CHAPTER ONE

On interpretations of quantum mechanics and a novel nonrepresentational framework

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Contents

Abstract

The von Neumann version of the Copenhagen interpretation of quantum mechanics, QM, is critically examined and contrasted with alternative realist formulations which show that the notions of both an observer and the collapse of the wave function in the consciousness of the observer, which are necessary elements for observation in the von Neumann version, are untenable. The common trait in the realist formulations, in addition to dispensing with the notion of an observer, is that they distinguish between recordings and observations and regard measurement as a full-fledged quantum physical process. Moreover, since in their context it becomes superfluous to include

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the observer's consciousness, we critically assess approaches which rely on purported connections between quantum mechanics and the brain arising from the von Neumann "consciousness-dependent" version of quantum mechanics. We also comment on *bona-fide* recent applications of quantum mechanics to consciousness and neural processes. To further develop a realist-like approach, we advance here a nonrepresentational framework of quantum mechanics that fulfills many of Bunge's constraints [Bunge, M. (Ed.) Quantum Theory and Reality, Springer Berlin Heidelberg (1967), 105–117]. The nonrepresentational nature of this framework aims at fulfilling the tenets that a quantum physical theory cannot belong to the set of material elements and that it should be mathematically rooted on an abstract Hilbert space. In addition, the present formulation emphasizes the development of a connection between the abstract and the laboratory worlds. This is done in order to bypass the semiphysical character of present-day quantum mechanics which leads to many unwarranted and paradoxical situations.

1. Introduction

Ever since the early days of quantum mechanics, there has been a manifest interest in describing phenomena embodied in the term "consciousness" by means of concepts introduced in this new discipline. It was thought that as much as relativity did away with the traditional concepts of space and time, so quantum mechanics would do away with time-honored concepts of classical physics such as particle position and momentum which, according to the new mechanics, could not be known simultaneously with absolute accuracy. Moreover, the formulation of this new physics was rigged with outstanding if not surprising concepts such as wave/particle duality, indeterminacy, and later on entangled states, and super-luminal transport. In the context of the Copenhagen interpretation, there are still other concepts such as wave function collapse (de-coherence)[1] purportedly occurring in the observer's brain and, thus, relatable to consciousness.

Part of the motivation for linking quantum mechanics to the workings of the brain probably stemmed from the fact that the deterministic world-view inherited from Newtonian mechanics left no room for free will, and this certainly is at odds with religious beliefs. On the other hand, quantum mechanics opened the options for indeterminacies and restored in this way the possibility of willful choice. Let us quote Eddington on the implications of the new quantum theory voiced in the Gifford Lectures in 1926[2]: "This means a denial of determinism, because the data required for a prediction of the future will include the unknowable elements of the past." For a different perspective of quantum mechanics and determinism and a discussion on determinism and free will, see, however, Margenau.[3] The incorporation of quantum mechanics as a basic tool for the description of the workings of the brain certainly responds to this need of restoring the possibility of free will: as exposed by Stapp,[4] "The new theory departs from the old one in many important ways, but none is more significant in the realm of human affairs than the role it assigns to your conscious choices. These choices are not fixed by the laws of the new physics, yet these choices are asserted by those laws to have important causal effects in the physical world. Thus contemporary physical theory annuls the claim of mechanical determinism. In a profound reversal of the classical physical principles, its laws make your conscious choices causally effective in the physical world, while failing to determine, even statistically, what those choices will be." In another part of his work, Stapp states: "Quantum physics constitutes a refutation of the idea that the motions of the atoms in our brains are, like the motions of planets in our solar system, independent of our mental intentions."[4]

The interest in connecting quantum mechanics to consciousness has a long and vivid history that has been quite aptly recorded in the work of Tarlaci[5] who provides a long list with names of those who advocated this connection as well as with a brief description of the main theses propounded in their works. Much of this connection has to do with the measurement problem in quantum mechanics that relies on the Copenhagen interpretation of quantum mechanics (of which there are variants). In one of them, stemming from von Neumann's ideas on the measuring process in quantum mechanics it was demanded that in this process there should be both a "collapse" of the wave function and the participation of an observer in whose brain, ultimately, this collapse occurred. Stapp again: "Quantum physics elevates our conscious intentions from physically impotent side effects, of a physically predetermined evolutionary process, to dynamically essential instigators of our physical actions! … It is time, now, to accept the quantum advance in our understanding of nature not only in technology but also in neuroscience…"[6]

Notwithstanding the commendable purpose of restoring indeterminism and free will in physics, the introduction of subjective factors into quantum mechanics has unwittingly produced much confusion. We argue that such confusion is neither necessary nor that it is an inescapable consequence emanating from the very nature of quantum mechanics. For this purpose, we present in Section 2 a succinct and critical discussion of von Neumann's interpretation of quantum mechanics followed by a presentation of the salient points of two realist formulations due to Popper and Bunge, respectively. Finally, we make some comments on the application of quantum mechanics to consciousness.

We advance in Section 3 a nonrepresentational framework for quantum mechanics that emphasizes its abstract nature and its intrinsic separation from semiclassical interpretations. We discuss in some detail how to establish connections that link abstract to laboratory space. Finally, in Section 4 we present some conclusions.

2. Subjective and realist interpretations of quantum mechanics

For purposes of clarity it is important to define the terms "subjectivism" and "realism." We adopt here the definitions given in the Cambridge Dictionary of Philosophy:[7]

- Subjectivism: Any philosophical view that attempts to understand in a subjective manner what at first glance would seem to be a class of judgments that are objectively either true or false.
- (Scientific) Realism: The view that the subject matter of scientific research and scientific theories exist independently of our knowledge of it, and that the goal of science is the description and explanation of both observable and unobservable aspects of the world. Scientific realism is contrasted with logical empiricism and social constructivism.

2.1 The Copenhagen interpretation

The orthodox interpretation, represented by Bohr and Heisenberg, may succinctly be expressed as[8] "… the correct interpretation of most of the writings of Bohr and Heisenberg can be summarized in the claim that the final state of the pointer reading is definite, though unknown, when the final state of the micro-system plus apparatus is reached—but before registration upon the consciousness of the observer. It is extremely easy to present a long list of statements by the two above mentioned scientists pointing out that, within standard quantum mechanics and with reference to a measurement process, one does not need to call into the game a conscious observer. In brief, the crucial step of the process, i.e., wave packet reduction, takes place when a micro-system in a superposition of different states interacts with a macro-system in a ready state in such a way that the different states of the superposition lead to macroscopically different situations of the macro-system itself (typically, the positions of the pointer)."

Of particular interest for the present work is the view introduced by von Neumann in The Mathematical Foundations of Quantum Mechanics.[9] His view although included in the Copenhagen interpretation of quantum mechanics introduces an important variation, namely, the presence of human observers. Considering a measurement process and denoting the system as S and the measuring apparatus as M he claims that: "In the measurement we cannot observe the system S by itself, but must rather investigate the system $S+M$ in order to numerically obtain its interaction with the measuring apparatus M." von Neumann's measurement theory provides a statement concerning $S + M$, that should describe how the state of S relates to certain properties of the state of M (namely, the positions of a certain pointer, since the observer would read these). Moreover, it is rather arbitrary whether or not one includes an observer in M, and replaces the relation between the S state and the pointer positions in M by the relations of this state and the chemical changes in the observer's eye eventually in his brain (i.e., to that which he has "seen" or "perceived")." Yet, a physically determined gangway (bridge) was never indicated.

A serious difficulty in von Neumann's measurement theory is that it does not deal with real measurements. The reasons are that no universal measurement apparatus exists. This implies that each measuring instrument works in its own way and hence one must resort to different physical theories for their description. In addition, each instrument has particular pointers that require the incorporation of particular physical laws to the instrument workings. Thus, a spring balance is calibrated using Hooke's law. In this perspective the claim that the eigenvalues of an operator are the possible values that arise from the "measurement" of a dynamical variable is simply inadequate.

2.2 Realist interpretations

The intellectual climate by the time that quantum mechanics had been created was strongly characterized by a tendency to disbelieve abstract concepts and to emphasize rather the operational approach whereby an experimental set-up based on the observer's actions led to scientific facts. The influential book by Bridgman, advocating an operational approach to science, published in 1927,[10] provides a fair example of this tendency.

In a way, the motivation for this program was commendable in that it attempted to rid physics from metaphysical elements, which had no bearing on the "observable" world. But the emphasis on observable phenomena instituted, albeit unintentionally, a new metaphysics, which purported that the world is made of sense experience. Thus, rather than a realist epistemology, an observer-centered one was adopted. This led, as commented by Bunge,[11] to a situation where "…the atomic physicist learned to state that every atomic state was the outcome of some laboratory manipulation, the very idea of an autonomous external world being a metaphysical legacy from classical physics. Observers and observables—or rather the corresponding words—began to invade the whole new physics."

The amazing fact, from the present vantage point, is that the groundbreaking spirit of the relativistic and quantum revolutions was dressed in an utterly inadequate subjective and phenomenological garment. Quantum mechanics is a mathematical construct (a framework), which allows us to breed semiclassic models that may help describe (characterize) the behavior and properties of atomic, molecular, condensed matter, and subatomic systems. In its phenomenological costume it is laden with measurement problems, e.g., with the collapse of the wave function and the need for an observer's consciousness. Many aspects of this theory have been criticized; and thought experiments have been devised in order to show that it is incomplete or to highlight its inconsistencies and paradoxes (e.g., the EPR controversy, Schrödinger's cat, Wigner's friend, etc.). Nevertheless, it is a highly successful theory which continues to be used in spite of all its apparent difficulties.

Some of the above problems are not genuine and result from the application of an inadequate subjectivist epistemological perspective. In fact, the mathematical formulation advanced by von Neumann, which provides a rigorous abstract framework, is tinged by this perspective and unwarrantably introduces as a basic ingredient the artifact of the observer's consciousness. The so-called Copenhagen interpretation was strongly criticized in the nineteen sixties but, later on, practitioners became used to it. Yet, alternative realist formulations were set forth. Next, we discuss two such formulations (which are complementary) directed at laying the groundwork for "ghost-free" (or observer-free) quantum mechanics: Popper's and Bunge's approaches. Let us remark that these realist formulations of quantum mechanics are not related to what is known as "macroscopic local realism" which has been shown to be at odds with quantum mechanics.[12,13]

2.3 Popper's Theses

In the article "Quantum Mechanics without 'The observer' " Karl Popper[14] expounds in thirteen theses his criticism of the Copenhagen interpretation of quantum mechanics. Here we shall not mention all of them but just those necessary to argue plausibly on the validity of Popper's realist formulation. The first thesis is that the kinds of problem that quantum theory is intended to solve are essentially statistical. The second: quantum mechanics thus must be essentially a statistical theory. The third asserts that the interpretation of this statistical nature of the theory as incomplete knowledge of the system is false and leads to the intrusion of the observer. The fourth (dubbed by Popper "the great muddle") consists in taking a distribution function, i.e., a statistical measure function characterizing some sample space or population of events, and treating it as a physical property of the elements or of the population. The fifth thesis is that the Heisenberg uncertainty relations are just the lower limits of the statistical dispersion of the results of sequences of experiments. The sixth thesis, that the statistical laws of the theory, including the Heisenberg formulae, refer to a population of particles (or of experiments with particles) that are, quite properly, endowed with positions and momenta (and mass-energy, and various other physical properties such as spin). The seventh thesis gets to the core of the argument and in order to describe it, following Popper, we resort to the following definition: $p(a, b)$ is the relative probability for an event a to occur given b (relative probability of a given b) for $a, b \in S$ and where $0 \leq p(a, b) \leq 1$. It is assumed that also $-a$ (non a) and the "product" $(a \cdot b)$ belong to S. It is clear that $p(a, a) = 1$, $p(-a, -a) = 1$ and $p(a, b) + p(-a, b) = 1$. For $b = -a$ then $p(a, -a) + p(-a, -a) = 1$ and it follows that $p(a, -a) = 0$.

In order to apply these notions to quantum mechanics consider a semitransparent mirror and assume the probability that light will be reflected by it to be 1/2. Thus the probability that light will pass through (or be transmitted) is also 1/2. If we denote by a the event "passing through" and the experimental arrangement by b, then $p(a, b) = 1/2$ and also $p(-a, b) = 1/2$ where "$-a$" stands for the event of "reflection." This thought experiment was described by Popper[14]:

> *"Now let the experiment be carried out with one single photon. Then the probability wave packet attached to this photon will split, and we shall have the two wave packets,* p(a, b) *and* p(−a, b)*, for which our equation* p(a, b) *= 1/2 =* p(−a, b) *will hold. "After a sufficient time", Heisenberg writes, "the two parts will be separated by any distance desired…" Now let us assume that we "find", with the help of a photographic plate, that the photon (which is indivisible) was reflected. (Heisenberg says that it is "in the reflected part of the packet", which is a misleading metaphor.) "Then the probability", he writes, "of finding the photon in the other part of the packet immediately becomes zero. The experiment at the position of the reflected packet thus exerts a kind of action (reduction of the wave*

> *packet) at the distant point occupied by the transmitted packet, and one sees that this action is propagated with a velocity greater than that of light." (Cf. [9] Cp. [26], p. 39; where the italics are mine.)."*

Popper continues: "Now this is the great quantum muddle with a vengeance. What has happened? We had, and still have, the relative probability $p(a, b) = 1/2$ and $p(-a, b) = 1/2$ take the information $- a$ (which says that the particle has been reflected), then relative to this information we get $p(a, -a) = 0$, $p(-a, -a) = 1$. The first of these probabilities or wave packets is indeed zero. But it is quite wrong to suggest that it is a kind of changed form of the original packet $p(a, b)$ which *immediately becomes zero*. The original packet $p(a, b)$ remains equal 1/2 which is to be interpreted as meaning that if we repeat our original experiment, the virtual frequency of photons being transmitted will equal 1/2." Popper concludes: "And $p(a, -a)$, which is zero, is quite another relative probability: it refers to an entirely different experiment which, although it begins like the first ends according to its specification only when we find (with the help of the photographic plate) that the photon has been reflected. No action is exerted upon the wave packet $p(a, b)$, neither an action at a distance nor any other action. For $p(a, b)$ is the propensity of the state of the photon relative to the original experimental conditions. This has not changed, and it can be tested by repeating the original experiment."

Popper gives the following simple and interesting example as an analogy for the collapse of the wave function. Assume that a penny is tossed. Since its states are heads and tails, the probability of each of its possible states equals 1/2. "As long as we don't look at the result of our toss, we can still say that the probability will be 1/2. If we bend down and look, it suddenly 'changes': one probability becomes 1, the other 0. Was there a quantum jump owing to our looking? Was the penny influenced by our observation? Obviously, not; (The penny is a 'classical' particle.) Not even the probability (or propensity) was influenced. There is no more involved here, or in any reduction of the wave packet, than the trivial principle: if our information contains the result of an experiment, then the probability of this result, relative to this information (regarded as part of the experiment's specification), will always trivially be $p(a, a) = 1$."

Through his perceptive exposure of a logical flaw in the statistical interpretation of QM, Popper dispenses with both the observer and the "collapse" of the wave function. Above all, there is no need to invoke the observer's consciousness as an apodictic element in this process.

So far, this is Popper's position; let us now report on Bunge's position.

2.4 Bunge's interpretation

Bunge[15] starts by asserting that the mathematical formalism of quantum mechanics, the theory for microsystems endowed with mass, should be neutral with respect to physical or psychological interpretations. The problem has to do with the use of a subjectivist epistemology, which may inject subjective characteristics into objective statements. Of course, the propensity for this kind of action or interpretation was present in the dominant cultural climate corresponding to the time of the creation of quantum mechanics. In particular Bunge mentions that an objective statement: "The values Q that a system may take on are the eigenvalues at the operator representative Q" may be transformed in the context of a subjectivist epistemology into: "The values that an observer can obtain upon measuring Q are the eigenvalues of the operator representing Q."

The logical reorganization of quantum mechanics carried out by Bunge was motivated by the following reasons:

(1) Inconsistency of the orthodox (Copenhagen) interpretation
(2) Semi physical character of the usual interpretation
(3) Uncritical character of the orthodox attitude.

The aim of Bunge's axiomatic presentation of quantum mechanics[15,16] is to provide thoroughly physical and consistent formulation to the foundations of quantum mechanics. It is realist axiomatic in the sense that it upholds the notion of an external world that is independent of the observer. In addition, it pays due homage to the theory and its accomplishments: "Since the basic quantum formalism has had such a marvelous success—no matter how badly new theories are needed to cope with high energy events—the good old QM [quantum mechanics] deserves being depurated of its *ad hoc* operational interpretations dictated by a dusty philosophy rather than by any inner physical need. To this end, all we have to do is to lay bare the mathematical skeleton of the usual theory, display it orderly, and reinterpret it in a purely physical way."

This axiomatic presentation is carried out such that any proposition of the theory is either a logical postulate or a logical consequence derived from the postulates. This approach guarantees the absence of statements that are unrelated to the primitive concepts contained in the primitive basis. Similarly, the semantic structure is presented explicitly in order to avoid unwarranted assignation of meaning.

The primitive base is formed by a set of underlying concepts, which in Bunge's case form a 17-tuplet and in Perez-Bergliaffa's et al. a nine-tuplet.[17]

We shall not delve in depth into details of these axiomatic forms but just mention some of their salient traits in order to give a flavor of what is attempted with them.

It is important to note that the concepts of position and momentum are not present among the basic axioms. In Bunge's words: "We have abstained from stating that x represents the position and $(-ih/(2\pi))\nabla$ the momentum of σ, and this because 'position' and 'momentum' are classical concepts which have no place in QM except as classical limits. In this theory x is just a name for an arbitrary point in configuration space, not a particle coordinate, while $(-ih/(2\pi))\nabla$ is in itself physically meaningless yet a self-adjoint operator. Only eigenvalues, densities and averages (may) have a physical meaning."[16]

One of the important consequences of a realist axiomatic formulation of quantum mechanics is that one may dispense with the notion of observer as well as with the participation of the observer's consciousness. Therefore, there is no (induced) collapse of the wave function and thus there is no need for strange interactions, which purportedly would be substantial in our creation of the perceived world.

2.5 Some comments on the application of quantum mechanics to consciousness

The nature of consciousness has been a long-standing issue in western human history. However, it is only recently that much progress has been made in its understanding from a physics perspective.[18,19] Critical in this sense have been the developments in neuroscience. Indeed, "The capacity of the neurosciences to absorb and use information from the physical sciences is increasing every year, with the techniques of the physical sciences adding to the rigor and depth of current neuroscientific work."[20]

Let us distinguish two contrasting standpoints from each other, concerning the application of quantum mechanics to the understanding of the brain and consciousness. The first one is based on the tenet that in quantum mechanics there exists an observer and a collapse of the wavefunction in the observer's brain. The second, that since the brain and neural structures are made of atoms and molecules, quantum mechanics may be applicable not only in the form of quantum chemical calculations of molecular stabilities and interactions but also in other specific phenomena involving, for example, bio-photon excitation and entanglement.

Within the first approach, due to the unwarranted insertion of the observer's consciousness in the von Neumann interpretation, it is claimed that consciousness owes its origin to a quantum mechanical phenomenon which exerts a basic influence on mental processes. A representative expression of this posture is: "Contemporary basic physical theory differs profoundly from classical physics on the important matter of how the consciousness of human agents enters into the structure of empirical phenomena. The new principles contradict the older idea that local mechanical processes alone can account for the structure of all observed empirical data. Contemporary physical theory brings directly and irreducibly into the overall causal structure certain psychologically described choices made by human agents about how they will act."[5]

A more daring variant on this subject asserts that there is gravitationally induced spontaneous quantum state reduction.[21,22] Penrose argues that "even within the framework of completely conventional quantum theory, there is a fundamental issue to be faced, when gravitational effects begin to become important." By invoking quantum gravity it is claimed that there occurs an "objective reduction" (i.e., a "collapse") of the quantum state. Moreover, "consciousness depends on biologically 'orchestrated' coherent quantum processes in collections of microtubules within brain neurons, that these quantum processes correlate with, and regulate, neuronal synaptic and membrane activity."[22] The problem is that once more, the collapse of the wave function occurs in the observer's brain. Objectivity refers to a purported physical phenomenon, namely gravity, and its effect on particular biological structures, as the source of consciousness.

However, von Neumann's introduction of an observer as a necessary element of quantum mechanics is not tenable according to the realist interpretations. It follows from the discussion above (Section 2.2) that quantum mechanics can be rigorously formulated without resorting to the observer's presence. This further implies that there is no "collapse" of the wave function on the observer's consciousness and therefore that all theories of consciousness based on this purported "collapse" are necessarily flawed.

As we discuss below, quantum mechanics has some bearing with respect to the treatment of the processes occurring in the brain, but certainly not in terms of the collapse of the wave function and its sequels. In the words of Gell-Mann, "While 'vital forces' have fortunately disappeared, consciousness remains as the last refuge of obscurantists in science. There are still some scientists who resist the obvious conclusion that mental processes in animals, including humans, simply emerge from biology plus accidents, that the mind is just the activity of the brain and of chemicals distributed throughout the body, that psychology emerges from neurobiology."[23]

The second standpoint focuses on phenomena observed in the brain that may be explained in terms of the usual practice of quantum mechanics. It starts from the recognition that the brain is a biological system, formed by very complicated assemblages of molecular structures. Among these structures particularly important are the microtubules[24] conjectured in the Orch OR theory to be the sites of the objective reduction due to gravitational effects. These microtubules, it turns out, play an important role as biological sites for the occurrence of quantum interactions and it seems probable that neuronal microtubules are involved in the process of consciousness and cognition. This contention finds support in the fact that microtubules are involved in the action of general anesthetics and antidepressants.[25,26]

Biological systems are parts of living organisms which have been designed in the course of evolution. Because these systems interact in complicated ways with their surroundings and function at physiological temperatures, there has been some skepticism concerning whether quantum mechanics may be rightfully applicable to this biological domain. The reason is that the behavior of biological systems contrasts sharply with the usual quantum systems which work at low temperatures and are isolated from their environments. Nowadays, however, this perspective has changed and the current belief is that: "The basic biology of the brain, elevated though it is by the inexplicable phenomenon of consciousness, is perhaps not, on a mechanistic level, so very different from other processes that take place in the body. It is no wonder then that interest has grown in whether quantum biology might have some contribution to make toward understanding the detailed physiological mechanisms that constitute the central nervous system."[26]

The discovery of quantum effects on soft biological tissue at room temperature has led to emergence of quantum biology.[27,28] Quantum coherence in photosynthesis, enzyme catalysis, olfaction, avial compass, DNA replication are examples of these effects. "Such advances demonstrate that decoherence may fail to destroy quantum correlations in biological tissue at physiological temperature (in the 'warm, wet, and messy' biological tissue), and it actually seems that at least in some cases molecular architecture and function has been designed in such a way as to avoid deleterious effects of noise, in order to preserve quantum coherence and in a way as to benefit living organisms."[29]

Of course, since the brain is a biological system made up of molecules, the usual application of quantum chemistry to determine structure and interactions may be consistently carried out. But actually, the interest in linking quantum mechanics to the brain lies in the " irreducible quantum phenomena that require in one way or another superposition of quantum states, typically at a larger scale, compared to the molecular scale, and involving large polymers and complex chemical reactions. Nontrivial quantum effects are related to quantum coherence."[29] The entanglement among quantum states corresponding to these biological structures is an open possibility in the study of quantum phenomena in the brain. As stated by Guevara et al., entanglement is "a phenomenon that results when the wavefunction describing the state of a group of particles cannot be factored out as the product of the sates of individual particles. Entanglement is a simple consequence of the superposition principle applied to multiparticle systems. It implies that the properties of certain configurations of particles are intrinsically intermingled (entangled) in such a way that results of experiments on different particles are correlated in a nontrivial way, impossible to explain in terms of classical physics."

A fruitful area of research on neural processes focuses on the action of chemicals such as anesthetics that precisely disrupt these processes with the aim of understanding the mechanism of consciousness. In fact, a quote attributed to Turin says: "the only thing we are sure about consciousness, is that it is soluble in chloroform."[30] But more seriously, "Given that the definition itself of consciousness is elusive, and given that it is even more baffling how it arises in our brains, many believe that research into how anesthesia operates might lead to a better understanding of how the brain sees itself and the world around it."

As an example of quantum effects in the brain, we can mention the experiments of Turin et al., who showed "that volatile general anesthetics cause large changes in electron spin in Drosophila fruit flies and that the spin responses are different in anesthesia- resistant mutants."[31]

Another example comes from the study of the mechanism of anesthetic-induced unconsciousness. It has been found that anesthetics act in quantum channels in brain microtubules.[32] This interaction is mediated by neuron biophotons. The latter are coherent photon fields characteristic of living biological systems, namely, light emitted by cells during specific metabolic processes.[33,34] Biophotons have been identified in neural tissue and have been " hypothesized as auxiliary carriers in neuronal information transfer."[35]

In an experiment using entangled pairs of photons at a wavelength of 800nm (in the biophoton range) from an external source, Burdick et al., have shown that halogenated ethers interact with these entangled photons. " This is the first experimental evidence that halogenated anesthetics can directly undergo quantum interaction mechanisms, offering a new approach to understanding their physicochemical properties."[35]

Recently, gold nanoparticles have been used to measure ultraweak biophotons in a physiological solution in ATP driven biosynthesis. In the words of Li et al., "All of our results strongly indicate that ATP could release photons to drive a biosynthesis, which can greatly promote the development of biochemistry and quantum-efficiency chemical reactions." These results have important implication for the understanding of energy-efficient information processing in the brain because neuronal spiking activities are driven by ATP hydrolysis.[36]

2.6 Some final comments on interpretations

The disputes about interpretations of quantum mechanics may endlessly proceed because their grounds lie at a philosophical level and there are few chances of moving them into a physico-mathematical ground beyond ideologies. Whereas very little can be added to these disputes, experimental quantum physics continues its development which requires the introduction of physically based measurement frameworks. Observers of any kind, in particular those capable to put mental attention to what is going on, cannot be part of the internal aspects of the framework. So, mental forces even coming from Wigner's friends would have no place in a physical measurement framework.

Where does the need to introduce a decoherence principle come from? A tentative answer may be: Basically it originates in the desire to produce an interpretation of the abstract quantum mechanical formalism in classical physics terms. Those terms were the only ones known before the advent of Heisenberg's quantum (matrix) mechanics and later of Schrödinger's wave mechanics. The use of the word "mechanics" already conveys a certain classical picture lying at the ground of quantum physical descriptions. The emergence of pure quantum physical concepts such as coherent quantum states, entanglement, and spin were thence misrepresented with classical physics pictures and images.

Leggett has shown that idealized macroscopic quantum coherence experiments are incompatible with quantum mechanics under the tenets of macroscopic realism and noninvasive measurability at the macroscopic level.[13]

Recent work on the interpretation of quantum mechanics based on revivals of Schorödinger's cat[8] or Wigner's friend[37] assumes the presence of an observer which by the action of "observation" produces a "collapse" of the wave function into one of its superposed states generating in this way a definite knowledge of the system's state. Based on the analysis we have carried out in this section, where we have attempted to show the plausibility of a realist interpretation of QM, it seems evident that these revivals are based on superfluous tenets which do not contribute to the clarity of QM.

3. A nonrepresentational framework for quantum mechanics

We present here the salient features of a nonrepresentational framework for quantum mechanics.[38–42] Our aim is to place this framework in perspective as a realist-like formulation which, while adhering to the basic principles of quantum mechanics (time-independent Schrödinger equation, unitary time evolution of a system, etc.,) focuses, nonetheless, on the behavior of quantum states or q-states and dispenses in this way with semiclassical interpretations. The points we emphasize are the following:

(1) The framework for a quantum physical theory cannot belong to the set of material elements. It is bound to be mathematically rooted; e.g., elements of abstract Hilbert space with inner product and mapping to the field of complex numbers; they may also be elements of Fock vector space with self-adjoint operators of different types. Moreover, the theory must be "thoroughly quantal: no point particles and no waves and thoroughly physical: no observer-dependent features."[15]

(2) A connection between abstract and laboratory worlds must be introduced (worked out) in order to bypass the semiphysical character denounced by Bunge.[15,16] The reason is that the quantized exchanges of energy and angular momenta amid physical systems are mediated by q-events which refer to the "creation and transit" of energy quanta. The difference in energy levels of q-states belongs to abstract space whereas a quantum of energy and angular momentum appears and interacts at lab space. However, a q-event is not representable in either space be it abstract or laboratory. In an opposite direction, the energy/momentum quantum transferred to abstract space leads to entanglement representing the link between elementary materiality and a photonic q-state. Furthermore, this quantum physical "in-between" element is localizable in given measuring apparatuses.

3.1 Quantum states and their material linkups

A material system sustains a quantum state, namely, a q-state. The material system is determined by the nature and quantity of its basic elements, e.g., number of electrons and nuclei in the case of electromagnetic interactions (atoms, molecules, solids, condensed matter,...), In turn, material systems may relate to objects and things only in the laboratory (real) world. Yet, a q-state is a mathematical concept belonging to an abstract mathematical space, viz. Hilbert space. Hence, vectors in Hilbert space represent q-states. Changes of q-states are represented with operators mapping one state into another.

The statement that a material system may sustain a q-state implies a requirement for the material system that it be present in the domain where quantum changes may take place. Let us emphasize, however, that its presence is essential but its localizability is not an issue.

Thus, the concepts of material system and quantum state occupy a foundational place in quantum physical chemistry. It is on these foundations that one may construct quantum mechanical descriptions of processes sustained by physical, chemical, biochemical, and other types of materials.

3.2 Towards a laboratory space quantum physics

Abstract (mathematical) Hilbert and Fock spaces[9] provide the floor to introduce the concept of quantum state (e.g., linear superposition principle). The connection of abstract elements with those characterizing laboratory circumstances must be worked out independently of any representational model (see below). Therefore, even Bunge's efforts are betrayed by his "reinterpretation" condition. Moving from the abstract toward the laboratory space is not a simple exercise; this move calls up for a gangplank to the extent that these spaces are not commensurate in the first place. One speaks of quantum states in the former and of classical particle dynamics and/or wave motions in the latter. The connection must be consistently formulated first with quantum elements only. The constraint eliminates semiclassical pictures such as "wave/ particle" duality and, accordingly, the complementarity principle vanishes as it stands in excess, yet its historic role remains, of course. And the phenomenon of entanglement would embody the gangplank (bridge) to help in handling this new state of affairs.

Let us briefly sketch the required formalism:

The quantum state $|\Phi\rangle$ projected over (rigged) configuration spaces reads: $\langle x_1, \ldots, x_n|\Phi\rangle$ that can be mapped to a complex function over real support $\mathbf{\Phi}(\mathbf{X})$ where $\mathbf{X} \to (x_1, \ldots, x_n)$ form a vector space over the field of real numbers, i.e., a configuration space. The function $\mathbf{\Phi}(\mathbf{X})$ belongs to the domain of wave functions that are complex valued functions over real valued supports. These structures help introduce the concept of quantum states sustained by a given elementary materiality. For matter-supported *q*-states, the dimension of configuration space embodies the number of classical degrees of freedom. Caveat: there cannot be any attempt to "interpret" the numerical values (real numbers) as either particle positions or linear momentum in reciprocal space.

Quantum degrees of freedom enter at this level e.g., two-spinors or Dirac four-spinors. Operators carry information of classical magnitudes as parameters, never as dynamical variables. Inertial reference frames mediate the definitions of partite systems prompting for differentiation of *q*-system of interest and measuring *q*-devices that could display macroscopic dimensions: nonetheless, the interactions show the fundamental quantum nature expressed as *q*-events. In fact, there is no reason to search for a full quantum description *because there is no object description* in quantum mechanics: the quantum state is the fundamental concept. It is important to bear in mind that a *q*-state is not an object. *Q*-states have (if anything) a weaker metaphysical ground than the one associated to the term: "population of." If we retain the view: *q*-state sustained by the elementary materiality yet never "representing" such entities then it is clear that an infinite number of *q*-states can be sustained by one and the same elementary materiality set. Thus, there will only be the class of the *q*-state that matters.

Planck's seminal hypothesis for the quantum nature of energy/information exchange amid initially distinguishable partites is supplemented by entanglement which provides a key to such description. Consider radiation and material system: qualitatively, energy/information exchange takes on a quantum form; the energy amount being gauged by the classical radiation frequency with Planck's constant $\hbar$ thereby helping bridge aspects of classical space to *q*-space. Constructing such bridge seen from a classical world perspective would define an event; call it a *q*-event that can be detected at a laboratory domain. The latter cannot be described in the same terms that are used for *q*-states. Yet the result can be experimentally sensed; e.g., a click at a detecting apparatus or tracks in Wilson chambers. These can be elements to construct quantum measurements: quantum states for quantum measurements.[39]

While it makes sense to state that QM is a mathematical construct, the proposals saying that it allows us to describe the behavior and properties of atomic, molecular, condensed matter, and subatomic systems are not correct without further ado. From the fundamental abstract level there is no place to define entities (molecules, etc.), only spectral features (structures) and responses at best. It is actually a semiclassical model that can be used to construct such a type of gangplank picture; and it will remain a semiclassical model that one can judge by its usefulness but not by its truthfulness. Regardless of what might be affirmed, it cannot be assigned putative representational characteristics. And here lies the crux of this mode of apprehension. The gulf between laboratory and abstract (theory) domains is bridged yet not represented.

Thus, misunderstandings of all sorts have cropped up just from overlooking the fundamental difference between abstract and semiclassical frameworks. In the long run, the latter ones have weighed down quantum physical presentations with all sorts of inappropriate pictures. Furthermore, ideology-tinged categories are not appropriate to handle relations between abstract and laboratory situations: abstract remains abstract, laboratory *q*-states can be given particle and/or wave descriptions (communication devices). In any case, the gulf remains. Again, a reason for this situation is that both realms are not commensurate. This situation prevents pushing too far bare (simplistic) representational modes and languages.

Planck uncovered a quantized mode and set up the beginning of a fundamental change which, initially, at a slow pace contributed to the development of quantum physics and created illusions in other domains such as those evoked in the Introduction of this article. The exchange takes on the character of an event linking (bridging) the "in-between" of two otherwise non-commensurate systems, so to speak. Taking together these systems can be discerned (noticed) as particular forms of entangled states. These entangled states do not belong to the independent partite elements (i.e., radiation and matter). They would rather qualify as *q*-interactions (see below).

It comes as no surprise that the concepts of classical physics were not adequate to make sense of the emerging quantum physics. Quantum states become the fundamental elements (we have to live with them and abandon the classical concepts of waves and particles; send them back to the domains where they belong, which certainly are not those of quantum physics and chemistry). Fock and Hilbert spaces provide foundational elements to accommodate quantized fields related to radiation and matter fields.

Fock space corresponds to the basis space used to construct quantized forms linked to electromagnetic radiation energy. Unfortunately, a quantum of radiation energy named photon reintroduces once again a feeling of the classical idea of a particle. We stick here to *q*-states and, in particular, to photon-states and thus transport this back to abstract space. One point is clear: In our formalism the quantum theory does not describe particle dynamics, in contrast to the approach of "Bohmian mechanics."[43–45] Thus, in our formalism only changes of quantum states permit an appropriate description of dynamical changes (see below) and this holds for both abstract and semiclassical approaches.

3.3 Entanglement/disentanglement: *q*-events

Entanglement is specifically a quantum phenomenon; no laboratory space would explicitly sustain it in a representational mode. To fix ideas and language a short description for a specific case follows.

Consider the one-photon state associated with the $(|0_\nu\rangle|1_\nu\rangle)$ basis vector and a (general) *q*-state associated with the column vector $(C_{0\nu}C_{1\nu})^T$. A *q*-one-photon state looks like:

$$(|0_\nu\rangle|1_\nu\rangle)\cdot(C_{0\nu}C_{1\nu})^T \rightarrow C_{0\nu}|0_\nu\rangle + C_{1\nu}|1_\nu\rangle \tag{1}$$

and $|C_{0\nu}|^2 + |C_{1\nu}|^2 = 1$. The basis kept fix; *q*-state takes on the form of sets of complex numbers (amplitudes) ordered as column vectors: e.g., $(C_{0\nu}C_{1\nu})^T$.

Preparing a vacuum state translates into *q*-state: $(1_{0\nu}0_{1\nu})^T$; this state hinges abstract domain to a situation where no photon energy is available at laboratory level and as a gangplank to a state having one effective photon in the field; this *q*-state would read: $(0_{0\nu}1_{1\nu})^T$. These two generic *q*-state fit to the amount of energy exchange involved that would corresponds to one energy quantum; and the latter is numerically agreed to take the value *hν*; it is not "moving by itself." In words, radiation field (*q*-field) sustains the *q*-state $(0_{0\nu}1_{1\nu})^T$. The novelty in quantum physics is that the set of *q*-states showing nonzero components $(C_{0\nu}C_{1\nu})^T$ such that $|C_{1\nu}|^2 + |C_{0\nu}|^2 = 1$ exist with $C_{0\nu} \neq C_{1\nu} \neq 0$ and yet it does not have any classical correlate, namely, it cannot be described in classical physics words. The usefulness of the sustainment idea lies in that it avoids precisely any classical physics picture. This latter state stands for a *q*-entangled state, a new form characteristic to quantum physics where the energy quantum is not available for exchanges with other partite states at laboratory level. Actual energy displacement at laboratory premises calls for a gangplank. This latter bridges two domains, otherwise poles apart.

Thus, one does not find a one-particle representation in a classical physics set up anywhere. Yet, associating the *q*-state $(0_{0\nu}1_{1\nu})^T$ to an *I*-frame one can *conventionally* use a propagation direction **k** and the origin of this vector to locate a source and/or indicate a target direction in space-time: i.e., a semi-classical model. Thus, an inertial frame (*I*-frame) opens the *q*-state to a semi-classical form where origin (location of) and direction in space-time will be of help in describing laboratory situations (circumstances). In this manner, quantum behavior can be assigned to *I*-frames (as global system) and/or to internal states sustained by configuration space.

Consider now matter-sustained *q*-state with basis set: $(\ldots, i, m(i), \ldots\rangle$. The principal quantum integer number i vehicles an order relationship, the subsidiary *q*-numbers $m(i)$ are signaled for completeness sake. The set of energy eigenvalues $\{\epsilon_i\}_{i=0,1,\ldots}$ (i.e., the spectra) correspond to an ordered set. The Hamiltonian operator H_{op} takes on the form: $H_{op} \to \sum_k \epsilon_k |k\rangle\langle k|$ and the operator commutator $[H_{op}, |i\rangle\langle j|]$ when acting on a given *q*-state, say $|\Psi\rangle \to \sum_k C_k(\Psi)|k\rangle$ and projected over $|j\rangle$-state yields: $(\epsilon_i - \epsilon_j)|i\rangle C_j(\Psi)$, i.e., it carries information from a root state $|j\rangle$ to a target one $|i\rangle$. All this belongs to abstract space.

Now, the response related to $\langle j|\Psi\rangle$ in the intensity regime picks up the amplitude proportional to $|C_j|^2$. We can grasp a sort of bridge from abstract space to a laboratory space, via the difference between eigenvalues that are assigned (by us) to electromagnetic energy quantum: $(\epsilon_i - \epsilon_j) \to h\nu_{ij}$ and the numeric value is given a correspondence to a particular laboratory radiation frequency, say, ν. This corresponds to the semiclassical Bohr's postulate with a blessing. One can see that this operation is modulated by root state amplitude C_j. *Only nonzero-valued amplitudes can be sensed with an appropriate radiation at the laboratory level.*

Determining the spectra already gives information of the amplitudes characterizing the *q*-state that one is to probe (photon field). But more important to this model, it indicates that the interaction if "successful" imposes angular momentum conservation (e.g., allowed transition) both ways on the measured system and on the measuring (probing) device. Remember, once energy is transferred from the photon field to the measured one, there is also the transfer of one unit of angular momentum i.e., it is a quantum-controlled process. This also is what a gangplank refers too.

Thus a change of the *q*-state $(0_{0\nu}1_{1\nu})^T$ into the state $(1_{0\nu}0_{1\nu})^T$ results from the interaction with a "massive" *q*-state (matter sustained one) and in this change a one photon energy is traded. Thus there is no need for an observer during the *q*-change. The probing and probe systems would concomitantly change as shown in the analysis produced by.[40,41]

The elements $|C_j|^2$ are at best partially imitated through the gangplanks by the set of click locations on a detector sensitive surface. The register simultaneously includes a part from the system being probed and the response of the detecting device. This nonseparability spoils the simple classical physics picture underlying common probabilistic descriptions. The energy and angular momentum conservation hold for the global system. The huge difference with respect to the Copenhagen viewpoint resides in the unnecessary presence of Wigner's friends (i.e., there is no collapse) and population views, quantum states change into other quantum states. This point is examined below in more detail.

For the time being, this closes the presentation of the gangplank appearance; nowhere a collapse of the wave function is compulsory. There is no reduction of the *q*-state. The source of the energy quantum must be introduced first to complete a laboratory description. In the in-between the q-state always read (0 1): either it is "waiting" or it was "left" once energy is in transit. The scheme referred to above, i.e., the photonic framework,[42] corresponds to a simultaneous field quantization of radiation energy and matter-sustained quantum fields: one does not go without the other. As a consequence, new physics may emerge in this novel context.[41]

3.4 Entanglement: A condition to open (close) *q*-systems for energy exchanges

For nonrelativistic models, "exchanges" of energy and momentum for independent partites result with the help of base states designed to present entanglement. Two independent *q*-systems are given first as simple logical-partites-sum (⊕). As each partite can be associated to arbitrary *I*-frames, these latter must be tuned in to facilitate at least classic collisions conditions: this tuning-in process (preparation) results in prompting possibilities for entanglement (⊗). Entanglement is *q*-characteristic so that classical distance, time, and orientation are not necessarily relevant. For partite to implicitly interact implies that their *I*-frames would overlap and the 2-partite system can be matched to an appropriate 1-partite entangled system.[42] Simply,

$$Partite{-}1 \oplus Partite{-}2 \quad (\rightarrow\ ?\ \leftarrow) \quad Partite{-}1 \otimes Partite{-}2 \rightarrow S_{12} \tag{2}$$

S_{12} is one possible 1-partite state eliciting specific entanglement interaction (e.g., bonds) not existent for the simple entangled $Partite - 1 \otimes Partite - 2$; the latter corresponds to a one-*I*-frame aggregate. It clearly looks like chemistry. To reverse the latter situation work must be done or collected, i.e.:

$$S_{12} \rightarrow Partite{-}1 \otimes Partite{-}2 \quad (\rightarrow\ ?\ \leftarrow) \quad Partite{-}1 \oplus Partite{-}2 \tag{3}$$

The symbol (→? ←) suggests a way toward entanglement; a kind of gangplank and it costs "real" energy to move around.

What about objective/subjective collapse of the wavefunction? Before displaying the q-approach it is important to briefly overview Bitbol's viewpoint[1] that might help "disentangling" this issue. Actually, through this new subject an important contribution to the understanding of QM has emerged that deserves mentioning. He wrote: "It has been shown that decoherence theories offer quantum theory a proof of mutual consistency between (i) the semi-classical presupposition of its empirical basis, and (ii) the definitely nonclassical structure of its probabilistic predictions." Bitbol continues: "this is less than what realist philosophers of physics were hoping for, namely a way to derive the classical appearances from the alleged 'quantum reality'."[1]

Besides the consistency issue, just noted, there is little more that can be recovered concerning representational issues, as we will show, without explicit decoherence one can construct a quantum physical model of probing and measurement.[40–42] In short, the preceding statement can be seen as a description of the relationship coming from the abstract side: from excitation operator leading to $(\epsilon_i - \epsilon_j)|i\rangle C_j$ energy transfer is modulated by the q-state whose amplitude brings in the possibility to get nonclassical probabilistic predictions; and this is because it is a quantum physical magnitude and not just a counting result; it will then include all nonclassical correlations. Moreover, the quantum character of $(\epsilon_i - \epsilon_j)$ forces a localized expression to the energy exchange at laboratory premises (e.g., clicks).

Thus, clicks or spots do not necessarily imply mere classical particle impact and, collecting them do not necessarily prompt for probabilistic particle interpretation; for the present approach this is a possible way. As they contain information quanta, so to speak, that are wasted in probabilistic schemes.

3.5 Recording and irreversibility

The gangplank symbol (→? ←) mentioned above is not a representable element in quantum theory. It is at best a signal for including external actions dictated by the actors' free will or a stochastic event. The click is the endpoint of this phenomenon: e.g., an imprint on a sensitive surface: a q-event.

Because it is the q-state that is being measured, the amplitudes might and will conform nonclassical patterns once all pertinent information is gathered. An interference pattern for instance can be seen as a 3-D image formed by spared sets of clicks that are actually the expression of a q-state and certainly not particle impacts.[17] Merely counting does not show all the richness that a q-measurement can elicit. Probabilistic schemes do not match quantum aspects; the discussion above by Popper is fairly instructive if one thinks it over from the present viewpoint.

Thus, as one collects information (click distributions, for instance, and supplementary information), it is not the counting that matters but the expression behind the theory, namely, terms related to $(\epsilon_i - \epsilon_j)|i\rangle C_j$. Energy gaps and root q-amplitudes are implicit once imprints are collected and saved, for instance, on a photographic plate (or any memory device so that images or patterns can be formed). There is no trace of a standard decoherence phenomenon; a coherent q-state is being recorded translated into an intensity regime (imaged).

Yet an observer being external to the system will only realize the presence of a sort of random click distribution. This is true if the number of events set aside is too small. The decoherence that is implied in the standard approach would be at the bridge between two states that can even differ in the number of I-frames characterizing the semiclassical model.

We need a more detailed understanding of q-states, q-interactions, and q-events if we want to say something meaningful concerning q-states sustained by brain-matter elementary constituents. Although, clearly the term: "elementary constituents" remains to be elucidated. Also q-states can be imaged as well as brain activity; these two concepts share this ground. Yet, what we "see" are not dynamics of material elements (particle motions), but q-states mediated responses in an eventually time-dependent regime. The time involved actually belongs to laboratory characteristic dynamics.

3.6 Quantum photonic states physics and the brain

Quantum phenomena, seen from the present standpoint, offer a different way to evaluate what is possible and what is not possible, in contradistinction to the standard view. Brain and mind would now possibly correlate with materiality and q-states altogether. In quantum physical as well as biological levels these elements feature as fully nonseparable with reciprocating effects. Neither q-states nor minds are objects in the phenomenological sense. We cannot speak of them as objective elements. Although in semiclassical frameworks such stance would allow model construction that may open the way to further experimental testing.

Communication between partite material systems takes an interesting form in the framework of the present scheme. For once communication is done, the information can "propagate" at speed only limited by that of light. The set of new possibilities can be incorporated, without further ado, via rigged basis set levels. All those new elements that characterize "fused" partites that now form one nonseparable partite state (being more than the sum of separate partites) will emerge. In terms of possible connectivity of large elementary material regions these can form/deform in characteristic times much shorter than classical physics sustained ones, for in the present model one part of the communication is "mediated" by gangplanks. Thus, it is the semiclassical framework that must be used to connect abstract to laboratory levels; this is the pragmatic approach. Pictures obtained with microwave probes of brain processes can well be pictures of those *q*-states sustained there.[46]

Much more can be said concerning picturing *q*-states. Q-technology is on the move and one can expect new knowledge if we leave alone Wigner's friends and focus on the *q*-physics sustained by brainy elements, material sustenance, and supported *q*-states. Thus, within the present framework, the distinction between quantum states and the basic brain materials sustaining the functionality requires the appraisal of both abstract and laboratory agendas. Early introduction of decoherence was understandable in view of the dominant representational mode in use at that point in time. Tenets and ideas used so far to introduce the quantum paradigm fail to provide a sound scheme. It is the semiclassical framework which in a way sustains pictures of the quantum aspects that might be useful for knowledge production. And thereafter, experimental tests eventually designed to probe models in Popper's perspective. In this context one can get size-dependent optical, electronic and optoelectronic properties, e.g., colloidal quantum dots. Quantum networks belong to the semiclassical quantum systems. Experimental testing targets, basically, on the usefulness of such models.

Brain-sustained activity seems to be related to quantum phenomena arising from electron and nuclear spin and also from entanglement. In this vein, among many others, the hypothesis has been advanced that " consciousness is a multiscale phenomenon that could appear both as a result of large-scale interactions in neural networks or due to nontrivial quantum phenomena within cells."[29]

Yet in the present framework to the extent that the stable nature of materiality depends on quantum effects, there cannot be any activity independent of quantum effects of one kind or another. There will always be quantum-mechanics-in-the-brain, albeit not necessarily producing useful knowledge. But the sustainment of brain functionalities would definitely be expressing quantum effects.[31,35] One point is clear however, quantum physics does not elevate our conscious intentions to dynamically essential instigators of our physical actions.

4. Discussion

We have critically examined the proposition emanating from the von Neumann version of the Copenhagen interpretation of quantum mechanics, which introduces the notion of an observer and the collapse of the wave function in the observer's brain. Based on this notion a great deal of speculation has been put forward concerning an alleged emergence of consciousness as a result of this type of quantum activity in the brain. We have discussed Popper's and Bunge's realist versions of quantum mechanics. The latter is an axiomatic presentation which not only dispenses with the observer but also casts doubts on the role that classical notions such as position and momentum have in quantum mechanics.

In order to avoid the pitfalls of mixing indiscriminately quantum and classical concepts in a representational context, we have sketched here a nonrepresentational framework of quantum mechanics where it becomes superfluous to include the observer's consciousness. In addition, a distinction is made between recording and observation; measurement is regarded as a full-fledged physical process.

The basic elements of this construction are matter *q*-fields supplemented by electromagnetic *q*-fields plus the bridges which must be constructed to link abstract space and the laboratory level. Inertial frames necessarily appear in the scheme allowing configuration spaces, signal production, entanglement and exchanges. Moreover, Planck's discovery enters the quantum field approach in a natural manner.

In the semiclassical model, the vector potential $A(\mathbf{x})$ is distributed on the matter-sustained Hamiltonian, the time-like component, corresponding to the Coulomb potential included in the charge-matter term and a time-dependent one converted into an operator value form for electric and magnetic fields. The latter are found in Maxwell electrodynamics providing the form to the operators. A semiclassical scheme obtains underlying laboratory applications. Necessarily, the latter is very useful but not apodeictic so that results therefrom obtained must be verified experimentally. It is here that Popper's ideas are relevant.

By introducing this framework we aim to eliminate from the outset uncritical representational elements added to the abstract quantum formalism and to expunge quantum mechanics from historically introduced interpretational issues. As the theory is communicated in mathematical language, the weirdness bestowed on quantum mechanics by interpretations no longer makes sense. Differentiating between the abstract (mathematical) and the laboratory formalism is required to ground the measurement problem in quantum physics before bringing observers into the framework. Quantum entanglement/unentanglement occupies the center stage that in the present context requires a more careful treatment; the *q*-phenomenon was not identified in von Neumann extraordinary book.[9] Here it is a key communication element. As a result, there is latitude on how to pose the problems anew either empirically or theoretically. Traditionally, however, the semiclassical approach had been adopted as the only possible framework.

The present approach, by distinguishing abstract from semiclassical domains, differs radically from either the empiricist or the representational frameworks. The reason is that we are addressing quantum states sustained by particular elementary materiality and the latter, definitely, does not represent them in a classical physics sense. It follows that a *q*-event crystallizes (so to speak) the quantum exchange between the measured *q*-state and the measuring *q*-state at laboratory domain. Because energy is exchanged in finite amounts (quanta) it can match an event and if it is put in evidence it will look spatially localized (the "click" as it were). A spot recorded is not necessarily in a one-to-one relation with a particle taken in the classical physics sense. The spot distribution of anything would disclose the wavefunction of the measured system: Probabilistic tenets are made irrelevant. And as a consequence, quantum mechanics is not necessarily a statistical theory.

Importantly, it follows that abstract quantum physics should not be used to describe processes sustained by brain tissues. Instead, the semiclassical approach would produce useful results that must be experimentally tested. No representational model is possible to help "visualize" brain behavior. Yet, quantum physical phenomena by including quantum electromagnetic effects (spectroscopic tools) would probe materially sustained quantum states and possible time dependent evolution. A recent example is found in Ref. 47 where magnetic resonance signals are mapped onto a sensitive surface reflecting the distribution of *q*-events. What to do with such pictures is a medical care issue and in this respect, they are most useful. Another example is given in the experimental determination of quantum effects arising in the interaction of halogenated ethers with entangled photons.[35]

Finally, let us recall Bitbol's incisive comment once more: "In an empiricist framework, the only thing which can be demonstrated by decoherence is that a classical system of probability valuations which are liable to the ignorance interpretation, can emerge (approximately) from a quantum system of probability valuations which is definitely averse to any ignorance interpretation. One has no good reason to expect anything more spectacular, let alone even more metaphysical, from decoherence theories."[1]

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