The quantum and the classical domains as provisional parallel coexistents .

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An essay in honour of Newton da Costa
with admiration, friendship and *saudades*

ABSTRACT. We consider the problem of the relationship between the quantum and the classical domains from the point of view that it is possible to speak of a direct physical description of *quantum systems having physical properties*. We put emphasis, in evidencing it, on the specific quantum concept of indistiguishability of identical in a conceptual way (and not in a logical way in the vein of «da Costa's school»). In essence, the subsequent argumentation deals with the relationship between the classical and the quantum, with the problem of the quantum theory of measurement. Even in the absence of a definitive response to this problem, the best attitude for the time being, as we cannot reduce the classical and the quantum one to the other, seems to be to accept their pacific coexistence, and this is possible with the tolerance principle of the «pragmatic truth» developed from a logical point of view by Newton da Costa.

RESUMO. *As áreas quântica e clássica enquanto provisórios coexistentes parallelos*. Abordamos o problema da relação entre as áreas do quântico e do clássico considerando que é possível falar de uma descrição física direta de *sistemas quânticos tendo propriedades*. Insistimos, para isto, sobre o conceito especificamente quântico da indicernabilidade dos idênticos de um ponto de vista conceptual (não de um ponto de vista lógico à maneira da «escola da Costa») como evidenciando isto. O essencial da argumentação a seguir tem como enfoque a relação clássico-quântico, com o problema da teoria quântica da medição. Mesmo não tendo uma resposta definitiva para este, a melhor atitude por enquanto, já que não se podem reduzir um ao outro o clássico e o quântico, nos parece ser esta de aceitar sua coexistência pacífica, o que é possível com o princípio de tolerância da «verdade pragmática» desenvolvida logicamente por Newton da Costa.

RESUME. *Les domaines quantique et classique, provisoires coexistants parallèles.* Le problème des rapports entre les domaines quantique et classique est abordé en adoptant le point de vue selon lequel il est possible de parler de description physique directe de *systèmes quantiques ayant des propriétés*. Pour ce faire, un accent particuler est mis sur le concept spécifiquement quantique d'indiscernabilité des identiques de manière conceptuelle (et non logique à la manière de l'«école de da Costa»). L'argumentation porte ensuite essentiellement sur la relation classique-quantique, avec la question de la théorie quantique de la mesure. Même en l'absence d'une réponse définitive à ce sujet, la meilleure attitude à prendre semble, en l'état actuel des choses, puisque le classique et le quantique ne peuvent être réduits l'un à l'autre, de s'en tenir à leur coexistence pacifique, ce qu'autorise le principe de tolérance de la «vérité pragmatique» développée sous l'aspect logique par Newton da Costa.

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1
INTRODUCTION.
LOGICAL AND CONCEPTUAL APPROACHES IN QUANTUM PHYSICS

Newton da Costa and his collaborators' approach to the logical and epistemological aspects of scientific theories and theoretical physics[1] are of concern for quantum theory along two paths (letting aside a third one, that of *decidability theorems* which they, up to now, have developed only, as far as I know, for classical dynamical theories[2]). The first one is their treatment of the *indistiguishability* of identical particles, by which they suggest considering the problem not from a conceptual or a theoretical but from a logical point of view. As quantum systems or particles that are totally identical cannot be dealt with as if they were independent and separated, because of the «quantum statistical» properties, they suggest considering them as a generic kind of particles that are referred to elements of ensembles that are not independent and distinct one from the other[3].

The mathematical set theory at the basis of their physico-mathematical treatment is no longer the classical (Zermelo-Frenkel) set theory, but a different one that includes the impossibility to distinguish, in an ensemble of identical elements, one of these elements from the others, although we can count them. In such a way, the physical theory itself - i.e., the usual quantum theory - remains unaffected, and the necessary change required by the quantum specificity -

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[1] See, for example, the recent books : da Costa [1997a & b], da Costa, Béziau & Bueno [1998].

[2] Da Costa & Doria [1991], da Costa [1997a], p. 182-186.

[3] See, in particular : French & Krause [1995], French & Krause [1999], Krause & French [1995]. See also, in a similar direction : Dalla Chiara & Toraldo di Francia [1993].

irreductible to classical physics - is brought to the deep root of the theorical and mathematical representation, the underlying logics itself.

This is an elegant and formal way to continue dealing with the «quantum-classical» concepts of quantum mechanics, describing quantum systems whatever they are with the help of classical particle concepts, these being transformed by being submitted to non classical rules for their utilization and for attribution of physical meaning to them. The logical refoundation of the whole theoretical structure is pragmatically equivalent to the rules of the quantum algorithm, but with a different basis, justified in reason (and in logics), when the standard justification of the quantum rules remains essentially pragmatic and even «*ad hoc*», not to say arbitrary. This attempt at a logical refoundation of quantum mechanics adds to the various solutions proposed to the quantum mechanical interpretation problem.

The most «dramatic» stake of the quantum debate is whether the quantum theory and concepts describe or not *real physical systems* that have *definite physical properties*. The logical approach aims clearly at such a description while keeping *quantum mechanics* - the theory - as well as *a good part of its standard interpretation* (bohrian complementarity). It can be viewed therefore as a tentative to reconcile a realist view of the natural world with the statements of the Copenhague interpretation that are usually presented and conceived as being of a subjectivist type. But here the subjectivist character would be left aside, as the corresponding statements would be given, through the new logics, a possible objective basis. Unless, indeed, one wants to refer the new approach to a «logical foundation for a subjectivist conception», but this would be a question of mere definition. In any case, the method would be an objective one, with a new logical basis.

In what follows, I will in a first stage consider another proposal, alternative also to the standard interpretation, accepting both quantum theory and its classical logics foundations, but modifying the usual understanding of quantum concepts so as to make of quantum theory a *direct representation of physical entities and properties*. This approach has in common with the «logicist» one the founding role given to *indistinguishability*, but this time conceived not as a *logical requisit* but as a *conceptual* or even a *principle physical statement*.

After sketching this proposal of a «proper direct quantum representation» for quantum physics, I shall evoke next the problem of the relation, in this perspective, of the quantum to the classical domains. This problem is generally considered as that of a reduction of one to the other, be it of the quantum specificity to a classical description through macroscopic measurement arrangements, or of the classical level of the organization of matter to its elementary quantum constituents. But it can also be that of a self-consistency of the description, from a theoretical point of view, of each of these two levels, the classical and the quantum, up to a quasi-autonomy of both. We shall show that this could well be so, as a provisional state of things. We might henceforth find some intellectual support in provisionnally accepting such a duality of representation in what we refer to as the second path of da Costa's contribution to the logical approach to physics, namely his conception of *pragmatic truth* or «quasi-truth».

2
ON A PROPER THEORY OF THE REPRESENTATION OF QUANTUM SYSTEMS

Let us consider as a possible alternative conception of the «quantum puzzle», an objectivist and realist one, that would keep quantum theory as it stands and is used, but that would free it from the «superfluous rags» (or old clothes : «les oripeaux superflus») of the philosophical observationalist interpretation. According to this «critical realist» conception, physics and physical theory, and in particular quantum physics and theory, aims at a «direct» description («direct» in a manner that must be explicited[4]) of physical reality, through concepts and relations of concepts based on usual logics and mathematics. Quantum theory as formulated in its whole mathematical scheme is proposed to be considered as such a theory, adequate to the whole of presently known quantum phenomena. This requires modifying the *meaning content* of the *quantum concepts* with respect to their definition in the standard interpretation, as expressed by the conventional rules added to the theoretical formalism in order to ensure the connection with physical phenomena through experiments.

Instead of *clearing out* these concepts, as they are given inside the theory, of any *direct content of meaning* as the standard interpretation does (considering them as mere mathematical forms), one can, on the contrary, consider that *their physical meaning content* is closely given by the relations of the theoretical formalism itself and by nothing external to it. The only external interventions are those of experiments, that provide precise values for the quantities involved. Such features are *a priori* nothing exceptional for a physical theory, in which the concepts content is *relational*, the paper of the theory being to give an exact expression of these relations bound by *physical principles* (from where the privileged role of mathematics in physics)[5].

State functions or vectors in Hilbert space and the *quantum magnitudes* or *quantities* (under their operators form) related with (or characteristic of) quantum systems are, in this view, afforded content and direct physical meaning by the theoretical relations themselves : they represent or describe respectively *physical quantum systems* and their attached *properties*[6].

Note that the problem of the physical meaning of the «mathematical concepts» of the quantum formalism is related with the peculiar expression of the *principles* of the theory that, in the standard presentation, are simply the

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[4] Paty [in press, b].

[5] Paty [1998 & in press, c].

[6] See a detailed epistemological analysis of quantum physics from this point of view in Paty [in press, b & 1999].

application rules of the mathematical formalism[7]. In all other physical theories, the physical principles are generalized facts of experience synthetized in *statements of property* for physical systems to which all other physical concepts and laws are bound. *Such facts exist* as well *in quantum physics*, but they have not been expressed as such physical principles from which, with the help of the proper concepts, the theory could be derived. *Non-local separability*, as well as the *quantum statististical behaviour* (of the Bose-Einstein, or of the Fermi-Dirac types), or *self-interference* of quantum particles through a diffraction grid, but also the *superposition principle* for the state function, could be such principles. They all correspond to fundamental precise general *facts and properties* of the quantum systems and of their physical theoretical description that are, actually, so deeply interrelated among each others that they appear as various aspects of a same and one specific quantum characteristic.

In particular, quantum statistics properties are synthetically summed up by the concept (or property, or principle) of *indistinguishability* of identical quantum particles and systems, which corresponds to fundamental phenomena and to powerful predictions, such as *Planck's black body radiation law* and *Bose-Einstein condensation* for «bosons» statistics[8], and *Pauli's exclusion principle* for fermion statistics[9]. This generic property[10] has an immediate expression in the theoretical formalism of the state function of a quantum system, through the principle of (linear) superposition, and appears to correspond to rich physical predictible consequences, from the level of the *elementary constitution of matter* up to *that of cosmic objets*[11]. Indistiguishability is therefore much more than a pure formal feature of the mathematical description of quantum systems.

Systems constituted of such indistinguishable elements can be counted but cannot any more be ordered. Considered under the physical point of view, these elements are not independent, and their are related together by a phase. Considered under the point of view of ensembles, they have cardinality but they have not ordinality. Sometimes called «quasets»[12], which is purely mathematical, they have also received the denomination of «vague objects»[13], but this is clearly inadequate to designate what is actually an *increase of physical properties* given by indistinguishability to quantum particles when compared to ordinary

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[7] As expressed, for example, in Dirac's and von Neumann's axiomatic presentations of quantum theory (Dirac [1930], von Neumann [1932]).

[8] Griffin, Snoke & Stringari [1995].

[9] More on it in Paty [in press, b].

[10] Hans Reichenbach spoke of it in terms of what he called «*genidentity*», i.e. the physical identity of a thing in the course of time, which he distinguished from *logical identity*. He saw *indistinguishability* of quantum particles as a reduction of the «material genidentity» to a mere «functional» one (Reichenbach [1956] 1982, p. 38, 224-236).

[11] Such as degenerate stars, white dwarfs and neutron stars, where the tendency to gravitationnal collapse is equilibrated by the electrons or neutrons degeneracy pressure (due to the exclusion principle). On the cosmological aspect of the indistinguishability concept, see Paty [2000a].

[12] Dalla Chiara and Toraldo di Francia [1993]

[13] This denomination, proposed by Lowe [1994], has been discussed by French & Krause [1995], [1998].

distinguishable ones. In the same way, one could hardly claim the state function (ψ) to be a loose description beacause of its unability to make know «everything» (i.e. actually, classical magnitudes…) of such elements or systems, when, on the contrary, quantum theory knows a lot more about them than classical theory does for classical states, for quantum theory qualifies the quantum states overwhelmingly.

A property of such an importance and of such a generality could well be called a *principle*. Its physical consequences would imply it to be a *physical principle* in the full meaning of the term. As such, it would immediately determinate the physical meaning content of the concepts and magnitudes by which it is expressed or which are related to it in the theoretical formalism. The rules of utilization of the quantum magnitudes would be the mere consequences of such a physical meaning (in particular Max Born's «probabilist interpretation of the state function»). The state function itself, an «amplitude of probability» (a physically meaning function, not a mere mathematical one), would be the direct representation of the quantum system, as it immediately provides quantitatively the phenomena and properties related with indistiguishability.

Other factual and theoretical evidences have contributed to enhance in our conceptions the direct relationship between the fundamental concept of state function and quantum specific physical properties. Non-local separability between subsystems of an initially given overall system has been shown to be a physical property of correlated individual systems (individual in the cardinal sense of counting), expressed in the mathematical formalism by the non-factorizability of the subsystems state functions[14]. Diffraction experiments with single quantum particles (performed with extremely attenuated and high time definition beams of photons, electrons, neutrons, atoms…, crossing the two-slits arrangement one by one) have shown that quantum individual particles interfere with themselves, this property being completely contained in the form of their state function[15]. Furthermore, coherent superposition states materializing a kind of «Schrödinger's cat experiment» have been seen to propagate through space during a short interval of time before decoherence happen through interaction with the environment[16], which reinforces again the feeling that *the state function describes a physical state*, and is not only an artificial (mathematical) construction of our knowledge of it.

One is therefore tempted to take seriously the possibility to deal wholly with quantum systems by making use of quantum theory alone, i.e. by taking the state fonction ψ as the *complete* theoretical representation of a given (individual) physical system at the quantum level. And, actually, physicists working in quantum physics and studying quantum processes will agree that, to

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[14] Bell [1987]. See our analysis of the non-local separability concept in Paty [1986], [1988], chapter 6, & [in press, b].

[15] More on this in Paty [in press, b]. This *property* had been stated by Dirac already in 1930, despite the reluctance of the «orthodox interpretation» (which he shared) to speak in these terms (Dirac [1930]).

[16] Schrödinger [1935], Haroche, Brune & Raimond [1997].

their work, quantum physics is the proper theory required at the quantum level of phenomena. They import from experiments the data that serve them to fix exactly the system state functions and the magnitude operators (the so-called «observables») with which they are dealing. But for the rest, they stand at the quantum level with quantum theory as their tool-for-thought (outil de pensée).

Now, to be consistent in such an apparently simple view, we have to inquire the state of things that has always been considered as an obstacle to it, namely the «unavoidable» intervention of the «classical level» of physics, both conceptually and operationally.

3
THE CLASSICAL AND THE QUANTUM DOMAINS. FRONTIER OR BARRIER ?

The main foundational problem of quantum theory has been traditionally considered as being the problem of its relationship with classical physics. Stated in this fashion, it seems to be a problem of the *description* of phenomena or systems. But it is also, more deeply, the problem of the relationships between classical and quantum *physical systems*, and the relationships can, in principle, be considered both ways, from the classical level of our experience to the quantum one and, conversely, from the quantum underlying level of microphysics to the classical one of macrophysics. But such a symmetrical concern would presuppose that we can consider a classical and a quantum level so to speak on an equal «ontological» ground (the word «ontological» referring here to predicates of physical existence). One is used to speak of objects existing at the classical level, as they can be described through properties attributed to them, and as the phenomena observed at this level can be referred to these objects (or objectal physical systems).

In the usual interpretation of quantum mechanics, this is not the case for the quantum level, where we start from *phenomena*, diagnosed as not belonging to the classical domain from some anomalous behaviour irreductible to the classical description, and thus qualified as *quantum phenomena*. But the latter cannot be referred to objects of a quantum level, having properties, for their «observed properties» (which, actually, are classically observed, and classically defined) are context dependent in the following sense : they are given a definite value only when a measurement has been prepared for a given type of quantity and thus performed.

The present dissymetry of the classical to quantum relationships, considered in the above terms, is due to the type of approach that gives privilege to the «classical mode of description», to use Bohr's terminology - Bohr who considered the use of classical concepts even for the quantum domain as a necessity for human knowledge. With Bohr's conception, we are brought to the quantum problem of measurement, from which this necessity is postulated, the compelling use of classical concepts for the quantum domain being related, in an operationalist view, with a subjectivist conception of knowledge[17].

The «unsurpassable necessity» to use classical concepts in the quantum domain has also been claimed by a non operationalist but empiricist conception, such as Hans Reichenbach's one, with the advantage to restore objectivity. Reichenbach saw, in particular, Heisenberg's relations not as "a limitation of human capacities of knowing", but as formulating, "rather, a physical law holding for all physical quantities"[18], and indeterminacy as "an objective

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[17] Bohr [1958].

[18] Reichenbach [1956] 1982, p. 223-224.

property of the physical word, without reference to an observer". He rightly noticed also that "since measuring instruments are macrocosmic objects, we may say that the indeterminacy arises when relationships between macrocosm and microscosm are involved", and added that "Heisenberg's principle states that there is no way of determining microscosmic quantities in terms of macrocosmic quantities to a higher degree of exactness than that formulated in the [Heisenberg's] inequality".

However, in his objective empirical understanding of the uncertainty principle, which he brought to the necessity, for human beings, to base "their inferences concerning the microcosm (…) on macroscopic observations", because their perception bears on the "macroscopic sphere", Reichenbach restricted as much as Bohr did the description of the quantum domain to concepts adequate to the macroscopic world. He did not let space for the invention of concepts that would be proper to the quantum world. Although Reichenbach's views are interesting by their absence of observationalist presuppositions and their claim of objectivity (quantum features definitely belong to nature), we still find them confined in the limits of empiricism, with the illusion of a «natural knowledge» that would be directly related to perception.

Quantum systems are neither particles nor waves but manifest one of these aspects to the exclusion of the other when they are submitted to classical detectors for particles (electronic counters, sensitive photographic revelators) or ffor waves (diffraction grids to make interferences). This property has even been quantized, making of it a kind of generalized Heisenberg's inequality for these antagonistic classical properties[19]. Quantum systems, as we have argued, transcend these classical qualifications and require concepts of their own.

To require the compulsory use of classical concepts for the description of quantum phenomena is to bind oneself to a presupposition that one cannot actually stand up when one considers the genesis and history of the classical concepts of physics. Classical concepts have been elaborated from the experience of the macroscopic world. But how could one argue that these concepts continue to be valid in a domain such as that of quantum phenomena, which is, as we know, so distant from immediate apprehension ? Consider, for example, the «distance» in dimensions but also in «quality» (meaning properties) between a bunch of matter accessible to our senses and a few atoms, a «distance» which can appreciated by Avogadro's number ($N \approx 6 \times 10^{23}$ molecules per mole).

If, starting from a piece of matter at man's scale and conceived as occupying a given place in ordinary space, we want to get to a few (or a single) atom, in order to make a «visual» representation of them, we would have to peel off one by one, so to speak, all *N* atoms, repeating the operation *N* times. Nothing tells us that, in such a process, our notion of the ordinary space would stay the same. We can think as well in terms of volume of the occupied space : admitting that the sizes in space that are more or less accessible to our senses extend up to one micrometre (10^{-6} m or 10^{-4} cm), those of an atom, where quantum properties

[19] Englert, Scully & Walther [1995].

manifest themselves, are of the order of 10^{-8} cm, those of an atomic nucleus of the order of 10^{-13} cm or 1 fermi, and those of elementary particles even tiner. Physicists get at the individual atom not by hand peeling but with the help of appropriated instruments, and the junction is made indirectly. What is important is that it is actually realized and, as a matter of fact, individual quantum particles are non-localized.

A principle of correspondence is invoked that relates the classical properties to quantum ones by viewing the former as a limiting state of the latter : in our example, it would be effective for very large numbers of atoms aggregated together. On may consider our notion of *localisation in space* as merely an effect of such a process, and as an *emergent property*, that is manifested only when many quantum non localized entities (atoms) are aggregated, but that is not defined (or at any event not defined in the usual way) for individuals. As for the other way, nothing gives us the quantum concepts from the classical ones, and the only resource is to invent or elaborate them consistently such as to give account of the identified and studied *quantum* features. In other words, observation and measurement provide the data, but *intellectual reconstruction* is needed to understand them.

We notice, incidentally, that the problem of the quantum-to-classical relationship is not restricted to the «problem of measurement» only, and includes as well the difference or even the incompatibility between the concepts that are effective at both levels. A particular case would be that of the behaviour of *macroscopic quantum systems* : for example, a macroscopic Bose-Einstein's condensate, to whose dimensions physics does not a priori assign limits. Those which have been produced recently were made of tenths of thousands of atoms fallen down to the same «zero energy point» state, occupying all the space at their reach, and climbing with a null viscosity on the recipient walls[20]. We could imagine a lot more of such atoms and, why not, propose as a queer thought experiment this process occurring on the surface of a cold solid star (at quasi-absolute zero temperature) : the condensate, *a quantum physical state*, would be extended on the whole superficy of the star. No doubt, space as an emergent quantity would be present in such a macroscopic quantum state, but with all its points in phase, which is not a property of usual space. Possibly the interactions of such a quantum state with the environment (the vessel or the cold star) would make it rapidly decohere.

To come back to the, important from the fundamental point of view, "measurement problem" there is, for sure, a moment when the quantum theoretical description asks for classical physics, i. e. classical physical theory and concepts, through the determination of physical quantum states. But all the question is that of the nature of such an intervention. These states, for the *received, orthodox, interpretation*, are known to us only through classical definitions and determinations (for instance, through the independent

[20] Griffin, Snoke & Stringari [1995].

determination by measurement of «incompatible» magnitudes[21]). In other words, the «reduction» of the quantum state to its classical projection components is, according to this view, inherently present in the experimental determination of any quantum state (and therefore pertains implicitely to its definition). Consequently, there is - such is the claim - no independent «quantum world», that is to say that we cannot consistently conceive an intrinsic «world of quantum objects».

Alternative attempts to formulate and to solve the quantum measurement problem in the direction of the autonomous determination and definition of quantum systems have been generally performed with the aim of determining the interaction, at the quantum level, of the system under consideration with some significant quantum part of the macroscopic-classical measurement apparatus[22]. Another way to save the autonomy of the quantum world has been to postulate some modification of quantum theory that would avoid the measurement problem, such as David Bohm's pilot wave theory that adds non-local variables (in the quantum sense of *non-locality*) to ordinary quantum magnitudes[23]. Other approaches in the same direction of «no reduction» (in a physical sense) have been proposed, and they seem more satisfactory as for their principle, avoiding any dependence of the quantum level on the classical one[24]. But it is not clear to everybody, including to the author of these lines, whether there already exist a solution that would be universally accepted.

Reduction or no reduction conceptions have in any case to confront the problem of the making of macroscopical classical quantities from quantum systems, be it through measurement processes, by cascades of interactions started at the atomic level, or «naturally» through accumulated quantum systems up to a macroscopic organization, having definite space-time properties. Such interactions pertain to the realm of physics, even when they are not observed. In this respect it makes sense to try dynamical calculations on quantum-to-classical interactions : they actually oblige to explore dynamical possibilities such as quantum field theory with perturbation calculations, or non linear models which, in any case, will not not be confined in quantum mechanics in the resticted definition[25].

We shall not enter this problem and we shall limit ourselves to the

[21] Represented by anticommuting operators.

[22] See various theories reprinted in Wheeler & Zurek [1983].

[23] Bohm [1952]. Cf. Ben-Dov [1988], Freire [1995], and many commentaries on this approach, among which Freire, Paty & Rocha Barros [1999].

[24] See Everett [1957], and various reported theories in Cini & Lévy-Leblond [1990]. The recent theories of decoherence seem also to avoid reduction (Zurek [1991], Omnès [1994a & b]). According to Roland Omnès it has been even possible with such an approach to deduce all classical physics from quantum principles, and to show that macroscopic interferences such as the Schrödinger's cat are suppressed in a very short time by decoherence effect. Nevertheless it seems to me that the question of the nature of the theoretical quantities and mathematical scheme in these attempts remains ambiguous.

[25] See, for example, Ghirardi's and collaborators' attempts (cf. Ghirardi & Weber [1997] ; a general account of the problem is given in Ghirardi [1997]).

standard quantum theory, without reduction in either sense, to the quantum or to the classical. Actually, what we need at this stage is not reduction, but autonomy. Let us conclude this section by observing that measurement of quantum systems do not in principle reduce their knowledge to classical quantities, as it is by definition that measurement is performed on classical quantities - for measurement devices are macroscopic. It remains possible to imagine that quantum specific quantities are of a different nature than classical ones and that they can indirectly be fixed with the help of classical data given from measurement. As a matter of fact, the first stage of a measurement procedure in quantum physics is the preparation of the system, i.e. the choice of the theoretical quantity whose eigenvalues will be displayed by the apparatus. Insofar as the physical system is a quantum system, its state is a superposition of the prepared states that serve as the basis. The quantum nature of the system is destroyed, by performing a measurement, which yields a single value and the corresponding state. One should therefore not speak of *reduction* but of *projection*, imposed by the conditions of experimentation. *Measurement is projection* on the classical states corresponding to the separated components of the quantum state.

4
THE RELATIVE AUTONOMY OF THE QUANTUM LEVEL

The representation of a quantum system by a state function with the corresponding quantum magnitudes looks a very powerful one from the physical point of view, both for prediction and understanding of physical phenomena that have no counterpart in classical physics. It seems difficult to maintain that such a specific domain can only refer to classical concepts and to macroscopic measurement procedures. This domain deserves physical principles and concepts of its own. The *state function* seems perfectly adequate in this respect to a direct physical representation of a quantum system. The obstacle to this eventuality is the (classical) restriction that requires a physical state to be identified with one of the states prepared with a measurement device, *one valued state*, and not a phase-coherent superposition of various ones. Similarly, a *physical quantity* is usually thought to correspond to a one-valued response among the possible ones of the apparatus for a given choice of «compatible quantities» represented by commuting operators. In other words, physical assignment for states and magnitudes (or quantities) has usually been restricted to ordinary numerical values, and this is why quantum magnitudes, under the form of matrix operators, are not considered by the received view as properties of states, but only as a mathematical scheme usefully connected to results of experiments.

But in the theoretical scheme that gives access to the description of quantum phenomena, the state function, in its vector basis independent and invariant form, as a coherent superposition of basis (eigen) states, is conceived *as if* standing for the physical system. And its associated quantities are given their full linear or matrix operator form, being not reduced to their spectral components, with one unique numerical value for each. In their whole complex multiple-valued (operator) form, the theoretical quantities are to the basis invariant state of the system *as if* they were its *properties* insofar as one does not measure them and project them onto one single numerical (eigen-)value. And, insofar as one stands at the level of quantum sytems, everything works as if it was effectively so. From the conceptual point of view on states and quantities, the only difficulty to consider the state function of a system as a direct representation of its physical state, and quantum magnitudes operators as a direct representation of the physical properties of the system in this state, is that, in their quantum theoretical form, they are not endowed with simple numerical values and present themselves under a more complex mathematical expression.

Setting aside for the time being the question of experimental data and measurement processes, we argue that it is possible to consider that the physical quantum theory deals with quantum phenomena and systems in a completely consistent way because, as a matter of fact, it provides full access, conceptually and theoretically, to the quantum domain. I mean it in the following sense : quantum theory is the theory that gives or defines all the relevant characteristics needed to describe, even from a fundamental point of view, physical systems and phenomena, and events relating such systems and phenomena, at the quantum level (and when they are not yet available, quantum theory is able to construct them). Such is, indeed, how quantum theory (non relativistic or relativistic quantum mechanics, as well as quantum field theory) works in the atomic and subatomic levels[26]. It works in a quasi-autonomy (it might well be a complete autonomy from the purely theoretical point of view) with respect to macroscopic or classical considerations. This is obviously contradictory with the traditional interpretation of quantum mechanics which considers that such an autonomy for the quantum level would be mere illusion, for all knowledge depends on *perception*, and henceforth on *measurement*.

It would look unnatural as well to those who share an empiricist position on Reichenbach's line and restrict themselves to the perceptual standpoint. We can ask, actually, whether it is possible to think of an autonomous quantum description for objects or events that are not immediately accessible to perception nor directly conceivable. But, may we ponder, is knowledge doomed to stand at the level of mere perception ?

Clearly, any knowledge depends on *perception*, but it is organized by *understanding*, perception and understanding being the two pilars of rational activity[27]. The standard quantum-mechanical interpretation claim, but also the empiricist's one, equate in some way *perception* and *measurement*, making of the concepts of the classical description the *natural* ones, as if they were directly perceptible. By ignoring, or setting aside, the fact that even classical physics is based on the *understanding* of what is *primarily perceived* (for example, the

[26] See, for example, Bimbot & Paty [1996].

[27] Kant [1781, 1787].

metrical space concept is constructed by thought and not merely perceived[28]), it gives precedence to classical concepts on other (quantum) ones because they are supposed to be the concepts adequate to perception. Actually, all concepts are elaborated by thought, those of quantum theory for sure, but those as well of classical physics which is the theory of the usual measurement apparatuses.

With experiments and measurements we do not stand merely at the perceptual level, but we raise to the intellectual level of the understanding. In this, classical phenomena and systems are not different from the quantum ones. This means that we are not bound to choose the classical concepts as the reference for our intelligibility statements. *Quantum statements*, at their level (that of quantum phenomena, or of the «quantum world»), *are intelligibility statements*. In effect, physicists *think* of quantum particles and fields without referring to classical particles and fields. Their use and need of *experiments* is not referred to classical quantities, but to the *transcription of the results*, whatever be the rough form in which they are obtained (using projection on classical quantities), *in quantum terms*.

Considering theoretical physics as it stands today, we do not see any *a priori* foundational necessity to refer physical knowledge to classical physical theory. We may even say something more : to oblige the theoretical representation of a non classical level of phenomena to be submitted to the terms of the classical one forbids at the start, as a matter of principle, to pretend some day to get at a proper non classical theory. The standard, orthodox, profession of faith leads to systematic classical-dependency and to a vicious circle. It is an obstacle that blocks further deep progress for physical theory of phenomena whose access is «indirect» (or «far from our senses»). If progress has nevertheless been made, it is due to the fact that in practice theoretical quantum physics has developed itself as if it were autonomous with respect to the classical description. A simple proof of it is that the quantum measurement problem is never mentioned in the research papers on atomic and subatomic physics, and is called for only in the papers on foundational problems of quantum mechanics[29]. But for this «productive» physics foundations are kept in the vague, and it is not always clear whether the entities dealt with are not mere useful mathematical toys. The building of contemporary quantum physics is edified with very few worries about this kind of foundations (let us point out, however, the preoccupation of this physics for another kind of foundational problems such as symmetries, etc., which might be as much, and eventually more, important in the long range)[30]. But thinking about foundations might be useful some time to go further, as history of science tells. In the case, foundations are about *mathematically expressed physical magnitudes*, much more than anything else.

The *proper quantum description* as sketched earlier supposes that one takes the *state function* as the representation of a *physical state* and the theoretical

[28] See, for instance, Poincaré's analyses on it (Poincaré [1902]).

[29] This has been already noticed by Mario Bunge (in particular Bunge [1973]).

[30] See Paty [1988], chapters 4, 8 and 9.

quantity operators as the *physical magnitude or dynamical variables* of the quantum system. This interpretation is a statement of physical meaning regarding our understanding of the phenomena and not a metaphor. It corresponds to a *modification* of the *usual thought* of *physical states and quantities*. We no more confine these in the restricted definition of *having to correspond to single numerical values* as those given as classical measurement results : we widen and *extend their meaning* to mathematically more complex entities *expressing relations* which are not restricted to such numerical attributions. For, after all, the essential function of *physical quantities* is to *express relations*. These entities are given as vectors of a Hilbert space, invariant under basis transformations, representing physical states, and linear hermitian operators acting on them, expressing the quantities with the help of which one defines the basis system for the state vector. The numerical attributions from measurements are only *partial* (they are projections) with respect to the whole system state, *conditional* and *contextual* (due to the preparation that chooses the basis), and must be made *relational* through theoretical reading of them.

To summarize, one can say that the most important function of physical quantities is to express relations among them, that are those of the concepts to which they correspond[31]. The linear or matrix operator form of the theoretical quantities related with quantum systems express the relations of the quantum concepts corresponding to recognized physical properties, and therefore they can be said to represent the corresponding physical magnitudes. The state function or state vector, given for a chosen basis (of prepared eigenstates) in its coherent superposition form, and invariant through the changes of base, expresses the phase-coherent relations among the elements of the superposition that are responsible for such phenomena as interference from diffraction grids, and all of the other specific quantum physical phenomena.

5
RELATIVE AUTONOMY OF THE CLASSICAL DOMAIN AS WELL

Symmetrically to the argument about the autonomy of the theoretical description of the quantum level of phenomena and systems, we can ask ourselves about the status of the representation of the classical domain with respect to the quantum one. There is, clearly, a connexion between them in nature. We know that the properties of matter at a macroscopic level have their origin and causes in the microscopic and quantum organization and constitution of matter. As an example, the fundamental theory of condensed matter is atomic physics, and it goes also the same for physical chemistry. Another example is the constitution of cosmic bodies (atomic structure of the stars, fossile electromagnetic and neutrino

[31] This idea has been most clearly formulated by René Descartes in his *Rules for the direction of the mind* (Descartes [1628]). See Paty [1997, 1998 & in press, c].

radiations, etc.), and presumably the quantum field germ of the structure of the whole Universe, already determined in its primordial stage. The unity of matter is, for sure, a basic category for physical thought, but it would be prematurete to identify it with a corresponding presumed unity of our knowledge of matter, for, as we know, this knowlege is always incomplete and perfectible.

The diversity of the theoretical approaches in physics, considering its different domains, is due to our fundamental lacks of knowledge regarding an overall unification, but also to the fact that the reduction to elementary processes is not always productive. Our concepts are relative and we are not always in a position to say that those of an elementary level are complete enough to give account of a more complex, «emergent» one - the reverse being obviously also true. If there is nothing more, in principle, in molecular biology that in the arrangement of large and complex chemical molecules, quantum mechanics would nevertheless not give us by itself an appropriated and powerful description of this level of the organization of matter, for which specific molecular biology concepts are much more efficient.

The «non reductionnist» argument holds for classical physics when confronted with quantum one. The «principle of correspondence» is thought to apply in a large number of situations. But this may not be the case, for example, and by definition, when we deal with quantum concepts that have no classical counterpart or approximation. For example, when we speak at the macroscopic and classical level of the *stability of matter*, it means a global effect resulting from some quantum number conservation laws (baryonic number, leptonic number, electric charge, spin-statistics property, etc.) and we are left with no correspondence whatsoever.

But non-reduction works as well the other way. Consider, for instance, the concept of space as we are used to it when we think of the motion of bodies. Locality, or local separation of elementary physical systems, is a property at the classical level that is implied in the definition of the magnitudes by which we describe them in classical theories, and correspond to the use of the concept of material point and of differential calculus for continuous quantities. We don't know yet the exact connexion of this (emergent ?) property with the quantum description (as we have argued earlier). So that we keep with the «classical» description when we have to deal with physical systems that are well represented with the help of magnitudes defined on the space-time continuum. Special relativity has no problem with quantum non locality (or non-local separability), as quantum correlated distant subsystems cannot be considered as separated independent systems of the material point type to which one would apply space-time causality relations. In this case, quantum theory and special relativity have incommensurable objects.

The problem of the measurement of quantum systems can also be considered from this point of view. The process is indeed that one of the measurements of classical quantities (i.e. the spectral distribution of the theoretical quantities corresponding to the quantum system). Taking the quantum level as the fundamental one, we may look the measurement process as a cascade of interactions starting at the quantum level, between the studied system and a quantum part of the apparatus, to end at the macroscopic level of the whole device, yielding finally a thermodynamic amplification of the initial signals. If we were to give a overall description of the process, we would need a full quantum theory of the macroscopic device, of its atomic structure, and perhaps of all its fundamental constituents. In principle, this would mean to dispose of the unified fundamental theory of matter which is not yet known. In practice, it would mean to calculate approximately the chain of elementary atomic interactions involved and to average over the atom distribution inside the detection system. Clearly we shall have in the end a statistical distribution of a statistical mechanics type.

But what would be the help, for our understanding of the phenomenon under study (a quantum property), to perform this calculation when its net result is already given by the «measurement rule» ? We may therefore take the classical result given by the measurement device as it is given from each «single particle» experiment, that is statistically, inferring from the *measured statistical frequencies* the corresponding probabilities and the theoretically significant *probability amplitudes*, i.e. the components of the state function with their relative phases.

On the whole we may say that classical physics is, in a large number of respects, independent of quantum physics, at least from a practical point of view. The result of the measurement of macroscopic events initiated by a quantum trigger bears the trace, in terms of classical quantities, of the initial quantum property, summarized by the phase coherence in the probability amplitude. This trace of the initial probability amplitude is gathered from the obtained statistical probabilities from where it has to be reconstituted.

The relation of the quantum and the classical goes on henceforth in its indirect way - indirect as is our knowlege of both of them.

6
A PROVISIONAL DUALITY OF REPRESENTATIONS AND THE IDEA OF PRAGMATIC TRUTH

Our intention in what precedes has been twofold : i) to show the inner consistency of a pure quantum theoretical description of individual physical systems at the quantum level, without any need to refer ultimately to a classical description (the deep reason of this legitimacy is that theories and concepts, be they of the quantum type or classical, are constructions by the mind) ; ii) to argue, with the autonomy argument, that the *recipe* of the measurement rule, that connects the quantum representation with the measurement of magnitudes is not, from the point of view of quantum theory representation, a fundamental theoretical problem, and even not a conceptual one (it remains a practical rule, but that can be explained in terms of physical processes, at the pure classical level).

We might therefore consider that, in the present situation of physics, a reduction of the quantum and the classical one to the other is not much in the news («n'est pas à l'ordre du jour») and even that it is not so fundamental for the physical theories as they stand. And we might keep on usefully thinking in the quantum way for the quantum domain and classically for the classical one. Only in a further stage of fundamental physics, when a unified theory of matter will be in view, should the classical-to-quantum connexion express fundamental relations as limiting conditions of the new theory.

For now, considering the status of approximation of the quantum theories we dispose of, measurement processes yield the indirect connexion between both domains once it is admitted that physical theoretical probabilities correspond to experimental observed frequencies or statitistics. This «quantum-to-classical connexion rule» is enough at present to deal fully with both quantum and classical theories, even in the absence of a solution of the problem of a «quantum theory of measurement».

For this pacifical coexistence, we may find a useful aid in Newton da Costa's conception of *pragmatic truth* or «quasi-truth»[32]. We may indeed understand the word *pragmatic* in a sense that does not preclude the need for a more ambitious conception of truth, that would be related to *the fundamental* and not only to *usefulness*. For the *temporarily useful* is pragmatic. Quantum physics, but «classical» physics as well[33], in its present situation, can usefully be seen under this meta-theoretical choice as pragmatically true, from various points of view making a joint use of concepts or theories that are not in accordance. Newton da Costa and his colleagues have consided a pragmatic conciliation in Bohr's spirit of the concepts of wave and particle, through appeal to complementarity[34]. One may also consider, from a more fundamental theoretical point of view, another pragmatic juxtaposition : that one of the *quantum theory* for the description of quantum states and of the *classical theory* for the description of the observation device and the obtention of measurement results, that leads to the *«quasi true» representation* that present quantum theory is. And, can we say, that classical theory is as well.

There is a difference in the application of a pragmatic truth for these two cases. For the first one, it is a last resort for the use of too coarse concepts, unable to substitute fundamentally and in the long term the search for a proper quantum theory. For the second one, on the contrary, one precisely considers such a theory as already obtained although one does not yet dispose of a linking up, satisfactory from the physical and theoretical point of view, between it and classical physics.

If these ideas are meaningful, what would yet remain as an unsolved problem would be the theoretical unification of the representation of both "quantum" and "classical" physical systems. Or, to say it better, of a quantum, discrete, representation, and a continous space-time one. But this persistent duality of our theories of the material world, unsatisfactory from a fundamental point of view, can nevertheless be provisionally tolerated, thanks to the notion of

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[32] Da Costa [1986, 1989] ; Da Costa, Mikenberg & Chuaqui [1994].

[33] «Classical physics» stands, here, for physics using classical concepts (it includes relativity theories).

[34] Da Costa & Krause [1994], da Costa [1997], p. 168-172.

pragmatic truth. It allows us to continue doing quantum physics in a wholly consistent manner, fully rational and logical, that is by describing the phenomena of a *quantum world of objects*. But we are still left with two completely (in a logical sense) consistent, independent and disconnected, theoretical descriptions of the physical domains of objects and events. And, for various reasons, physical as well as epistemological, our provisional pragmatic intellectual security leaves us with a fundamental disatisfaction. But this is another story[35].

Let us conclude with a call to both tolerance and reason, by allowance of peaceful conditions for fundamental physical thought.

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[35] See, for ex., Kouneiher [1998].

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