Physical Measurement Theories

As we have seen, none of the interpretations of quantum mechanics in the literature provide a resolution to the measurement problem as we define it. At this point, we will consider physical theories that attempt to resolve the measurement problem. Physical theories provide criteria that address the requirements R1.1-R1.4 in the case of a Category 1 theory or R2.1-R2.3 in the case of a Category 2 theory. Each theory will be described, classified as either Category 1 or 2 and will be evaluated in terms of how well it currently meets the respective requirements that have been set forth to resolve the measurement problem.

Physical theories can also be categorized as to whether or not a measurement device can only detect certain stimuli that are above a single quantum threshold. If the theory predicts that a measurement can only reliably occur after a given threshold is reached that is above a single quantum, then such a theory is called a *threshold measurement theory*.

Consciousness

Many of the pioneers of quantum mechanics believed that consciousness and/or free will are related to quantum mechanics, among them Bohr, Heisenberg, von Neumann, Renninger, Wigner, London, and Bauer. A number of contemporary physicists continue this line of inquiry, including Penrose and Stapp. There are those who also believe consciousness is a necessary condition for measurement. An argument is provided by London and Bauer [212, p. 217]. The authors consider the coupling of a system to a device that is then seen by a conscious observer. The system is desired to be measured for which the outcome of the system $F = f_k$ corresponds to the system being measured into its eigenstate $u_k(x)$. The readout $G = g_k$ is the apparatus eigenvalue corresponding to the apparatus eigenstate $v_k(y)$. The interaction between system and apparatus is such that when the system is definitely in eigenstate $u_k(x)$, the apparatus will readout the eigenvalue g_k corresponding to the apparatus eigenstate $v_k(y)$. The authors show that the interaction of the system and apparatus will cause the system to evolve to a mixed state in the basis of the apparatus eigenstates, in a similar manner as we have already shown via the methodology of external orthogonalization. From there, the authors describe the role of the conscious observer:

> *We note the essential role played by the consciousness of the observer in this transition from the mixture to the pure case. Without his effective intervention, one would never obtain a new ψ function. In order to see this point clearly, let us consider the ensemble of three systems, (object x) + (apparatus y) + (observer z), as a combined and unique system. We will describe it by a global wave function…*

$$\Psi(x,y,z) = \sum_k \psi_k \, u_k(x) v_k(y) w_k(z)$$

where the w_k represent the different states of the observer…. The observer has a completely different impression. For him it is only the object x and the apparatus y that belong to the external world, to what he calls "objectivity." By contrast he has with himself relations of a very special character. He possesses a characteristic and quite familiar faculty which we can call the "faculty of introspection." He can keep track from moment to moment of his own state. He attributes to himself the right to create his own objectivity—that is, to cut the chain of statistical correlations summarized in $\sum_k \psi_k\, u_k(x)v_k(y)w_k(z)$ by declaring, "I am in the state w_k" …. It is only the consciousness of an "I" who can separate himself from the former function $\Psi(x, y, z)$ and, by virtue of his observation, set up a new objectivity in attributing to the object henceforward a new function $\psi(x) = u_k(x)$.

By claiming that a conscious system can cut the chain by declaring "I see $G = g_k$," London and Bauer are claiming that a conscious system that becomes aware of a phenomenon and apparatus that was hitherto in the superposition $\sum_k \psi_k\, u_k(x)v_k(y)$ is a sufficient condition that will cut the state from the unitarily predicted state of $\sum_k \psi_k\, u_k(x)v_k(y)w_k(z)$ to the product state $u_k(x)v_k(y)w_k(z)$.

London and Bauer state that,

a measurement is achieved only when the position of the pointer has been observed.

London and Bauer are also claiming that consciousness is a necessary condition for measurement. One might contrast this to Bohr [213] [214]:

See the print edition of The Quantum Measurement Problem for quotation.

From this statement it appears that Bohr does not consider a conscious system to be a necessary condition for measurement but rather "some kind" of remembrance related to "permanency" is a necessary condition. In other writing, Bohr refers to the additional conditions of "amplification" and "irreversible functioning" to represent permanent marks [215, p. 73]. However, by referring to direct sensations it appears that Bohr considered that conscious sensation is a sufficient condition for measurement. This is confirmed in a letter that Bohr wrote to Pauli in 1953 [213]:

I put the main emphasis on the fact that so-called conscious experiences involve something that can be remembered and hence must correspond to special situations in the organism which have precisely the permanent character required as a basis for *observation.*

The properties of irreversibility, permanency, direct sensations, remembrance, suitable amplification, are all properties that Bohr believes are related in some manner to measurement. Although such properties are important, as has already been presented, none of these conditions as of yet provides a resolution to the measurement problem in a manner to fully satisfy the Requirements R1.1-R1.4 for a Category 1 theory and R2.1-R2.3 for a Category 2 theory.

Heisenberg [216, p. 54] in explaining the Copenhagen Interpretation states:

> *... and we may say that the transition from the 'possible' to the 'actual' takes place as soon as the interaction of the object with 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 by the mind of the observer. The discontinuous change in the probability function, however, takes place with the act of registration, because it is the discontinuous change of our knowledge in the instant of registration that has its image in the discontinuous change of the probability function.*

Heisenberg attributes the discontinuous change in the observer's mind with the discontinuous change of the probability function. On the other hand, Heisenberg attributes the transition from possible to actual with the interaction of system and device. Heisenberg attributes the transition from possible to actual with the effect of unitary decoherence due to the uncontrollable interaction of system and device.

However, Heisenberg appears, similar to London and Bauer, to be attributing the breaking of the unitary interaction which results in loss of entanglement and discontinuous change in the probability function only at the instant of registration in the observer's mind. The attitude of Heisenberg is explained by statements by Renninger [106]:

> *In a personal correspondence Prof. Heisenberg kindly informed me about his opinion with respect to the investigations explained in the present work, and allowed me kindly to summarize his ideas as follows: It is incorrect to think, that the Copenhagen interpretation of quantum theory claims that the principal unavoidability of the influence of a measurement on the object system is related to a proper measurement "process," and that possibly, becoming aware of it later on, has the effect of reducing the wave function "retroactively." However, it is not possible at all to objectify a "measurement process" in the sense of Re in all possible cases. Simply and solely it is the circumstance of becoming aware of the measurement result that is objectifiable and responsible for state reduction, which, hence, is relegated to the "cut" between the object*

system and the apparatus system. However, what is meant by the unavoidable disturbance of the physical process by the measurement is already the possibility of a measurement, i.e., the existence of the measurement apparatus. It is precisely this existence, that brings about a partly undetermined interaction between the measurement apparatus and the object system, and that after carrying out the experiment leads to the uncertainty relation. On the other hand, the act of the registration, that leads to the reduction, is in fact not a physical, but in a sense a mathematical process. Of course, with the erratic change of our knowledge there corresponds also an erratic change of the mathematical representation of our knowledge.

Renninger also is in agreement with Heisenberg's viewpoint:

If Mr. Heisenberg's described view were the common opinion, then my considerations were indeed unnecessary, because basically they are the same, as follows from the last three sentences. At any case, it seems to me that there exists a proper measurement process, and that becoming aware of the result reduces the state (e.g., a – present or absent – to be developed mark on a recorder), at a time instant that is determined more or less exactly by the measurement proper

Wigner also believed that the measurement problem and consciousness are related. In the paper [217] the well-known Wigner's friend argument is presented. Wigner has a friend that observes a quantum object (such as a photon) that is initially in a superposition of positions and either sees a flash, indicating that the friend has observed the quantum object, or does not see a flash. The object has two states ψ_1 and ψ_2. The observer sees the object and Wigner asks his friend what was seen. If the observer sees the object in state ψ_1 (ψ_2), the observer evolves to the final state χ_1 (χ_2) and the joint state of object and observer evolves to a product state $\psi_1 \otimes \chi_1$ ($\psi_2 \otimes \chi_2$). The observer's final state χ_1 is representative of the case when the observer responds to Wigner's question that he has seen the flash, whereas when the observer responds not to have seen the flash, the observers final state is χ_2. Now the object is initially prepared in a linear superposition of $\alpha\psi_1 + \beta\psi_2$ and the experiment is repeated. If one assumes that the quantum state obeys Schrödinger's equation, then the final state of object and observer is $\alpha\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$. Wigner then asks the observer whether or not a flash was seen. According to the measurement postulate, the observer will respond with a probability $|\alpha|^2$ that he did and $|\beta|^2$ that he did not. Furthermore, according to the measurement postulate, the object-observer state changes to $\psi_1 \otimes \chi_1$ when the observer responds that he has seen a flash or to $\psi_2 \otimes \chi_2$ if the observer responds that he has not seen a flash. However, suppose that Wigner then asks his friend what he saw just before Wigner had asked him whether or not a flash was seen. Wigner's friend is found to always answer that he already told him that he saw the flash. Wigner concludes that the state of the wave function right before Wigner asked his friend the question was already either $\psi_1 \otimes \chi_1$ or $\psi_2 \otimes \chi_2$ and not $\alpha\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$. Hence the unitary predicted state is contradicted by such an experiment.

On the other hand, suppose that Wigner's friend is replaced by a single atom initially in a ground state which, in the process of interaction with light, could change state to an excited level. Then Wigner contends that the final state of light-atom is $\alpha\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$. Moreover, Wigner expresses the fact that the differences between the state $\alpha\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$ and the state of either $\psi_1 \otimes \chi_1$ or $\psi_2 \otimes \chi_2$ include observable consequences. The fact that there are observable consequences is an important observation by Wigner and is a major theme in Chapter 3 and throughout this book. But suppose now the atom is replaced by a conscious being. Wigner claims that the state $\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$ is not realistic because it would imply that Wigner's friend was in a state of, "suspended animation" before he answered Wigner's question. Wigner concludes [217, p. 263]:

See the print edition of The Quantum Measurement Problem for quotation.

Wigner is making the argument that it is not necessary for Wigner to ask his friend what he saw in order to conclude that the state of the wave function is either $\psi_1 \otimes \chi_1$ or $\psi_2 \otimes \chi_2$. It is only necessary to know that Wigner's friend had already observed the system. That is, even before Wigner's friend responds to Wigner's question of whether he saw a flash, the state of Wigner's friend must have been either $\psi_1 \otimes \chi_1$ or $\psi_2 \otimes \chi_2$. If Wigner knows that a conscious system has interacted with a quantum system in a manner which would be in the unitary predicted state $\alpha\psi_1 \otimes \chi_1 + \beta\psi_2 \otimes \chi_2$, then Wigner is claiming the actual state of the system plus conscious system is actually $\psi_1 \otimes \chi_1$ or $\psi_2 \otimes \chi_2$. Wigner is arguing is that such interaction of a quantum wave function by a conscious observer is a sufficient condition for measurement. In regards to whether or not a conscious observer is a necessary condition, Wigner states: [217, p. 256]:

See the print edition of The Quantum Measurement Problem for quotation.

Ludwig believed that unitary evolution is valid only for microscopic systems and Wigner for all inanimate objects, which for Wigner includes both microscopic systems and a subset of macroscopic objects. Hence for Wigner it appears that consciousness is a subset of only macroscopic objects. However, Wigner does not reject Ludwig's argument--as he states such a narrow limitation may be justified ultimately. A logical possibility in Ludwig's argument is that there exists a macroscopic object that is not conscious but nonetheless is a measurement device. Hence it appears that Wigner believed that consciousness is a sufficient condition for measurement and would have agreed that from a scientific basis, consciousness has not yet been established as a necessary condition. d'Espagnet in [218] reached a similar conclusion:

The doctrine that the world is made up of objects whose existence is independent of human consciousness turns out to be in conflict with quantum mechanics and with facts established by experiment.

Several models have been put forward for which consciousness and/or free will are related to quantum phenomenon. These include Eccles [219], Stapp [220] [221] and Penrose-Hameroff [222]. Penrose-Hameroff propose [222] that gravitational reduction results in consciousness via microtubular mediated orchestrated gravitation objective reduction. Such orchestrated reduction is a self-collapse mechanism for which the neurons are synchronized in a manner to mediate gravitational collapse (to be discussed further) resulting in consciousness:

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, and that the continuous Schrödinger evolution of each such process terminates in accordance with the specific Diósi–Penrose (DP) scheme of 'objective reduction' ('OR') of the quantum state.

It is further stated in [222] regarding orchestrated objective reduction:

If, however, a quantum superposition is (1) 'orchestrated', i.e., adequately organized, imbued with cognitive information, and capable of integration and computation, and (2) isolated from non-orchestrated, random environment long enough for the superposition to evolve by the U formalism to reach time τ by $\tau \approx \hbar/E_G$, then Orch OR will occur and this, according to the scheme, will result in a moment of consciousness. Thus if the suggested non-computable effects of this OR proposal are to be laid bare, where DP is being adopted and made use of in biological evolution, and ultimately orchestrated for moments of actual consciousness, we indeed need significant isolation from the environment.

The general idea behind the Penrose-Hameroff proposal, whereby consciousness is related to quantum measurement, appears to be a reasonable concept. The specifics of the Penrose-Hameroff proposal, whereby microtubules mediate objective gravitational reduction, appears to be at the level of conjecture/hypothesis at this time, as there is little evidence that gravitational forces could be sufficiently isolated and distinguished from other stronger forces that will exist at room temperature. This does not mean that such hypotheses are not a step in the right direction. On the contrary, hypotheses are necessary to be put forward as regards the scientific method. However as will be discussed further in Chapters 6 and 7, society has established bulwarks from which defenders can be expected to be put forth that defend the status quo and attack. This is unfortunate yet has been the reality of the situation going back to the time of Aristotle.

Sufficiency of Consciousness

It appears that if one puts one's emotions aside on the matter and examines this issue in only a logical deductive manner, that one only has to consider whether or not one phenomenon implies another phenomenon. In this case the two phenomena under question are consciousness and measurement. From the arguments made by Bohr and Wigner, it does appear that the ability to become aware of a phenomenon is at least a sound scientific hypothesis of being a sufficient condition for measurement. For example, let us suppose that the human eye can distinguish the case of darkness versus the stimulus of N optical photons reliably. That is, if one generates N optical photons and directs them toward the eye, one sees a flash that can be reliably distinguished from no photons impinging on the eye. There will be some reaction time or latency time for an observer to state unequivocally that he became aware or not aware of the phenomenon, call this time T_L.

Now consider that we replace the beam splitter and single photon state in the UMDT of Figure 3.4 by the state $(|0\rangle_B|N\rangle_C + |N\rangle_B|0\rangle_C)/\sqrt{2}$ that is an entangled state of N photons and the vacuum. Furthermore, both Devices 1 and 2 are removed and replaced with two conscious observers that can distinguish the photons. In fact, such a state could be produced and the experiment performed with the development of a reliable optical controlled-not gate in quantum computing. The question is what would happen if this experiment were performed. If the entire chain of sight through the human mind is Schrödinger unitary, then both conscious observers would have to exist in a superposition of seeing and not seeing the photon.

Suppose that a quantum optics group actually performed this experiment and found that both individuals report the experience that either they have seen the light, or not seen the light in time T_L. This would indicate that the entire chain through the human mind is not Schrödinger unitary. One could argue that the two individuals initially exist as an entangled superposition of quantum states for a short time, and this is only resolved when a measurement mechanism, other than the individual's consciousness, causes the collapse. But then, one would expect that the individual should experience conscious outages when the quantum state is in a superposition, and individual awareness could only occur when some other measurement mechanism causes the collapse. This might be possible if an individual experiences time passage as a stroboscope effect.

Consider that a conscious system measures a system whereby 1) the direct interaction of the system with a conscious system or 2) the initial interaction with the system is unitary and later an external measurement mechanism acts on a conscious system in a superposition. It appears to be inconsequential whether 1) occurred or 2) occurred in order to establish the condition of sufficiency of consciousness to account for measurement. That is, suppose a conscious system becomes aware of an external phenomenon because either 1) the direct interaction caused measurement or 2) an external mechanism acted on a superposition of consciousness. In both cases a conscious observer ultimately becomes aware of the phenomenon; hence all such accounts indicate consciousness is a sufficient condition for the measurement of such phenomenon.

Is consciousness a necessary and sufficient condition for measurement? Maybe and maybe not. We don't know at this time if conscious systems becoming aware of a system is the only reason that measurement of the system can occur. Consciousness as a complete explanation of the measurement problem at this time only partially fulfills Requirement R1.1, and substantially more work would be needed in order to determine how it meets R1.2, R1.3, and R1.4.

The Contrapositive

Consider the sufficiency of consciousness to measurement as believed by Bohr and Wigner expressed by the following statement:

> Given that a system of particles *A* becomes conscious of a phenomenon *B*, then the interaction between *A* and *B* is a measurement process.

The contrapositive statement is:

> If the interaction between *A* and *B* is not a measurement process, then *A* cannot become conscious of the phenomenon *B*.

Let us now consider the restriction that evolution takes only two forms: 1) Schrödinger unitary evolution that occurs in non-measurement phenomenon and 2) non-Schrödinger unitary evolution that occurs in measurement phenomenon. Then such a restriction would imply the statement:

> If *A* is a device and *B* is a stimulus to the device, and the interaction is via Schrödinger evolution, then *A* will not become conscious of *B*.

Under such conditions neither *A* nor *B* can become aware of the other via their unitary interaction. Hence suppose that an individual atom is verified experimentally to couple unitarily in its interaction with a given stimulus such as a photon. Then in the interaction with the stimulus, the atom would have to be said to not become aware of the stimulus during its interaction, including when the stimulus (if it is a photon) is completely absorbed by the atom.

Under the restriction considered, this would imply that there exist configurations of matter that cannot become self-aware of a particular stimulus, and only some proper subset of all matter configurations can be considered to be systems that can become self-aware of a particular stimulus.

Threshold vs. Non-Threshold Theory

Consider a conscious system that interacts with an external phenomenon. It is stated in [223, p. 113]:

> *See the print edition of The Quantum Measurement Problem for quotation.*

Generally, organs such as the eye and nose provide an amplification of the input stimulus. It is not known whether or not the amplification in the eye and/or nose is itself a measurement or whether such amplification is unitary in which case the output from such organs would not be subject to measurement until further in the chain. And has already been discussed, amplification is not a sufficient condition for measurement and it is not known currently whether or not amplification is a necessary condition for measurement. Hence it is not known at this time whether or not consciousness, as a theory for which measurement occurs, is a threshold or non-threshold theory.

Mind-Body Dualism

The dualistic demand for two substances has been called for by Descartes regarding the philosophy of mind-body. In Descartes' theory, the substance that is responsible for the creation of being and soul is different than non-animate substance.

The Copenhagen interpretation does advocate two complementary descriptions of matter, one of which is deterministic for non-interacting systems, and another nondeterministic description which Bohr would say is forced upon us due to uncontrollable and unknowable interactions in the process of macroscopic amplification, which constitutes measurement. But the two complementary descriptions in the Copenhagen interpretation were meant to both apply to systems of protons and electrons and other particles, only in different circumstances. There are not two different categories of substances that are responsible for measurement versus unitary evolution in the Copenhagen interpretation.

That consciousness and volition might be related to measurement has indeed appeared to some extent in investigations by Bohr, Wigner, von Neumann, London, Penrose, Stapp, and others. Nevertheless, it has not been shown nor claimed by any of these authors, to the authors' knowledge, that the existence of consciousness and/or volition demands a theory with two distinct types of matter.