A Realist View of the Quantum World

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Abstract

A realist view of the quantum world is given along the lines of Werner Heisenberg's Copenhagen interpretation of quantum mechanics and set in contrast to that associated with John von Neumann by Henry Stapp. This view is distinguished by, among other elements: i) the notion of quantum potentia and its actualization which results in classical recorded values of measured quantities, ii) the grounding of the existence and chancy character of individual measurement events in the plenitude principle as applied to the set of eigenvalues of observables on the space of quantum states, and iii) the identification of the individuals of the theory by a straightforward individuation principle.

Henry Stapp, in honor of whom this paper is contributed, has advocated a view of the quantum world [1] taking its lead from John von Neumann's treatment of measurement [2]. Both this view and a different one developed along the lines offered by Werner Heisenberg, which I advocate, are discussed here. In addition to Heisenberg's actualization of potentia, my view includes principles grounding the individuation of quantum objects and the chancy nature of outcomes of measurements on them.

Stapp views the quantum world as fundamentally "psycho-physical" ([1], p. 10) as a consequence of a specific, de facto "choice of placement" by von Neumann of the moveable *Schnitt* (cut) introduced by Heisenberg that, for the purposes of prediction, analyzes the world via two different sorts of system: a classically describable measuring one lying at a scale "above" *Schnitt* that is directly experienceable, and a necessarily quantum-mechanically described measured one lying "below" the *Schnitt* that is indirectly experienceable [3, 4]. Stapp argues that the quantum world is psycho-physical because "a person's immaterial conscious mind interacts with that person's material brain" upon measurement ([1], p. 7) at the *Schnitt*, considered a causal interface. I have recently argued, by contrast, for a much different view based on a strict adherence to Heisenberg's 1935 prescription for the *Schnitt* as well as his mid-1950s articulation [5] of the Copenhagen interpretation centering on the notion of actualization of quantum potentia. My view is unambiguously realist, neither depending on consciousness nor disallowing the description of objective reality. It is one that should be natural for physicists because, typically, they are both realist and aligned with the Copenhagen approach (cf. [7]) despite often heard claims that the latter is anti-realist in various respects.

For Heisenberg, the observer/measuring apparatus (not necessarily involving consciousness) lies above the *Schnitt* and can be considered to probe the quantum system lying below; the quantum system cannot be visualized but only indirectly described, via quantum states (except upon interaction, when the manifestation of their properties are classically describable). The freedom of the physicist to choose the placement of the *Schnitt* was shown by Heisenberg as due to the linearity of the Schrödinger state evolution [4], but he argued that the allowed range of placement of this cut is limited and always made *between physical systems*. "The claim...that it is indifferent at which location the cut *between the parts of the system to be treated quantum mechanically and the classical measuring devices* should be drawn, should thus be made more precise...this cut cannot be shifted arbitrarily in the direction of the atomic system. Rather, there are physical systems—and all atomic systems belong among these—that the classical concepts are unsuitable to describe, and whose behaviour can therefore be expressed correctly only in the language of wavefunctions" (emphasis mine) [4].

Nonetheless, according to Stapp, by virtue of the manner of application of his Process 1 (associated with "state collapse"), von Neumann "places" the *Schnitt* precisely "between" the brain the mind/ego of an observer, not in the physical world but "at" a boundary that he calls the mind–brain connection. He holds that, in accordance with von Neumann's assumption of the psycho-physical parallelism, a non-linear state change (the logically prior Process 1) occurs "at this interface," despite the fact that it is inexplicable by currently known scientific laws. In my view, bringing mental elements into physics is unnecessary because a minimally realist Copenhagenist approach suffices for the prediction of observable events. Moreover, supplementing such a view with Aristotelian causation during measurement, as Heisenberg does in his Copenhagen interpretation, renders his approach conceptually superior.

The concern driving the placement of the *Schnitt* is an important one, that of establishing a connection between human experience and physics, in light of the apparent difficulty in providing a deterministic physical account of measurement, the infamous quantum measurement problem. However, it arises from *the failure to place the* Schnitt *between systems in the world* as Heisenberg prescribed, i.e. before any conscious brain. If an entire chain of entities interacting in measurement X, Y,... , in the environment of the system of interest S and the measuring apparatus A, a good measurement would involve all these becoming correlated and the corresponding *fully quantum* state evolving according to the unitary, Schrödinger state evolution which dictates, upon completion of the interactions involved, the time-evolved joint state

$$|\Psi\rangle = \sum c_i |s_i\rangle |a_i\rangle |x_i\rangle |y_i\rangle \ldots \ , \tag{1}$$

a superposition where $\{s_i\}$, $\{a_i\}$, $\{x_i\}$, $\{y_i\}$, etc., are the Hilbert space eigenbases for S, A, X, Y,... possibly including a brain. Physically, when interpreted as anything but a calculational tool, this produces an unresolved logical regress in the closed system approach to finding a definite measurement outcome.

Again, however, a difficulty only arises from the unrestricted application of the quantum formalism, a problem identified and engaged by Heisenberg already in 1935 ([3]) through his *bipartite division* of the physical world via the *Schnitt*, precluding a superposition such as this, with one side considered describable classical mechanically and its complement being treated via the quantum formalism. Heisenberg restricted the placement of the *Schnitt* so as to avoid any measurement problem and noted that it can only be made *between symbols for systems lying within the physical world.* Eq. 1 does not correctly portray the world's ontological structure: Heisenberg's restriction of the placement of the *Schnitt* in the physical realm clearly precludes its placement "above" the brain. For him, any analysis of measurement treating both the entirety of the world from S up to and including the measuring apparatus and/or brains quantum mechanically already constitutes a misuse of the calculus of theory (see quote above), the primary role of which is to predict what can be observed directly. Moreover, Stapp introduces extraphysical factors. "In the quantum world the observing processes of acquiring empirical knowledge must disturb, or perhaps even bring into existence, the values that we observe... This non-materialistic action injects the mind of the observer as a causal agent into realistically interpreted orthodox quantum mechanics. It gives our minds an essentially dynamical role to play, and hence a natural and rational reason for them to exist" [1], p. 9.

It is important to note here that, on the contemporary philosophical conception of realism, *the independence of the knowable world is what realism amounts to*; Heisenberg's restriction of the location of the *Schnitt* similarly preserves the objectivity of physics. The utility of the collection of statistical correlations appearing in Eq. 1 is unchanged by the relocation of the cut (which is made for the purpose of *calculation*) and the corresponding system redesignation (and hence the referent of $|\Psi\rangle$) "upward" toward systems in the classical realm, so long as one considers two fundamentally differing sorts of system, S' and the remainder of the world A'; S' holistically subsumes any previously considered quantum system S together with anything else below the cut, and $A'(=A+W)$ is the thereby newly chosen "apparatus plus the rest of the world" (W) above the cut. Importantly, the apparatus side plays no formal role in the (by nature, statistical) quantum mechanical predictions about outcomes it subsequently displays. Heisenberg also warns that, "Of course, the introduction of the observer must not be misunderstood to imply that some kind of subjective features are to be brought into the description of Nature. The observer has rather only the function of registering decisions, i.e. processes in space and time, and it does not matter whether the observer is an apparatus or a human being... It must also be pointed out that in this respect the Copenhagen interpretation of quantum theory is in no way positivistic. For whereas positivism is based on sensual perceptions of the observer as elements of reality, the Copenhagen interpretation regards things and processes which are describable in terms of classical concepts, i.e. the actual, as the foundation of any physical interpretation" [5], p. 22, cf. e.g. [6].

Although Stapp agrees that definite measurement outcomes could occur in macroscopic measuring devices having *no* consciousness without appreciably affecting the predictions of standard quantum mechanics, he argues that: i) there is no empirical evidence for such state change events that are not associated with human consciousness, and ii) if they do take place, to be natural they must have evolved by natural selection in a way associated with the appearance of human consciousness in the history of nature [1]. However, claim

(i) is false, in the sense that there is no direct empirically evidence whatsoever for any role for consciousness in measurement, though it might appear to be the case if one were to mistake *the acquisition of knowledge of a changed state of affairs for a change in the state of affairs itself*; cf. [10]. As for claim (ii), it is purely speculative at this point. Following Heisenberg, I submit that it is solely upon the physical interaction of the quantum system with the classically describable apparatus that actualization takes place, as an individual, physically causal but non-deterministic chance event [11, 12], with the result appearing in a classical record of the outcome independently of any consciousness that might (or might not) become aware of it later. This provides an explanation of the appearance of definite outcomes and involves a physical Aristotelian casual element rather than a psycho-physical one.

Note also that whenever a Lüders measurement of a quantity is repeated on a system without its having meanwhile interacted with another portion of the world the same value is found in the registered result, satisfying Einstein's criterion for the existence of an element of physical reality [13]. How, then, are the quantum physical states related to the measurement results appearing in the classical record? The answer to this question can be found already in the first, 1930 edition of *Quantum mechanics* of Paul Dirac, who provided such connection between physical experienceable properties of the traditional, classical sort with quantum measurement outcomes [14]. "If a state ψ_r and an observable α are such that, when an observation is made of the observable with the system in this state the result is certain to be the number a, we assume this information can be expressed by the equation

$$\alpha\psi_r = a\psi_r \tag{2}$$

Conversely, when an equation of this type is given we assume it has the physical meaning that a measurement of the observable α with the system in state ψ_r will certainly give for result the number a or that the observable α has the value a for the state ψ_r, to use a classical way of speaking which is permissible in this case" ([14], p. 30), that is, the Eigenvalue–Eigenvector (EE) link. This manifestly interpretational rule provides a prescription for attributing meaning to statements about the properties of quantum systems incorporating Einstein's reality criterion [15] and allows the physicist to attribute state assignments on the basis of empirical data.

In Heisenberg's approach to the quantum formalism, the complex amplitudes $\{c_i\}$ of the state $|\psi\rangle = \sum_i |\psi_i\rangle$ of a system, when squared, provide the objective probabilities $\{p_i\}$ of its being found upon measurement to possess the possible values of the corresponding properties [17]: The measured value of a property becomes definite (actual) with probability p_r, as opposed to indefinite (potential) [5, 10, 11] upon a precise measurement providing outcome

r by the measuring apparatus in conjunction with the remainder of the world which, again, is macroscopic and classically describable (cf. [8]). Quantum probability is the "graded possibility" of the occurrence of events, cf. [18]; Heisenberg emphasized that this fits naturally with Aristotle's theory of causation: "...in modern physics the concept of possibility, that played such a decisive role in Aristotle's philosophy, has moved again into a central place" ([22], p. 298). Moreover, contrary to a widespread belief regarding Aristotle's theory of causation and explanation, no teleological ("final") cause appears in this case [11]. The associated non-deterministic change of state-vector evolution occurs precisely with the intervention of the measuring apparatus and the rest of the world as its proximate cause: There is not a lack of causation upon these events, but rather Aristotelian *chance* causation not captured by the fundamental quantum law of motion for closed systems which applies only to systems *not* being measured [10, 11].

In any well performed measurement by a properly calibrated apparatus, some member from a set of possible values must occur (according to the Plenitude principle, with the specific actual value appearing by chance from among the possible (according to the Principle of indifference), namely, those that are eigenvalues in Eq. 2 (according to the EE link) [12]. This neither requires nor refers to mentality, brains, or knowledge: "the transition from the 'possible' to the 'actual' takes place as soon as the interaction between the object and the measuring device, and thereby with the rest of the world, has come into play; it is not connected with the act of registration of the result in the mind of the observer" ([23], p. 54-55). After measurement, the once again isolated quantum system "no longer contains features connected with the observer's knowledge... it is also completely abstract ... and the representation becomes a part of the description of Nature only by being linked to the question of how real or possible experiments will result" ([5], p. 26).

The objects of the quantum ontology may be circumscribed within the Copenhagen approach via the Principle of identity of indiscernibles (PII) [18].

> *Principle of identity of indiscernibles* (PII). "If, for every property F, object x has F if and only if object y has F, then x is identical to y."

Because quantum objects have been shown to be fully described via their state vectors [19], it motivates a specific form of individuation, the *Quantum principle of individuation* (QPI) when applied in the context of the equivalence classes of quantum state vectors, the rays [20, 24, 21].

> (QPI) A system is an individual if and only if its state is entirely specifiable by a ray in the Hilbert space associated with it.

Finally, consider the relation of this objective, realist ontology to the experimenter's knowledge, in particular, in actualization: "it does not matter whether the observer is an apparatus or a human being; but *the registration, i.e. the transition from the possible to the actual*, is absolutely necessary here, and cannot be omitted from the interpretation of the quantum theory" ([23], p. 137; my emphasis). Upon attending to the registered result, any conscious observer only learns that "a certain one among the various possibilities *has* proved to be the real one" (my emphasis) [5, 10]. Although knowledge plays a role in quantum mechanics in assigning the state of the individual system on the basis of empirical data, physical reality itself is objective. "The criticism of the Copenhagen interpretation of quantum theory reflects an anxiety that, with this interpretation, the concept of "objective reality" which forms the basis of classical physics might be driven out of physics. As we have shown here, this anxiety is groundless, since the 'actual' plays the same decisive part in quantum theory as it does in classical physics" [5]. Moreover, this interpretation has proven highly valuable to the advancement of physics [25].

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