Measurement Problem a Prediction Problem in Quantum Mechanics and Classical Physics

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ABSTRACT

Quantum mechanics is based on Schrödinger's wave function with linear superposition of vectors in a Hilbert space. Due to superposition, multiple physical states are considered simultaneously for the same time point, but when the corresponding quantum mechanical experiments are realized, there is only one outcome and not a superposition of pointer positions. This observation characterizes for about a century the quantum mechanical measurement problem with multiple interpretations, which can be classified as potentiality, proposed by Heisenberg, or as real physical entities, for instance fields. Potentialities are yet inexistent in reality and unobservable in the present, since they represent a possible future. Thus, they can only be an intra-mental representation of a future process and not a physical extra-mental process ongoing in the present. There is coexistence of a physical object observable in reality and a mental prediction by an observer for the future behavior of this object. The characterization of quantum mechanical formalism by some physicists corresponds to a prediction and therefore to a mental representation of the future behavior of elementary particles and not to a description of an ongoing extra-mental process. Prediction in life and science has a characteristic, which resembles the measurement problem, since it undergoes a "multiple-to-one" reduction of mental potentialities to only one observable real outcome. Besides quantum mechanics, such reductions can also be found with many kinds of predictions, in classical physics for regular and irregular dynamic processes and in humans for programming future actions. Superposition in classical physics only concerns variable effects, but in quantum mechanics includes variable effects plus non-localizable causes. Quantum mechanics, interpreted as prediction of future outcomes with multiple potentialities but only one realization, would resemble the general prediction problem in life and science and thereby loses its weird aspects.

Key Words: Quantum mechanics, classical physics, measurement problem, prediction problem, mental potentiality, physical reality

DOI Number: 10.14704/nq.2015.13.4.872 **NeuroQuantology 2015; 4: 413-419**

1. Introduction

About 90 years ago, physical research on elementary particles was confronted with major experimental problems defined by the Heisenberg's uncertainty principle, that is the impossibility to measure simultaneously and with precision the location and momentum of an electron. If the location is precise, its momentum will be imprecise and vice versa. *"When dimensions are simultaneously measured for a particle such as space and momentum (x, p), energy and time (E, t), the exact measurement of one dimension makes the other extend to infinity"* (Tarlaci, 2012; p. 223).

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Received: August 29, 2015; **Accepted:** October 15, 2015

A mathematical method for calculating the behavior of elementary particles was the introduction of Schrödinger's wave function (1926), which is based on superposition of vectors in a Hilbert space and leads to probability amplitudes for experimental outcomes. A quantum superposition of different states is never observable in the macrocosm (Omnès, 1994), thus superposition seems to be limited to the atomocosm. Nevertheless, in quantum mechanical experiments only one outcome with a precise pointer position in the macrocosm can be observed, which leads to the measurement problem signifying, that superposition in the atomocosm is reduced to only one outcome in the macrocosm. This problem was interpreted in different ways as a collapse of the wave function (Heisenberg, 1958), as decoherence (Zurek, 1981), as a spontaneous random collapse (Ghirardi *et al.,* 1985) or without collapse as multiple worlds with branches (Everett, 1956) or as multiple minds (Zeh, 1998). Conte (2010, 2011) introduced Clifford algebra for understanding the foundations of quantum mechanics. Tarlaci (2012; p.216) evoked the essential question concerning the general problem: *"What will take the system out of a superpositional state and reduce it to a permanent reality?"* and further on *"Before observation, the wave function is in a free and independent state. ... When it is observed or viewed, many possibilities condense into one."* (Tarlaci, 2012; p.221).

Some physicists hold quantum physics for real physical entities in the form of fields in space-time. Bell (1987; p.128) claimed. *"no one can understand this theory until he is willing to think of ψ as a real objective field rather than just a 'probability amplitude'. Even though it propagates not in 3-space but in 3N-space"*. Albert (2013; p. 53) concerning quantum mechanical wave functions argues, we have *"to think of them as concrete physical objects"*. Ney (2013; p.168) writes: *"familiar macroscopic objects (tables, chairs, people, mental states and so on) may be reduced to an ontology in which one of the fundamental objects is the wave function interpreted realistically."* Some wave function realists, such as Bell, Albert and Lewis, deny that it is an abstract, mathematical object. They claim that the best realist understanding of the wave function is a field with much higher than 3 or 4 dimensions. Physicists call it a 3N dimensional configuration space with 3 space coordinates for each of the *N* particles. North (2013; p.185) wrote *"I assume realism about quantum mechanics, so that the wave function directly represents or governs .... the ontology of a quantum mechanical world."* Schlosshauer (2007) describes a quantum mechanical experiment, in which silver atoms can be deviated by their spin in a Stern-Gerlach apparatus and confirming the coherent superposition state directly.

From a bio-psychological viewpoint, a different interpretation of the wave function, as a mental potentiality system (Jansen 2015), allows the characterization of the wave function problem as a prediction problem trying to get a probabilistic estimation of future experimental outcomes. Since the future can never be observed, it can, however, be imagined before the experiment with potentiality, which is a mental representation with multiple superposed possibilities, out of which only one could correspond to observable reality in the outcomes of an experiment.

2. Quantum Mechanics as Potentiality

Some physicists and philosophers considered quantum mechanics as potentiality starting with Heisenberg (1962; p.180), who classified it as potentia. *"One might perhaps call it an objective tendency or possibility, a potentia in the sense of Aristotelian philosophy. "... So the physicists have gradually become accustomed to considering the electronic orbits, etc., not as reality but rather as a kind of potentia."* Aerts (2010; p.27) writes *"A quantum particle is not an entity 'spread out in space', which it would be if it was a wave, but rather an entity only potentially present in space."* Stapp (2008; p.12): *"I shall pursue the approach of Heisenberg, according to which the physical/mathematical probability functions of orthodox quantum mechanics describe potentialities (Aristotelian potentia) for actual events, which are quantum collapses that constitute objectively real transitions of potentialities into actualities."* According to Schlosshauer (2007; p.18-19) *"Born and Pauli ... formulated their famous interpretation of quantum states as representing a probability amplitude, i.e., as specifying the probabilities of the outcomes of all possible measurements that could be performed on the system. The act of measurement was then assumed to play the fundamental role of dynamically actualizing these potential properties."*

From a bio-psychological viewpoint, it is essential to define what *potential or potentiality* could mean. It is first of all the negation of actuality, which signifies, that it is not yet observable reality in the actual present and therefore not an observable physical entity in space-time. Therefore, the non-existence of potentiality in the present indicates a dynamic process happening in the future. Thus it could only be a mental representation of a future process in the mind of an observer, who has the capacity to imagine and predict future dynamic processes with or without applied mathematics. If quantum mechanics is considered as potentiality, it can only exist as a mental representation of future physical processes, which stays in contrast to the claim of some physicists that quantum mechanics are physical reality. The imagined future behavior is unconsciously projected on the actually observable physical reality, with which it seems to fuse to include the present and the future in one inseparable unit. Nevertheless, observation of the present and prediction of the future have to be distinguished by their degree of certainty. Whereas observation has a high degree of certainty, prediction of the future always entails uncertainty, since with evolving knowledge even scientific assertions may have to change, such as Einstein's laws had to replace Newton's laws. Only after verification of regularity in the past and present, the future behavior may be considered with greater certainty.

Thus, there is coexistence of two completely different entities, the observable extra-mental physical reality in the present with certainty and the mental representation by an observer of its behavior in the future with uncertainty. However, the mental representation of the physical world can itself be considered as reality, but as an abstract intra-mental reality of an observer, which is not the same reality as extra-mental physical entities in space-time (Dorato, 2015).

3. Quantum Mechanics as Prediction with Potentiality

The interpretation of quantum mechanics as potentiality, describing the future behavior of elementary particles, can be assimilated to a prediction of the future with potentiality. This corresponds to the description of the wave function by Schlosshauer (2005; p.4): *"... the linearity of the Schrödinger equation entails that the total system SA, assumed to be represented by the Hilbert product space $H_S \otimes H_{A'}$ evolves according to*

$$\left(\sum_n c_n|s_n\rangle\right)|a_r\rangle \xrightarrow{t} \sum_n c_n|s_n\rangle|a_n\rangle. \qquad (2.1)$$

This dynamical evolution is often referred to as a pre-measurement in order to emphasize that the process described by Eq. (2.1) does not suffice to directly conclude that a measurement has actually been completed."

The designation of the wave function as a pre-measurement, which is not yet completed, has all the characteristics of the prediction of a future state, which is not yet observable and does therefore not yet exist in space-time. Therefore, it can only be mentally represented in its abstract form by an observer. Dorato (2015; p.3) defined *"... an entity x is abstract if and only if it is either not in space-time or is causally inert or both".* Thus the wave function as a prediction can only be a mental representation of a future behavior and not a description of an actual physical state, observable in the present.

In the same sense, quantum mechanics was interpreted as a prediction and not a description by Bass (1971; p.54) *".... The state ψ is a pure state of the joint system $S_1 + S_2$ that is to say, we may not assert that before the measurement the joint state is actually x_+ or $\hat{\Phi}_{--}$, but that we do not yet know which..."* and *"... However this does not complete the process of measurement because we still know only the probabilities $|\propto_+|^2$; $|\propto-|^2$ of eigenstates x_+ $\hat{\Phi}_+$; x- $\hat{\Phi}$-; ; neither of which can as yet be said to be realized: the pointer position is yet to be read"* (Bass, 1971; p. 55). Lacking knowledge and the fact that eigenstates are not yet realized also indicate that the wave function has to be interpreted as a mathematical prediction of future events and not as a description of observable ongoing events in the present. Only the observation after an experiment will reveal the final outcomes.

Any mental representation of the future requires potentiality, meaning that the mentally represented states may or may not happen. Due to this uncertainty, when estimating the future, all possible states have to be imagined for the same time point in a kind of mental superposition of multiple states, which is generally found in life and science to approach the unobservable future. An abstract mental representation of the wave function is the opposite of extra-mental reality in space-time. Nevertheless, the mental representation based on potentiality can predict possible experimental outcomes in the future with probabilities (Jansen, 2015).

4. Measurement Problem in Quantum Mechanics

Schlosshauer (2005, p.4) describes the quantum mechanical measurement problem as the problem of definite outcomes:

> *" … the right-hand side* (of equation 2.1) *is a superposition of system-apparatus states. Thus, without supplying an additional physical process (say, some collapse mechanism) or giving a suitable interpretation of such a superposition, it is not clear how to account, given the final composite state, for the definite pointer positions that are perceived as the result of an actual measurement— i.e., why do we seem to perceive the pointer to be in one position* $|a_n\rangle$ *but not in a superposition of positions?"*

The classification of the wave function as a prediction entails some consequences, valuable for all predictions in life and science, which could explain the definite outcomes. The unobservable future can only be predicted with potentiality by considering multiple possibilities for the same time point, but after realization only one will become observable at the same time. Therefore, there is a "multiple-to-one" reduction of possibilities between the prediction with potentiality for the future and the observation of reality in the present. Concerning quantum mechanics, multiple states are considered in superposition before the experiment, but there is no superposition of the pointer position of a measuring device after the experiment. This corresponds to the well-known measurement problem in quantum mechanics, but can in its generalized form also be found in classical physics.

5. Measurement Problem in Classical Physics

For static processes in classical physics, precise effects follow precise causes, for instance seeing the red of a tomato corresponds to the perception of electromagnetic waves of about 700 nm (Figure 1A). If the cause is known, the corresponding effect can be extrapolated with high, but not absolute certainty into the future, since color blind people will see the tomato in grey, although the wave length of the electromagnetic waves are the same.

The situation is different for dynamic processes, which can be regular like the moon phases or irregular like a dice. Whereas classical events are observable in space-time, their future appearance is an abstract mental representation, which is not necessarily in synchronicity with the observable real event.

5.1 Regular Behavior

The moon regularly follows at least 6 consecutive phases: New moon, waxing crescent, first quarter, full moon, last quarter, waning crescent (Figure 1B). When a person wants to predict the moon phase for the next night, before she can see it, she is obliged to consider all six phases by a mental representation of the moon in a kind of mental superposition. Although the sequence of the changes is regular, there is no indication for the moon phase of the next night, since the mental representation and the real moon phases are completely independent entities without any synchronicity. Thus the prediction of the actual moon phase requires the mental superposition of 6 phases, out of which only one will be observable during the next night, which corresponds to a "multiple-to-one" reduction, similar to the quantum mechanical measurement problem. Nevertheless, in classical physics, there is also a linkage of the moon phases to other regular events, like a calendar, which allows getting indirect information on the moon phase to be expected during the next night.

5.2 Irregular Behavior

The best representative of irregular behavior in classical physics is a dice. Nevertheless, for a high number of trials, the mean outcome of dice throws becomes predictable. The high number of outcomes compensates for the variability of individual outcomes, thereby reaching a similar percentage for each of the six possibilities. This can be expected for a completely homogeneous dice, but if it is biased with lead at one side, the outcomes will follow a Gaussian curve with the highest outcomes for the side opposite to the lead.

When only irregular outcomes can be observed in the present, any prediction of future outcomes also remains irregular. Thus for the prediction of the next toss, the mental representation of the future outcome has 6 possibilities in superposition, out of which the dice will only show one outcome in reality. The "multiple-to-one reduction" of potentialities between prediction and observable reality shows the same general prediction problem as the measurement problem in quantum mechanics (Figure 1C).

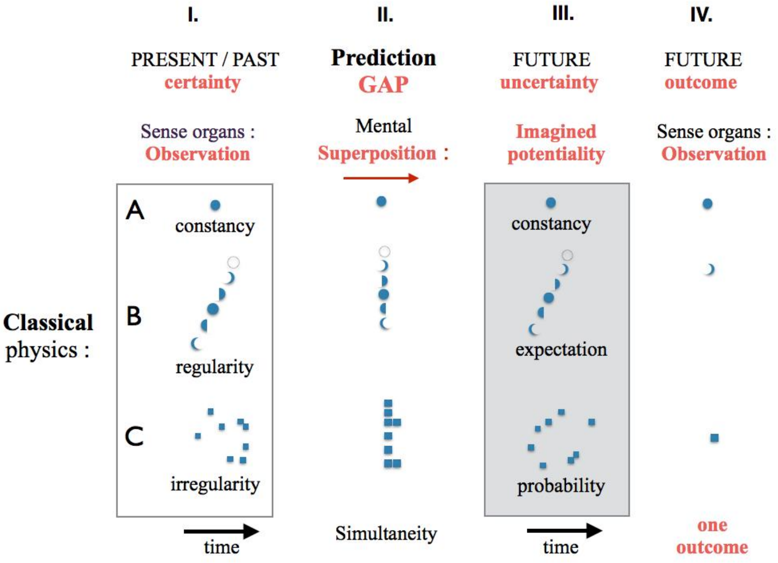


Figure 1. Mental Representation by observation and imagination. The present and past (I) can be observed with certainty, but the future only imagined with uncertainty (III). In order to overcome the gap of uncertainty, multiple past observations can be simultaneously imagined in mental superposition (II), although they might happen at different time points in an uncertain future (III). Nevertheless, verification of the predicted potentiality by new observations (IV) only leads to unique outcomes after a "multiple-to-one" reduction between imagination of potentialities (III) and observation of reality (IV).

6. Measurement Problem in Normal Life

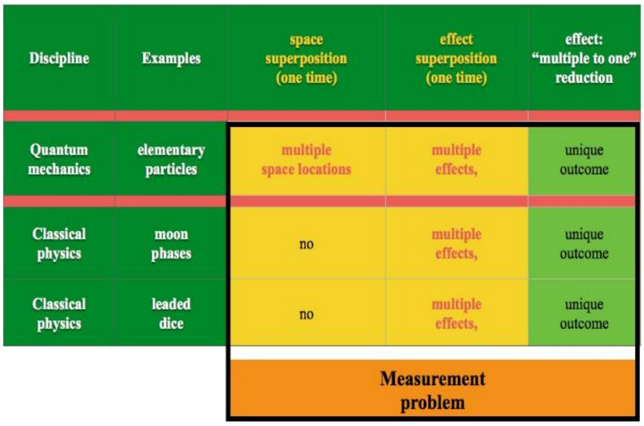
A person is aware of her Present, Past and Future. She lives in the Present, has knowledge on her Past through encoded events in memory and imagines her Future by projecting rearranged past experiences into the future (Jansen, 2014). The present is directly observable with all sense organs, whereas the past is no longer observable and no longer allows direct contact with sense organs, nevertheless, it can be imagined with the help of experiences retrieved from memory. Although the future remains unobservable, it can be imagined by re-arranging past experiences from memory according to expectation in the future.

An unobservable future can, nevertheless, be imagined with potentiality, which remains uncertain until it is realized. However, uncertainty obliges the consideration of multiple possibilities, which corresponds to a superposition of multiple potentialities. It is evident that only one of the superposed possibilities could be realized at the same future time point. Thus any imagined prediction requires superposition of potentialities and thereafter a "multiple-to-one" reduction, when imagined representation of potentialities is confronted to the observable event in reality. A person can superpose different actions for the next morning depending on the weather conditions, for instance with fine weather a walk, with windy weather wind surfing, with cold weather skiing and with very bad weather reading a book. The weather conditions are the trigger mechanism for the following decision. Nevertheless, all imagined actions and the corresponding weather conditions are in a kind of mental superposition before the real weather on the next morning becomes observable (Jansen, 2008).

This situation corresponds to the general conditions of the measurement problem and becomes obvious in Schrödinger's wave function with superposition, although it leads to one definite outcome. Nevertheless, when changing from imagination of the future to observation of the present, the reduction of multiple potentialities to one observable outcome is a phenomenon generally accepted in life and science.

7. Difference between Quantum Mechanical and Classical Superposition

If quantum mechanical formalism is considered as the mathematical concretization of a human mental process and if it represents a prediction of future outcomes of experiments, it has to undergo the same "multiple-to-one" reduction of future potentialities to only one observable outcome. This aspect of quantum mechanical superposition is identical to the classical superposition, but there is an important diverging aspect. In the atomocosm only effects are observable, whereas their causes are non-localizable in space, due to Heisenberg's uncertainty principle. An electron cannot simultaneously be examined for its location and momentum, which renders the cause of an observable effect non-localizable. This stands in contrast to classical physics, where effects are variable, but their causes are in general localizable in space, like for the moon phases or the outcomes of a leaded dice. Thus quantum mechanical formalism had to be adapted by considering a double superposition of variable effects and unknown localizations, which corresponds to non-locality.



Discipline	Examples	space superposition (one time)	effect superposition (one time)	effect: "multiple to one" reduction
Quantum mechanics	elementary particles	multiple space locations	multiple effects,	unique outcome
Classical physics	moon phases	no	multiple effects,	unique outcome
Classical physics	leaded dice	no	multiple effects,	unique outcome
		Measurement problem		

Table 1. Mental and Quantum Mechanical Superposition. In quantum mechanics, causes are non-localizable and effects are varied. Thus multiple potentialities of space and multiple potentialities of effects are superposed for the same time. Nevertheless, verification by observation only leads to unique outcomes. In classical physics, all causes are localizable and need no superposition, only the variety of effects have to be superposed as well for regular dynamics like the moon phases or for irregular dynamics like a leaded dice. The "multiple-to-one" reduction is characteristic of the measurement problem in quantum mechanics as well as in classical physics.

Schrödinger's wave function takes account of non-locality in the atomocosm by the infinity of superposition of the wave function to approach the unknown three-dimensional space. Thereby non-locality is imposed by the mathematical formalism and all experimental outcomes treated by the wave function remain necessarily non-local. The introduction of hidden variables in the wave function, trying to reintroduce locality again, are inadequate to the basic non-local construction of the Schrödinger equation.

8. Conclusion

The measurement problem in quantum physics, known for almost a century, has found many interpretations by theoretical physicists and philosophers of science, which did not yet lead to a general agreement. The interpretations could be classified in two categories, those interpreted as potentiality starting with Heisenberg (1962) and those claiming physical reality, as a kind of field theory. Reality and potentiality are completely opposite interpretations for quantum mechanics, the first concerns extra-mental physical reality in space-time and the second the intra-mental representation of physical reality with abstract concepts, like mathematical formalism. Whereas extra-mental physical reality is observable, directly or indirectly with instruments, intra-mental reality remains abstract and unobservable.

Potentiality is part of the intra-mental representation of physical reality, which is the opposite of actuality, since it cannot be observed in the present, but predicts a yet unobservable future. Therefore, it is not yet existent in physical space-time in the present and can only be mentally imagined for the future with abstract concepts, like applied mathematics (Dorato, 2015). Thus there is coexistence of an observable object in extra-mental reality and the intra-mental representation by an observer of its potential behavior in the future, which seems to form a unit. Nevertheless, both remain separate entities, since observation of reality is much more certain than the prediction of an unknown future behavior.

Since the future is unobservable, any prediction with potentiality remains uncertain, if it will or will not be realized (Jansen, 2011). Schlosshauer (2005) characterized the wave function as "pre-measurement" and Bass (1971) wrote that it cannot "be said to be realized". Thus superposition corresponds to a prediction of the future with multiple potential outcomes. When quantum mechanics is interpreted as potentiality, it is subject to uncertainty of all predictions, which are mental representations of the future and not descriptions of an ongoing extra-mental process in the present.

Prediction of a potential future followed by observation of real outcomes always shows the same characteristics in life and science, a "multiple-to-one" reduction of potentialities to only one observable outcome. This corresponds to the "measurement problem" found in quantum mechanics based on linear superposition of multiple states. However, the "multiple-to-one" reduction can also be found in classical physics for a prediction of regular events, like the moon phases, or of irregular effects with a leaded dice and in humans for the prediction of future actions, which depend on yet unknown conditions.

Although quantum mechanics has the characteristics of the general prediction problem, it also shows important differences. In classical physics, all causes and their effects are localizable in space-time, whereas in quantum physics only the effects can be localized. Non-localizable causes require wave function formalism adapted to non-locality. Thus, a distinction has to be made between classical and quantum mechanical superposition depending on the possible or impossible localization of causes.

If quantum mechanics can be interpreted as prediction with potentiality of future experimental outcomes and not as a description of an ongoing physical process, it would resemble the general prediction problem in life and science. In life the "multiple-to-one" reduction from imaginable potentiality to observable reality is found to be normal, whereas in quantum mechanics the same reduction is judged as weird, although it should also be considered as a normal process.

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