CAN WE REDUCE CHEMISTRY TO PHYSICS?

by

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1. CRITICAL REMARKS

Reductionism, if accepted, is usually accepted on faith and without logical evidence or sound reasons. Overblow claims in the philosophical literature[*] for the reducibility of chemistry to physics are not justified by present scientific knowledge. Most theoretical concepts of chemistry have not yet been successfully reduced to quantum mechanics and it is an open question whether such a reduction can always be achieved.

Very vaguely, reductionism claims that all the laws of higher levels can be explained by those of the lowest level so that nothing intrinsically new enters at the higher levels.Such assertions are obscure if they are not supplemented by a delineation of what is meant by "explaining". Every scientific craft has its rules of thumb and many analogies which are heuristically important but which have no explanatory power.

For example, the concept of valency is of great importance to chemistry but to this day there is no theory of valency (proof: for every statement of any kind of valence model one easily can find a counterexample). Hence it makes no sense to say, for example, that "the theory of valency by Heitler and London has reduced the concept of valency to quantum mechanics". Models,

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[*] Compare for example Russell (1948), Kemeny and Oppenheim (1956), Oppenheim and Putnam (1958).

analogies and rules of thumb have an intuitive appeal, they are helpful and important but they should not be confused with theories and they should not be accepted as reductions.

In order to avoid muddled arguments I restrict my discussion to <u>theory reductions</u> and to well-defined theories which are logically consistent and empirically reliable. Furthermore, it should be recalled that derivations of limiting theories without the use of mathematically proper limit procedures are usually fallacious.

Practicing scientists are eminently interested in any intertheoretical relations, and in chemistry reductionistic ideas have been quite successful. However, it turns out that the intertheoretical relationships as they manifest themselves in the mathematical structure of the current theories in exact sciences do not fulfill the relations postulated by the philosophers of science[*]. The moral of this affair is that abstractions should come after detailed investigations of concrete examples, not before.

The traditional discussions of reductionism rest on much too simple a view of the structure of scientific theories. Nearly all of the philosophical studies of theory reduction have their origins in an analysis of classical physics and reflect the dogmas and limitations of this approach. Experiments

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[*] Compare for example: Kemeny and Oppenheim (1956), Oppenheim and Putnam (1958), Nagel (1961), Sneed (1971), Stegmüller (1973).

involving molecular phenomena made it clear that Newtonian physics and classi-
cal statistical mechanics do not suffice for a fundamental theory of matter.
Because the logical and conceptual structure of classical physics fails as a
foundation for a theory of molecular matter, it also fails as a foundation
of chemistry, molecular biology and biology. If one wants to discuss the
hypothesis that there is a global theory for the behavior of matter, one has
to define the concept of theory reduction in accordance with the conceptual
and logical basis of quantum physics which is utterly different from that
of classical physics.

The traditional concept of theory reduction assumes that a reducing
theory can explain everything that can be accounted for by a reduced theory
and that a reduced theory cannot provide a more complete description than
the reducing theory (Sneed, 1971, pp. 218-219). That is, traditional theory
reduction presupposes that subtheories can always be totally ordered. This
is indeed true for classical theories, but wrong for quantum theories. The
subtheories of a non-Boolean theory (like quantum mechanics) may be in-
comparable and form a directed set which cannot be totally ordered (Primas,
1977).

The underlying logic of the theories of classical physics is Boolean,
like in the predicate logic of Frege and Russell. Many philosophers of
science failed to notice that quantum mechanics has a radically different
logical structure than classical physics, and that this fact has crucial

consequences for theory reduction.

In non-classical theories with a non-Boolean propositional calculus a restriction of the domain of discourse can lead to the emergence of novel properties and the appearance of qualitatively new phenomena (Primas, 1977, 1981). This feature of theory reduction in the framework of non-Boolean theories refutes some profound objections against reductionism. It is no longer necessary that "the vocabulary of the reducing theory must be at least as rich as the vocabulary of the reduced theory" (as required by Sneed, 1971, p. 220) but higher level concepts (like temperature, entropy, shape, adaptive behavior, function, purpose) which have no meaning with respect to elementary particles, can emerge by a restriction of the universe of discourse. Accordingly, the ideas of emergence and holism are not a priori in conflict with the idea of the reducibility of complex chemical or biological phenomena to physics.

2. CAN MACROPHYSICS BE REDUCED TO MICROPHYSICS ?

On the one hand, chemistry deals with the composition and the properties of substances and with the transformations they undergo. On the other hand, chemistry studies the properties and the behavior of atoms and molecules. Both the macrostructure and the microstructure of matter is therefore of importance to chemistry.

Chemical systems are typically partly quantal and partly classical so they do not share the simplicity of purely quantal or purely classical systems. In one and the same object, quantal and classical subsystems coexist and interact with each other. A naive application of traditional quantum mechanics[*] to such systems gives no reasonable description. In fact, contemporary quantum chemistry uses additional ad hoc rules to describe molecules. For example, the all-important concept of molecular structure is a classical idea, foreign to traditional quantum mechanics. In a consistent theoretical description it comes into being by the breaking of some logical symmetries but usually it is smuggled into quantum chemistry via the so-called Born-Oppenheimer approximation.

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[*] By traditional quantum mechanics I mean the theory as discussed in the texts by Dirac (1930) and von Neumann (1932). In the modern terminology, traditional quantum mechanics is the theory of reversible dynamical W^*-systems whose algebra of observables is a factor of type I and whose kinematical group is the Galilei group.

A presumed reduction of chemistry to traditional quantum mechanics implies an explanation of the properties and the behavior of substances in terms of electrons and nuclei, hence also a successful reduction of macrophysics. Such a reduction would be a triumph indeed, it would for example include the resolution of the notorious "measurement problem of quantum mechanics" which is known to have no solution within the mathematical and conceptual framework of traditional quantum mechanics.

In order to understand measurements, macrophysics and chemistry from a quantum theoretical viewpoint we must first understand the existence of classical subsystems in a quantum world. That is the main problem and a tough one.

If we would adopt the popular view that the reducing theory has a broader scope than the reduced theory then macrophysics could definitely not be reduced to microphysics. The shape of a macroscopic piece of matter and its temperature are example of concepts of macrophysics which are not definable in terms of traditional quantum mechanics.

The nonreducibility of the phenomenological concepts of thermodynamics to mechanics compelled hardboiled reductionists to say that temperature is not a true physical quantity but only a parameter for the estimation of the energy distribution, or that "strictly speaking" the second law of thermodynamics is false. The reason for this muddle is a widespread category mistake: taking

the concept of substances as being on equal footing with molecules. Substances are either gaseous, liquid or solid - molecules are not. Substances can have a temperature - molecules cannot. Thermodynamics is not the same as statistical mechanics, chemical kinetics is not the same as collision theory. These theories refer to different levels of description in the sense of Russell's notion of type. Their intertheoretical relationships are of great interest to chemistry but much more complicated than our popular texts say.

Thermodynamical and mechanical descriptions of one and the same object are sometimes possible but these two descriptions are mutually exclusive (Bohr, 1932). None of them is more authentic than the other, none can replace the other, both are necessary, none is sufficient. We say that thermodynamical features of macroscopic matter stand in a complementary relationship to the underlying molecular structure[*].

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[*] It is difficult to find the works of Bohr a really satisfying characterization of the notion of complementarity. The best formulation I know is due to Klaus Michael Meyer-Abich (1965):"Komplementarität heisst die Zusammengehörigkeit verschiedener Möglichkeiten, dasselbe Objekt als Verschiedenes zu erfahren. Komplementäre Erkenntnisse gehören zusammen, insofern sie Erkenntnis desselben Objekts sind; sie schliessen einander jedoch insofern aus, als sie nicht zugleich und für denselben Zeitpunkt erfolgen können. Die Struktur des Objekts, die darin zum Ausdruck kommt, dass es komplementär erfahren und beschrieben wird, kann mit Bohr als Individualität oder Ganzheit bezeichnet werden." For a precise mathematical definition of complementary properties and complementary theories in the context of the theory of W^*-systems, compare Primas (1981, 1982).

Complementarity cropped up as a fundamental trait in the discussion of quantum phenomena. The gist of quantum mechanics lies in comprising all the possible complementary description within a single logically consistent theory. We can interpret the formal logical structure of quantum mechanics (also called "quantum logic") as a logic of complementarity.

3. QUANTUM MECHANICS IS A HOLISTIC THEORY

A basic premise of classical science is the tacit assumption that we have not to consider the whole universe at once but that in a useful approximation we can go ahead by compartmentalization. That is, classical science concentrates its attention to small parts of the world and examines them as well-isolated objects. This isolation procedure is then counteracted by the introduction of "interactions" which connect the otherwise isolated parts in such a manner that the resulting behavior depends only on the states of the isolated objects and the interaction between them. Accordingly classical physics (and also the so-called "general system theory") assumes that reality can be divided into individual objects having independent ontological status.

This preconception is reflected in the logical structure of classical physical theories and system theories. It is in fact a mathematical property of classical mechanics and of classical electrodynamics that for <u>every</u> decomposition of a system into subsystems the states of the subsystem already determine the state of the entire system[*]. This property is called <u>separabi-</u>

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[*] Here and in the following "state" always is understood as <u>ontic state</u>, i.e. as the maximal partial truth function on the lattice of temporal propositions of the system considered. This ontic state at a fixed time refers to those potential temporal properties which are actualized at this instant and which are supposed to have reality beyond the observing mind and independent of it. In algebraic quantum mechanics ontic states are (cum grano salis) represented by <u>pure</u> normalized positive linear functionals on the algebra of observables (for details, compare Primas 1980, 1981).

lity. If a system does not possess this property, we call it nonseparable. If there exists no nontrivial decomposition of a system into subsystems such that the states of the subsystems determine the state of the entire system, we call it maximally nonseparable of holistic.

Quantum theories are nonseparable and exhibit holistic effects. In particular, traditional quantum mechanics is the first mathematically formalized holistic theory. The essential difference between classical theories (including all variants of systems theories) and quantum theories is not the occurence of Planck's constant of action (classical systems may very well depend on Planck's constant) but the fact that quantum systems are entangled by the holistic Einstein-Podolsky-Rosen correlations. The existence of such holistic correlations (which have nothing to do with interactions) is a compelling consequence of quantum mechanics and is experimentally well confirmed.

The universal existence of Einstein-Podolsky-Rosen correlations implies that the concept of a "system" cannot be used without explanations. Quantum mechanics describes the world as an undivided whole and any analysis of it into parts requires an abstraction from some factually existing holistic correlations. The fact that the world exhibits itself in well articulated parts reflects the action of our pattern recognition devices which work only in virtue of the associated abstractions of irrelevant details. What is considered as relevant and what is irrelevant is, of course, not determined by

quantum mechanics.

    The world cannot be described by a single compartmentalization but has to be viewed from a number of mutually exclusive perspectives. Different perspectives imply different abstractions which yield different nonisomorphic decompositions of the world into parts. In a quantum-theoretical description, the corresponding abstractions are made by dismissing some of the Einstein-Podolsky-Rosen correlations. The possibility of mutually incompatible viewpoints is related to the existence of incompatible properties in quantum systems. Maximally incompatible properties are called complementary. In exactly the same sense (which easily can be formalized), maximally incompatible viewpoints of subtheories are called <u>complementary</u>.

4. EMBEDDING OF COMPLEMENTARY DESCRIPTIONS INTO A GLOBAL THEORY

Any compartmentalization separates things from their natural embedding. If we want a theoretical description of how the world is, the unavoidable compartmentalization has to be balanced by an attempt to grasp things in their interrelations, their conflicts and contradictions, that is by some kind of dialectical thinking. Of course, there are no contradictions in nature but conflicts may arise by tacitly using different frames of references.

In spite of the importance of dialectical thinking in informal discussions of human experience, it has contributed little to a formal unification of the compartmentalized domains of scientific knowledge. At least within the domain of molecular phenomena we have nowadays a more powerful method: the embedding of the <u>local</u> descriptions given by a Boolean frame of reference[*] into a

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[*] A point of view relative to which a <u>classical</u> partial description of the world can be given will be called a <u>context</u>. More precisely, a context is defined as a part of the world which is singled out by a well-defined set of prior conceptions whose ontological structure is amenable to the application of classical two-valued logic. As a consequence, a context is a <u>Boolean frame of reference</u> so that within one and the same context all properties are compatible and all experimental questions are simultaneously decidable.(Compare also Primas, 1980, 1981).

comprehensive <u>global</u> description, called <u>quantum logic</u>. Since there exists incompatible frames of reference, quantum logic is in general non-Boolean. Boolean frames of reference only give a <u>partial description</u>, nevertheless they play a distinguished role in quantum logic. The different frames of reference necessary for a full description of nature can be pasted together to structured families of Boolean algebras, called <u>Boolean atlases</u> which can be used to represent non-Boolean quantum logic. This framework is the conceptual basis of the theory of the so-called W^*-systems, a form of generalized quantum theory which covers traditional quantum mechanics, classical mechanics, electrodynamics and dissipative dynamical systems.

The possibility of embedding the formal structure of complementary descriptions of one and the same object into a single global theory opens the possibility for a fruitful discussion of their intertheoretical relationships. Given the formalism of a theory, we are within certain limits free to choose its interpretation. If the interpretative rules and the regulative principles of different theories are not the same, these theories have no common vocabulary and a comparison makes not much sense. That is, if we would like to discuss the reducibility of chemistry to quantum mechanics, then the interpretations of chemical theories and of quantum mechanics cannot be chosen independently.

It is part of every chemist's creed that he is studying the properties of real things like flowers, cells, crystals or molecules. Accordingly chemical

theories are always about individual things in objective reality and not about our knowledge. In everyday life nobody is prepared to abandon realism, so if we discuss a quartz crystal as an object of chemical investigations we hardly can avoid the view that such a crystal exists objectively in nature. Quartz crystals of enormous size can be found in the alps, they exist in two enantiomorphic forms called "right-handed" and "left-handed" which are mirror images of each other and rotate the plane of polarized light in opposite directions. Accordingly the handedness of quartz is considered by everybody as a real objective property. For a chemist, there is no difference in principle between the handedness of a macroscopic quartz crystal and the handedness of a single molecule of alanine, intermediate molecular systems of any size can be provided easily. Hence if in everyday life we attribute a real objective existence to quartz crystals then we have to attribute a real objective existence to molecules of any kind, hence also to atoms and to electrons. If the chirality of a quartz crystal is accepted as a real objective property, independent of our knowledge or measurements, then we also have to accept the chirality of a single molecule of alanine as a real objective property. If this reasoning is accepted one is forced to adopt an individual and ontic interpretation of all theories involved in a reduction of chemical theories.

Many physicists and philosophers have claimed that a consistent ontic interpretation of quantum mechanics is impossible. This view is wrong. An individual and ontic interpretation is consistent with the formalism of quantum

mechanics if and only if we adopt a <u>non-Boolean</u> propositional system.

We take the notion of a <u>property</u> as primitive concept. Quantum logic is defined as the propositional calculus of the propositions about the properties[*]. Characteristic for nonseparable systems (like quantum systems) is the existence of incompatible propositions so that the set of all propositions of a nonseparable system cannot be a Boolean lattice (as it is in all classical theories). In a nonseparable system not all propositions of the system can be truth-definite (i.e. either true or false) at the same instant. The ontic interpretations posits that propositions which are true at a certain time t correspond to properties the system <u>has</u> at time t. Propositions which are not truth-definite correspond to potential properties not actualized. Hence only the actualized properties are identified with elements of reality, the set of all truth-definite propositions characterizes the ontic state of the system[**].

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[*] Note that quantum logic is a logic of properties, not a deductive logic. The metalanguage of quantum logic corresponds still to the usual two-valued Boolean logic.

[**] For more details on the ontic interpretation of general W^*-systems compare Raggio (1981) and Primas (1980, 1981).

5. EXAMPLES OF SUCCESSFUL THEORY REDUCTIONS

A large number of physical and chemical theories can be formulated as dynamical W^*-systems and therewith embedded in a common structural and interpretative framework. In this way it becomes possible to study their intertheoretical relations in a rigorous way. In this structure quantum mechanics can be regarded as the basic theory so that our main interest lies in the reducibility of the W^*-theories of macrophysics and of chemistry to quantum mechanics.

Quantum mechanics describes an unbroken wholeness. How do we come to recognize objects in a holistic world? Apart from the unbroken wholeness there are no absolute objects or patterns. An indispensable prerequisite of every description of nature is a splitting of the world into essential and accidental parts. What is essential is not given by quantum mechanics but depends on the particular viewpoint adopted. Since the quantum world is nonseparable, there is no such thing as a perfect testable description of nature. A good description always is a good caricature, exaggerating some aspects by deliberate simplification and by permitting extravagance. <u>Every testable description of nature is a caricature involving deliberate drastic simplifications</u>. The nonseparability of nature implies the existence of incompatible aspects, that is, of aspects which cannot be put in evidence in one and the same description. To ask whether one caricatural description is "better" than another cannot be answered without considering "better for

what purpose". A caricature is neither a replica of something nor does it rely on pre-existing forms. In art, a caricature is a true creation by the artist, a creation which enables us to see reality from a new perspective.

In order to derive chemical facts from quantum mechanics, we have to know what a chemist is considering as relevant and what as irrelevant. The main reason why only a tiny part of chemistry has been reduced to molecular quantum mechanics is that most chemical concepts are not (or, maybe, not yet) defined in a language which can be translated into quantum mechanics. For example, keto groups play an important role in chemical toxonomy, but this concept has no natural place in the framework of traditional quantum mechanics. Accordingly, the main stumbling block for reducing chemistry to quantum mechanics is to characterize the caricatures chemists use tacitly.

The basis tools for creating caricatures are abstraction and emphasis. In exact science, the only way known to create theoretically consistent caricatures are singular limiting procedures like asymptotic expansions. Different limiting processes represent different viewpoints and create different patterns which may be appropriate for different aims. Inevitably, a price has to be paid for making asymptotic caricatures: we may say things about nature which are not strictly true. Since chemistry can be derived from quantum mechanics only if one destroys some of the holistic correlations of a full quantum mechanical description, it would be unwise to object that we look at nature through half-shut eyes.

In recent years considerable progress has been made in establishing precise links between microscopic dynamical laws and the dynamics of higher level systems [*]. In the thermodynamic description of irreversible processes one encounters many situations where some of the variables vary on a much slower time-scale than others. A rigorous asymptotic description of such systems is possible by rescaling some of the variables. In this way one can suppress in a consistent way some of the holistic Einstein-Podolsky-Rosen correlations so that holistic systems may factorize asymptotically into uncorrelated systems. The asymptotically induced new patterns give often an excellent caricature of the observed systems.

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[*] Examples: The van Hove limit for the rigorous derivation of Markovian master equations for open quantum systems, the Boltzmann-Grad limit for transport equations in the kinetic theory of dilute gases, the Brownian-motion limit for the Markov process of a Brownian particle, the Hartree limit in the limit of infinitely many particles. For a review of these asymptotic limits, compare e.g. Spohn (1980).

The recent impressive progress in algebraic statistical mechanics has fulfilled the long-standing desideratum of reduction of thermodynamics to quantum mechanics at least to some extent. This reduction has been achieved with the aid of new and very sophisticated mathematical tools, showing that the elucidation of a theoretical pluralism is not sheer routine. A full clarification of the theoretical relations between chemical substances and molecules is still out of sight[*] but at least we know that thermodynamic systems have an algebra of observables of type III. Since the notions of temprature and chemical substances are intertwined, we can state an important result of algebraic quantum theory in the following form: molecules are described by quantum theories of type I while chemical substances are described by theories of type III. These two descriptions refer to different levels of the same reality, they are mutually exclusive but both indispensable for chemistry.

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[*] For example, we do not know how to characterize chemically pure substances in the sense of chemical thermodynamics. Furthermore, we have no reasonable idea how to reduce the notion of chemical purity to molecular concepts. For example, liquid water is supposed to be a pure chemical substance but to this day nobody has been able to advance a sound molecular argument in support of this claim. Note that from a molecular point of view we not even know how to characterize a liquid.

The molecular theories of type I are in the main a mathematically precise formulation of the methods of quantum chemistry but they are not identical with traditional quantum mechanics. The intertheoretical relations are well understood. They throw considerable light on the problem of emergence of new qualities on a higher level description.

The basic technical tool for the description of <u>emergent quantities</u> in the framework of quantum theories is the concept of classical observables. Properties which are truth-definite in every ontic state of the system are called classical. Correspondingly, observables which have a sharp value in every ontic state of the system are called <u>classical observables</u>. Traditional quantum mechanics has no classical observables, classical mechanics has only classical observables. Chemically relevant molecular systems always have both quantal <u>and</u> classical properties, they are described by the type I theories in which some but not all observables are classical [*].

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[*] In algebraic quantum mechanics observables are represented by elements of an algebra and classical observables by elements of the center of the algebra of observables. The center of an algebra is defined as the set of all elements of the algebra which commute with every element of the algebra. The algebra of observables of traditional quantum mechanics is a factor of type I, hence an algebra with a trivial center. The algebra of observables of every theory of classical physics is commutative, hence identical with its center. The algebra of observables of a generic type I theory is a non-commutative W^*-algebra of type I having a nontrivial center.

In this scheme the reduction of a higher level description to quantum mechanics is identical with the problem of emergence of new qualities: how can classical observables be derived from quantum mechanics? Since the coming into being of new classical observables is the same as the coming into being of new superselection rules, the answer is: by discharging some of the Einstein-Podolsky-Rosen ocrrelations. Although this recipe is general and in principle straightforward, a rigorous mathematical discussion is in every example somewhat different and always exceedingly subtle. Successful reductions in this sense are related with the emergence of the classical observables mass, chirality, molecular shape, temperature and chemical potential, which arise by appropriate singular limits from traditional quantum mechanics.

As a first example consider the concept of mass in the sense of Lomonossow's and Lavoisier's phenomenological law of conservation of mass in chemical reactions. This law follows directly from the Galilei group. The so-called "nonrelativistic" quantum mechanics is Galilei-relativistic and has the mass as a classical observable (which is in the traditional formulation treated as a parameter of the theory). In Einstein-relativistic quantum theories the mass is an observable but not a classical observable. The contraction of the Lorentz group to the Galilei group is a singular limit which is difficult to discuss but which can be worked out rigorously. This limit creates a novel classical property: the mass in the sense of Lomonossow and Lavoisier.

As a second example we consider the chemist's notion of a molecule with its spacial structure. The shape of molecule is an allimportant concept in chemistry and in molecular biology, it is a classical concept which has no place in traditional quantum mechanics. In spite of the contrary claims in many of our textbooks, this concept cannot be derived by purely logical arguments from traditional quantum mechanics. However, it can be retrieved from this theory by the singular Born-Oppenheimer limit $m/M \to 0$, where m is the electron mass and M is a typical nuclear mass. In quantum chemistry this singular limit is hidden under the innocent name "Born-Oppenheimer approximation" or "adiabatic approximation". However, it is conceptually important that quantum chemistry is not the same theory as traditional quantum mechanics. Quantum chemistry possess a family of new classical observables which describe the molecular structure and the molecular shape, it is the theory which originates by an asymptotic expansion of traditional quantum mechanics around the singular point $m/M = 0$ which corresponds to the viewpoint of the chemists. As any particular viewpoint it is not "true" but in general it is the only description which is useful for chemists.

6. ON THE EMERGENCE OF HIERARCHICAL PATTERN

The preceding discussion of the Born-Oppenheimer limit is just a simple example of a hierarchical system generated by an asymptotic expansion about a singular point.

A complex system is called <u>hierarchical</u> if it can be decomposed into an ascending family of successively more encompassing subsystems such that every lower level system is subordinated by an authority relation to the next higher level where the higher level in the hierarchy has always a much longer reaction time than a level classified as lower.

Most systems of interest to chemistry and biology have a marked hierarchical pattern with grossly differing reation times. For example, in molecular spectroscopy one classifies spectra according to the ratio $\epsilon^2 = m/M$ of the electronic mass m and a mean nuclear mass M. If the so-called electronic spectra (visible and ultraviolet light) are discussed in the original time scale $\tau_0 = \epsilon^0 t$, then the so-called vibration spectra (in the infrared region) are governed by the time scale $\tau_1 = \epsilon t$, while the rotation spectra (including spin resonances, in the radiofrequency region) have to be discussed in the time scale $\tau_2 = \epsilon^2 t$. In the biological domain it is more difficult to give precise scaling parameters, nevertheless phenomenologically many hierarchical levels are clearly indicated, for example:

(i)   the biochemical scale (a fraction of a second or less),

(ii)   the metabolic scale (in order of a minute),

(iii)   the epigenetic scale (several hours),

(iv)   the development scale (days or years),

(v)   the evolutionary scale (thousands to millions of years).

Scientists and philosophers claiming that there is only one correct explanation of natural phenomena should ponder over the enormous simplification in description one can get if a language adapted to the hierarchical level is used. It is true that a description of a hierarchical system with a language belonging to a low level is possible but it may be very complex and almost incomprehensible.

How can we find a language adapted to a hierarchically higher level? It may be expected that the singular limit $\varepsilon \to 0$ with properly rescaled observables creates new classical observables and therewith new algebras of observables. The new language adapted to the hierarchical structure of the original system is given by the language of the W^*-system created by the singular limit $\varepsilon \to 0$. An asymptotic expansion around this singular point accounts for the differences between the original system and its caricature.

7. CONCLUDING REMARKS

In its quantum-mechanical description the world appears very differently structured from what the Cartesian-Newtonian view understands by the "empirical world". In quantum mechanics there are no isolated systems unless <u>we</u> isolate them by neglecting Einstein-Podolsky-Rosen correlations between the investigated object and its environment. Without abstractions there is no science. There is no such thing as a perfect description of nature: every testable description of nature describes only certain aspects and neglects other aspects. Inevitably, such a description is true only within the adopted partition of the world, that is, within the chosen context. It would be very narrow-minded to use only one context: we have to learn to be able imaging different points of view.

Classical physics has believed in a universal frame of reference, a universal context that permits independent variations of its elements. This doctrine has encouraged the search of basic building blocks of matter through which one hoped to understand nature. Such an approach has the flavor of a purely empirical undertaking in which discoveries play the basic role. However, quantum mechanics taught us that the hunt for a universal context is in vain.

While classical science encourages discoveries within a single given context, modern quantum theories encourage the invention of new contexts,

complementary to those already known. A theoretician has the creative free-
dom to find new viewpoints. Presently, the most effective strategy is to
begin at some rather fundamental level and working upwards to hierarchically
higher levels. But we should not be dogmatic and leave the door to alterna-
tive approaches open. The "top-down" is at present technically rather diffi-
cult and certainly not fashionable, but it may be a sensible alternative for
the future.

The idea of reductionism has been very much oriented on classical science
which presupposes that the world can be understood by understanding its parts.
If we take quantum mechanics seriously, it refers to the undivided wholeness
of nature. Wholes are not explicable in terms of their parts because wholes
have no parts.

Holism is often considered as the opposite of reductionism but this view
must be rejected as naive. Quantum logic is a perfectly well-defined holistic
theory and non-Boolean theory reduction represents a sophisticated variant
of reductionism. As examples from chemistry show, in this framework re-
ductionism is in harmony with holism, and the emergence of essential novelty
in a higher level description is a compelling consequence of the theory.

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