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Revisiting Quantum Mechanical Weirdness From a Bio-psychological Perspective

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Quantum mechanics has some weird aspects, which we simply have to accept, according to Tegmark. However, approaching this issue from a bio-psychological perspective allows for an alternative interpretation that avoids this supposedly inherent weirdness. Physical laws are established based on repeated observations or measurements, which involve sense organs. Our capacity for memorization and abstract reflection allows us to draw conclusions on physical reality, which can thus be represented with mathematical formalism. Therefore, physical laws are dependent on pure bio-psychological functions. If quantum mechanics is seen in the bio-psychological context, normal mental functions might explain phenomena such as the collapse of the wave function. If events of interest occurred regularly, similar to classical physics, the same pattern of regular events would be anticipated in the future. Conversely, if events that occurred in the past were irregular, like in quantum mechanics, they would also evolve in an irregular manner in the future. Prediction of irregular behavior requires the ability to imagine multiple possibilities in a kind of mental superposition. Only when one of the imagined possibilities is realized, the mental superposition of the future will collapse to one observable behavior occurring in the present. However, in mental representation, similar to classical physical formalism, some aspects of reality can be lost. When time and space coordinates are replaced by calculated time intervals and spatial distances, time periods and spatial lengths become independent of their initial reference frames. Consequently, the concepts of past, present, and future become irrelevant for time intervals. In quantum mechanics, as well as in mental imagination of potentiality, the notions of the unity of one space for one time and the time arrow are also eliminated. This analogy suggests that physical formalism does not correspond to independent physical reality, but rather to mental functions, which allow establishing a mathematical model of extra-mental reality. If quantum mechanics is conceived as mental potentiality for modeling physical reality, the weird aspect of the collapse of superposition disappears and becomes a simple transition from imagined potentiality in mental representation to observed reality, which could explain the measurement problem.

Keywords: quantum mechanics, wave function, superposition, measurement problem, weirdness, observation, reality, potentiality

1. Introduction

The problems encountered by the founders of quantum mechanics differed from those classical physics aims to address. To address these issues, Heisenberg (1927) introduced the uncertainty principle, according to

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which, at the scale of elementary particles, location and velocity cannot simultaneously be determined with precision. Schrödinger (1926) described the wave function that incorporates all information about a particular phenomenon, which is linear superposition. Thus, it predicts quantum mechanical outcomes based on probability estimations. According to the Copenhagen interpretation, superposition in the wave function has to collapse or irreversibly reduce to the state that is captured by the measurement instruments. Everett (1957) put forth another interpretation that does not require a collapse of the wave function, but rather indicates that superposition signifies multiple parallel entities that simultaneously exist as multi-worlds. The quantum mechanical formalism was also successfully applied in psychology in the context of decision theory (Aerts et al. 2011; Busemeyer & Bruza 2011).

Some aspects of quantum mechanics do not have correspondence with phenomena studied by classical physics. For example, Heisenberg's (1927) uncertainty principle and Schrödinger's (1926) superposition in the wave function with the collapse to a single eigenstate that is instantiated during measurement imply that it is impossible to capture the true essence of any phenomenon. Tegmark (2014, 227) referred to these assertions as quantum mechanical weirdness, by arguing that "even more accurate experiments have ruled out many attempts to explain away the quantum weirdness." He further noted (228), "I feel that the experimental verdict is in: the world is weird, and we just have to learn to live with it."

2. General Remarks on Physical Experiments

In interpreting the laws of quantum mechanics, physicists generally strive to apply the established physical formalism to everyday phenomena. Since the structure of the formalism like superposition is necessary for predicting experimental outcomes, it should reflect the structure of nature itself. This is an ontological interpretation of quantum mechanics based on general indeterminism, which inevitably introduces some weird aspects, such as the extrapolation of indeterminism to the entire universe and the collapse of superposition to a single state as a result of measurement.

A different interpretation can be obtained by observing experimental outcomes (Table 1). In classical physics, identical experiments are expected to yield the same outcomes (to the extent that measuring apparatus and other extraneous factors allow). Consequently, the mathematical formalism ascribed to the experimentally observed phenomena can be extrapolated to predict all future outcomes of identical experiments, neglecting small manipulation variations and inherent device limitations. In contrast, in quantum mechanics, when experiments are repeatedly performed under identical conditions, the results will vary considerably. Consequently, no assumption about the future outcomes can be made. Instead, individual future outcomes are conceived as a range of possibilities assembled in a global representation. This is mathematically represented by superposition in a Hilbert space. However, one experiment necessarily leads to only one outcome with respect to the global representation of multiple possibilities for the future. In quantum mechanics, this is interpreted as a collapse of superposition of all predicted possibilities during measurement. The same collapse is also encountered in daily life, when multiple future actions are imagined, but only one of those can be realized.

From a bio-psychological perspective, the aim of classical formalism as well as quantum mechanics is to understand the laws governing prior experiments, allowing prediction of future experimental outcomes. However, as future does not yet exist, it cannot be considered observable reality. This proves that physical formalisms do not describe ontological physical reality, which cannot be captured with sense organs (Omnes

1994). Nevertheless, mathematical formalisms employed to describe physical phenomena can be interpreted as a mental representation of a potential future (Jansen 2015). In a mental representation of everyday life, regular events that took place in the past are expected to occur in the same regular manner in the future, while those characterized by irregularities are expected to exhibit similar irregularities in the future.

2.1. Observation Categories

Observations of outcomes yielded by physical experiments can be classified in three categories. Observation Category I (Table 1) pertains to classical physics, such as Galilee's inclined plane, where regular experimental outcomes in the past justify the use of the corresponding physical formalism for the prediction of future outcomes. Galilee observed that physical experiments could be represented well by mathematical formalism, which yields identical results whenever applied. Conversely, physical experiments inevitably produce slight variations due to manipulation or device errors that cannot be avoided. Therefore, physical formalism appears to better represent physical laws than experimental outcomes, in which inherent uncertainties introduce unavoidable measurement differences.

Observation Category II pertains to statistical observations affected by multiple individuals, such as cyclists of a race, which inevitably lead to multiple different performances. Thus, classical statistical evaluations are adopted to describe the range of outcomes as a distribution characterized by a mean and standard deviation. The concepts of distribution mean and standard deviation are artificial mathematical conventions that allow simplified evaluation and comparison. Clearly, natural phenomena cannot be simplified to means and standard deviations.

Table 1
Observation Categories

	OBSERVATION		REFLECTION
Categories	**Entity**	**Outcome**	**Formalism**
I **Unique regular**	1	1	classical physics
II **Multiple multiple**	multiple	multiple	classical statistics
III **Unique irregular**	1	multiple	quantum mechanics

Three categories of observation lead to different experimental outcomes, ranging from one unique object with only one outcome or multiple varying outcomes under identical experimental conditions, to multiple objects with multiple outcomes, which require appropriate physical formalism.

Observation Category III concerns behavior of a unique entity, like an electron, that would produce multiple outcomes under identical experimental conditions, as described by Heisenberg's uncertainty principle. Consequently, prediction of its future behavior requires superposition of multiple physical states in a Hilbert space. Quantum mechanical superposition comprises of all possible outcomes in the future, only one of which is realized as a result of the measurement process. If an experiment is performed, the collapse of superposition would lead to only one of all predicted possibilities. According to this view, the collapse merely reduces the perspective from a global one, incorporating all possibilities in the future, to one individual outcome realized in the present, which was already included in the global prediction of future outcomes.

The liability and the capacity of mathematics for exploring slightest differences in the behavior of physical objects may have given the impression to physicists that mathematics is the only way of understanding physics. Max Tegmark (2014, 6) opined "that our world not only is described by mathematics, but that it is mathematics, making us self-aware parts of a giant mathematical object." As a mathematician, Stewart (2017, 129) challenged this view, stating, "There is strong consensus that mathematics isn't reality, it just resembles reality in a useful way."

2.2. Ontological and Epistemic Interpretations

Under the assumption that mathematics is the best representation of physics, some physicists proposed an ontological interpretation of quantum mechanics, implying that the mathematical structure of the formalism based on superposition of an infinite number of potential outcomes reflects physical reality (Albert, 2013; Ney 2016). Von Neumann (1932) defined the concept of indeterminism as an inherent property of elementary particles and extrapolated the wave function from the atomocosm to the macrocosm and to the entire universe, which is supposed to be in physical superposition. This is usually seen as a weird aspect of an ontological interpretation, since it does not conform to observations in the macrocosm. Another weird problem concerns superposition, which necessarily collapses to only one outcome during measurement. At present, numerous physical interpretations of this problem exist, none of which have gained wide acceptance in the scientific community (Cabello 2016).

In contrast, Heisenberg (1927) proposed an epistemic interpretation for explaining the uncertainty principle of quantum mechanics. According to his famous microscope thought experiment, as high-energy photons are capable of displacing electrons, when making observations, the experimenter inevitably affects the electron properties. Therefore, their location and velocity cannot be simultaneously determined with precision. According to this perspective, elementary particles are no longer thought to be indeterminist; rather, transformative detection by a transformative observation system renders the experimental outcomes indeterminist (Jansen 2018). Since transformative detection leads to indeterminism, the real properties of elementary particles can never be captured. The epistemic interpretation avoids one of the weird aspects of quantum mechanics, since it limits transformative detection uncertainty to the atomocosm, whereas the macrocosm and the entire universe are posited to be deterministic. Still, the second weird aspect is also eliminated, since Heisenberg (1971) interpreted quantum mechanics as "potentia" in the sense put forth by Aristotle. However, potentiality can only be a mental representation of possible future realizations, as it never corresponds to actual reality (Jansen 2015).

3. Bio-psychological Perspective on Physical Experiments

From a bio-psychological perspective, physical events are first observed with sense organs and then interpreted by cognition, which leads to physical formalism and culminates in the construction of physical laws. Thus, human observer has a central role in the elaboration of physical laws and his/her mental functions have to be considered, since they may have left some traces in the final concept of physical laws. This aspect is presently insufficiently considered.

Observation involves senses and mental functions that allow interpretation of what is being observed. However, it is important to distinguish between observable reality and mental potentiality, as only the former requires sense organs, thereby creating a great gap between the two. Observation requires the mental function of *elementary sensation* with sense organs, whereas mental reorganization of past events allows the future to be envisaged as potentiality. This necessitates capacity for *abstract reflection*, but does not involve active sense organs. Both *elementary sensation* and *abstract reflection* require *memory imagery* and imagination, whereby the former allows for the storage of observations and the latter assists in their further reorganization. When mathematical formalism is compared to mental functions, the apparent weirdness of quantum mechanics might disappear. The transition from mental potentiality predicting multiple future possibilities to a specific observation in the present clearly induces a collapse of superposition to a single outcome (Jansen 2008). This suggests an astonishing isomorphism between mental functions and the wave function, which may help in better understanding the quantum mechanical weirdness.

Observation via the mental function of *elementary sensation* requires an uninterrupted physical chain of interactions from extra-mental reality through sense organs to specialized locations in the brain (Jansen 2016). *Memory imagery* is simultaneously formed, as these observations are stored in one’s mind. Recalling past events does not require active sense organs, and thereby interrupts the physical chain of interactions with the extra-mental reality. Finally, *abstract reflection* permits reorganization of past events for a better understanding and prediction of potential future events. Observation by elementary sensation with active sensory organs reflects the immediate present, whereas memory imagery and abstract reflection are only based on memorized past events (Table 2). Therefore, relying solely on past events to predict the future is inherently flawed. If past events exhibit a high degree of regularity, as in classical physics, their future occurrences can be predicted with relative certainty. However, if past events are characterized by a high level of irregularity, like in quantum mechanics, their future occurrences will also be highly irregular and can only be subjected to probability estimations. Uncertain future events in daily life can be likened to mental superposition of all possible events. Different activities can be planned for the next day, which will remain in superposition until tomorrow arrives and only one of these plans is realized. Depending on the circumstances, only one activity can take place, leading to a collapse of the mental superposition of all possibilities. In the same vein, in quantum mechanics, linear mathematical superposition of all future possibilities is created in a Hilbert space, collapsing to one realization in the present as a result of the measurement process. This can be illustrated with the famous Wigner’s friend thought experiment (Wigner 1961).

Table 2

Mental Representation of Reality or Potentiality

Mental representation		**Mental functions**	**Tense**	**Assurance**
Reality	**observable**	**Observation** (with sense organs)	**Present**	**Certainty**
	memorized	Observation (retrieved from memory)	Past	Certainty
	extrapolated	Cognitive Evaluation (from regular past observations)	Future	Confidence
Potentiality	imagined	Cognitive Evaluation (from irregular past observations)	Timelessness	Probability

Mental functions determine the tense. The present requires active sense organs, the past memory imagery without active sense organs, and the future reorganization of past events, also without sense organs. Observation in the present leads to certainty, which can also be ascribed to past events, as their outcomes are already known. Extrapolation of regular past events to the future allows confidence, whereas predicting future based on irregular past events requires potentiality with probability estimation.

4. Wigner's Thought Experiment

Wigner considered human consciousness as an essential factor for the collapse of superposition in the wave function. In his Wigner's friend thought experiment, the friend performed a quantum mechanical experiment while Wigner was absent from the lab. Prior to the experiment, the friend could predict the probable future outcomes with the help of the wave function superposition. Once the experiment was complete, he would observe only one of these potential outcomes, thus resulting in the famous collapse of the wave function.

As Wigner was not present during the experiment, he had no knowledge of its outcome. Consequently, he had to rely on his mental representation to calculate all possible outcomes, corresponding to the superposition in the wave function. In other words, he performed the mental function of abstract reflection to estimate all potential future outcomes. The actual result of the experiment his friend performed could only be known to Wigner once he was back in the lab and could observe with his mental function of elementary sensation the experimental results. Therefore, in Wigner's consciousness, the collapse of the wave function occurred at a much later time point than it did for his friend. This distinction in perspectives shows that Wigner's prediction with superposition of potentialities was not observable reality, but a mental representation in consciousness, since a physical collapse would have taken place at the precise moment at which his friend conducted the measurement. Wigner's collapse only occurred in his mind when he actually observed the outcome. This thought experiment indicates that the wave function should be viewed as a mental representation of potentiality, which estimates with probability what could happen in the future.

Bass (1975, 55) concurred with Wigner, stating that mental representation in consciousness is required for the expected collapse of superposition during the measurement. He observed, “we still know only the probabilities ... neither of which can as yet be said to be realized: the pointer position is yet to be read.” According to this interpretation, only conscious observation of the pointer position of a device reveals the final result of an individual experiment.

5. Space and Time in Mental Representation and Physical Formalism

In Galilee’s experiments (Straulino 2008) involving a bronze ball traveling along an inclined plane, different path lengths corresponded to different time intervals and allowed the establishment of their mathematical relations. In this calculation, clock time with the start and end points was replaced by time intervals and the path length by path length differences. This is a mental transformation of the initially observed parameters. Time periods and path lengths can now be independently used in arbitrary time and space frames and have lost their relation to the past, present, and future represented by the initial calendar time. Therefore, in mathematical formalism describing classical physics, tense cannot be taken into account. A similar abstraction occurs in mental representations in everyday life. For instance, one easily retains an estimated time period and the distance of a recent car trip, which can then be projected on other possible trips.

5.1. Time

When Wigner’s friend performed classical physical experiments, he observed regular time periods during repetitions, which encouraged extrapolation of the observed phenomena to the future for the constitution of a physical law. Since, in reality, the future is not yet existent, the extrapolation of a law used to describe it can only be a mental representation of a potential future, obtained with the mental function of abstract reflection.

Wigner’s friend could also perform a classical experiment in his present, which once realized became a past experiment he could store in his memory. Wigner, who was absent from the lab during experimentation, had no knowledge of his friend’s experiment. Thus, he had no means of knowing whether any measurement was performed. In his mental representation, he could not know if the experiment was completed or was still ongoing, and could thus not assign it to his own present, past, or future. A calculated time interval related to the experiment is already an abstraction from reality, since any link to a common reference like calendar time is eliminated. Only the common calendar time would determine, if Wigner’s present when he thinks on the experiment corresponds to the past, present, or future of his friend’s experiment. A calculated time interval without any relation to a common reference in physics, as well as in daily life, explains why past, present, and future must be eliminated even from classical physical formalism. Einstein (Davies 1984, 128) expressed this supposition in the following way: “subjective time with its emphasis on the now has no objective meaning.” He also wrote in a letter to Besso (Holt 1999, 5), “The distinction between past, presence and future is only an illusion, however persistent.”

In quantum mechanics, according to some physicists, tense as well as the notion of time, should be completely eliminated (Rovelli 2009; Barbour 2009). For example, Zeh (2000, 2) stated, “As we have known since Heisenberg’s discovery, there are no paths in the quantum mechanical theory (therefore, in principle, no time-dependent pointer positions on clocks exist)” (translation by the author). Nevertheless, other authors, like Smolin (2013), still insist on the necessity of time in physics.

5.2. Space

An observed space can be defined using coordinates in a reference frame, thus permitting the distinction between *here* and *there*. When Wigner, while away from his lab, imagined his friend's location, according to his spatial reference system, he was *here*, and could only have a mental representation of his friend's location, which would be designated as *there*. Sense organs have limited access to space and only allow one space location to be related to one time point. During observations, spatial distances can be measured with respect to an observable reference frame. In mental representation, on the other hand, the reference frame can be arbitrarily changed, thus allowing—via abstract reflection—superposition of Wigner's actual *here* and his friend's *there* simply by switching from one to the other, almost instantaneously. Consequently, in mental representation, the unity of one space for one time point (a requirement for reality) can be lost.

In quantum mechanical formalism, the unity of one observable space for one time point is completely eliminated in the wave function by linear superposition of multiple locations for the same time point, thereby resembling Wigner's mental representation. The wave function allows a mathematical superposition of a particular *here* with multiple *there* spatial locations, which is interpreted as non-locality in the formalism. In Wigner's mental representation, he could also superpose near and remote spatial locations when he instantly changed from his *here* to the location of a scientific robot he knew was at that moment on Mars. A change over this distance would exceed the speed of light and correspond to Einstein's spooky action at distance. As claimed by Bell (1987), quantum mechanical formalism is structurally non-local, which means that it resembles the simultaneous mental representation of a *here* with a very distant *there*. Following the claim Einstein made at the Solvay conference 1927 (Fine 1996), quantum mechanics is incomplete and is thus insufficient for representing observable reality. Nevertheless, according to Heisenberg (1971), it can represent Aristotle's potentia or mental potentiality.

6. Mathematics/Reality Correspondence

Imagination, akin to physical formalism, dispenses with some aspects of time, as it does not require time coordinates, and thus loses the relationship among past, present, and future. Nevertheless, mathematically established time relations are expected to predict outcomes of future experiments. Therefore, abstract physical formalism has to correspond to concrete parameters observable in physical reality, since any new experiment performed in reality is again subjected to time coordinates in local time scales. Thus, each experiment would be conducted in a new present, moving to the past the moment it is completed. In the equations describing phenomena in classical physics, correspondence is inevitably achieved, as individual time coordinates are provided for individual experimental outcomes.

The situation is markedly different for quantum physics, as it postulates existence of multiple realities that are in a mathematical linear superposition. In order to account for the uncertainty principle, in the physical formalism, several potential physical states are considered to coexist simultaneously by superposition for the same time point. As a result, quantum mechanical superposition no longer corresponds to a specific outcome for a specific time point. After linear superposition, the mathematics-reality correspondence is not guaranteed. Quantum mechanical formalism even allows superposition of contradictory states for the same time interval, such as the living and dead cat in Schrödinger's thought experiment, where the mathematics-reality correspondence is completely lost. This argument gives further credence to the earlier assertion that quantum mechanics cannot be used to describe physical reality, since philosophical considerations restrict the concept of reality to non-contradiction for the same time point, as claimed by Aristotle (Gottlieb 2011, 2): “It is impossible to hold (suppose) the same thing to be and not to be.”

Nevertheless, quantum mechanical superposition resembles mental superposition in the form of potentiality, since contrasting events can be simultaneously imagined, whereby they are in a kind of superposition in the mental representation of possible future events (Jansen 2008; 2011). In this sense, Schrödinger’s cat thought experiment involving superposition of a living and a dead cat for the same time point can only be considered as potentiality in mental superposition.

7. Reality Versus Potentiality in Physics

The concept of reality does not have one unifying meaning. Hence, in order to avoid any misinterpretation, the meaning of the word “reality” has to be defined precisely. The following interpretations could be used:

- Reality could correspond only to physical factors. Mental phenomena then become illusions of the brain.
- Reality can mean true (in opposition to false). Since geocentrism with the sun orbiting around the earth is false, heliocentrism is true and therefore captures the reality.
- The ultimate reality of the universe can be considered by mathematical equations, as proposed by Tegmark (2014).
- Reality can also define the extra-mental world perceptible with all human sense organs, whereas its mental representation without active sense organs is potentiality for biopsychology.

In Oxford Dictionary, reality is defined as follows: “The state of things as they actually exist, as opposed to an idealistic or notional idea of them.” Reality as the state of things actually existing referenced in the aforementioned definition corresponds to observation with sense organs, whereas the idealistic or notional idea of reality is a mental concept pertaining to imagined potentiality based on suggestion, estimation, or theory.

In the same sense, reality is defined from a bio-psychological perspective as the opposite of potentiality, which only represents an existing or not yet existing potential world. Reality can be completely divergent from its mental representation, akin to Popper’s theory on scientific laws. Scientific laws are provisionally considered as the best available theories until they are falsified or replaced by better theories. Therefore, physical laws are not conclusively verifiable, but rather conclusively falsifiable (Thornton 2013).

There is a great gap between reality of the observable extra-mental world and its mental representation. A false mental representation can lead to a reality shock, for instance, when a stair step below our height level is not visualized by our mental representation and one hits it with the head. This reality-potentiality gap experienced in everyday life is a fundamental demarcation line between reality and potentiality. Reality and potentiality have distinct characteristics. Reality is observable by elementary sensation and is consequently limited to the present (Jansen 2016). Memorized imagery is related to past events, whereas abstract reflection allows past events to be interpreted and reorganized for the prediction of the yet unknown future. Since the latter can be different from observable reality, they are considered forms of potentiality.

Classical physics based on regular past outcomes can be described by physical laws with certainty, which can be applied to both past and the future, such as the duration of Earth’s revolution or the timing of ocean tides. In quantum mechanics, superposition of multiple space locations for the same time point is logically excluded in reality by Aristotle’s law of non-contradiction. Before the election of a president, one could imagine multiple candidates in mental superposition taking office in the future. However, after election results are announced, the superposition collapses, since only one individual can take on the role of the president at any one time. The superposition in the wave function of contradictory events for the same time point, exemplified by Schrödinger's living and dead cat, further supports the argument that quantum mechanics cannot be applied to physical reality, but can only represent mental potentiality. With the interpretation of potentiality, the wave function can be considered as a mental model for predicting future outcomes in extra-mental reality, with each of the conceived outcomes having certain probability of occurrence.

8. Conclusion

Feynman (1999, 186) wrote: "... trees are made of air, primarily. When they are burned, they go back to air, and in the flaming heat is released the flaming heat of the sun which was bound in to convert the air into tree, and in the ash is the small remnant of the part which did not come from air that came from the solid earth, instead."

Should the objective reality of a tree be thought of as merely a system comprising of air and flaming heat that leaves behind residual ashes once burned? These constituents do not represent the complex physicochemical constitution required for a living tree. The decomposition to air and ashes is merely a reduction of a complex reality to a much simpler reality, as it represents only the elements of a much more complex entity. Thus, the reality of a living tree is only partially represented by its components.

Physical formalism and reality have a similar relationship. Physical formalism is an abstract reduction of reality to the basic laws of physics, which only partially represent the full complexity of reality. In classical physics, the reduction is limited for instance to the loss of tense, whereas in quantum mechanics, the reduction is much more important, as it results in breaking the link between time and space, and the loss of the time arrow, and necessitates replacing space with non-locality. Therefore, the failure to capture the whole complexity of reality creates some weird aspects.

Observation seems to yield certainty, but its interpretation is only potential and may or may not be true. Physical formalism can be extrapolated to both distant past and the future, such as the Big Bang or the Big Crunch, whereby the uncertainty increases with the distance from the present. The observable duration of the Earth's revolution is highly certain, but cannot be extrapolated to the beginning of the Earth about 4.5 billion years ago. Classical physical formalism exhibits a greater mathematics-reality correspondence than quantum mechanics. Category I observations of regular past can be used to make more reliable predictions in classical physics, whereas Category III observations of irregular past render all outcomes based on the past events probabilistic, as in quantum mechanics.

Von Neumann's (1955) ontic interpretation of quantum mechanics with inherent indeterminism of elementary particles was extrapolated to the entire universe. This has led to the weird conclusion that even the macrocosm has to be indeterminist, which does not correspond to human perception. In contrast, Heisenberg's epistemic interpretation that transformative detection systems are the cause of indeterminism limits indeterminism to the atomocosm under the Heisenberg cut, and thus eliminates the weird aspect that arises under von Neumann's interpretation (Jansen 2018). However, his proposition has been abandoned by many physicists, according to Zeh (2013, 97), "Heisenberg's early attempts to understand his uncertainty principle simply as a consequence of unavoidable perturbations of the electron during measurements ... failed as a consistent explanation."

If quantum mechanical formalism can be accepted as a mental representation model of extra-mental reality, biopsychology could explain the proposed collapse of the wave function to a singular outcome due to a shift between mental functions. Abstract reflection and memory imagery, which do not require sense organs, produce a mental representation of potentiality, which may or may not correspond to physical reality. In mathematics, this concept is expressed by superposition of multiple possibilities in a Hilbert space. However, observation with elementary sensation is dependent on active sense organs that interact with extra-mental reality. The change from mental representation of potentiality to observable reality therefore collapses the mental superposition of future possibilities to only one realized outcome in the present.

In biopsychology, reality and potentiality are opposite concepts, whereas in physics potentiality can also be considered as reality. Hence, in order to avoid confusion, potentiality has to be precisely defined. Potentiality can be explained by taking a seed as an example, which may or may never develop into a plant, since its germination and subsequent plant growth depend on a wide range of extraneous factors, such as availability of water, nutrients, and sunlight. Consequently, potentiality is a mental representation of a possible future, rather than an observable reality.

The quantum mechanical formalism can be used in other fields beyond physics, such as psychology for decision making (Aerts et al. 2011; Busemeyer & Bruza 2011) or in biology for photosynthesis (O'Reilly & Olaya-Castro 2014). In essence, it can be adopted as a general mathematical model for describing irregular observations in the past. Classical statistics are a different example of a mental mathematical model, which simplifies natural phenomena by presenting them as distributions with means and standard deviations although nature does not need means or confidence levels. In the same sense, the wave function might be interpreted as a mental representation model based on mathematical formalism with superposition, which is necessary for calculating probabilities of uncertain physical states and allowing predictions of nature's behaviors based on these probability estimations. If quantum mechanics are no longer considered as physical reality but as mental potentiality, its weird aspects disappear.

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