Chapter 15
Is There a Link Between Quantum Mechanics and Consciousness?

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> *"I think I can safely say that nobody understands quantum mechanics".*
>
> Richard Feynman in *The Character of Physical Law*. Modern Library, 1994

15.1 Introduction

This essay examines the link (if any) between consciousness and quantum mechanics. A short history of quantum mechanics and a description of the 'double slit' experiment is presented in Sects. 15.1.1 and 15.1.2, respectively to enable the reader to grasp an understanding of the problems associated with quantum measurement. The 'Measurement Problem' that arises from the 'Copenhagen Interpretation' of quantum mechanics is presented in Sect. 15.2 and the need for a conscious observer to collapse a wave function is discussed in detail. The paradoxes of 'Schröedinger's Cat' and 'Wigner's Friend' are also examined in Sect. 15.2.1. Both of these paradoxes suggest a link between human consciousness and the quantum realm and are still a source of active debate among physicists, philosophers and neuroscientists.

Alternative interpretations of quantum mechanics such as the 'Heisenberg-Dirac Propensity Interpretation', Everett's 'Relative State' or 'Parallel Worlds' interpretation and Bohm's 'Hidden Variables' interpretation are discussed in Sect. 15.3. The role of consciousness in the 'Parallel Worlds' interpretation is discussed in greater detail along with four variations due to Squires, Deutsch, Lockwood and Albert and Loewer. A more detailed review of quantum theories of mind due to Stapp, Hodgson, Penrose and Eccles follows and the quantum field theory of mind due to Ricciardi, Umezawa, Freeman and Vitiello is discussed in Sect. 15.4.

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The Penrose and Hameroff theory of mind is examined in Sect. 15.5 together with the proposal that the brain is a quantum computer and the suggestion by Penrose that Libet's backwards referral result (where cortical activity in response to a stimulus must proceed for 500 ms to elicit a conscious response) can only be explained by retro causation in the brain.

Decoherence theory is the study of how the interference effects due to the superposition of quantum mechanical states are suppressed. The same process that is responsible for the suppression of interference effects in the quantum world is also responsible for the suppression of interference effects in macroscopic objects in the physical world but the extremely short decoherence time means that such effects are not observable for a long enough period to be detected. For example a particle larger than a 1 g mass has a decoherence time of only 10^{-23} s. The relationship between decoherence and wave function collapse and the observer problem is discussed in detail in Sect. 15.6. The suppression of interference terms and the effect of decoherence time on neural and sub neural events is also examined and the meaning of decoherence for collapse theories of mind is also investigated.

15.1.1 A Brief History of Quantum Mechanics

In 1900 and 1901, Planck[1] came up with a theoretical derivation of the Stephan-Boltzmann equation,[2,3] which describes the radiation emitted by a 'black body' (a black body absorbs all light that is incident upon it and also acts as a perfect emitter when the surface temperature is raised). Planck suggested that the total energy emitted was made up of elements of energy called quanta. Planck hypothesized that the energies of the atoms of a black body radiator are similar to the energies in a harmonic oscillator such as a pendulum, which are restricted to certain values. Each energy level is an integral multiple of a basic unit and is directly proportional to the frequency of the oscillator. The constant of proportionality between the energy and the frequency is called Plank's constant 'h' and has the value of 10^{-34} joule-seconds.

In 1905 Einstein[4,5] examined the photoelectric effect where electrons are ejected from the surface of certain metals when light of a particular threshold frequency is incident on the surface. Maxwell's wave theory of light did not explain the photoelectric effect and Einstein proposed a quantum theory of light to solve this. Einstein realized that Planck's theory made implicit use of a light quantum hypothesis and Einstein suggested that light of a certain frequency also has a certain quantized energy. Only light with sufficient energy would be able to eject

[1] Planck 1901.

[2] Stefan 1879.

[3] Boltzmann 1884.

[4] Einstein 1905.

[5] Einstein 1906.

Fig. 15.1 Continuous spectra of solids (*above*) and line spectra (*below*) for hydrogen

electrons from a metal surface. More intense light (more quanta) only results in more electrons and not more electrons at higher energy. Einstein suggested that light at long wavelengths (low energy) would not be able to cause the emission of any electrons, as the light would not have enough energy to break electrons away from the surface. Different metals were found to have different energy thresholds at which emission would occur. Einstein proposed that light is emitted, transmitted, and absorbed as particles he called 'photons'. The photon energy was dependent on the frequency of the light.

In 1913, Bohr[6,7,8] used quantum theory to explain both atomic structure and atomic spectra. Bohr derived the relation between the electrons' energy levels and the frequencies of light given off and absorbed and explained the structure of narrow light and dark bands found in atomic spectral lines, (see Fig. 15.1 above), however, Bohr's theory did not explain why some energy changes are continuous and some are discontinuous and there was no explanation of how an electron knows when to emit radiation.

During the 1920s, the final mathematical formulation of the new quantum theory was developed when Louis de Broglie[9] proposed that light waves sometimes exhibit a particle nature as in the photoelectric effect and atomic spectra, and at other times light waves may exhibit a wavelike nature as in the double slit interference experiments (see 15.1.2). This "matter-wave" hypothesis was later confirmed in 1927 by Davisson and Germer,[10] who observed wave–like effects in a beam of electrons.

Two different formulations of quantum mechanics were proposed independently by Erwin Schrödinger and Werner Heisenberg following de Broglie's suggestion. The first of these was "wave mechanics" due to Erwin Schrödinger.[11] This formulation uses a mathematical function called a 'wave function', which is related to the probability of finding a particle at a given point in space. Quantum systems can exist in this undetermined state until observed. The act of observation (or measurement) collapses the wave function into one particular stable state.

Bohr believed that the wave function represents our knowledge of the physical phenomenon we are studying, not the phenomenon itself. The wave function contains potentialities which are actualized or realized when an observation is made.

6 Bohr 1913a.

7 Bohr 1913b.

8 Bohr 1913c.

9 De Broglie 1924.

10 Davidson and Germer 1927.

11 Schröedinger 1926.

The observation causes the wave function to "collapse" into an actual manifestation and not a potentiality. This later became known as the "Copenhagen interpretation" of quantum mechanics. Problems and paradoxes associated with this and other interpretations will be discussed in greater detail.

An alternative mathematical formalism called "matrix mechanics" was developed by Werner Heisenberg.[12,13] This theory does not use a wave function but was shown to be mathematically equivalent to Schrödinger's theory. Heisenberg wrote his first paper on quantum mechanics in 1925 and in 1927 stated his "uncertainty principle". The uncertainty principle states that the process of measuring the position of a particle disturbs the particle's momentum and the process of measuring the momentum of a particle disturbs the particle's position so that the knowledge of a particle's position or momentum are mutually exclusive events.

The uncertainty principle places an absolute limit on the accuracy of measurement and as a result, the prior assumption that any physical system could be measured exactly and used to predict future states was abandoned. By combining Planck's constant, the constant of gravity, and the speed of light, it is possible to create a quantum of length (approx 10^{-35} m) and a quantum of time (approx. 10^{-43} s), called Planck length and Planck time, respectively.

15.1.2 The Double Slit Experiment

The double slit experiment was first carried out by Thomas Young[14] in 1804 and demonstrated the wave nature of light, which was previously believed to have only a particle nature. Young actually used the edge of a thin card to show interference effects, which is equivalent to the double slit arrangement shown below. (Note: You can carry out the same experiment by placing your forefingers together and observing a light source between the gap of your fist and second knuckles, you will see vertical bands due to interference.)

If we consider a wall with two narrow slits and a source of small indestructible balls that are fired at two slits as shown in Fig. 15.2, below. The wall behind the slits is impacted by any of the balls that pass through the slits. The distribution of balls on the screen indicates that any ball that was initially behind a slit passed through that slit.

If we now consider a source of monochromatic light waves with the same slit setup and a fluorescent screen we find that each slit becomes a new source of light waves and when these two light waves combine on the screen they interfere with each other and result in an interference pattern composed of dark and light bands as shown in Fig. 15.3, below. The dark bands represent destructive interference and the light bands represent constructive interference.

[12] Heisenberg 1925.

[13] Heisenberg 1926.

[14] Young 1804.

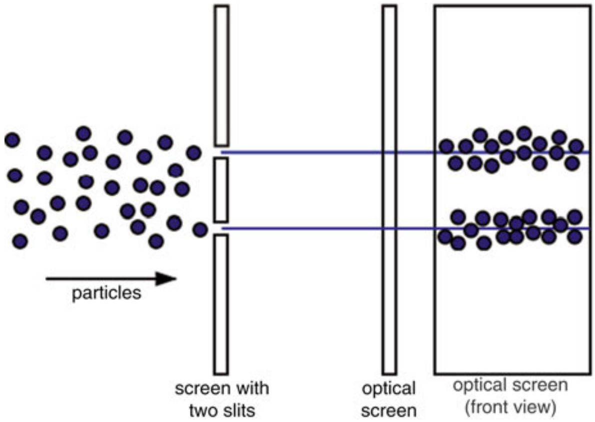

Fig. 15.2 Pattern produced for solid balls

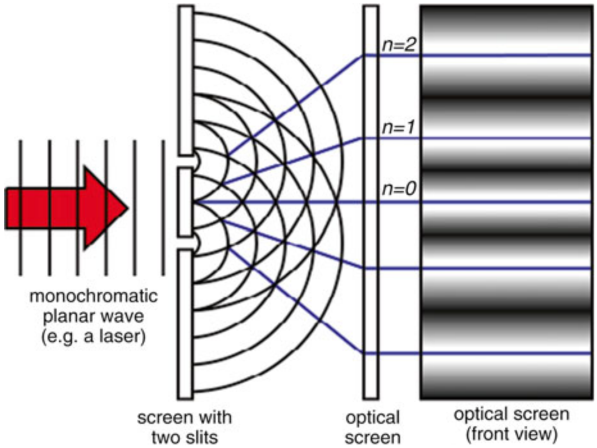

Fig. 15.3 Interference pattern for light waves

If the same experiment is carried out with electrons as a source we would expect the result shown in Fig. 15.2 due to the particle nature of electrons but because electrons also have a wave nature we end up with the interference pattern shown in Fig. 15.4, below.

If we now set up an experiment where we shine light on the electrons to determine which slit they are coming through then the resultant pattern is the same as shown in shown in Fig. 15.2. The act of observation and the knowledge that the electron has passed through one slit or the other destroys the interference pattern. If we close one of the slits then we get half of the solid ball pattern in Fig. 15.2.

If we now carry out the same experiment with a photon source that is limited to only one photon at a time over a period of days or months, then we still get the interference pattern shown in Fig. 15.4. The only explanation is that the photon has

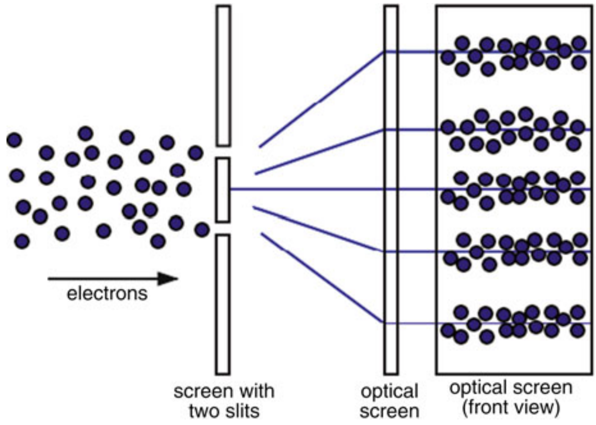

Fig. 15.4 Interference pattern for an electron source

the ability to interfere with itself. This behavior has also been observed with single electrons. The apparent 'wave–matter' duality of photons and electrons can only be explained with the aid of quantum mechanics.

15.2 The Measurement Problem

The quantum measurement problem came about as a result of the Copenhagen interpretation of quantum mechanics due to Neils Bohr.[15,16] The consensus at this time was that the time dependant Schrödinger equation predicts quantum states with many alternatives contained in a superposition of states. However, these alternative states are never observed (or actualized). Bohr's interpretation creates a division between the quantum world and the classical world and any measurement can only be performed with a classical apparatus. Bohr also proposed that this dividing line was not fixed and could in principle extend even to the human brain. The only requirement is a suitable measuring apparatus.

Quantum mechanics is a mathematical framework that describes the behavior of light and matter on the molecular, atomic and sub-atomic levels. Quantum theory has had many successful predictions and is considered to be the basis for all of physics but one aspect of the theory has remained unsolved for over 60 years. This problem, known as *'the measurement problem'*, is that the conditions for the actualization of potentialities (a superposition of quantum states) are not explicit in the formalism of quantum mechanics. That is, there no well defined physical or non-physical process responsible for the reduction of a superposition of quantum states (or potentialities) to a particular quantum state (or actuality). For example,

[15] Bohr 1928.

[16] Bohr 1935.

if a wave function represents the statistical probability of a particle's being observed, then a 'measurement' is said to 'localize' the particle otherwise the position of the particle is indeterminate.

Two very different and somewhat *ad-hoc* transformations occur in quantum mechanics, the first is a deterministic transformation of the wave function in accordance with Schrödinger's equation.[17] The second is a probabilistic transformation where the wavefunction undergoes a change from a pure state to a mixed state, which can only take place during a measurement (a 'pure' state is a linear superposition of all possible states and a 'mixed' state is one of all of those possible states). The problem is that the second type transformation is incompatible with the first type of transformation and Schrödinger's equation. Quantum physics (ie; Schrödinger's equation) applies to a quantum system up to the moment that a measurement is performed and classical physics applies to the measurement result. Quantum theory cannot explain how classical, physical phenomena emerge from quantum phenomena.

Another major problem with quantum theory is the notion of what constitutes a measurement. Is the dissociation of one molecule sufficient? Can a single photon perform a measurement or do we need a larger, macroscopic physical system. There is nothing in the formalism of quantum mechanics that defines what it is that constitutes a measurement. There is no clear demarcation between the macroscopic classical world of the measured state and the microscopic quantum world of the unmeasured state. The measuring apparatus is also subject to the laws of quantum mechanics regardless of the size or complexity of the apparatus. Maxwell[18] suggests that one solution to the above problem is to consider that the second type transformation can only occur when an observer becomes conscious of the result of the measurement.

This hypothesis proposes that a wave function is collapsed or reduced by some non-physical interaction between the consciousness of a human observer and the quantum system being examined as any physical interaction can just be considered as being part of the apparatus used to carry out the measurement. Maxwell[18] was not happy with this and considered it "*bizarre in the extreme that a purely physical process should occur only in those systems that interact with conscious observers*". Maxwell also suggested that the notion of a conscious observer could include any self-aware primate.

What is the dividing line between a measuring device and the quantum system being measured? Mathematically, a quantum system is a complex wave function (or pattern) of superposed wavefunctions. The components of the superposed state produce a complex interference function (or pattern) that describes the quantum state of the system. Any measurement performed on the system causes the interference effects to cease and leaves the system in a definitive quantum state (or 'measured state'). This process is irreversible.

[17] Schröedinger 1935.

[18] Maxwell 1974.

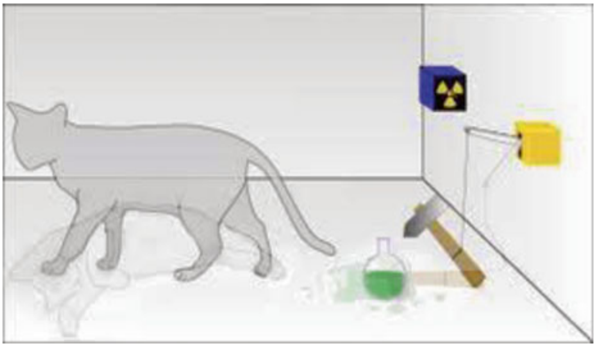

Fig. 15.5 Schrödinger's cat

Von Neumann[19] showed that during a measurement interaction, the combined system of object plus apparatus goes into a superposition of states where each state consists of the '*eigenstate*' of an observable together with a distinct state of the measurement apparatus (e.g.; a physical pointer on a dial). When an observer looks at the pointer, images from back of the retina form electrical impulses that travel to the visual cortex in the brain and become correlated with states of the combined system. Von Neumann suggests that this process can be extrapolated to include a correlation with the consciousness of the observer. The observer's consciousness will then go into a superposition of states where each state corresponds to a particular disposition of the measuring apparatus (e.g.; a pointer on a dial). Although Von Neumann's theory does not indicate exactly where and when the reduction of the wave function actually occurs he does suggest that this should occur no later than the registration of the measurement in the consciousness of the observer.

15.2.1 The Paradoxes of Schrödinger's Cat and Wigner's Friend

The paradox of Schrödinger's cat was published by Schrödinger[17] in 1935 to show that the description of a wave function was incomplete. Schrödinger suggested the following scenario (see Fig. 15.5): a cat is sealed in a box and a radioactive source is used to trigger a hammer that breaks a bottle containing cyanide killing the cat. The cat is said to be in a quasi alive-dead state until an observer opens the box and reduces the wave function to either a cat-dead or a cat-alive state (It should be noted that Schrödinger regarded this as a feature of description rather than an actual physical event). The paradox is that the cat is apparently in a linear superposition of cat-alive and cat-dead states until the box is opened by an observer and the wave function collapses to reveal one or the other observable states.

[19] Von Neumann 1955.

A second paradox was suggested by Wigner,[20,21,22,23] who used a 'friend' of the experimenter in place of the cat, and a light globe in place of the cyanide that is placed in a box. The light is turned on when a radioactive particle is detected and the 'friend' is instructed to report his observation to the experimenter. When the friend opens the box the larger wave function of the source, detector, light and friend will be reduced to a light on or light off state. If a second observer is introduced then he will collapse the wave function consisting of the source, detector, light, friend, and first observer. Wigner concluded that this process would lead to an infinite regress. Because of this paradox, Wigner concluded that human consciousness must be involved in the collapse of the wave function otherwise we end up with conscious observers in a multiplicity of states due to uncollapsed wave functions. If the first observer is conscious then he or she will collapse the wave function prior to the observation (or enquiry) of the second observer.

Although Schrödinger did not consider the cat paradox as a real physical situation, it was considered to be a serious problem by his colleagues and a long line of scientists and philosophers to this day. For example; Barrow and Tippler[24] proposed a number of ways to avoid the paradox such as Solipsism (the view that only oneself exists). They also suggest that any conscious being can collapse a wave function by observation and not just a trained observer and perhaps a 'community' of conscious beings can collectively collapse wavefunctions. They also proposed that an 'ultimate observer' may be responsible for the collapse of wavefunctions. Another proposal (that is shared with a number of alternative interpretations of quantum mechanics) is that the wave functions never collapse.

Hodgson[25] has three problems with the above proposals; Firstly, if it is the consciousness of one particular person that brings about the collapse of a wave function, then the wave function must be collapsed for all other conscious beings at the time of observation to avoid the observation of 'different observables' being observed. We then need a mechanism that explains how every conscious mind is connected. Secondly, there is the possibility of error in the observer due to say brain dysfunction or error due to the malfunction of the measuring apparatus and Thirdly Hodgson considers the case where two photographs of the observable are taken in succession. Does the observation of the second photograph immediately bring about the collapse of the first photograph?

Schröedinger himself suggested that wave function collapse occurred whenever a permanent record of the system was made and Heisenberg[26] proposed that

[20] Wigner 1961.

[21] Wigner 1962.

[22] Wigner 1967.

[23] Wigner 1977.

[24] Barrow and Tipler 1986.

[25] Hodgson 1991.

[26] Heisenberg 1958.

thermodynamic irreversibility was responsible. Davies[27] and Penrose[28,29] both propose that wave function collapse could only occur in the presence of a gravitational field.

15.3 Interpretations

Interpretations of quantum theory may be grouped into five main classifications: Bohr's 'Copenhagen' or 'Orthodox' interpretation, the Heisenberg-Dirac 'Propensity' interpretation, Everett's 'Many Worlds' interpretation, Bohm's 'Pilot Wave' interpretation and the 'Real Particle' interpretation. Each of these has a specific role for consciousness (the views of Bohr, Schrödinger, Heisenberg and Pauli on the 'hard problem' are summarized in Smith[30,31]).

15.3.1 Bohr's 'Copenhagen' or 'Orthodox' Interpretation

In 1926 and 1927 the Copenhagen interpretation of quantum mechanics was formulated by Bohr[15,16] and Heisenberg.[26] The most commonly accepted version is: "*Quantum mechanics is a tool for producing predictions rather than a theory for describing the world, whereas, classical terms have direct factual reference.....the classical level and the quantum level are entirely distinct and the transition from one to the other cannot be further analyzed*" (Feyerabend[32,33]).

Bohr and Heisenberg believed it was impossible to distinguishing between the objective and subjective at the quantum level and followers would write of the interaction between the observer and object causing large changes in the system under observation. It was commonplace to find expressions such as *'the observation disturbs the phenomenon' and 'the measurement creates the physical attributes of the object'*. Bohr[16] was to later change his view to a completely objective interpretation and suggested that "*it is not possible to conceive the quantum-mechanical state of an isolated microscopic system*", the system must include the measuring apparatus.

In Bohr's 'Copenhagen' interpretation, quantum theory does not describe a physical world that is independent of human observers. There is also some uncertainty in

27 Davies 2004.

28 Penrose 1986.

29 Penrose 1996.

30 Smith 2006.

31 Smith 2009.

32 Feyerabend 1968.

33 Feyerabend 1969.

the meaning of the term "wavefunction". The 'Copenhagen' interpretation is incomplete as it does not tell us how or when a measurement actually occurs. The theory requires a "*cut*" between the quantum system being measured and the classical system doing the measurement but does not say where the "cut" will occur. The sudden change to the wave function during measurement is just part of quantum theory. The reason for the change is not explained in the theory.

15.3.2 The Heisenberg-Dirac 'Propensity' Interpretation

Heisenberg's 'Propensity' interpretation of quantum mechanics, refers to things in nature as "*events*" and quantum theory specifies the tendencies or "*propensities*" for events to occur. In Heisenberg's ontology the wavelike properties of nature are embedded in expectation values of Heisenberg operators. The wavelike properties of nature are interpreted as objective tendencies for "*actual events*" to occur and the actual events correspond to the particle aspects of nature. Events are accompanied by change in the Heisenberg state of the universe due to wave function collapse.

According to Heisenberg[26] "*The observation itself changes the probability function discontinuously; it selects of all possible events the actual one that has taken place … the transition from the 'possible' to the 'actual' takes place during the act of observation. If we want to describe what happens in an atomic event, we have to realize that the word 'happens' can only apply to the observation, not to the state of affairs between two observations. It applies to the physical not the physical act of observation, and we may say that the transition from 'possible' to 'actual' takes place as soon as the interaction of the object with the measuring device, and thereby 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*".

Actual 'events' can be "*recorded*" *or embedded in an* enduring structure that enables re-verification of the event such as, the blackening of a photographic plate. This ontology allows the external world to carry on existing irrespective of human observation. Schrödinger's cat is either dead or alive and not in a quasi alive-dead state until an observer opens the lid.

Stapp[34] suggests that "… *the general shape of enduring physical objects, including all of their quasi-permanent marks and deformities are considered to be fixed by the ongoing flux of actual events. These fixed, quasi-stable features of objects, and similarly of biological organisms, provide a quasi-stable matrix of robust quantum properties around which the more transient quantum properties evolve. Thus, physical objects, and also biological organisms are considered to be 'really there'….even though the object or organism is interacting with its environment in a way that is violently disturbing huge numbers of non-robust degrees of freedom*".

[34] Stapp 1993.

15.3.3 Bohm's **'Pilot Wave'** *or* **'Hidden Variables'** *and* **'Real-Particle'** *Interpretation*

The '*hidden variable*' interpretation considers quantum mechanics to be incomplete. Hidden variables or parameters describe how a range of discrete quantum states differ from each other. Bohm's '*Pilot Wave*' interpretation[35,36] allows classical deterministic laws to govern the evolution of the universe. Reality consists of quantum type wave functions and a classical world of particles and fields embedded in a '*quantum field*', (see Smith[31] for a non-mathematical account). The 'Real-Particle' interpretation of quantum mechanics is an interpretation postulated by David Bohm in which the existence of a non-local universal wavefunction allows distant particles to interact instantaneously. This interpretation posits that both wave and particle natures are real. The wave function of a particle evolves according to the Schröedinger equation. It assumes a single deterministic universe that evolves without the collapsing of wavefunctions when a measurement occurs. Bohm also established that the non-relativistic form of Schrödinger's equation is compatible with point particles provided that all such particles are linked simultaneously throughout the universe.

15.3.4 Everett's "Relative State" or **"Parallel World's" ("Many Worlds")** *Interpretation*

Everett's "*Relative State*" interpretation[37] proposes that the actual physical world is radically different from that perceived by human consciousness. Everett claims that wavefunctions never reduce and that "*The wavefunction changes with time only and always in accordance with the Schrödinger equation*". External reality splits into many branches or 'worlds' where each world contains one of the many different results due to observation. In Everett's view making observations is equivalent to reducing wave functions. A human observer or human consciousness is not needed.

A major problem with other interpretations is that a quantum system, such as the Schrödinger cat example, suddenly jumps from a superposition of states to a particular state as a consequence of a measurement. In the "many worlds" interpretation there is no actual reduction to only one state as all states, which make up a superposed state, coexist. According to Everett the universe splits into a number of copies with each copy containing one of the superposed states. For example; Schrödinger's cat would split into two coexisting parallel worlds, one containing a dead cat and one containing a live cat. The observer would also split into two.

[35] Bohm 1952.

[36] Bohm 1990.

[37] Everett 1957.

DeWitt[38] expresses the process as follows: "*Every quantum transition taking place in every star, in every galaxy, in every remote corner of the universe is splitting our local world into myriad copies of itself.....here is schizophrenia with a vengeance*".

15.3.4.1 Problems with the Many Worlds Interpretation

Firstly, we now need to explain what process causes the split. Is the split due to the 'act' of observation using some physical force or field or is the split caused by the interaction of an observer's consciousness. If the latter then we are left with a variation of the original measurement problem where we need to explain how individual consciousness's can split both the universe and itself?

Secondly, Squires[39] asks what the probabilities in the wave function are now probabilities of. For example; in the many worlds theory the probabilities of observing a particular spin state are no longer the same probabilities as the Copenhagen interpretation as one 'Me' observes one spin state and another 'Me' observes another spin state.

Thirdly, Deutsch[40] suggests that "*different parallel universes may be linked by being part of a physical object*" and that "*physical reality is the set of all of the universes evolving together*" so that interference effects involve some sort of fusion of worlds. In a Young's two slit experiment each path is represented by different worlds before detection, which fuse to form one world when interference is detected.

Fourthly, how do we determine which state (or universe) the observer is in? Lockwood[41] suggests that we have the experience of being in all of these states but at any one time, we are only conscious of one of these states. Lockwood suggests that the current state is designated by consciousness and that only states that are shared eigenstates of a favored set of observables can be designated.

Fifthly, Hodgson[25] suggests that the many worlds hypothesis does not in fact answer the measurement problem. Hodgson suggests a Schrödinger's cat experiment where the probability of observing a dead cat is 0.01 rather than 0.5. The experiment is repeated 100 times which results in 2^{100} worlds where the observed results would be grouped around a probability of 50 % and not 1 %. This result appears to violate the statistical predictions of quantum mechanics.

We may overcome this problem by splitting into 99 worlds (each with a live cat) and one world with a dead cat, however, Hodgson suggests that to have the probability outcome determine the number of worlds would be difficult as probabilities include irrational numbers which would result in partial worlds. Lockwood[41] also expresses a similar suggestion and states "*what one would need is a continuous infinity of worlds, for each outcome, with a measure, in the mathematicians sense, that was proportional to the probability in question*".

[38] De Witt 1970.

[39] Squires 1990.

[40] Deutsch 1985.

[41] Lockwood 1996.

15.3.4.2 Variations to the Many Worlds Interpretation

Variation due to Squires

To avoid the problem of splitting mentioned above, Squires[39] proposes the existence of "selectors" that have "the power to select results for particular observations" and that the selection mechanism is human consciousness. Consciousness makes a random selection of what to observe and has no influence on the 'wavefunction'. Part of the wave function then becomes 'more real' and it is this part that is observed. This avoids the splitting into two 'me's' with each aware of a different result.

Everett[37] believes this modification to his theory "*does not have trajectories for the particles; indeed the external world does not even have particles; these are entirely a creation of conscious mind; like free will and redness, they are experiences*". There is also a problem when two observers each observe the same process but the detectors are separated by a large distance. If one observer makes a measurement and records say a particle in a plus spin state then the other observer will not see the particle according to Squire's variation. However, Quantum mechanics gives an equal probability of observing plus and minus spin states so how does the wavefunction inform the second observer that no particle is there if the first observer does not alter the wavefunction?

Squires[39] came to the conclusion that: "*It is with considerable hesitation that I suggest that the answer must lie in some sort of universal nature of consciousness*". Here, Squires refers to a universal mind through which individual minds interact but not at a conscious level. (This would need some sort of non-physical coupling between conscious individuals and a universal mind). This is a problem for any time period without consciousness as there could be no particle decay and the vacuum state of the universe (which fixes all physical parameters) would not exist and we must admit a degree of consciousness to every sub atomic particle and every rock and tree frog. Cochran (1971)[42] hypothesizes that the heat capacities of proteins may have a rudimentary degree of life.

Squires proposes that this problem can be eliminated if we consider that all past and present history of the universe is a subset of a much larger universal wavefunction that has been constantly evolving (equivalent to a quantum form of the '*Strong Anthropic Principle*').

Variation due to Deutsch

Deutsch[40] suggests that an infinite and constant number of parallel universes have always coexisted and their number remains constant. When a choice is made over a quantum event then the universes are partitioned into groups where one outcome occurs and groups where the outcome occurs. The universes increase in complexity in accordance with the second law of thermodynamics (This is a problem for quantum processes in biological systems which appear to develop against the rules of the second law).

[42] Lockwood 1996.

Variation due to Lockwood

Lockwood[41,43] suggests it is misleading to talk of physical worlds splitting as dividing or splitting in the relative state interpretation is equivalent to going into a macroscopic superposition. In the case of Schröedinger's cat, one could say that the universe as a whole is also in a superposition of cat-alive, cat- dead states, however, Lockwood[43,44] believes, "*Only in a Pickwickian sense could the rest of the universe be 'affected' by what befalls Schrödinger's cat*". Lockwood suggests that it is not the observer that splits the universe, it is the universe that splits the observer, as different *eigenstates* of a system become correlated with different brain states of the observer.

Lockwood's view implies that all human decisions are in fact indeterminate as all actions and their results become real alternatives. This would result in no real moral value for any action as (irrespective of the action) all alternative actions are realized (a similar problem occurs in the 'Orthodox Interpretation' where the reduction of 'potentialities' to 'actualities' involves random choice).

Variation due to Albert and Loewer

Albert and Loewer[45,46] propose a 'many minds' variation where any "*sentient physical system*" can take the part of an observer. This would involve an infinite set of minds and the "*array of choices embedded in the Schrödinger equation corresponds to the myriad of experiences undergone by these minds rather than to an infinitude of universes*".

15.4 Quantum Theories of Mind

The following is a brief review of quantum theories of mind due to Stapp, Penrose, Hogson, Eccles and Freeman and Vitiello.

15.4.1 Stapp's Theory

Stapp's proposal[34,47] is based on Heisenberg's picture of the physical world. Heisenberg suggested that atoms and electrons are not "*actual*" things such as a table or chair. The physical state of an atom or group of atoms or electrons is represented

[43] Lockwood 1989.

[44] Lockwood 1989.

[45] Albert and Loewer 1988.

[46] Albert and Loewer 1989.

[47] Stapp 2001.

by a set of "*objective tendencies*" or "*propensities*" for "*actual events*" to occur and these events can be measured or observed in the real physical world. These propensities or tendencies follow continuous deterministic mathematical processes, which obey the laws of classical physics. A second dynamic process brings about the occurrence of "*actual*" things in nature. This second process is termed a "*quantum jump*". Individual "quantum jumps" cannot be described by any physical theory but collectively they do obey statistical rules.

According to Heisenberg,[26] the deterministic part of quantum mechanics represents probabilities but the mathematical framework of quantum mechanics does not indicate what these probabilities are the probabilities of. Heisenberg suggested that these probabilities are "*objective tendencies*" for actual events to occur where the actual event is defined as "the actualization of one of the distinct metastable configurations of the observable degrees of freedom generated by the mechanical laws of motion, and the eradication of those remaining patterns of physical activity that might have been actualised, but were not". Stapp proposes that Heisenberg's picture couples quantum theory to an evolutionary description of physical reality and is not just a statistical set of rules about connections between human observers. I believe that Heisenberg's view only sidesteps the measurement problem as we are still left with the problem of how the potentialities are in fact 'actualized'.

Stapp[48] suggests that conscious events can be identified with physical brain events for the following reasons:

(a) Each nerve terminal in the brain exists in a mixture of quantum states. This is due to calcium ion precursors at synaptic junctions that require quantum theory to fully describe their behavior. Therefore, according to Stapp, the entire brain contains a cloudlike mixture of quantum states.
(b) Classical physics cannot explain consciousness without dualism which is not an issue if quantum mechanics is reintroduced into the problem.
(c) The decoherence time for ions (in aqueous solution) is much too short for quantum effects to play any significant role, however, Stapp suggests that the "quantum Zeno effect" can lengthen the decoherence time. The "quantum Zeno effect" occurs when the act of rapidly observing a quantum system forces that system to remain in an indeterminate state and prevents the system from collapsing into a particular, determined state. This effect is not diminished by the environment so that the decoherence time is extended. The simple observation of a quantum system suppresses certain of its transitions to other states. Stapp claims that the quantum Zeno effect is the main method by which the mind holds a superposition of the states of the brain in the process of attention. This is the principal method by which the consciousness can bring about change.
(d) Stapp proposes that each individual is equipped with three representations or schemas: a body schema used to execute bodily responses, an external world schema associated with the external world and a belief schema which is the current representation of a general historical schema. Projected self and world

[48] Stapp 2007.

schemas are selected by a conscious acts and are used to guide the organism. As these schemas may be manipulated by appropriate processing they are in a sense 'classical'. Stapp suggests that these schemas may be represented by physical structures in the brain and these structures are equivalent to observables in quantum mechanics.

Stapp[34] believes that the billions of synapses which are coupled together in a non-linear fashion should result in "a *huge number of metastable, reverberating patterns of pulses into which the brain might evolve*". Non-linear systems in the brain are sensitive to variations in input parameters (in this case, synaptic parameters). Synaptic processes are dependant on a small number of calcium ions resulting in a large number of metastable states into which a brain may evolve (see Smith[31] for more details). In the absence of quantum jumps, "*a brain will generally evolve quantum mechanically from one metastable configuration into a quantum superposition of many metastable configurations… that ascribes non-negligible quantum probabilities to several alternative possible metastable states of the 'self and world schema'*" Metastable patterns will become unstable due to the fatigue characteristics of synaptic junctions. The system will then be "*forced to search for a new metastable configuration, and will therefore continue to evolve, if unchecked by a quantum jump, into a superposition of states characterized by increasingly disparate self and world schema's*" (Stapp[34]).

Stapp maintains that a materialist theory will eventually account for consciousness but disagrees with Dennett's multiple drafts model (Dennett[49]), where the idea of a single stream of consciousness is an illusion. (Note that there is a great deal of evidence for fragmentation such as the Kolers-Grunau result, the Gray Walters precognitive carousel and Libet's subjective delay (Dennett[49])).

According to Stapp there are two factors that determine which alternative brain activities are actualized by an actual event. The first factor is local deterministic evolution governed by the Heisenberg (and Schrödinger) equation of motion. Historical influences such as learning and values may also influence tendencies associated with alternative courses of action.

The second factor selects one particular course of action from top-level patterns in the brain. This second factor according to quantum theory is chance. Stapp believes that "the basis for quantum choices cannot be conceptualized in terms of the ideas that it employs so that such choices appear to come from "*nowhere*" and must therefore be "*irrational*". This makes free will a problem for Stapp's hypothesis.

There is one further implication for the Heisenberg interpretation of quantum mechanics when applied to choices between distinct alternatives. Such choices are not due to local actions but are the result of global actions that transcend space and time (due to Bell's theorem[50]). Quantum theory predicts that "*although the flow of conscious events associated with a particular human brain has important personal*

[49] Dennett 1991.

[50] Bell 1987.

aspects, … the fundamental process that is expressing itself through these local events is intrinsically global in character" (Bell[50]). The term "pure chance" is used to describe this global process.

15.4.2 Hodgson's Theory

Hodgson[45] suggests that the mind and brain are "both manifestations of the same underlying reality" and that mind can be interpreted as an emergent function of the brain only if we assume there is an underlying quantum reality associated with both the physical brain and mental events of consciousness. Hodgson believes that the external world is the result of gross statistical properties of a cosmic code. We detect and interpret this code as sensory events and objects. Hodgson does not believe that mental events are the result of gross statistical properties of quantum events in the brain and proposes that mental events are related to quantum processes directly. Hodgson further suggests that associated with what appears to be an "*apparently unified and indivisible conscious experience … is a pattern of physical events which are substantially cotemporaneous and spatially extended.*" Perception of an object such as a red ball moving through the air involves the recognition of various features such as color, shape and movement and the comparison with previous beliefs about what the object is. These processes involve spatially and temporally extended regions of the brain but the subjective experience appears to imitate the physical character of the external world.

The fact that changes in our experience appears to be simultaneous (when presented to consciousness) can be explained by short-term memory. However, Hodgson suggests that short-term memory alone cannot explain the feeling of a specious present and our feeling of the passage of time. Contributions to experience from short-term memory may also involve neural events from spatially extended regions of the brain. From Hodgson's view we can never be "truly aware" of an external reality.

Some evidence of this is found in patients with short-term memory dysfunction (one such patient would write every 10 min, the statement that: *now for the first time I am truly aware*). It may well be that we can consciously experience external reality without associations with prior concepts from long-term memory and contributions from short-term memory. Such an experience would be without any categorizing or labeling.

It would appear that mental events somehow span space, enabling simultaneous experiencing of spatially separated physical events. "*Instantaneous correlations of spatially separated events are only found in the potentialities of quantum state*" thus Hodgson[45] believes it is "*plausible to associate mental events closely with the quantum physical states manifested by brain events*".

The integration of mental events to produce a collective *"wholeness"* underlies the hypothesis of both Hodgson and Stapp. However, this is undermined by the fact that consciousness may be due to a collection of conscious subsystems that are somehow integrated into a collective whole. A well known example is found in *split brain patients* with apparent dual centers of consciousness leading Nagel[51] to write "*If I am right, and there is no whole number of individual minds that these patients can be said to have, then the attribution of conscious, significant mental activity does not require the existence of a single mental subject.*"

Conscious subsystems are also found in the experiments of Libet, Feinstein and Pearl,[52,53] which show there is no conscious sensation (of stimulation to the skin) unless preceded by unconscious cortical activity for periods up to half a second. Libet suggests that the delay has the function of "*keeping ongoing sensory inputs from reaching conscious levels*" and provides "*an opportunity for modulating a perception*". Hodgson suggests that it may be possible for decisions to be made by conscious subsystems without our knowledge and that "*consciousness of such parts may at different times be (or be not) integrated into a single consciousness*". Examples are also found in patients with multiple personality disorders where each individual personality may be entirely controlled by a conscious subsystem.

15.4.3 Penrose's Theory

The core of Penrose's theory of consciousness (Penrose[29,54,55,56]) is that the shared *"global"* character of conscious thought is similar to a quantum state or quantum states. Examples are found in mathematics where conscious thought instantaneously grasps a complex whole. Penrose also believes that "*the action of conscious thinking is very much tied up with the resolving out of alternatives that were previously in linear superposition*" and these alternatives are similar in nature to superposed quantum states. The main difference between Stapp and Penrose is that Penrose considers this process to be non-computational and believes that "*appropriate physical action of the brain evokes awareness*" but "*this physical action cannot even be properly simulated computationally*" (Penrose[54]).

Penrose considers that quantum systems may evolve in two different ways. The first way is a deterministic "*unitary*" process (U) and the second way is a "*collapse*" or "*reduction*" process (R). The (R) process is a physical action that "*is non-local in a way that is consistent with the type of violation of Bell's inequality that has been observed in actual experiments*" and is non-computational. Penrose believes there is a similarity between consciousness processes and R-type processes and states, "*the phenomenon of consciousness are dependent upon some physical process that underlies the R-procedure of quantum mechanics*".

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[51] Nagel 1976.
[52] Libet et al. 1979.
[53] Libet et al. 1992.
[54] Penrose 1989.
[55] Penrose 1994.
[56] Penrose 1997.

Penrose also believes that Libet's backwards referral mechanism is evidence for retrocausation in conscious thought and is subject to the laws of quantum mechanics (Libet found that cortical activity in response to a stimulus must continue for about 500 ms to elicit a conscious sensation. The timing of the sensation is then subjectively *referred* back to the initial stimulus), however, there is no scientific evidence for time-reversed processes in our brains that may or may not require quantum mechanics. It should be noted that Libet did not agree with Penrose's interpretation and believed that the backwards referral mechanism was an 'as if' situation rather than physical retrocausation.

Penrose together with Hameroff[57] suggest that microtubules may be plausible sites for quantum mechanical processes involved with consciousness. Microtubules lend structure and create pathways for chemical transport within nerve cells and computer models show that the insulating properties of microtubules may allow vibrational pulses to explore multiple pathways. The main problem with this hypothesis is how microtubules communicate with cells. The use of neuromodulators would require activity that is very large on a quantum scale. There is also the problem of a mechanism for quantum coherence in microtubule clusters and the requirement of a yet to be determined theory of quantum gravity essential to the whole theory. More recent findings in neurobiology by McKemmish, Reimers, McKenzie and Hush[58] suggest that "tubulins do not possess essential properties required for the Orch-Or proposal" and "recent progress in the understanding of the long-lived coherent motions in biological systems" indicate that coherent computations in microtubules is not possible.

15.4.4 Eccles's Early Quantum Theory of Mind

Eccles[59] proposed that quantum processes in brain dynamics and nerve terminals were the basis for the link between mind and brain. However, this approach introduces a bias to quantum statistics. Initially, Eccles[60] believed that quantum indeterminacy would take over at the microscopic scale in the brain. However, the magnitude of diffusion forces found in synaptic junctions were found to be much larger than any quantum effects (Beck[61]). Eccles[62] suggested that: "*mental events alter the probability of vesicular emission that is triggered by a presynaptic impulse*". Beck and Eccles proposed that exocytosis (the release of vesicular contents from a neuron) must be atomic in nature, i.e.; "an incoming nerve impulse excites some electronic configuration to a metastable level which is separated

[57] Hameroff 1994.

[58] McKemmish et al. 2009.

[59] Eccles 1990.

[60] Eccles 1986.

[61] Beck 1996.

[62] Eccles 1994.

energetically by a potential barrier from a state which leads unidirectionally to exocytosis" (Beck[61]). Quantum tunnelling through this potential barrier results in the generation of a superposed state of two wave functions representing the penetration or non-penetration through the barrier. Any 'act' of observation due to conscious choice collapses the wave function into one state or the other (exocytosis or non-exocytosis).

Eccles proposed that quantum processes in thousands of presynaptic membranes in cortical pyramidal cells resulted in unitary mental event or 'psychon'. Each psychon influenced the probability of exocytosis in all the synapses associated with a dendron. "Our mentality consists of a shifting mosaic of psychons each linked to a cortical dendron" (also see Smith[31]). Earlier, Eccles[60] suggested that mind is independent of brain due to a pre-existing "mental field" which is accessible to any brain sufficiently complex (He withdrew from this view at a later date).

There are three main problems with Eccles approach: firstly, there is no indication of how consciousness selects which state is to be realized. Secondly, recent research in neurobiology has yet to find any quantum like processes that may be responsible for the release of neurotransmitters into the synaptic cleft or to affect the initial trigger due to the influx of Ca^{2+} ions (see Smith[31] for a summary) and thirdly, for the "*hard problem*" we are left with a form of dualism.

15.4.5 Ricciardi, Umezawa, Freeman and Vitiello's Quantum Field Theory of Mind

Ricciardi and Umezawa[63] were among the earliest to suggested that quantum field theory may be applicable to brain states. Umewaza suggests that memory states are similar to the states of a many-particle system such as is found in the vacuum states of quantum fields. Umewaza proposes that the brain is a many-particle system and that neurons behave as particles. Coherent neuronal assemblies would then be analogous to the dynamically ordered states of a many-particle system and the encoded content of a neuronal assembly would be consciously accessible via an external stimulus. This allows the formation of memory states with a finite lifetime and conscious recall of content.

Vitiello[64,65] further considered the problem of dissipation from interaction with the environment and suggests that the doubling of collective modes (in the form of differently coded vacuum states of quantum fields) would enable the possibility of memory storage without overprinting. The affect of external stimuli on the stability of such states has been investigated by Stuart, Takahashi and Umezawa[66] and the

[63] Ricciardi and Umezawa 1967.

[64] Vitiello 1995.

[65] Vitiello 2001.

[66] Stuart et al. 1978, 1979.

affect of chaos and quantum noise have also been addressed by Pessa and Vitiello.[67] Vitiello, also proposes that a "time-reversed copy" of brain states may be possible so that "consciousness seems thus to emerge as a manifestation of the dissipative dynamics of the brain". In a later publication, Freeman and Vitiello[68] suggest that electric field amplitudes and neurotransmitter concentrations remain purely classical and do not require the application of quantum theory.

Vitello's theory of mind allows mental activity to be correlated with the dynamics of neuronal assemblies and avoids many of the restrictions associated with the standard version of quantum mechanics. However, there are two problems with this theory, firstly, if brain states are determined by quantum field theory then where is the neurobiological evidence for this? And secondly, the majority of presentations of this view do not distinguish between mental states and material states.

15.5 Penrose and the Brain as a Quantum Computer

One of Penrose's more speculative suggestions regarding human thought is that he believes human minds are non-algorithmic and therefore cannot be equaled by any form of artificial intelligence. Similar claims have been made by Godel[69,70] where Godel suggests "… the human mind (even within the realm of pure mathematics) infinitely surpasses any finite machine, or else there exist absolutely unsolvable diophantine problems". Penrose proposes that 'non-algorithmic' is the same as 'non-computable' in the sense that human thought cannot even be approximated by a formal operating system that is algorithmic. Searle[71] also believes that AI programs cannot 'think' in the same way that humans think irrespective of complexity but could possibly imitate consciousness, however, imitation doe not imply 'consciousness' (human consciousness).

Penrose believes that all mental processes are basically physical processes and that Godel's theorem that "no consistent algorithm can produce a proof of its own consistency" and "the totality of processes by which I can come to accept mathematical statements as true is either unknowable to me, or unsound" (Godel[70]). Penrose deduces from this that "Human mathematicians are not using a knowably sound algorithm in order to ascertain mathematical truth" (Penrose, 'Shadows of the Mind' 2.5). Penrose claims that behavior that imitates human consciousness will never be observed because of the reliance on algorithmic computation and its limitations that are not evident in our non-computational processing brains.

[67] Pessa and Vitiello 2003.
[68] Freeman and Vitiello 2006.
[69] Godel 1931.
[70] Godel 1951.
[71] Searle 1980.

Searle[71,72] argues that computation uses the manipulation of symbols, however, the symbols themselves are observer relevant and not part of reality ie; "Gravitational attraction, photosynthesis and electromagnetism are all subjects of the natural sciences because they describe features of reality, but the feature of being a bathtub or a five dollar bill exists only to observers and users".

The question "Is consciousness a computer program" becomes "Can a computational interpretation be assigned to specific brain processes that characterize consciousness?" In other words nothing is intrinsically computational and "computation exists only for some agent or observer who imposes a computational interpretation on some phenomenon". This implies that a computational model of consciousness cannot in itself be conscious (for example, the computational model of sitting in a bath of water does not leave us wet). I believe that Penrose makes the same mistake in his use of the Godel argument.

The argument that human mathematicians can come up with mathematical truths that cannot be proven through computation has been extensively debated for over 40 years without resolution (see Lewis,[73] Bowie[74] and Feferman[75]), however some experimental data suggests that human thought processes involving expert knowledge may be in part non-computational. Dreyfus[76] suggests, "It is not possible to capture expert knowledge in an algorithm, particularly where it draws upon general background knowledge outside the problem domain". There has been limited success in building expert knowledge into rule-based machines but recent progress has seen artificial neural networks capable of learning and recognizing complex patterns. Such networks do not follow explicit rules but can be approximated by an algorithm; however, if Penrose is correct and human thought processes cannot even be approximated by an algorithm then artificial neural networks do not provide a counter argument.

Penrose's arguments for non-computational human thought are at best vague and are an insufficient basis to propose that non-computational processes in microtubules (assisted by quantum gravity) are responsible for our inner subjective life. The experimental results from current neuroscience and the effects of decoherence must also be considered in any theory of mind. Koch and Hepp[77] suggest: "The critical questions we are here concerned with is whether any components of the nervous system – a 300 °K wet and warm tissue strongly coupled to its environment – display any macroscopic quantum behaviours, such as quantum entanglement, and whether such quantum computations have any useful functions to perform".

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[72] Searle 2007.

[73] Lewis 1979.

[74] Bowie 1982.

[75] Feferman 2006.

[76] Dreyfus 1972.

[77] Koch and Hepp 2006.

15.6 Decoherence

The main argument against large-scale macroscopic states and small-scale sub-cellular quantum states occurring in the brain is that the brain physiology is a wet, hot environment. Localized quantum states are prevented from linking or associating with other localized quantum states due to 'decoherence'. Decoherence looks at the way a quantum system interacts with it's immediate environment and in particular to the suppression of interference. A simple example of interference is a two-slit experiment (see 15.1.2) in which photons are fired at two narrow slits to a screen on the opposite side. Over a period of time an interference pattern emerges on the screen. If one photon at a time is used the interference pattern is still observed as a result of the photon interfering with itself. If one slit is covered or an act of measurement detects a photon at one of the slits then the interference pattern vanishes as only one component of the interference survives the measurement.

The time taken for the suppression of interference is termed the *decoherence time*. At the end of the decoherence time any coherence or phase relationships between components of the quantum system are destroyed. For example, the decoherence time for a 1 g mass at room temperature is less than 10^{-23} s and a dust grain interacting with background radiation in free space has only a few nanoseconds before any coherence is destroyed (Zurek[78]). The main issue for the formation of coherently linked quantum states in the brain is "whether the relevant degrees of freedom of the brain can be sufficiently isolated to retain their quantum coherence" (Tegmark[79,80]).

15.6.1 Decoherence Mechanisms in the Brain

The quantum-brain models examined previously rely on extended periods of coherence that approach classical neural processes. Stapp[34] suggests that some neural processes can be isolated from their environment whereas Zeh,[81,82] Zurek,[78] Tegmark,[79] Scott,[83] Hawking[84] and Hepp[85] argue that any quantum macrostates in the brain would be rapidly eliminated due to decoherence.

Decoherence times for typical sub-neural interactions were derived by Tegmark.[79,80] Tegmark found that decoherence times for ion-ion collisions was of

[78] Zurek 1991.

[79] Tegmark 2000a.

[80] Tegmark 2000b.

[81] Zeh 1970.

[82] Zeh 1999.

[83] Scott 1996.

[84] Hawking 1997.

[85] Hepp 1999.

the order of 10^{-20} s and for ion-water collisions was approximately 10^{-20} s and coulomb interactions with distant ions were found to have a decoherence time of approximately 10^{-19} s. Cognitive processes for speech, thought and visual processing have dynamic timescales of 1 s to 10^{-2} s. A single ion traversing a cell wall would have a decoherence time of approximately 10^{-14} s. This is obviously many orders short of the timescales associated with classical neural events and we are forced to accept the conclusion that any macroscopic neural or sub-neural event can be sufficiently explained using classical statistical mechanics.

15.6.2 Decoherence and 'Collapse' Approaches

It is useful to look at the role that decoherence plays in the collapse approaches to quantum mechanics due to Von Neumann and Penrose. Von Neumann[19] proposed that the collapse of a wave function is facilitated by an observer's consciousness. Collapse occurs whenever a permanent record is made in the visual cortex or the fluorescence on a screen or whenever consciousness is involved in an observation. Von Neumann assumes that there is an absence of interference between the components of the wave function. The presence of interference would affect the timing and the resulting classical outcome. For example, the collapse of the wave function in a two-slit experiment may occur anywhere from behind the slits to the screen. The reduction of any interference (decoherence) is thus essential to Von Neumann's collapse approach.

The Penrose and Hameroff[55] 'collapse' theory suggests that coherent superpositions of dimer states in microtubules can give rise to rise to excitations that travel along the dimmers at speeds greater than 1 m/s (Sataric, Tuszynski and Zakula[86]). Penrose and Hameroff believe that these long range coherent processes may act as a type of quantum computer in the brain and suggest that microtubules are the site of human consciousness ie; coherent superpositions in tubulin proteins give rise to a sub-conscious process neural event and the self-collapse of superposed states leads to a conscious neural event. In this 'Orch-OR' (Orhestrated Objective Reduction) model (see Smith[31]), the self-collapse is triggered by a (yet to be determined) quantum gravity mechanism (Penrose[29]). This is a type of "*pan-protopsychist*" solution to the 'hard problem'.

To prevent decoherence taking place there would be a requirement to maintain coherent superpositions of microtubule states for up to hundreds of milliseconds. Hagan, Hameroff and Tuszynski[87] claim that Tegmark did not look at superposed protein conformations which may extend the decoherence time to 10^{-5} to 10^{-4} s but the main problem with the 'Orch-Or' model is that any neural system that is isolated from the environment will eventually become 'conscious' if decoherence is prevented.

[86] Satari et al. 1993.

[87] Hagan et al. 2002.

15.6.3 Problems with Decoherence

A major problem with decoherence is to explain how a particular state is chosen in preference to another. We have two alternatives: either the system interacts with the immediate environment until probabilities associated with the system result in a collapse into one particular eigenstate. A measurement must be made to determine which state the system is in. As the system is already collapsed then the observer and the observation have no influence on the outcome. The system evolves without the help of a conscious observer. The other alternatively is to propose a decohered system that remains in a superposed state until a measurement is made and an outcome is observed. In this case it is the measurement itself that determines the outcome. Both situations predict that the system will be in one or another eigenstate.

Because of decoherence it is difficult to see how clusters of neurons, individual neurons or microtubules can exist in an extended, coherent linear superposition of quantum states at typical body temperatures. Any system larger than a molecule can be adequately described with classical probability calculus. It is the interaction between objects and their environment that brings about wave function collapse. The consciousness of an observer is unnecessary as the interaction with the environment rapidly destroys any coherent phase relationship between any macroscopically distinct states. The theory of decoherence can also be derived from within the formalism of quantum theory.

15.7 Conclusions

In my opinion, the role of the observer in quantum mechanics is still a matter of dispute. Any modification to the mathematical formalism is unlikely to improve the situation. The Copenhagen interpretation must accept the external world as physically "real", whereas, the "many worlds interpretation" (favored by Squires, Deutsch and Lockwood) provides a solution to the measurement problem but with a large amount of metaphysical baggage. The only "reasonable" variation of the "many worlds" theory that is closest to Everett's intentions is the "many minds interpretation" but this also comes with unresolved philosophical and scientific issues. The Heisenberg-Dirac interpretation, which is favored by Stapp, appears to sidestep the observer problem.

Large, high temperature items such as Wigner's friend, Schrödinger's cat, neurons and microtubules are unlikely to exist in a linear superposition of quantum states. Macroscopic systems are just not found in linear superpositions of coherent states and therefore may be adequately described by well-defined classical states. The paradox of Schrödinger's cat or Wigner's friend may be explained with the use of classical probability calculus and if this is the case then no observer is required to collapse the wave function.

I find Penrose's arguments unconvincing as cognitive studies show that formal reasoning in humans usually involves the use of heuristic shortcuts even amongst experts. There is also no evidence that physics is non-computable or that some yet to be determined quantum process is essential to cognition. Penrose and hameroff's view that awareness is the result of quantum computation in microtubules is difficult to accept and as Chalmers[88] in Psyche (1995) suggests; "..why should quantum processes in microtubules give rise to consciousness, any more than computational processes should?" Penrose also makes no mention of subconscious processing and argues that introspection must be conscious. However, the vast majority of mental processes are in fact subconscious (such as habituated stimuli, automatic skills and visual cognition).

The requirement due to decoherence that objects larger than a molecule cannot exist in a state of linear superposition is also a problem for the Penrose-Hameroff theory. The decoherence time to go from a superposition of states to a classically described state is orders of magnitude shorter than typical neuronal or sub-neuronal interaction times (this is also a problem for any theory of mind that requires quantum coherence such as the theories proposed by Stapp and Hodgson).

The concept of quantum type processes being responsible for higher brain function will remain a concept until validated by replicable experiments. It is more probable that a theory of brain function based on classical physics will adequately explain the integrative and holistic nature of conscious thought mentioned in the theories of Stapp, Hodgson and Penrose. A workable model may perhaps be found in future chaos or connectionist theories of mind. Regardless of choice, an understanding of consciousness will most likely require a similar paradigm shift found in the disciplines of philosophy, physics and neuroscience when confronted by Newton's gravity, Einstein's relativity and De-Broglie's 'matter-wave' hypothesis.

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