, namely phenomena of life. That is the basic characterization of both kinds of phenomena; those characteristic of self-organizing bodily actions and those characteristic of organic functioning.

There will be phenomena expressing the ability of organic beings to be self-preserving by means of the ability to pursue purposive behavior. And there will be phenomena expressing the ability of the parts of organic beings to fulfill forms of organic function. Now for reasons given below, these two kinds of phenomena of life are mutually exclusive. This is because there are in principle only two kinds of experimental arrangements, each giving rise to a certain kind of life phenomena, in our investigation of the laws governing the world of animals and plants. And yet, as we have seen, the two kinds of phenomena must be regarded as related. The reasons both for the exclusiveness and for the relatedness are these:

There will be a limit on the extent to which one can control the appearance of definite kinds of phenomena. There is, for instance, a physical aspect to such things as food supply, energy supply, digestion, or energy absorption that must form part of the conditions of any experiment. But each of these cannot be controlled in detail if the aim of the investigation is to examine the behavior of the organism itself. Similarly, if we want to investigate the physical, chemical, or physiological functioning of some part of the organism, we not only have to keep the organism alive, but we also have to allow a certain lattitude in respect to how the organism behaves in given surroundings.

In short, since it is characteristic of living organisms that they are able to respond to conditions for their life to unfold, there will be a limit to the meaning of what the consequences of a determinate fixation of given elements of the surroundings of organic life might be. As Bohr put it in a concluding remarks on the issue:

> "In biological research, references to features of wholeness and purposeful reactions of organisms are used together with the increasingly detailed information on structure and regulatory processes ... We have here to do with a practical approach to a field where the means of expressions used for the description of its various aspects refer to mutually exclusive conditions of observation. In this connection, it must be realized that the attitudes termed mechanistic and finalistic [i. e. vitalistic] are not contradictory points of view, but rather exhibit a complementary relationship which is connected with our position as observers of nature." *(APHK, p. 92)*

It may be asked how specifically the complementary character of the two kinds of phenomena of life of which we have spoken relates to our position as observers. We shall not make too much of the fact that our lives connect with those of the plants or animals investigated, in biological research, we shall instead take into consideration the fact that in biological research we involve our understanding that there is life in Nature and how lives are manifest. We shall acknowledge that this pre-understanding can never transcend whatever understanding is required to practice any scientific-theoretical form of experimentation. There is a restriction on how different from us any living organism might be conceived to be. Of course there is all the difference in the world between being a human being and being either an animal or a plant. But organic beings cannot, at some point, turn out to be machines, nor complex chemical systems. That is no hypothesis. What it means to be alive is something the understanding of which is deeply rooted in the way in which we conduct our own lives, and in how we regard ourselves as belonging to a unified organic Nature – indeed, how we belong to the unified Nature in total.

The Subject of Psychology

Having recognized how Bohr wanted to present the framework of complementarity analogously in physics and biology, one can already begin to outline what seem to be Bohr's general approach to any field of intellectual inquiry. However, I shall postpone giving this account until we have seen how Bohr made use of the framework in psychology and in cultural studies. As regards psychology, Bohr's considerations were much inspired by his reading of the novel *The Adventures of a Danish Student*, by Poul Martin Möller. In the novel some questions are raised by one of the characters, who asks what is required in "observing oneself". The upshot of the answer suggested in the novel is that it is not really oneself that is observed, but instead certain actions that one has intentionally performed or certain emotions that emerge in relation to consciously paying attention to some features of a given situation. It is also suggested that there is no clear-cut answer to the question of who does the observing. In fact, there is a sense in which it must be different observers. Of course, this is the well-known view of Bohr that the "subject-object cut" varies – that there can be no absolute such cut.

These deliberations about the possibility of psychological self-investigation are obviously related to those I discussed in the former chapter in the paragraph on the practical aspects of the framework of complementarity, not the least of which are the considerations about the relationship between the notions of freedom and causation. I am, however, not so sure that Bohr has much more to offer in his analysis of the particular scientific discipline of psychology. Perhaps the primary conclusion of Bohr in respect to psychology is that the distinction between "inner" and "outer" ought not to be fundamental. That is not where the subject-object cut lies.

Be that as it may, I will instead point to some interesting parallels between the views of Bohr and those later proposed by Maurice Merleau-Ponty. As with Merleau-Ponty, Bohr's focal point is the following: The structures of consciousness (each of which characterizes specific forms of our apprehension of phenomena) can be regarded as real, only insofar as they can be regarded as forming part of a practical effort to orient oneself in given surroundings. It is no coincidence, given the close parallel of their respective views, that both Bohr and Merleau-Ponty make use of the example with the stick that I have mentioned several times in preceding chapters.

Moreover, this also implies another parallel to Merleau-Ponty and to other phenomenologists. Bohr never urges us to study the lives of human individuals in abstraction from their cultural and historical situation. Now, a lot of what I have to say about Bohr's analysis of the cultural sciences have close similarities with a hermeneutic view known, perhaps, best from the works of H.-G. Gadamer. But before turning to that, let me stress my reason for not relating Bohr to "hermeneutics" as it is traditionally understood: Our stress has so far been on ways in which we must realize ourselves as belonging to Nature. Thus, the stress has been on the reality of things, on the power of whatever might constrain our possible activities. Hermeneutics seems to be concerned mainly with the ways in which forms of understanding condition and give rise to *one another*. This is a too narrow perspective in our context, despite the fact that hermeneutics may have something important to say about how this conditioning and production of forms of understanding may happen and about what aspects of rationality will be involved in the process.

Bohr on Culture and Cultural Studies

It should be noted how Bohr introduces and characterizes the very notion of culture:

> "... each ... culture represents a harmonious balance of traditional conventions by means of which latent potentialities of human life can unfold themselves in a way which reveals to us new aspects of its unlimited richness and variety. Of course, there cannot, in this domain, be any question of such absolute exclusive relationships as those between complementary experiences about the behavior of well-defined atomic objects, since hardly any culture exists which could be said to be fully self-contained. On the contrary, we all know from numerous examples how a more or less intimate contact between different human societies can lead to a gradual fusion of traditions, giving birth to a quite new culture". *(APHK, p. 30-1)*

According to Bohr, a culture is a harmonious balance between conventions, traditions (including, for instance, the various scientific disciplines), institutions, the forms of art or the religious traditions of a society. Also, Bohr refers to the interplay of such traditions as forming a frame within which the lives of individuals unfold. It follows that there can be no unfolding of any human life without such a cultural frame. Bohr even takes as an example of this, the very question of what it means to be human. Bohr finds that,

> "... we may to a large extent consider biological traits and spiritual traditions as independent of each other, and it would even be tempting to reserve by definition the word 'human' for those characters which are not directly bound to bodily inheritance". *(APHK, p. 29)*

This definition of the term "human" relates the notion solely to sociocultural matters, but not *in contrast to* the biological aspects. We shall understand the definition of human as cultural, instead, as expressing a way for biological aspects to be in a "human way". However, the definition does imply that the notions of social roles, and functions become crucial. About this Bohr says:

> "In fact, when studying human cultures different from our own, we have to deal with a particular problem of observation which on closer consideration shows many features in common with atomic or psychological problems ... What I here allude to is the experience, well known to explorers, of the shaking of their hitherto unrealized prejudices through the experience of the unsuspected inner harmony human life can present even under conventions and traditions most radically different from their own. As a specially drastic example I may perhaps here remind you of the extent to which in certain societies the roles of men and women are reversed, not only regarding domestic and social duties but also regarding behavior and mentality." *(APHK, p. 30)*

Maybe the concept of being embedded may illustrate matters. I believe that Bohr conceived of the physical aspect of things as being embedded in the whole of the organic world, and he conceived of our biological life as being embedded in the wholeness of a sociocultural form of existence; if you like, in the wholeness of a form of life that

involves such aspects as traditions, values, roles and institutions. Thus, for instance, to live as a woman is not something one can possibly do before one enters into a cultural setting. That is, there can be no gap between the possibility of merely *being* a woman and really living as one. If you insist on regarding "women" as a biological category I would reply that to be a "woman" in the biological sense is constituted by some characteristic bodily conditions for the possibility of entering into any of the possible forms of human life, including those we might picture as the "female forms". But saying this will have no point insofar as it will explain nothing about what might be such female forms. What is more, as Bohr says, the roles can be totally reversed between men and women such that the very distinction between "male" and "female" loses any ontological sense. The meaningful ontological descriptions that might be given concerning the category of being a woman are completely determined by the descriptions that would make sense of the possible shapes that a number of individual lives may take on, including the associated descriptions of the human characters thus displayed.

As Bohr makes clear, the importance of stressing this lies in the implications for our understanding of apparently strange and inhuman forms of human behavior. Certainly, Bohr makes the remarks I am discussing before an audience that included German scientists in the year of 1938. Nazism is lurking around the corner, and even many of Bohr's own friends in physics ought to recognize something terribly important.

The biological, seen in abstraction from other aspects of our lives, is precisely not what we have in common as human beings. Stanley Cavell has suggested that this is the view expressed by the words of Shylock in Shakepear's *The Merchant from Venice*, when Shylock tries to make clear that Jews are human beings just as fully as anybody else,

> "I am a Jew. Hath not a Jew eyes? Hath not a Jew hands, organs, dimensions, senses, affections, passions? fed with the same food, hurt with the same weapons, subject to the same diseases, healed by the same means, warmed and cooled by the same winter and summer, as a Christian is? If you prick us do we not bleed? If you tickle us, do we not laugh?, if you poison us, do we not die? and if you wrong us, do we not revenge. If we are like you in the rest, we will resemble you in that."
>
> *(The Merchant from Venice, Act III, Scene 1, Line 55 – 71)*

Certainly, Shylock does not mean to state a list of bodily facts about Jews. His point, as Cavell says, is just the opposite. Those who think that Jews (or Blacks, or Women) are not really human – to the same extent as the Superior White Male – commit the error of having a schematic view about the bodily existence of others. Such people *reduce* the essence of Man to biological matters. That is the message of Shylock. If you want to look so closely at what belongs to my race, look closer. I can laugh, I can cry, and I can die. I can observe and I can listen. That is what we all have in common – not anything that belongs to our merely having a body, but anything that forms part of the possibility of using the body in a life shared with the life of others.

I already alluded to the views of Merleau-Ponty as being close to those of Bohr's. Certainly, no one can criticize Merleau-Ponty for not taking the bodily aspects of our lives into account. Consequently, even if Bohr lays so much stress on the socio-cultural character of human lives, Bohr ought in no way to be criticized for ignoring the concrete, factual, or biological aspects of our lives. Instead, one must acknowledge that he very much takes these into account. Introducing the framework of complementarity into cultural studies gives expression to this. The framework implies a warning against

having a too narrow and morally questionable understanding of the bodily and biological aspects of our human existence.

In the quote presented earlier, we might further note two crucial parts of Bohr's understanding of the concept of culture. First, the reference to cultures (as representing harmonious ways in which various traditions can be combined within unitary forms of life) includes the recognition that no culture is closed. Certainly, the identity and stability of any cultural society has to do with its readiness and ability to relate to, and learn from, other cultures. Thus emerges both a Hegelian point concerning the otherness of any culture, as well as a Hegelian-Gadamarian point concerning a possible fusion of different forms of social behavior, insofar as a mutual recognition between the two outlooks can be established. Bohr explicitly stated, long before Gadamer, that,

> "... hardly any culture exists which could be said to be fully self-contained. On the contrary, we all know from numerous examples how a more or less intimate contact between different human societies can lead to a gradual fusion of traditions, giving birth to a quite new culture."
>
> *(APHK, p. 31)*

If one carefully reads the various texts of Bohr on this issue, a certain picture or metaphor, is clearly, but also implicitly, suggested; the picture of what lies at the root of our human reality. We can picture a tree, where the trunk reflects the unity of a number of branches, the relations between which have thus been supplied with some integrity. However, below this integrity, there is something lying at the root of the trunk – roots which are themselves branching in ever new and hidden ways. Bohr wants us to recognize that there can be no understanding in respect to the unity of the tree if one does not take into account the history of the developing roots, the basic elements of which are always at stake beneath the explicit, definite branching of the tree above the ground. The branching thus becomes a symbol for the history of hidden forms of branching at the root that nevertheless contains some universal aspects – namely those keyfeatures of wholeness that are expressed by the keyconcepts of complementarity: the concepts of "light", "life", and "culture".[252] All of this, Bohr says, goes to express that any framework, any logically coherent expression of a set of interrelations, any clearly formed branching, will nevertheless always expose something peculiar, insofar as it will expose the *Eigen-Art* of the framework. So too, will any real culture, in the sense of a harmonious interplay of traditions and institutions etc., always expose a peculiar individuality:

> "The knowledge of the history of a Culture, like the knowledge of it's conditions, forms part of the presupposition for a deeper understanding of it's *Eigen-art*." *(Bohr 1985, p. 247, translation mine)*

Bohr also expressed the point like this in answer to his question of what, if anything, constitutes, a special "Danish culture":

[252] I think that the concept of *language* may be included in this range of keyconcepts, which explains my caution regarding Chevalley's suggestion that Bohr's notion of "Synthesis" answers to Humboldt's conception of language. Using the metaphor above, such a Humboldtian conception of language represents too much "the branching in the clear", whereas the Romantic conception I associate with Bohr's, is concerned with "the branching of the roots". For example, what characterizes artistic creation is not the possibility of making sense across the etstablished linguistic rules, but rather the intuitive grasp of a hidden wholeness which makes such understanding possible.

> "If we ask ourselves how we can talk about a special Danish culture the answer will depend on the viewpoints which the question presupposes. On the one hand, the more we try to get hold on our very essence the more there will emerge common human aspects. On the other hand the more we try to capture all features of our existence the more we will come to feel the difference to other societies." *(Bohr 1985, p. 247, my translation)*

There is an essential link between the peculiar harmonious balance within a given social form of life on the one hand, and the "adaptation", as Bohr called it, of the conditions of this balance to similar such conditions within other forms of life. Thus, to adapt the relations between various cultures to one another, will entail adapting to one another what has conditioned each peculiar cultural branching. So, whenever we manage to establish forms of interrelation between two cultures, we will have grasped a feature of a deep-seated unity; the unity of the conditions for any harmonious cultural branching.

Later, we shall come to add an important detail to this picture, because Bohr developed a specific idea regarding the question of how two cultural branchings may adapt to one another. He developed this idea by taking seriously that the fact of individual sciences is already a manifestation of such an adaptation. This not only helps specify the framework of complementarity, but as we shall see, in one stroke, it acquired a quite new dimension. But I have to postpone my account of this dimension a couple of paragraphs. For there are still two aspects of the framework as characterized thus far that will be important to mention: First, a more substantial account of Bohr's Romantic philosophical inheritance, and second, an account of what I shall call "the logic" of the framework (as characterized so far).

There are many ways in which the views of Bohr's are consistent with Romantic philosophical conceptions, including the organic metaphor alluding to what lies at the root of our lives. Such talk was typical of the post-Romantic ideas that flourished in Danish academic circles at the time when Bohr grew up. One prominent example would be the widely read anthropologist Troels-Lund, many of whose essays Bohr would have known, including the modern Danish classic, *Everyday Life in the Nordic Countries in the Seventeenth Century*.

Bohr's romantic inheritance, however, becomes especially clear through his invocation of the metaphor of a *home* for reflexive thought. It was Bohr's view both (a) that such thought is never really "at home", and (b) that reflexive thought can only address an assembly (and not a community) of representatives from various different "homes".[253] However, by so doing, reflexive thought will always address the assembly with the prospect of bringing something with it back home.

Bohr made frequent use of such Romantic philosophical talk in what I will call his *Manifesto*. I am here referring to a speach that Bohr delivered at a party in 1928 where Bohr and his former *Studenter-Kammeraten* celebrated the 25th anniversary for having passed their *Studenter-eksamen* (undergraduate degree, typically at the age of 19). The speech that interestingly was written at the time of the publication of the Como-Lecture, contains some of Bohr's most informative and important reflections on, what I term, the *general* framework of complementarity:

> "Everywhere new forms of outlook are brought up and new fields and connections (*Zusammenhang*) dawn upon us. But as every road we choose

[253] See the "*Manifesto*", below!

> is branching and curving we soon lose our sense of direction and will sooner or later return to our point of departure. Despite of this we are always able to return home enriched (*mit einem Ertrag*). The richness of that which we can collect and piece together is unlimited. As we investigate into deeper and deeper presuppositions we realize broader and broader connections. In this way our lives are informed by still richer impressions of an eternal and unlimited harmony; only, the harmony itself can never be caught, it can only be glimpsed. And with any effort to catch hold on it, it slips by the nature of its essence through our fingers. Nothing is fixed. Every thought, even every word, is only suited to underline a connection, which can never be fully described, but always reflected deeper. *Such is, undeniably, the conditions for human thought* ... we can only complete our picture of the conditions of life by recognizing the play of oppositions. It is precisely in this vertigo of facing the unlimited we recollect those vague forebodings which form the background of the spontaneous excitement of the youth"
>
> *(Bohr 1985, p. 263, my translation from the Danish, italics mine).*[254]

The logic of the general framework of complementarity

I shall make further comments on this *Manifesto* below. But first let me try to sum up a core part of the ground covered above. We have seen how Bohr suggested analyzing biological phenomena and the objective features characteristic of organic life. We have seen how he suggested analyzing cultural phenomena concerning the lives of individuals within a given manifold of social traditions. And we have seen how it all relates to the issue of the subject-object cut. All in all, this points to the following *general* framework:

Within special fields of experience there may be oppositions that seem to give rise to epistemic dilemmas if one asks the wrong questions – "What is the nature of light?", "What is the essence of life?", "What is my true Self", "What is the foundation of an organized Society?" Now, there is something to learn from these oppositions; namely the impossibility of connecting them into one "picture" about the respective "natures", "essences", or "fundamentals". Thus, we have to recognize what Bohr calls an "individuality" in respect to the oppositions that points back to the wholeness of the observational situation, on the background of which our talk (and experience) of any of the oppositions makes sense. Consequently, by recognizing this wholeness as characterizing the *materials of such observational situations*, we further recognize an aspect of the world in which we ourselves are both actors and spectators. At this point, what has dawned upon our understanding is the possibility of observing a new kind of phenomena – phenomena of energy transformations, phenomena of life, phenomena of culture, etc.

Within each science we have to do with real, objective forms of stability in their harmonious interplay. The recognition of such interconnected kinds of stabilities stem from recognizing a way for us to belong to the world; a way that becomes manifest only when we realize the wholeness of the conditions of observability of various kinds

[254] Quite a party speech that! One may hope that Bohr's schoolmates had not had too much to drink before having to listen to it. But then, Bohr ends his talk by praising the special *Studenter Geist*which, he thinks, characterizes his particular generation of students.

of phenomena. Specifically, we are referring to phenomena of a kind that cannot be further analyzed, if the "reality" of the respective forms of wholeness is acknowledged. All in all, this is what I see as the logic of the general framework of complementarity.

The Unity of Knowledge elucidated in terms of the Unity of Scientific Methods

As mentioned above despite the fact that the considerations we have run through form the core around which Bohr's general framework of complementarity revolves, we have not yet come to its primary point. So far we have considered the possibilities of analysis and synthesis *within separate* fields of experience. It is true that there are some considerations of crossfields of study, as when in biology we take the physical functioning of organs into account. But that is not yet an inquiry into the principal interconnectedness between, and mutual conditioning of, the distinct and different forms of synthetic experience. Indeed, it is to this interdisciplinary connectedness that the general framework of complementarity is first of all directed. *The general framework is directed towards an elucidation of the philosophical question concerning the unity of knowledge*. As Bohr put it, after having mentioned the prospect that any logical frame, any conceptual framework, may prove too narrow,

> "... such developments ... entail a general lesson of importance for the problem of unity of knowledge. In fact, the widening of the conceptual framework not only has served to restore order within the respective branches of knowledge, but has also disclosed analogies in our position with respect to analysis and synthesis of experience in apparently separated domains of knowledge, suggesting the possibility of an ever more embracing objective description." *(APHK, p. 68)*

However, in our effort to elaborate a "more embracing description"; we cannot just try to elucidate the analogy of which Bohr speaks in the quote. So, although we as observers of objective phenomena within various fields of experience must recognize the general logic of the given situation, that will not be enough. Consequently, I find that there is a dimension in Bohr's general framework of complementarity that can easily be missed, though it ought not be.

In accordance with most German philosophers since Kant, Bohr recognizes that we have an intellectual disposition to try to transcend the bounds of any given science (just as any political, ethical, or religious institution). But this urge to radical reflection can only be nourished within pre-established settings and against the backdrop of well-grounded intellectual traditions. That is the sense in which intellectual reflection must always already have a specific "home".[255] But note, this is not meant to point to some everyday or ordinary attitude. To the contrary, the point is that the conditions for radical forms of scrutiny are culturally given as well. According to Bohr, the manifestation of the culture of a society are the efforts and abilities to initiate such an intense scrutiny. This implies that one should not be satisfied simply with recording the given harmony between different elements of tradition within a given social setting. One must be ready and able to reflect on the conditions for the given harmony, so as to make it possible

[255] Bohr in effect makes a distinction, to be acknowledged, between a *society*and the *culture*of a society. I suggest that the notion of the culture of a society" for Bohr is related to the metaphor of the home of intellectual reflexive thought. Compare, Goethe's notion of a "culture of knowledge" in *Maximen und Reflextionen*.

to inquire how that, which is not yet harmoniously incorporated into the socially given form of life, may become thus integrated.

Now, it must not be ignored that any scientific discipline as such includes elements that are rooted in various intellectual and cultural traditions. In line with this, Bohr was indeed anxious to remind us that the individual scientific disciplines form part of the culture of given societies in the sense just explained. Thus, to inquire into the observational situation of particular kinds of contemporary research already constitutes an inquiry into the *cultural* character of the form of scientific research in question. As Bohr says:

> "Of course it is impossible to distinguish sharply between natural philosophy and human culture. The physical sciences are, in fact an integral part of our civilization, not only because our ever increasing mastery of the forces of nature has so completely changed the material conditions of life, but also because the study of these sciences has contributed so much to clarify the background of our own existence." *(APHK, p. 23-4)*

It is important to see this issue properly. It is not an issue of cultural relativism with respect to the sciences. The point is instead that the possibility of justifying the claims made within given scientific disciplines will always be conditioned by some sort of self-understanding. Indeed, "to be an observer" and to be "accountable" is for Bohr two sides of the same coin. This is not to argue for a subjectivist reading of Bohr. It is not to say that Bohr believed that any objective judgment is conditioned by subjective elements beyond rational scrutiny. On the contrary, Bohr wanted to demonstrate that objectivity has more to it than justifying statements of fact. When someone judges objectively, something characterizing the subjective conditions of the objective judgement in question is exposed, such that these conditions become available for scrutiny. In effect, Bohr is arguing that objectivity and the possibility of self-criticism are essentially linked.

Consequently, there is an important insight that forms the base of Bohr's general framework of complementarity: The claims and methods of the various sciences *form part of the "materials of observation"* within various forms of cultural understanding; in analogy with the way in which the ideal conceptions of forms of energy and ideal conceptions of organic purposiveness form part of the material of experimental physics and experimental biology, respectively. Thus there is an important link between given scientific practices (on the one hand) and the traditions within a cultural form of life (on the other). This is why the relation between different scientific traditions symbolizes a "harmony" between various cultural traditions within a single Society.

I shall elaborate on this link below. First, there is a somewhat trivial aspect of the view currently argued. The view implies that there is no content in any objective claim of knowledge that cannot be scrutinized in the sense that one can always question the possible relations between such claims and other kinds of claims. There can be no kind of physics that is not vulnerable to questions concerning how physics and chemistry, physics and biology, physics and technology, physics and psychology, or physics and politics are interrelated. The same is true with any other pair of sciences. But the view also has a not so trivial feature:

I suggest there is an analogy between Bohr's understanding of individual scientific practices as complex cultural traditions, and Kant's consideration that all "domains of knowledge" might, in principle, be related to one another in "encyclopedic"

fashion. This is to say that *the issue concerning the possible relations between different kinds of experiences must be related to the ultimate question about the UNITY and SYSTEM of knowledge*. Thus, in my view, Bohr advocated something answering to a claim made by Kant in the *Third Critique*. According to Kant, in order to grasp the Unity and System of human knowledge, we must be able to make "encyclopedic introductions" of the various specific domains of experience, such that the totality of our knowledge will not be constituted by a patchwork of "propaedeutic [context-specific] introductions".[256]

In order to take these remarks seriously, one must realize that Kant never denied that human Reason has a historic dimension. In fact, he was one of the first to stress that.[257] The categorical forms of the Understanding may be a priori, but the reflection of how the elucidation of these a priori forms of Understanding comes to shine over all forms of Thought is an ongoing process. In that sense, human Reason has a history that, Kant says, can be characterized (a) by its increasing "discipline" concerning propaedeutic clarity in particular domains of experience, and (b) can be characterized by an improved ability to recognize the unity within the growing *system* of individual sciences. This latter ability characterizes the culture of human Reason in its effort to balance the propaedeutic with the encyclopedic dimensions of human Thought.

I think Bohr's general framework of complementarity must be seen along such lines. Thus I understand Bohr as follows: As more and different kinds of science develop, there is an underlying unity that is also gradually disclosed. I want to suggest that that was part of the message of Bohr's short introductory address to the Unity of Science Conference, held in Copenhagen in 1936 – a conference that should address, precisely, the outlines of a new *encyclopedia of unified science*. Bohr contributed to that enterprise by saying:[258]

Analysis and Synthesis in Science

> "Notwithstanding the admittedly practical necessity for most scientists to concentrate their efforts in special fields of research, science is, according to its aim of enlarging human understanding, essentially a unity. Although periods of fruitful exploration of new domains of experience may often naturally be accompanied by a temporary renunciation of the comprehension of our situation, history of science teaches us again and again how the extension of our knowledge may lead to the recognition of relations between formerly unconnected groups of phenomena, the harmonious synthesis of which demands a renewed revision of the presuppositions for the unambiguous application of even our most elementary concepts. This circumstance reminds us not only of the unity of all sciences aiming at a description of the external world but above all of the inseparability of epistemological and psychological analysis. It is just in the emphasis on this last point, which recent development in the most different fields of science has brought to the foreground, that the program of the present great undertaking distinguishes itself from that of previous

[256] Kr .d. Uk., Erste Fassung, p. 57
[257] The very concluding paragraphs of *The First Critique*concerns "the culture and history of Reason".
[258] Bohr (1936)

> encyclopedic enterprises, in which stress was essentially laid on the completeness of the account of the actual state of knowledge rather than on the elucidation of scientific methodology. It is therefore to be hoped that the forthcoming *Encyclopedia* will have a deep influence on the whole attitude of our generation which, in spite of the ever increasing specialization in science as well as in technology, has a growing feeling of the mutual dependency of all human activities. Above all, it may help us realize that even in science any arbitrary restriction implies the danger of prejudices and that our only way of avoiding the extremes of materialism and mysticism is the never ending endeavor to balance analysis and synthesis." *(1936, p. 28)*[259]

No doubt, Bohr developed this view by realizing that although the different sciences could never adapt to one another, still *the relations* between the methods of the various sciences could adapt to one another.[260] Recall, a framework in the Bohrian sense means a "logical representation of *the relations* between different kinds of phenomena". Now, although any such framework will suffer from the groundlessness and limitation expressed by Schiller, still by launching ever more general and all-embracing frameworks, one can gradually sense an inner harmony emerging. One may grasp how the various *relations* between different kinds of phenomena adapt to one another, which is to say that one recognizes common elements within the conditions of the possibility for the various kinds of phenomena. It is these common elements that are symbolized by the key concepts of complementarity: light, life and culture.

Thus, we see that Bohr, in his thoughts on the prospects for an encyclopedic understanding of unified science, makes use of his model of what lies at the root of our various intellectual traditions. The branching above ground, the elements of which may be related to similar elements of other branchings, symbolizes the unity of what, deep down, conditions each of the branchings. But this is to say that the new encyclopedia of unified science hinges on regarding the development of both the individual sciences, and science as such, as being a sort of cultural development. What gradually comes to the fore is not just a growing stock of insights, but instead certain universal characteristics of skilled, human activity. The conjunction of those universals symbolizes something profound about the fact that we are part of that Nature towards which our scientific efforts are directed. Here, I refer to such universals as "matter", "light", "life", "culture", and "language". These are, if you like, *Ur-phänomene*, basic features of Reality without which, and only through which, the experience of Reality is possible. This points to a certain parallel between Bohr and Goethe that I will not pursue since Bohr does not really say much on the issue. However, I will end my presentation of Bohr's general framework of complementarity with some general metaphysical considerations, and thus try, in more systematic fashion, to place that framework within the post-Kantian philosophical landscape.

[259] I think that Bohr's use of the term "psychology" is unlucky. The term makes sense in that it shall refer to an *attitude*; but the attitude in question is (I would say) a purely *epistemological*attitude; an attitude towards given forms of experience.

[260] By the way, I find it instructive to compare this with the view expressed by Bohr in his famous address to the UN of 1950: "I address the organization which is founded in order to further the cooperation between Nations in all matters of common interest. I do so by bringing forward some considerations regarding the requirement for *bilateral relationships* to adapt to ane another, imposed by the enormous evolution in our time, in science and technology." (Bohr 1985, p. 231, translation & italics mine

The Unity of Nature, symbolized by The Unity of Knowledge

According to Bohr, the encyclopedic interrelation of the various scientific domains is not a task that can be achieved simply by cultivating human Reason as Kant wrongly thought. Bohr, in contrast, and much in line with Kant's successors within the tradition of German Idealism, regarded the interest in, and ability to, produce rational encyclopedic accounts as an ongoing, provisional, and organic process. Let me elaborate on this.

Following German Idealistic thought, Bohr regarded the ability to establish encyclopedic views as an exposition and expression of a *Geistige Wesen*. This *Wesen* characterizes a way to be situated in Nature in ever-new ways as an observing human being. As I see it, this view forms the basis on which Bohr invoked the concept of culture. Now, Bohr's *Manifesto* involved making a series of claims including,

i) There can be no universal culture
ii) There can be no universal science, however unified
iii) There can be no world community, but only some organ like the U. N. clarifying what may be *Allgemein* in respect to the bilateral relations between individual nation states
iv) There can be no universal philosophy, nor a transparent form of self-conscious human being.

By claiming all this, Bohr in fact reiterateed some of the views of the later Schelling to the effect that the emergence of both the social and the linguistic sciences has exploded the original Hegelian vision of a phenomenology of *Geistige Wesen*. Hegel's question about the logic and structure of the development of this *Wesen* has exploded into a more complex issue concerning the ever-changing interplay between our various cultural, scientific, and linguistic forms of self-reflective being.

All in all, then, Bohr may be said to follow the German Idealistic philosophers – and not Kant – in his understanding of the issue of the unity of knowledge. First, the issue deals with recognizing how cultural forms of life may embody an acquired ability to establish encyclopedic insight. Second, the issue of the unity of knowledge formed part of an elucidation of the very unity of Nature. What is clearly at stake for Bohr is the exposition of the unity of Nature. Like Schiller, Schelling, and Hegel, Bohr was concerned with the issue of how to expose this unity in terms of an exposition of the limiting features of various self-reflective, rule-governed practices.

However, this of course still involves a Kantian inheritance. To demonstrate the uniformity of what lies at the root of various rule-governed activities – however limiting such uniformity may be – is the best means there can be of demonstrating both

(a) *a claim* to the effect that our well-founded practices must include some ideal forms of rationality
(b) *a condition* to the effect that the wide-ranging series of activities that are licensed within these practices can never be fully exposed in terms of this idealization.

Thus *a critique of judgment* is called for which will elucidate our ability to judge when rules run out – a critique that refers to our judging in accordance with a "*system* of things", the reality of which is presupposed in our judgments, but can never in itself be grasped.

At this point, I want to underscore two ideas that were originally advanced within German Idealism and some version of which, I think, Bohr advanced as well.

(1) One may suggest that there are certain permanent features of the ongoing historical genesis and transformation of various forms of Being. This is not to say that history repeats itself or runs according to a certain pattern or logic. It is instead historic change, as such, that permanently is part of the emergence of forms of Being (somewhat in the platonic sense of a *worldsoul* that permeates the dynamics of things, or in the Goethean sense of a principle of power, an *energeia*, that permeates all forms of Nature).
(2) Second, one may think that metaphysical reflections, as such, and in themselves, *exemplify and constribute to* this interplay of power, structure, emergence, stability, and transformation; for is not human thought and human language, itself, a historico-dynamical phenomenon? Consequently, the possibility of making sense of the structure of Reality in certain symbolic forms, this possibility does in itself *transform the possibility of making sense* of the world. The sciences, the arts, and the various forms of philosophy can all be seen as such symbolic forms.[261]

The heart of the matter is that if we choose, head on, to speak about a general development of, say, "knowledge", "language", "experience", "understanding"; then

[261] I make use of Cassirer's term, but do not mean to make explicit use of his philosophy.

we face the problem about reflexivity. In other words, the problem about what we are to say in respect to the developing knowledge *of* knowledge, the language on linguistic features, or the experience of being experienced or the like. These are the kinds of problems that the notion of a "symbolic form" will help us to avoid.[262]

Now, I make these remarks in order to say something about what I would like to call the Thesis of Unity – the Thesis that, we have seen, Bohr advanced to the effect that the unity of *knowledge* (corresponding to (2), the unity between all symbolic forms) may be seen as expressing the unity of *Nature* (corresponding to (1), the unity between all modes of being).

The relation between the Thesis of Unity and the two ideas (1) and (2) points in two directions. First, to adopt the two ideas provides a way in which to state the Thesis of Unity – and my suggestion is that this is how Bohr proceeded. He did not pull the Thesis of Unity from his sleeve; instead, he based the Thesis on certain premises corresponding to our points (1) and (2). Second, as they stand, (1) and (2) are merely regulative principles that should be assessed *only* in so far as they form part of the background of formulating a further thesis such as the Thesis of Unity.

A case in point is the gradual development of the idea of "causality" and with it, "explanation". Thus, in so far as we succeed in picturing the atomic realm as a historico-dynamical, material causal *Zusammenhang*, and do so by means of certain formal kinds of thought; this all implies that not only do we acquire a new outlook, a new understanding for what it is for atoms to be both stable and dynamical systems; we also achieve a new perspective on what it means, and what it takes, to be able to describe the atomic realm, precisely, like that.

Consequently, I have been arguing that Bohr's framework of complementarity, when seen as a continuing generalization of the concept of causality, can be seen, also, as an attempt to account for these highly complex issues in respect to the unity of thought. I see this as a main point of the general framework of complementarity.

6.2 The Unity of Semantics and Pragmatics within the Framework of Complementarity – concluding considerations

The semantics and pragmatics of the strict framework of complementarity

Part of what leads to various untenable accounts of Bohr's semantic views is an unacceptable Quietist conception of the language of both classical mechanics and of ordinary contexts in general.[263] Such contexts are romanticized insofar as it is taken for granted that *there* we (1) have clarity and (2) know *wherein* clarity consists. But we do not know this, and that, in fact, is one of the main lessons of the quantum theory. According to this theory, our previous ways of thinking and talking were muddled and confused. Part of what was confused was our failure to discriminate between various contexts, such as the two different contexts in which we may deal with the same stick – as was illustrated by our previous example of a stick that can be seen as either an object or a tool. Anything that enters into a clear and determinate statement *about* the stick cannot be immediately transferred into whatever kind of clarity we may seek in

[262] In saying this, I *do* adopt Cassirer's ambition

[263] In the sense that there is no need to analyze or elucidate what it takes to establish an "ordinary" linguistic practice in that one pictures, as it were, a home ground on which radical reflection is not part of what constitutes the practices in question.

the practice of *using* the stick. Similarly, the use of concepts in describing experimental arrangements should never have been thought to shape the use of the same concepts in order to report the results of measurement.

The best way to silence the Quietist interpretations of Bohr's semantic view might seem to be by inquiring into what would be involved in formulating a semantic theory or a theory of meaning. Such a theory should provide a systematic representation of the general practice of linguistic means within certain contexts. Of course, to Bohr there is as yet *no* definite particular practice to record in respect to the quantum theory. At best, the issue could be how certain features of the linguistic practice of classical physics might be modified. But how are we to picture such a situation in linguistic terms? To say that in the context of the quantum theory "one can no longer say that ..." will always be more than a report of some sort of incapacity of ours. Even if we stress, as we should, that in a sense it is Nature that places a *limit on what we can say*, this situation is still very different from a situation where, as it were, we have the carpet pulled from under our feet.

What has come to an end is not some capacity to apprehend a pre-determined or given objective reality. *What has come to an end is the intelligibility of our own former practice, including its aspirations and ideals*. What we used to do no longer makes sense. Among other things, we set out to explain natural phenomena and to seek an objective order within the succession of such phenomena. We wanted to trace, in space and time, the objective features for which we had developed theoretical accounts of causal relations. Such aspirations and ideals must be radically modified if not totally given up. In short, we have to revise our understanding of what it is we have achieved once we have established an explanatory science. In my opinion, by underscoring the practical aspects of our scientific experimental efforts, we may also learn how and why the revision of principles for using *linguistic* means should be seen as forming part of a broader kind of self-criticism.

Consequently, **if** the development of the quantum theory is said to go hand in hand with the development of a certain linguistic practice consistent with a certain theory of meaning, **then** there is no way in which this semantic account can be abstracted from a whole range of normative issues such as self-clarity, explanatory power, coherence, completeness, and exactness. In respect to these normative issues, it can never be a matter of merely trying to *restore* a set of cognitive values already existing in another context. On the contrary, when it comes to characterizing a possible semantics, we are trying to establish values and resources we cannot claim to possess already; we are trying to establish a practice in accordance with principles of aspiration. There is no pre-existing paradigm for this, and certainly not something called "classical physics."

The use of concepts in classical physics was always considered consonant with principles of thought regarding (a) the generation of intuitive representations of certain objects, and (b) the concrete experimental *Darstellung* of such intuitive representations associated with given experimental arrangements. These kinds of considerations are just as relevant for classical physics as they are for the quantum theory. The only thing that has changed is our attitude or vision towards the kind of control over the conditions for performing various kinds of experiments. Before returning to the issue of the normative features of semantics, I would thus like to further reflect on the notion of "control."[264]

[264] See point i) of my account of the Interaction Problem.

In the context of experimental physics, the term "control" refers to a kind of self-control, a control over what we have set out to do. Thus, in the context of the quantum theory it does not make sense to even *try* to measure the interaction between the means of measurement and what is being measured. For example, if we use a piano in order to play a tune, we play the tune and not the piano. It is not the fact of our employing a piano that constitutes the fact that we play the tune. Whatever we do to the piano apart from what is involved in playing the tune will not be playing that tune. Similarly, we cannot measure the means of measurement in order to demonstrate *how* or *that* we truly measure this or that. So the point is not that the objective structure of the real world excludes us from doing something substantial which, unluckily, is "out of our control," it is instead that there are ways in which it is pointless to try to analyze *that* we do or *how* we do what we do. This is a general characteristic of human action. There are limits to how we can describe, and thus scrutinize, our actions while performing them.

It should be noted that there is no simple or straightforward semantics associated with classical theoretical physics of the period between 1850 and 1920, and the kind of semantics involved is far from being robust, either in the form of a robust semantic realism or in the form of a robust semantic idealism. **If** the meanings of possible state descriptions in classical physics had been given in terms of space-time pictures, **then** a new semantics would have been called for within the quantum theory. But within the Helmholtzian tradition of theoretical physics, the meanings of state descriptions were never given in that way. Even if it had been possible to point out clear-cut pictorial forms, to space-time as a clear form of intuition, this was never sufficient to constitute the sense of possible physical judgments. Within the context of (neo)-Kantian epistemology, the determination of possible judgments requires an account of a systematic interrelation between ranges of concepts. It is only the use of such a *system* of concepts that is required to be exhibited in sensible intuition. This explains the complexities involved in demonstrating how the unity between a kinematics and a dynamics is required for the possibility of a mechanics and on which unity-determinate theoretical physical judgments may be based.

Before we start examining semantic considerations in quantum theory, we should be aware of what such semantics will involve: First, a clear account of the possibilities of observation corresponding to a set of means of observation. However, this account involves giving an account of how the possibilities of observation are dependent on the use of various linguistic means, such as the use of formal principles, rules of calculation, or syntactical stipulations. I think this reflects the view of the Helmholtzian tradition quite nicely. Second, a linguistic practice is entirely normative right from the start. The language game does not come first, in accordance with rules, and then only in a derivative sense further questions about what might rationally relate to the linguistic practice in question within this or that context. We shall thus look at things the other way round: a normative practice is given only if various features of that practice (e. g., its specific features of rationality, specific forms of clarity, or particular aspirations) will be elucidated by describing the practice as involving an effort to comply with certain *linguistic* rules.

Accordingly, following the proponents of the Helmholtzian tradition, what might count as the possibilities of observation within a given theoretical context has to be related in a *systematic* fashion to principles for applying the *concepts* involved in formulating a given physical theory. This kind of semantic criterion did not change with the advent of the quantum theory. The point, method, and character of the semantics

constructed when the quantum theory was in place did not differ significantly from the semantics of classical physics. The change that did occur had only to do with the necessity of generalizing the conditions for *applying* the new theory.

However, there is no special characteristic of classical physics that in any sense forms part of the foundation of atomic physics. There is nothing in the classical context that is in place and to which various parts of a supposedly more troublesome theory should be systematically related. As far as clarity, coherence, and completeness are concerned, the quantum theory is the best physical theory so far. In a methodological and epistemological sense it is the best. All the various *semantic* accounts of the philosophy of Bohr, including the Ordinary Language View, fail to see this properly. These semantic views seem to turn everything upside down. And, even worse, it is precisely when regarded as *linguistic* practices that the various forms of classical physics, seen in retrospect, must be considered muddled and confused. Quantum theory, on the other hand, exemplifies significant semantic progress.

The semantic issue of securing a rational foundation for applying theoretical concepts within the context of the quantum theory forms part of a broader issue concerning the rationality and coherence of a set of practical aspirations that are associated with the practice of experimental physics. Consequently, the semantics of the quantum theory is part and parcel of an attempt to clarify our (normative) situation as "observers" within a certain series of experimental arrangements, each of which is designed so as to *make sense* of certain physical effects, in order that we can "comprehend" these effects within the conceptual description of specific atomic physical phenomena. In short, the semantics of the quantum theory is but a means for us to be able to *scrutinize the conditions for the possible observation* of a certain (theoretically defined) range of phenomena. Thus, observation becomes less a matter of getting information than of *situating oneself* within the whole of various experimental arrangements.

Our new situation as observers of quantum physical phenomena does not entail that every conception we may happen to have is blurred because of some uncontrollable influence of subjective factors, but rather that we (for the first time in the history of physics) are able to thoroughly scrutinize the conditions for rationally applying the theoretical concepts to be used in the description of experimentally produced phenomena. But the general semantic principles concerning the normative and context-dependent character of these conditions of application remained broadly the same Helmholtzian ones.

The unity of semantics and pragmatics in quantum mechanics

In this book, I have been arguing that the assessment of the quantum theory has been displaced by too narrow a conception of both classical philosophy and classical physics. I have been arguing that both of these classical forms of thought embody rather complex structures of rationality with the result that one should consider the development of the quantum theory not as an attempt to construct a new form of scientific rationality, but rather as an attempt to *maintain and clarify* the characteristic complexity of the classical forms of thought.

This attempt was doomed to failure insofar as there has, in my view, *never* been a single physical theory matching the classical criteria. This becomes clear by tracking the development of Helmholtz's philosophical assessment of physics. Helmholtz's philosophy of physics sprang from the idea of fusing the following:

(a) The neo-Leibnizian tradition of associating (some version of) the principle of least action with the development of a formalism, like that of Lagrange and Hamilton, respectively

(b) The neo-Kantian idea of associating the tripartition between kinematics, dynamics, and mechanics with the table of schematized concepts, including that of causality

This fusion in turn formed the basis of a research program that ended up fueling the development of physical theory from the 1870s to the 1920s. In effect, Schrödinger's, Popper's, and Einstein's quarrels with the quantum theory were quarrels with that research program, which, they believed, should not be considered as "the end of the road."

I have criticized various attempts to disregard the Helmholtzian research program, not so much because I have wanted to set the record straight, but rather because in my opinion such attempts prevent us from adequately assessing the intent of the early quantum theory. In my view, the ambition of that particular theory was more modest than is often claimed. The ambition was to model a new realm of physical objects, the atomic structures posited within a shell model of atomic physical systems. The original Bohr model was of course understood to be merely heuristic, but the notions of "elementary particles" and "transition processes" were maintained as key notions and were associated with a certain *generalization of the concept of energy* – that of "binding energy." The ambition was furthermore to regulate the understanding of the experimental evidence available in accordance with certain principles of thought. The latter ambition involves (Kantian-like) attributing an objective *real* content to the given experience, and is not an expression of ontological prejudice.

In short, the quantum theory formed part of an attempt to objectively model a table of Atomic Elements (*Grundstoffe*), each of which was represented by a certain *configuration diagram* representing the series of possible energy states of elementary particles bound within the respective atomic systems – either concerning the electrons "surrounding" the nuclei or the elementary particles bound within these nuclei. History shows that the development of nuclear physics put an end to that research program. But history also shows that the development of a new model of atomic nuclei – the liquid drop model advanced partly by Bohr, as well as the continuing theoretical work of both Heisenberg and Yukawa – did *not* put an end to the utilization of the quantum theory.

One might say that the recent developments of nuclear physics (theory of quarks and colors) together with the exciting fusion of nuclear physics and astrophysics in the hands of theoretical physicists like Stephen Weinberg and Stephen Hawking go to show that today the quantum theory forms *part* of a wider theoretical scheme. However, the quantum theory still forms the main background on which to interpret and order any given experimental evidence. In that sense, it still forms the key to the physical understanding of the microphysical realm.

In short, there is as yet *no escape* from the quantum theory. One cannot do without it *whatever else* is the theoretical agenda of a piece of physics. The quantum theory does not form a basic "world picture" in the sense of Planck. In this respect Schrödinger, Einstein, and Popper were right. However, their respective visions of overcoming the quantum theory and substituting it with another *foundation of physics* has still not come true. And there are many reasons for claiming that part of what the quantum theory implies is that we should disclaim the very idea of "a foundation for physics."[265]

Thus, given the adequacy of these general remarks on the implications and characteristics of the quantum theory, I have been arguing that Niels Bohr provided a valuable analysis of these implications. This analysis has two main features, one of which was actually first elaborated by Heisenberg in his early paper from 1927. Heisenberg was the first of the quantum physicists to consistently argue that the concrete shape and utilization of certain experimental arrangements might condition the possible *use of concepts in the description of experimentally produced phenomena*. According to Heisenberg, this view was regarded as a modification – a sort of realistic turn – of Helmholtz's idea regarding how "the facts of perception" condition the possibility of developing theoretical concepts within the *representation* of physical experience. As is clear from the conclusion of the Como Lecture, already with Bohr's prompt response to Heisenberg in 1927 the view was provided with a *semantic turn*, as the conditional at issue pointed in two directions. For not only do certain facts about the experimental set-up condition the possible use of theoretical concepts, previously developed *formula* also condition the possible shape and character of "the facts of experimentation," to paraphrase Helmholtz. The theoretical formulation of the Indeterminacy Relations proves exactly that reverse conditional. It is only on a certain theoretical background that the spatio-temporal features of given experimental designs may be said to form part of a new kind of *intuition*.

For the following reasons, these remarks relate to the issue of what would be an adequate semantics for the quantum theory: Heisenberg's original idea of there being experimental constraints focused on the possible content of *Vorstellungen*, whereas Bohr focused on the restrictions of *Darstellungen*. In other words, Bohr focused on the intuitive representation of *concepts*, on the schematization of concepts within forms of measurement, whereas Heisenberg focused on the intuitive representation of *objects*. Consequently, with Bohr – and as Heisenberg conceded in his Chicago Lectures – the formal quantum physical account of the possibilities of experimental design conditions the sense in which one might experience a certain *kind of phenomena* (such as wavelike or particle-like ones). In that sense, as Henry J. Folse for one has pointed out, quantum

[265] In other words, there is no *one* principal foundation of the series of intellectual endeavors called "physics." Hence, Einstein's search for such a foundation was futile. But given certain Bohrian and Wittgensteinian reminders, it makes good sense to speak of the foundations of a particular discipline like the quantum theory.

physical phenomena are "features of description."

It was considerations like this that Bohr managed to thoroughly analyze in his more mature works. I have in particular pointed to the distinction between "quantum physical effects" (to be comprehended in order to constitute a measurement) and "phenomena" (to be synthesized according to the framework of complementarity in order to produce a theoretical judgment). In short, the intuitive representation of theoretical concepts – the schematization – is a necessary feature of what Bohr calls the "comprehension" of quantum physical effects. They are indeed intuitive *Darstellungen*, but they are such presentations only from the point of view of quantum theory. As such, the schematization of theoretical concepts forms a necessary part of interpreting certain "effects" as constitutive for definite phenomena (forms, if you like, part of the criteria of identity of such phenomena). And this in turn conditions the possibility of interpreting individual phenomena as corresponding to *objective* features of certain atomic states and transition processes.

The necessity of schematization is evident in the phrase that measurement by definition involves a "standardized comparison." Thus, it also involves a *pragmatic* component, which Bohr expressed by his motto that theoretico-physical experience was a matter of "reporting what we have done and what we have learnt." This must be seen aright. A more exact formulation would be the following: "what we have done in order to make sense of a *certain use of concepts*, and how we have been able to apply the concepts in question in our objective thought about real atomic structures." Here, semantics and pragmatics coalesce. We do not *first* have an ordinary kind of pragmatics (how we are all able to orientate ourselves within our immediate macroscopic surroundings including our ability to use a certain set of concepts) and *then* step-by-step manage to construct a special theoretical outlook. The constitution of pragmatics enters directly into the possibility of making sense by means of concepts.

This is true in respect to any linguistic context and is not unique to quantum physics. However, if there is any distinctive difference between classical forms of physical theory and quantum physics the difference must hinge on the *different manner* in which pragmatic and semantic features conjoin. This is why it is important to point to the pragmatic and semantic features of Kant's analysis of classical physics – however implicit – in order to assess the prospect of transforming the original Kantian account of classical physics so as to consider if, and how, such a transformation might play a part in interpreting a new kind of physical theory like the quantum theory. Hence, in the sense of a unity between pragmatics and semantics, the Kantian interpretation of physics became, in the hands of Helmholtz and others, an aspiration concerning a certain kind of *self-transparency* within the search for scientifically based knowledge.

In my view, this is the point at which one might draw a parallel between the semantics of Bohr and the later Wittgenstein, respectively, to the effect that classical physics is seen as involving a certain kind of pragmatic success – a functional success, if you like – but is also seen as lacking a required epistemic clarity. Classical physical theories are in effect descriptions of certain *models of the world*, descriptions that work well in accordance with certain explanatory criteria, but which place certain ontological limitations on the possible objective descriptions of its subject matter.

With the quantum theory, the required clarity is achieved, but at the price of the absence of a specific ontology corresponding to the models of the theory. The posits of the theory no longer form a definite field of independently existing objects. I have argued

that this view may still form part of a *realistic* understanding of quantum physics. It is not, given the pragmatics and the semantics of the quantum theory, that we *derive* the reality of the posits; the reality of these comes out within the very experimental practice corresponding to the theory. Nor is it *because* the experimental practice is possible that we can claim that atomic structures exist; it is because the practice explicitly *aims at* positing atomic structures that the pragmatic success and semantic consistency of the practice demonstrates the reality of the atomic structures. Paraphrasing Wittgenstein, one might say, "the kind of language game is the kind of certainty."[266]

Powers and emergence

Furthermore, in this book I have tried to give an account of how the tradition of theoretical physics that Helmholtz initiated was embedded all along in a broader tradition of physical thought within natural philosophy. At least until before the Second World War, the tradition of physical theory was often supposed to function in accordance with some basic metaphysical principles of physical thought. This guided not only the development of a series of specific physical theories, but also the understanding of the interplay between specific physical theories and general principles of thought.

With regard to this, it was always part of the tradition of theoretical physics to be open to reflection on the role of physical thought within other intellectual disciplines, and thus to help elucidate – also in respect to these other fields – the possible outcome of the interplay between theoretical understanding on the one hand and principles of thought on the other. In this respect, Bohr's framework of complementarity can be said to prolong a tradition of Natural Philosophy, a tradition which takes seriously (1) the question of how Natural Philosophy forms part of a philosophy of Nature, in the fullest sense of the term, and (2) how the answer to this first question will eventually inform all forms of philosophical questioning.

I would like to draw attention to a certain distinction that is regularly drawn within the metaphysics of German Idealism: the distinction between forms of *being* and modes of *existence*. I will use this distinction to illustrate a characteristic development of physical theory. In ancient thought, physics was supposed to deal with nothing less than the *whole* of the material world. With modern rationalism the idea lived on in the sense that physics had to do with *the* physical reality, a particular dimension of all Being or a certain kind of substance. One of the important implications of Kant's metaphysics of Nature was, of course, that the metaphysical idea of a field of objects of a certain kind was set free from the dogmatic idea of there being one and only one substantial, physical world. The "physical" way of *being* was seen as relative to a certain way for human understanding to *exist*. "Existence" here is something active, a dynamic unfolding of certain basic powers that may themselves be transformed in the process.

However, Kant did not push this idea to its (onto)logical conclusion. He was right in not seeing physical reality as something we *confront*, as a whole, but rather as something we manage to form/shape, reconstruct, or picture. In short, the physical world is not a pre-given reality for us to grasp but rather a complex structure for us to *demonstrate*. Now, this leaves the question open, as to whether it is the manner of demonstration or what is demonstrated that counts as real. For, certainly, being part of our manner

[266] (PU, IIxi, p. 224)

of demonstration is a way for things to *be*. Models, pictures, or acts of demonstration are all, in a sense, *real* objects.

What are we to say, then, about the fact that this real feature can be demonstrated by means of *that*? By drawing a parallel between works of art and scientific representations, Schelling, for one, got the idea that rather than showing something about the form of *being* of the feature demonstrated, such a fact showed something about its form of *existence*. For example, this is how we shall conceive of the distinctions between matter and light as two different forms of existence, just as we conceive of the difference between organic and in-organic forms of *existence*. Physics deals with matter and light, not qua modes of being, but qua modes of existence.

According to this view, objects (qua modes of existence) are only real within various phenomena (qua modes of being). It follows that it is only possible to analyze the experience of certain objects in relation to certain phenomena. As I see it, this is, incidentally, the distinction that Marx was later to associate with the distinction between forces of production (qua modes of existence) and relations-of-production (qua modes of being) as forming the two distinctive features of any real *product*.

I suggest that this illustrates how Bohr saw the ontological implications of the quantum theory. Atoms *are* not; they exist. They are powers, not powers "behind" the bodies, but powers "surrounding" the bodies. Atoms are like piles of sand that may come to *be* and that may take on a variety of shapes, but not any shape. In experiments, we try neither to shape the powers nor the bodies of the world. We try to regulate the way *in which powers enter into the shaping of objects*. We try to regulate modes of existence (forces of production) in order to see if certain modes of being (relations of production) emerge. In this sense, every physical experiment is an attempt to change the structure of the world, that is, to make a *new kind of emergence* come forth. By doing this, we want to let the world itself show its creative powers. We regulate, but only in order to let the world create what would otherwise, perhaps, not have been created.

This general notion of existence does not distinctively form the basis of a material mode of being. The manner in which modes of existence and modes of being, so to speak, are realized within distinct kinds of objects, may differ. In *this* sense, one may consider the atomic realm or the realm of electromagnetic fields as forming distinct fields of possible knowledge. But still, the topology associated with such a distinct field is in some sense to be regarded as an abstraction, as a "moment" within an overall dynamic (historical) process. The possibility of atoms presupposes the possibility for atoms to *emerge*, and implies the possibility for, say, molecules or organic systems to evolve.

Thus, the objective existence of powers can neither be seen as primary nor as secondary properties in the Lockean sense. They are neither a priori given inherent properties nor relative to *definite* conditions for their emergent potentiality. Like, say, a strong melody, they are the sort of item that *can* have a history – now sung like that, now performed like this, depending on the various, changing circumstances. It has to do with a kind of realism. It is not enough to say, as did Hacking, "if you can spray them they are real." Rather, one should say, if you can successively kick them, spray them, touch them, eject them, and so on. In short: **if** it makes sense to say that *the same* items have a variety of different emergent features, each of which can be operated upon within a range of specific (but historically related and mutually interdependent) language games, **then** the items in question can be said to objectively *exist*, without our having to ascribe a determinate mode of *being* to these items.

It is not our experience of things that is inexhaustible, as if it were impossible for us to "fully" grasp the true features of things. It is the things, or powers, existing as such that are unlimited and inexhaustible. For our part, we are able to make the objective powers of things manifest themselves in a *systematic* fashion. This is not to say that in reality there is no disorder and no regularities, and that order and regularity only exist "in the laboratory"; rather, this means that we are able to make the world manifest itself in a way that *is intelligible to us*. We manage to make the world speak to us, as it were, in a language we understand. However, just as the emergence of Jesus, of God in a human figure, was not a matter of God actually becoming a man in the sense of being *reduced* to being just that, the emergence of intelligible interrelations between physical features is also but a way in which *the world itself* reveals itself to human intelligence. This revelation is real and does *not* depend on human capacities.

With science, it is not a matter of cultivating and humanizing Nature. Rather, through science we manage to see the nature of things as forming a possible basis for our endeavors. Nature is revealed as a place "for us," not in the sense that Nature "matches," so to speak, a pre-determined human capacity and intellect, but in the sense that the possibility of developing and growing as human beings is being furthered and clarified. Therefore, rather than teaching us primarily to control Reality or to plan and predict things, the sciences present us with a variety of *tasks*. Possibilities, questions, obstacles, and visions are bound to pop up as a result of our scientific experience. In this sense, science belongs to modernity. Due to the sciences, mankind is doomed not to remain as it is. Through the sciences we are transforming ourselves, we are transforming our understanding of what it is for us to be of a Nature, to *have* a (Human) Nature, to *belong* to Nature, as such, and to be both *bound and set free* by learning more and more about the nature of things.

I am not saying that *only* the sciences have this function; however, following Bohr, I make the claim that in our modern times there is no way, in which we can ascribe similar fundamental anthropological functions to, say, the arts, to religions, or to politics if one were to *ignore* the impact of the sciences. In this respect, the sciences, the arts, religions, and politics (and Cassirer would include technology) have become *integral* to one another. Yet this is not to deny the distinct role of the sciences in revealing the objective features of the existing powers of the world.

The positive character of the framework of complementarity

Finally, I would like to make a comment on the connection between philosophy and the other sciences: In my view, in philosophy it is always necessary to be in a dialogue with something "outside" of philosophy itself. The ultimate strength of Bohr's philosophical essays is, I would say, to prepare for such a dialogue. These essays do not fully qualify as philosophical works. Instead they express what Witttgenstein called "reminders," recalling what the philosopher should bear in mind (consult, or perhaps even confront) in order to advance philosophical reflection in significant ways. In Hegelian terms, Bohr is a valuable Other to philosophical thought. However, given this characterization of Bohr's essays, one comes to realize their ultimate weakness.

The dialogue between philosophy and the individual sciences – and, similarly, between a searched-for common world of thought and some local setting – is in my view portrayed by Bohr in too positive a fashion. The scene set by Bohr is always the following one: Everything seems to be going well within a certain practice and then some crisis emerges. Philosophical reflection, however, brings to light a way forward if certain prejudices and rules are modified or set aside, and the practice continues, enriched. Subsequently, philosophical reflection produces an additional message: If all the various practices combined in the project of comparing how any of them might have gone through such a crisis, any of these practices could then be further enriched. In this way we could establish some common ground upon which the respective practices might cooperate or at least be informed by one another.

This account of human intellectual development is much too positive. To take it seriously, one has to include a negative side of the story. Within any human practice there will always be confusion, hesitation, conflict, and incoherence. Realizing this in respect to given practices, philosophers may come forward and introduce some visions and guidelines that might help shape the practices in question anew in significant ways. Put in our post-Hegelian terminology, also philosophy emerges as an Other to people who suffer from such intellectual kinds of misery, this might have some impact on the practices in question. However, *new* kinds of confusion, conflict, and incoherence may certainly arise as well, either because narrow-minded philosophers gave them bad advice, or because the participants within the various practices cannot grasp or live up to the guidelines provided by the philosophers.

In the case of Bohr, this negative dimension is missing, especially in his vision concerning the prospects of building, as Bohr put it, a common world of thought. It may seem otherwise. Bohr's vision meant to express an outspoken intellectual modesty. Bohr believed that there is no way in which the facts established by the sciences determine political or ethical attitudes and decisions. The results of science will always have to be related to a range of other sorts of considerations. In particular, we must take seriously the ideal that any particular theoretical claim will always express certain cultural values and interests, and thus also express certain ethnocentric views. To be sure, as we have seen, Bohr never entertained the idea that one could possibly come to build a world community or something like a truly unified science. This is impossible for the same reasons that make it impossible to establish a unified, general, and common form of art that would be accepted as such all over the world.

However, my critical point is that Bohr was nevertheless too optimistic and too much in line with the views of the Enlightenment concerning the possibility of building such a common intellectual world. Bohr was led to his view because he drew a very close parallel between what characterized a scientific conference (like the Solvay Meetings) and what characterized the kinds of inter-governmental conferences that distinguish the institutional political world (before Seattle 1999), and – as Bohr naively thought after the Second World War – would distinguish the U. N. At such a conference, it seems that people representing a variety of cultures and traditions meet on a neutral ground and with a common agenda. But here Bohr fell victim to quasi-Romantic *Schwärmerei* in the sense that he had a limited understanding of the arts, of the political world, and of our cultural history in general. This is a shortcoming that Bohr must be said to share with a number of post-Kantian intellectuals, characterized by their insistence that we recognize a universal form of Reason that – although it can never be realized within any particular practice or cultural setting – may still be said to regulate what essentially is at stake within any discursive intellectual activity. Bohr certainly entertained a vision similar to Kant's regulative idea of being a "citizen of the world."

Consequently, one may very well associate Bohr's framework of complementarity with the claim that it is possible to establish a universal and uniform kind of *criticism* in respect to any kind of discursive thought. This is not to say that Bohr believed in a universal method of philosophy – Bohr would have agreed that such a method is impossible – rather that he tried to characterize a universal *attitude* accompanying any method of intellectual inquiry.

Bohr believed that as long as we pursue the Helmholtzian program of "tracking down the relations between the manifold aspects of experience," and do so with the attitude mentioned on all levels of thought, and in every social setting, we can in general be said to advance in our understanding.[267] This is an overly positive and naive conception of the way in which (contextually constrained) special forms of thought and (intellectually mediated) common forms of thought are interrelated. The prospects for a new kind of encyclopedic understanding in the Kantian sense have "exploded" much more drastically than Bohr ever envisioned.

[267] (ATDN , p. 18)

Summary

The present dissertation argues that so-called "classical physics," which the early quantum mechanics either succeeded or vindicated, is in effect a construction of the late nineteenth century. This construction was based on two lines of heritage, a line going back to the Kantian metaphysics of Nature and a line going back to Helmholtz's reconstruction of the principles of classical mechanics, which reinterpreted the Lagrangean and Hamiltonian equations of motion. The dissertation claims that the synthesis between a metaphysics of Nature and an analytic account of motion was associated with a series of normative claims that were never met, and could never have been met, within the framework of the newly constructed "classical" physics. According to the thesis of this dissertation, the development of the early quantum mechanics was to a large extent but one of a series of attempts within the development of theoretical physics at the turn of the nineteenth century to meet these normative demands. At the time it seemed that classical physics could be expanded in the sense that it could cover ever more domains and still form an integrated unity of theoretical thought. Consequently, the early quantum mechanics seemed to corroborate Helmholtz's vision of a theoretical physics based on post-Kantian and post-Hamiltonian principles.

It is argued that while Max Planck focused on developing new forms of physical theory as such, Werner Heisenberg and Niels Bohr focused instead on reconstructing the metaphysical foundation of this development. The dissertation discusses how and why Bohr gradually felt the need to modify the very idea of a theoretical physics based on experimental evidence; in other words, the need to reinterpret both the character of theoretical physics and its metaphysical foundation.

Consequently, this dissertation is structured as follows. First, it presents Kant's metaphysics of Nature as well as Helmholtz's adaption of this in the construction of "classical physics." Second, by tracing the development of the content and role of the principle of least action as well as by presenting the philosophy of Max Planck, it shows that classical physics is associated with certain ideals that were never met. Accordingly, the dissertation presents the development of the early quantum theory less as an attempt to break with the Helmholtzian tradition than as an effort to meet certain normative criteria within the development of new forms of theory, and to meet them better than did classical physics. This led Bohr to develop his so-called framework of complementarity concerning such features of physical theory as causality and objectivity, to the effect that the neo-Kantian and the neo-Helmholtzian aspects of quantum physics were better integrated and the aspirations of physical theory as such were generalized, which in turn led Bohr to generalize the framework of complementarity by considering other fields of inquiry besides atomic physics.

Subsequently, the dissertation considers the status and character of the framework of the mature Bohr, especially regarding the question of realism, the linguistic features of physical theory, and the trans-disciplinary implications of quantum physics. In relation to this, Rom Harré's understanding and use of Bohr's philosophy is of central importance. Finally, the dissertation also critically discusses a few recent alternative interpretations of Bohr's philosophy of physics that have been advanced by John Honner, Jan Faye, and Henry J. Folse, respectively.

Considering the arguments and themes of the dissertation, the following elements of discussion should be underscored. **Part One** reconstructs the semantic features of Kant's analytic in order to elucidate what Kant called the metaphysical principles of the metaphysics of Nature. It explains how Kant considered the transcendental principles of Understanding – the so-called schematisms – to form the basic link between theoretical Reason in general and the metaphysics of Nature. The latter was clearly Kant's attempt to reconstruct the Newtonian Laws. The dissertation elaborates how Kant took that reconstruction to justify a certain dynamic conception of Nature, implying, however, that Kant reconsidered the relation between the three physical disciplines of kinematics, dynamics, and mechanics. It is one of the main threads of the dissertation that the special Kantian link between these three disciplines was adopted as a basic regulative idea within the development of new forms of theory in physics, from the pioneering works of

Helmholtz to Heisenberg's and Schrödinger's respective versions of quantum mechanics.

The dissertation argues that the Kantian schematisms represent a certain uniformity within the understanding of Nature that no longer seems plausible in light of recent physical theory. Consequently, it is considered how it was possible, in a neo-Kantian fashion, to develop new kinds of intuitive forms of physical theory that would still correspond with the basic Kantian view that it is possible to symbolize the unity of Nature by an investigation of the unity of Reason.

Part Two presents the main features of the new forms of physical theory developed from 1847 to 1930. The account has two main standpoints. First, it is argued that there was an organic relation between Helmholtz's paradigmatic idea of a new kind of theoretical physics and the dynamic metaphysics of Nature that especially Kant had developed, to the effect that the development of new forms of theory and the continuing transformation of that metaphysics of Nature were mutually conditioning. Second, it is claimed that this interdependence could be maintained primarily because the principle of least action, known since Leibniz and Maupertuis, continued to be developed. It is explained why this principle is more basic than the principle of the conservation of energy (the latter being derivable from the former), and it is explained how the transformation of the mathematical formulation of the principle of least action led not only to new conceptions of laws of Nature, but also to the specific kinds of theory that were developed accordingly. In particular, it is shown how Hamilton's version of the principle became a regulative idea for the development of physical theory, quantum mechanics included.

The following chapters show how Helmholtz, Planck, and Heisenberg, each in their respective ways, tried to generalize the neo-Kantian metaphysics of Nature. **Chapter one of Part Two** presents Helmholtz's inspiration from Fichte and Goethe, which leads to a post-Kantian integration of natural philosophy and a metaphysics of experience. **Chapter two of Part Two** presents Planck's idea of the continuing de-anthropomorphization of physical theory – a process that grounds the possibility of new abstract ideas of the unity of Nature still expressing a certain intuitiveness within our world view. According to the thesis, it was Planck's ambition to show how theoretical thought can at one and the same time develop so as to cover ever more domains and to achieve an ever more integrated unity. This view is illustrated by Ernst Cassirer's understanding of the development and role of the so-called natural constants within physical theory such as the elementary charge of the electron.

Chapter one of Part Three presents the considerations that led to Werner Heisenberg's formulation of the Indeterminacy Relations in his famous essay of 1927. These relations concern the requirement that empirical adequacy – not only of single physico-theoretical concepts, but also of the relations between these – be conditioned by the possibility of describing an experimental set-up by means of clearly defined empirical concepts. This is how new forms of physical theory acquire an intuitive interpretation. The Indeterminacy Relations thus express a formal aspect of what might be called the schematizaton of quantum physics (of the construction of theoretical concepts in intuition). Subsequently, the dissertation presents Heisenberg's Chicago Lectures from 1929, including a new account of the concept of causality in physics. It is argued that Heisenberg did not take the new quantum mechanics to imply a radical critique of the metaphysical principles of physics that had been assessed since Helmholtz.

Chapter two of Part Three presents Niels Bohr's development of the idea of complementarity during the years 1925–29, with special regard to the important year of 1927. It is argued that, according to Bohr, the necessary renunciation of classical forms of space-time representation does not imply renouncing the general demand concerning intuitive forms of physical theory. The account of the Como and Solvay essays underscores the respective notions of "abstraction" and "idealization." (1) The double meaning of the former, according to Bohr, is discussed with reference to the main example of an electron (which is an abstraction from an atom in both an ontological and a methodological sense). Consequently, an electron can count as part of both a given experimental arrangement and a given atom. (2) It is demonstrated how the notion of an idealization concerns a schematic simplification of the space-time configuration of given experi-

mental arrangements. This leads to a discussion of the way in which the kinematics and dynamics of an experimental arrangement conditions the possible information about certain atomic objects.

Chapter one of Part Four begins with an interpretation of Einstein's critique of the early quantum mechanics in order to elucidate the principles associated with the very idea of a foundation of theoretical physics, especially as formulated in Einstein's essay "Physics and Reality" of 1936. Consequently, the discussion of the so-called EPR paper of 1935, which Einstein wrote together with Podolsky and Rosen, concerning the incompleteness of quantum mechanics, aims only to supplement the interpretation of the paper of 1936. According to the dissertation, Einstein's critique was mainly directed towards his requirement that quantum physics be developed into a complete quantum field theory, i. e., a theory which has both matter and fields as its subject matter. Einstein thought that this development of quantum physics could in principle never be achieved. The dissertation argues that Einstein's considerations bear a certain resemblance to the views concerning the unity of physics already expressed by Max Planck. Consequently, it is shown how the famous discussion of the EPR paper concerning the implications of delayed-choice experiments is internally related to the questions regarding the historical development of physical theory and does not merely concern the issue of a realistic versus an instrumentalist interpretation of the experimental foundation of quantum mechanics. It is argued that Einstein's philosophy of physics centers on the question of how the development of theoretical thought can be informed as well as challenged by experience in general and experimental experience in particular. As for quantum mechanics, this leads to a discussion of how the experimental experience provided within the framework of quantum theory challenges the prospects for maintaining a complete description of quantum physical states, that is, a description in which it is possible to both specify and inter-relate the various individual features of the description. According to the dissertation, Einstein's claim concerning the incompleteness of quantum mechanics is based on his argument that this challenge cannot be met, in that there can never be a quantum field theory in which (physical) individuality does not imply (mathematical) singularity,

Chapters two and three of Part Four discuss two main views that Bohr, especially after 1938, held to be crucial in interpreting the quantum mechanical formula (though it is argued that the development of Bohr's thought never implied a radical break with his own former understanding since 1927). The first view concerns the concept of abstraction in relation to the Interaction Problem within the quantum theory, and the second view concerns the Observation Problem within that form of theory. The dissertation explains how the two views imply a link between the concept of causality and the notion of complementarity. Thus, it is argued that the special character of the quantum theory does not have to do with insurmountable difficulties in recognizing a causal connection between different kinds of experimental data, but has rather to do with the fact that the physical systems upon which one intends to perform measurements are characterized by a special (non-Laplacean) kind of causality. The argument hinges on a distinction, made by Bohr, between the "comprehension of data" and the "synthesis of phenomena" to the effect that the latter depends on the former. This point forms a main premise within the critique of other recent interpretations of Bohr's philosophy presented in Part Five. The following **chapter four** elucidates the interrelation between complementarity and causality, which is illustrated by a critical discussion of Jan Faye's claim that the principle of causality must be renounced within quantum physics. The dissertation argues that, on the contrary, Bohr thought that the (Kantian) principle of causality – which states that every change in Nature must have its own cause – was still valid in the context of quantum theory and that what was necessary was rather a new concept of causality.

The interpretation of Bohr's philosophy that the dissertation defends bears many resemblances to the interpretation of Bohr as a scientific realist presented by Rom Harré. This parallel is the focus of **chapter five of Part Four**. Harré's understanding of Bohr hinges on the idea that an experimental arrangement is analogous to Kantian schemata. The dissertation mildly criticizes this view of Harré's by discussing the character and role of criteria of identity. The chapter dis-

cusses how this idea is associated with the idea that scientific experience should be considered to involve a kind of domestication and cultivation of an otherwise wild and raw Nature. These ideas are criticized for being too "positive" as they suggest too close of a link between conceptualization and reality. However, the dissertation supports Harré's view that one cannot give an adequate account of the interrelation between theories, models, and reality that is based solely on considerations of analogies. The dissertation also criticizes Harré's and Nancy Cartwright's view that the development of models that further theoretical knowledge is associated with certain ontological determinations or "super types." Consequently, emphasis is placed on the heuristic function of models and schemes within the development of the sciences, a development that can still be guided by various metaphysical principles. Such principles, it is argued, are not to be seen as ontological determinations but rather as expositions of the possibility – to which Max Planck pointed – for theoretical knowledge; even if it developed in different directions in order to cover ever more domains, this knowledge can still form an integrated unity.

Part Five above all calls attention to the two "dogmas" that the dissertation considers as underlying the typical misreadings of Bohr: first, the dogma that classical physics forms a kind of epistemic paradise – a secure home ground for theoretical Reason – and, second, the dogma that ordinary language has semantic priority since it secures the proper meaning of basic terms. Having criticized both dogmas, in successive chapters the dissertation further criticizes some of the main and elaborate recent interpretations of Bohr's philosophy. Although John Honner's interpretation of Bohr's philosophy is in many respects original and interesting, **chapter two of Part Five** presents the argument that the interpretation follows the widespread and mistaken view that there are certain crucial affinities between Bohr's thought and the neo-Kantian semantics of P. F. Strawson. Thus, the dissertation discusses how Honner's association of Bohr and Strawson springs from a criticizable view on classical physics. It is claimed that Honner – even by comparison to Strawson – holds a rather strong view on the possibility of fixing the reference of theoretical terms by demonstrative means. The chapter furthermore contains a criticism of the pragmatic realism for which Honner pleads, a form of realism shown to go hand in hand with the kind of transcendental idealism that Honner ascribes to Strawson. **Chapter three of Part Five** criticizes H. J. Folse's view on classical physics, asserting that his view on the special character of quantum physics is misleading. It is argued that even if Folse does consider some important semantic notions, such as "the displacement of reference" and "criteria of identity," these notions cannot be adequately assessed within the limits of Folse's account – an account that is shown to be neo-empiricist, according to Folse's motto regarding "how science informs epistemology."

Since Jan Faye's account of Bohr's philosophy relates closely to that of Michael Dummett's, the dissertation contains a rather detailed presentation of that account. **Chapter four** shows how, according to Faye, Dummett's proposal concerning the possibility of a certain kind of anti-realism – so-called outright anti-realism – is analogous to Bohr's framework of complementarity. Following a discussion of this analogy as presented by Faye, the dissertation argues that one should be skeptical about the adequacy of this approach to Bohr's philosophical considerations, and, furthermore, that Faye's use of Dummett is somewhat narrow and contains a problem regarding the notion of "satisfaction-conditions," of which Faye makes significant use and which, according to the dissertation, has no place within the Dummettian semantic discourse to which Faye claims to relate. This critique of Faye is based on an interpretation of Dummett's recent linguistic philosophy. First, the dissertation gives an account of some of the basic concepts in this philosophy, such as a Theory of Sense, a logical theory, a semantic theory, and a meaning-theory. Second, it presents in detail the general semantic lesson that, according to Dummett, follows from the development of intuitionistic logic/mathematics. Finally, the dissertation invokes the important notion of a conservative extension of a given fragment of a language along the semantic lines suggested by Dummett. The discussion of Dummett's linguistic philosophy aims at demonstrating why one cannot claim the existence of any elaborated semantic model in terms of which one might further associate the strict framework of complementarity with either a semantic realistic or a semantic anti-realistic position; At least, there is no elaborated and clear-

cut way to use the Dummettian semantic framework in the context of physics. Consequently, the dissertation concludes that the semantic approach to the philosophy of quantum physics, of which Faye's is a prime example, does not help much in clarifying the question of what "realism" might be in the context of physics. In respect to classical physics and quantum theory, we especially remain unclear about how these respective linguistic practices contain deductive parts, or how deduction or inference are constitutive parts of the respective practices.

The **first chapter of Part Six** discusses the method and logic of what the dissertation considers as the general concept of complementarity, attempting to place this concept within a metaphysical field that contains both Romantic and dialectic positions. The chapter has two main points. The first concerns the development of a new conception advanced by Bohr during the years 1936–37 of the methodological unity of the various sciences. The second concerns the interpretation of the Kronborg paper of 1938, in which are developed the notions of culture and tradition corresponding to the new conception of the methodological unity of the sciences. In this way, the dissertation argues, Bohr elaborated a new version of the view that can be said to unite the entire range of German idealistic philosophers from Kant to Hegel: the idea that (only) a systematic reflection on the unity of knowledge constitutes a symbolization of the unity of Nature.

The dissertation concludes by drawing attention to how the semantic issue of securing a rational foundation for the application of theoretical concepts within the context of the quantum theory forms part of a broader issue concerning the rationality and coherence of a set of practical aspirations associated with the practice of experimental physics as such. Consequently, the semantics of the quantum theory is considered as part and parcel of an attempt to clarify our (normative) situation as "observers" within a certain series of experimental arrangements, each of which is designed to make sense of given quantum physical effects so that we can "comprehend" these effects within the conceptual description of specific atomic physical phenomena. In short, the semantics of the quantum theory is but a means to further the possibility of scrutinizing the conditions for the possibility of observing a certain (theoretically defined) range of phenomena. Thus, observation becomes less a matter of getting information than of situating oneself within the whole of various experimental arrangements. The dissertation illustrates and justifies these views by drawing on certain features of Wittgenstein's later philosophy as well as on the interpretation of Dummett's linguistic theory, which was elaborated in a former chapter.

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Steen Brock paints a cross-disciplinary picture of the philosophical and scientific background for the rise of the quantum theory. He accounts for the unity of Kantian metaphysics of Nature and the Helmholtzian principles and Hamiltonian methods of modern pre-quantum physics. Brock shows how Planck's vision of a generalization of classical physics implies that the original quantum mechanics of Heisenberg can be regarded as a successful attempt to maintain this modern unity of physics.

However, for Niels Bohr, the unity of science and metaphysics did not end in the world of physics. The development of quantum physics had general implications both for other sciences and for various philosophical issues. Brock discusses these matters in respect to recent topics within the philosophy of science and major interpretations of Bohr's ideas.

Brock offers an invitation to any intellectual, to follow a long and winding route of thought which, in the end, will take you to Bohr's ideas of complementarity, culture and Spirit.

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