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Relative State or It-from-Bit: God and Contrasting Interpretations of Quantum Theory

In this article I explore theological implications of two contrasting interpretations of quantum theory: the Relative State interpretation of Hugh Everett III, and the It-from-Bit proposal of John A. Wheeler. The Relative State interpretation considers the Universal Wave Function to be a complete description of reality. Measurement results in a branching process that can be interpreted in terms of many worlds or many minds. I discuss issues of the identity of observers in a branching universe, the ways God may interact with the deterministic, isolated quantum universe and the relative nature of salvation history from a perspective within a branch.

In contrast, irreversible, elementary acts of observation are considered to be the foundation of reality in the It-from-Bit proposal. Information gained through observer-participancy (the 'bits') constructs the fabric of the physical universe ('it'), in a self-excited circuit. I discuss whether meaning, including religious faith, is a human construct, and whether creation is co-creation, in which divine power and supremacy are limited by the emergence of a participatory universe.

By taking these two contrasting interpretations of quantum theory seriously, I hope to show that the interpretation of quantum mechanics we start from matters theologically.

Key words: Quantum theory, theology, relative state, many worlds, it-from-bit, observer-participancy, human identity, divine simplicity, co-creation, salvation history.

Theological thinking about quantum mechanics has tended to focus on the issue of Special Divine Action in relation to the uncertainty principle and quantum measurement.[1] Inevitably, this work has been inconclusive, but has nevertheless succeeded in opening up the discussion. There is now a greater realisation that the implications of quantum mechanics for our conception of the nature of reality will impact on our theological thinking. At the heart of the problem of interpretation of the theory is the relation between the microlevel and the macrolevel of reality. If the microlevel is as quantum mechanics suggests, how come the macrolevel is experienced as it is?

1 Russell, R.J., Clayton, P., Wegter-McNelly, K., Polkinghorne, J. (eds.) *Scientific Perspectives on Divine Action Volume 5*, Vatican Observatory Publications (2001); Saunders, N. *Divine Action and Modern Science*, Cambridge: Cambridge University Press (2002), pp. 94-172.

The orthodox Copenhagen interpretation, as first proposed by Niels Bohr, focuses on the idea that the measurement of a quantum system in an indeterminate state involves its interaction with a classical measuring device. It is the intervention of the measuring device that results in a determinate phenomenon being registered. However, the Copenhagen interpretation leaves open the questions of when and how the transition from indeterminate state to determinate result occurs. Seeking an explanation for this transition in terms of physical processes has attractions. For example, the phenomenon of decoherence, caused by environmental effects such as background radiation, suggests that the relationship between the micro- and macro-worlds is very subtle, but is unable to explain the fundamental issue of why a particular result occurs on a particular occasion.[2]

Other interpretations lead to more philosophical problems. An instrumentalist approach ignores the problem by denying the validity of seeking explanation;[3] a realist perspective implies unknown variables[4] or many worlds;[5] ascribing a central role to the consciousness of the observer leads to a fundamental dualism.[6] These issues reflect the challenge of quantum mechanics over the last century to the mechanistic view of the world, in which the concepts of causality, separability of objects and their influences, and the objectivity of phenomena are central. The fact that in quantum mechanics predictions are probabilistic,[7] that the principle of separability is violated[8] and that phenomena that are actually observed depend on the role of the observer,[9] suggests that the philosophical and conceptual framework in which science has so successfully developed needs to be extended before a satisfactory understanding of quantum mechanics can be gained. This does not mean a rejection of the insights of classical physics, but their inclusion in a larger perspective as a special case, applicable in certain circumstances.[10]

Here the aim is not a full-scale review of the interpretations of quantum mechanics and the philosophical framework they imply, but an exploration of

2 Polkinghorne, J. *Quantum Theory: A very short introduction*, Oxford: Oxford University Press (2002).

3 Carnap, R. *Philosophical Foundations of Physics: an Introduction to the Philosophy of Science*, New York (1966).

4 Albert, D.Z. *Quantum Mechanics and Experience*, Harvard (1992).

5 Deutsch, D. *The Fabric of Reality*, Harmondsworth: Penguin (1997).

6 Schrödinger, E. 'The present situation in quantum mechanics (1935) A translation of Schrödinger's Cat Paradox paper', Trimmer, J.P (trans.), in Wheeler, J.A. and Zurek, W.H. (eds) *Quantum Theory and Measurement*, Princeton (1983) pp. 152-167; Wigner, E.P. 'Remarks on the mind-body question', in Good, I.J. (ed.), *The Scientist Speculates*, London: Heinemann (1961).

7 Dirac, P.A.M. *The Principles of Quantum Mechanics 4th Edition*, Oxford: Oxford University Press (1958).

8 Redhead, M. 'The tangled story of nonlocality', in Russell, R.J. et al. *op. cit.* (1), pp. 141-158; Chiao, R.Y. 'Quantum nonlocalities: experimental evidence', in Russell, R.J. et al. *op. cit.* (1), pp. 17 – 40.

9 Bohr, N. 'Can the quantum mechanical description of physical reality be complete?', *Physical Review*, (1935) 48, 696 – 702.

10 d'Espagnat, B. *Reality and the Physicist*, Cambridge: Cambridge University Press (1989).

theological issues raised by two contrasting interpretations: the Relative State formulation of Hugh Everett III,[11] and the It-from-Bit proposal of John A. Wheeler.[12] The difference between these two approaches lies in the distinctiveness of their interpretation of quantum measurement. In comparison with the Copenhagen interpretation, the Relative State formulation treats the combination of microscopic system and macroscopic measuring device as one quantum state, whereas the It-from Bit proposal, at the other extreme, regards only registered phenomena as elements of reality. Consideration is first given to the standard formulation of the measurement problem as set out by von Neumann.[13] The approach I shall adopt is to take these interpretations seriously on their own merits, and allow theological questions to surface, rather than impose a theological agenda.

The Measurement Problem

In the standard formulation of quantum mechanics, von Neumann proposes two dynamics of change.[14] The first is the time-dependent dynamics of the Schrödinger wave equation. According to this equation, the wave function that describes a quantum state changes deterministically with time, as long as it remains isolated and undisturbed by measurement. In this respect, quantum mechanics is as deterministic as classical mechanics. If the state of a system at time T_0 is known, then it will evolve according to the Schrödinger equation to an equally known state at T_1. As with Newton's laws of motion, this process can be run mathematically both forwards and backwards in time.

The second dynamic is the collapse of the wave function when a measurement is made, and the change here is instantaneous, non-linear and apparently stochastic. It would be helpful here to explain briefly aspects of the mathematical formalism of quantum mechanics. The wave function is expressed as a vector, which at least in conventional space, can be thought of as having magnitude and direction. By analogy with a coordinate system in space, it is possible to define a vector in terms of base vectors, which form the basis of the vector space. For any vector space of two or more dimensions, there are an infinite number of possible bases, any one of which in principle can be selected. There must be as many base vectors as dimensions in the vector space, and they must

11 Everett III, H. 'Relative state formulation of quantum mechanics: Thesis submitted to Princeton University March 1 1957', in DeWitt, B.S. and Graham, N. (eds.) *The Many Worlds Interpretation of Quantum Mechanics*, Princeton: Princeton University Press (1973); Everett III, H. 'The theory of the universal wave function', in DeWitt, B.S. and Graham, N. (eds.) *The Many Worlds Interpretation of Quantum Mechanics*, Princeton: Princeton University Press (1973).

12 For an interesting autobiography of Wheeler, see: Wheeler, J.A. *Geons, Black Holes and Quantum Foam*, W.W. Norton and Company (2000).

13 von Neumann, J. *Mathematical Foundations of Quantum Mechanics*, Princeton: Princeton University Press (1955).

14 *ibid.*

be mutually orthogonal and of unit length. The vector is then built up as a weighted sum of base vectors. In quantum mechanics, the weighting is given by complex numbers of the form $z = a + ib$, where i is the square root of minus one. Now a vector can be transformed into a new vector by the application of an operator. If the new vector is a simple numerical multiple of the original, it is known as an eigenvector of the operator. In quantum mechanics, an operator that generates a set of eigenvectors defines an observable, that is a measurable property of the quantum system.

Mathematically the dynamics of collapse is expressed as the state vector jumping or collapsing onto one of the set of eigenvectors generated by an operator acting on the state vector. The probability of collapse onto a particular eigenvector is given by its squared amplitude,[15] which is the complex weighting factor multiplied by its complex conjugate, i.e. $zz^* = a^2 + b^2$, where the complex conjugate $z^* = a - ib$.

Von Neumann referred to this non-linear collapse dynamic as Process I, and the linear dynamic of the time-dependent, deterministic evolution of an isolated wave function as Process II. He did not specify when Process I occurred during the process of measurement, but once that question is asked, problems arise with this rather neat scheme. Is Process I a purely physical process, in which case does it have a physical cause, or is it irreducibly stochastic? Alternatively, does Process I occur when a conscious observer takes notes of the measurement, in which case what happens to the system being measured up to that moment of registration? Furthermore, what status in reality should be given to each of these processes? Is the wave function itself a fundamental description of reality, or is the collapse dynamic, and the determinate state that is observed as a result, the basis of reality?

The Relative State

Hugh Everett III[16] set out to produce what he called a metatheory from which standard quantum mechanics could be deduced. He considered that only von Neumann's Process II was necessary for establishing his metatheory and Process I could be subsumed within it.

The first conceptual leap in Everett's programme is to consider both the object and the observer as elements of the one enclosed isolated system. He argues that if there is something outside that system that interacts with the system, then a larger system can be imagined that encloses the external influence within itself. If it is suggested that no perfectly isolated system can exist,

15 This is known as Born's Rule, after Max Born, who originally proposed this interpretation of the complex weighting factors of the wave function.

16 For a full discussion of the Relative State Theory of Hugh Everett III, see: Barratt, J.A. *The Quantum Mechanics of Minds and Worlds*, Oxford: Oxford University Press (1999), pp. 56 – 91.

then his answer is that the whole universe is itself enclosed and isolated. The Universal Wave Function, y, describing the quantum state of the whole universe is a necessary conception in Everett's scheme. y would be so unimaginably complex as to be inexpressible.

Consider then both object and observer as comprising such an enclosed system, with no external influences. Separately, they will each be described by a wave function, but here we are thinking of a combination of the two, both object and observer. Such a combination of wave functions is equivalent to adding two systems together to make a single whole. Mathematically, this is achieved by forming the tensor product[17] of the state vectors describing the wave functions, by following certain mathematical rules. What results is a new wave function, which is made up of a set of pairings of each eigenvector of the object with each eigenvector of the observer. Each pairing is then an eigenvector of the combined system, with its own complex weighting factor. According to Everett 'a constituent sub-system cannot be said to be in any single well-defined state independently of the remainder of the system'. From this he defines the concept of relative state: 'To any arbitrarily chosen state for one sub-system there will correspond a unique relative state for the remainder of the composite system.'[18]

Where there are two interacting sub-systems, the chosen state of one will be strongly correlated with the relative state of the other. Measurements are an example of interactions between sub-systems that produce strong correlations.

For any chosen eigenstate of measuring device within the composite system, there is thus a relative state of the remainder of the system. To take a simple case, consider a measurement of x-spin performed on a single electron using a Stern-Gerlach apparatus.[19] The indeterminate x-spin of an electron will be in a complex weighted superposition of 'x-spin up' and 'x-spin down'. Before a measurement is made, that is, before the interaction with the electron, the measurement system can be assumed to be in a determinate state of 'being ready to make a measurement', corresponding perhaps to being re-set. After the interaction has occurred, the whole composite system of electron plus Stern-Gerlach apparatus cum recording device, becomes a complex weighted superposition of entangled states, which may be expressed as follows:

> 'State of composite system' is in a superposition of the product of 'a measuring system registering x-spin up' and 'the electron in x-spin up' multiplied by a complex weighting factor *plus* the product of 'a measuring system reg-

17 For a helpful explanation of Tensor Mathematics, see: Penrose, R. *Shadows of the Mind*, Vintage (1995), pp. 287–289.
18 Everett III, H. *op. cit.* (14), p. 142.
19 The spin of the negatively charged electron produces a magnetic field, the polarity of which depends on the direction of spin. A Stern-Gerlach apparatus utilises a non-uniform magnetic field, which deflects an electron as it passes through the apparatus, according to the direction of spin of the electron.

istering x-spin down' and 'the electron in x-spin down' multiplied by another complex weighting factor.

For 'measuring system registering x-spin up' the relative state of the electron is 'x-spin up' and for 'measuring system registering x-spin down' the relative state is 'x-spin down'.

Everett maintains that it would be meaningless to ask what absolute state of spin the electron is in, because the state of spin only has meaning when associated with a particular state of the measuring device. He suggests that 'so far as the complete theory is concerned all elements of the superposition exist simultaneously, and the entire process is quite continuous'.[20] Measurement as such cannot separate out a particular eigenstate of the object being measured. The measurement consists of the interaction of two sub-systems that form an entangled state in superposition, with no collapse of the wave function of the object occurring.

Everett attempts to define an observer in terms of the observer's past experience. For an instrument, this consists of the recordings of past measurements stored in its memory. The uniqueness of an observer is thus related to the sequence of recordings in the observer's memory. Each recording in the memory corresponds to the observer's recording the object in a particular state within the sequence of observation events. So in the example above, concerning the measurement of x-spin, the measuring system registering x-spin up will have an element corresponding to its 'x-spin up' in its memory, and similarly for its other eigenstates. Already after one measurement, the two eigenstates of the measuring system, while still in superposition within the composite system, will be differentiated by what is stored in the memory of each eigenstate.

Now, a second measurement performed on a second electron within the composite system will result in four possible sequences of elements in the memory of the measuring device, corresponding to different states as follows:

(1) x-spin up; x-spin up
(2) x-spin up; x-spin down
(3) x-spin down; x-spin up
(4) x-spin down; x-spin down.

Everett writes as if each of these sequences would represent an observer state in a superposition of states, identified by its past history of recording measurements. He refers to a branching process that occurs with each interaction of the object and the measuring device. With each interaction the observer state branches into a number of different states, each branch representing a different outcome of the measurement of the object into one particu-

20 Everett III, H. *op. cit.* (14), p. 144

lar eigenstate. Von Neumann's Process 1 only has significance from the point of view within a branch, from the subjective experience of the observer in that particular eigenstate, and with that particular sequence of memories. However, from a perspective outside the composite system each branch, that is each eigenstate of the observer, will exist simultaneously.

Everett clarified his position on the simultaneous existence of the branches in a note added in proof to his article,[21] in which he attempted to answer critics who could not identify in his scheme anything relating to the transition from possible to actual with respect to measurement. His answer was to assert that such a transition was unnecessary in his theory in order to be consistent with experience, because all branches, all elements of the superposition are equally actual. There is no need to suppose that all but one of these actualities is destroyed on measurement, since each element of a superposition evolves independently of the rest. In other words, the branches do not affect each other, and the observer of one branch is totally unaware of the other branches and of 'any splitting process'. The branches are orthogonal, not parallel, and therefore no communication can take place between them. It is only in interference phenomena that the existence of orthogonal branches can be inferred.

Worlds and Minds

Everett's metatheory can be developed in various ways, under three broad headings: the Bare Theory,[22] the Many Minds Theory[23] and the Many Worlds Theory.[24] Each of these approaches regards the Universal Wave Function as the total physical reality of the Universe, but they differ in the interpretation they give to the branching process.

In the Bare Theory, observers are under the impression that they get determinate results from measurements, whereas the underlying reality is of a composite system of observer and observed in a complex superposition of states. The perception of a state's being determinate, or the perspective within a branch, is really an illusion. To speak of an illusion presupposes the existence of a sentient, conscious observer, capable of false belief. The problem for the Bare Theory is that it does not explain sentience within the terms of the Universal Wave Function, but rather makes the further assumption that sentience is a real, determinate property of observers. Furthermore, if the Bare Theory is followed through rigorously, it challenges the notion of the authority of the observer's experience. Measurements, indeed the registering of any phenome-

21 Everett III, H. *op. cit.* (14), p. 146–147 (note added in proof).
22 Barratt, J.A. *op. cit.* (20), 92–120.
23 Lockwood, M. *Mind, Brain and the Quantum*, Oxford: Basil Blackwell (1989), pp. 219–239.
24 Deutsch, D. *op. cit.* (6); DeWitt, B.S. 'The many-universes interpretation of quantum mechanics', in DeWitt, B.S. and Graham, N. *The Many Worlds Interpretation of Quantum Mechanics*, Princeton: Princeton University Press (1973), pp.167–218.

non whatsoever, cannot be trusted, and there is a radical undermining of integrity.

In one version of the Many Minds interpretation,[25] an infinite number of minds, that are each determinate and not in superposition, is ascribed to each individual observer. When a measurement is made, each mind registers one of the possible results predicted by the standard theory. Each mind then represents a different perspective of the physical world, and the many-minded observer would therefore have an infinite number of simultaneous, mutually exclusive perspectives. However, according to each mind, its own perspective will be determinate. This version of the Many Minds approach makes the fundamental assumption that the observer has a determinate mental state, while the Universal Wave Function has to do only with the physical world. This approach is thus overtly dualistic.

Lockwood's version[26] of the Many Minds Theory attempts to dispense with the inherent dualism with the idea that the observer's mind splits as it registers an observation. In this respect it is the mirror image of the Many Worlds Theory. Instead of the observation splitting the world, here the world splits the mind.

The Many Worlds Theory is in fact a whole family of interpretations, with subtle differences among them.[27] The common thread of these interpretations is that independent, concrete, physical reality is ascribed to the objects of each branch of the Universal Wave Function, so that each branch bears a correspondence to what is termed a world or a universe, and that the Universal Wave Function describes the whole multiverse or quantum universe.

If we take as a model universe the situation described above of an electron and a measuring apparatus set up to measure x-spin, then, upon measurement, that universe will have split into two: one universe consisting of a copy of the electron determinately in x-spin up and a copy of the apparatus registering x-spin up; and the other consisting of another copy of the electron determinately in x-spin down and a copy of the apparatus registering x-spin down. Deutsch[28] boldly extrapolates from referring to copies of microscopic objects inhabiting different worlds, to copies of familiar macroscopic objects inhabiting them as well. But as Butterfield[29] points out, macroscopic objects are made up of microscopic constituents, copies of which inhabit many worlds also. This would force us to conjecture continuously multiple worlds, each of which is

25 Albert, D.Z. *op. cit.* (5), pp. 130 – 133.
26 Lockwood, M. *op. cit.* (27).
27 For helpful discussions on this point see: Butterfield, J. 'Some worlds of quantum theory', in Russell, R.J., Clayton, P., Wegter-McNelly, K., Polkinghorne, J. (eds.), *Scientific Perspectives on Divine Action* Volume 5. Vatican Observatory Publications (2001) pp. 111–140.
28 Deutsch, D. *op. cit.* (6).
29 Butterfield, J. *op. cit.* (32).

inhabited by a copy of the familiar object. Some of these copies are almost identical, differing by just one microscopic state. Others will be radically different. Even the model universe above would therefore in reality be a multiverse of prodigious complexity.

The sheer 'dizzying ontology'[30] of the multiverse has led commentators to dismiss this theory as highly implausible, but the main argument in its favour is that it claims not to introduce any new elements into Quantum Theory; in fact it assumes that Quantum Theory is indeed a complete description of reality. Neither does it introduce the fundamental dualism required by the Bare Theory or certain versions of the Many Minds Theory.

Implications

These varied approaches to interpreting Everett's Relative State Theory indicate the level of ambiguity of his metatheory. There are two technical problems that are not addressed by these interpretations: the difficulty of supposing that all arbitrary resolutions of the Universal Wave Function are legitimate, and the difficulty of interpreting probability amplitudes.

Everett maintained that a preferred basis should not be necessary in deriving his metatheory, because it would introduce a new element into the theory.[31] Essentially, in the standard formulation, the observer can arbitrarily choose the basis on which to resolve the wave function, although many bases will not result in physically meaningful quantities. Everett wanted to retain this freedom in his metatheory, but unless a basis is chosen that defines measurable physical quantities, branches will not be inhabited by familiar objects, and recognisable worlds would not result. The Many Worlds Theory appears then to require a preferred basis in order to define worlds.

The interpretation of the complex weighting of each eigenstate of the superposition of the composite system in Everett's Universal Wave Function is also problematic. In the standard formulation the squared moduli of these factors represent the probabilities of obtaining certain outcomes of measurement. In Everett's formulation the place of these weighting factors is unclear to say the least. If all eigenstates of the superposition exist or are actual, what does it mean to ascribe a probability to each actuality? Ingenious attempts to give a different meaning to the weighting factors, as described by L. Vaidman,[32] all prove to be problematic. Classically, probability can be defined in terms of fre-

30 The phrase is Butterfield's (*ibid*). Many superlatives have been used to describe the multiverse, leading many commentators to dismiss the theory on the criterion of parsimony (Ockham's Razor). See, for example, Polkinghorne, J. *op. cit.* (3), pp. 52 – 53.
31 Everett III, H. *op. cit.* (14), p. 146.
32 Vaidman, L. 'The many-worlds interpretation of quantum mechanics', in *Stanford Encyclopaedia of Philosophy*, http://plato.stanford.edu/entries/qm-manyworlds/ 2002.

quency of occurrence and by analogy it has been proposed that probability can be introduced into the Many Worlds interpretation by counting the number of worlds in which a particular outcome of a measurement occurs. If there are multiple copies of a type of world, and an identical experiment is performed in each, then the probability of a certain result occurring is proportional to its frequency across all the identical worlds. There is, however, doubt as to whether such probabilities are the same as those predicted in quantum mechanics from the application of Born's rule. Furthermore, probability is a more subtle concept than its definition based on counting alone implies. In response to this, Vaidman suggests that probability in the Many Worlds interpretation represents a measure of existence. Although within a particular world, it feels as real as in any other world, its measure of existence quantifies its ability to interfere with other worlds. This measurement of existence is then related to what Vaidman calls an ignorance probability, which is the subjective expectation that an observer has of ending up in a certain world before measurement is made.

These technical difficulties apart, there remain interesting and challenging philosophical and theological questions raised by the Relative State Theory and its interpretations. Here I shall touch upon some of the implications of the Many Worlds interpretation.

Identity of objects and observers

Fundamental problems concerning the identity of objects and observers occur when we consider the splitting of worlds. A world is defined at an instant of time, but at another instant the number of worlds will be different due to splitting. Are the worlds at one instant related at all to the worlds at another instant? In the model universe of the single electron and the measuring apparatus,[33] it is possible to regard each of the two universes created by splitting as inhabited by copies of the electron and measuring apparatus. Apart from the difference of the x-spin, there will be a family resemblance between the copies in each universe. Alternatively, the measuring apparatus may be thought of as existing in both universes, but with mutually exclusive properties of registering x-spin up in one universe and x-spin down in the other. However, we cannot have a sense of one object inhabiting many worlds or of copies existing in each different world, because we ourselves are only aware of existing in one world (although copies, or different states of ourselves may exist in other worlds).

The Many Worlds Theory challenges our everyday notions of human identity. What does it mean that before the measurement takes place, 'I' reside in one world, but afterwards there are different states of 'me' residing in 'many

33 See pages 159 and 160 above.

worlds'? Vaidman[34] argues that it is wrong to ask to which one of these 'I' correspond, because 'I' correspond to all. Furthermore, individual states into which 'I' split will each have a subjective identity, referred to as 'I'. There are difficulties with this view, in that it relativises identity: 'I' am defined in terms of the branch to which 'I' belong, and also in that it ignores the question of how 'I' am related to 'me' in other branches. Presumably 'I' share a common identity with other versions of 'myself' up to the common branch before 'my' own, and will share what 'I' am now with future versions. Unless one particular version of 'me' is selected at one instant, as in some way definitive of 'my' identity, every single version of 'me' is no more and no less the real 'me'. 'My' identity within a branch will be defined in terms of 'my' relationships within the relative state of that branch. Awareness of other identities in other branches is ruled out. If all future versions of 'me' will inevitably come to pass, because all branches are real, there is no way in which 'I' can help to shape 'my' own future identity, rather 'I' will be a product of multiple fates.

In the Christian tradition, human identity and dignity have been understood in terms of being made in the image of God. In the multiverse, all copies of 'me' would need to be seen as relating to the divine image. It does not seem very satisfactory to think of the divine image being split in the same way as a world is split by branching. In so far as all the different identities of copies of 'me' bear a family resemblance, and are related to one another in a shared previous history, rather like a family tree, then the divine image may be understood as referring to that family resemblance, rather than merely to individual copies. 'My' human dignity, deriving from the divine image, is assured through that family resemblance, and not through 'my' personal possession of that image. It could be argued that this is not so far from the proper understanding of human beings in the classical universe participating in the divine image as members of the whole human family.

God and the Quantum Universe

The Relative State Theory presupposes that the Universal Wave Function is the fundamental, complete description of reality. The Quantum Universe is necessarily an isolated system, because any interaction from outside the system will lead to further entanglement of the wave function of the Quantum Universe with that of the system with which it is interacting. Does God interact in any way with the Quantum Universe? Any action of God that influences the evolution of the Universal Wave Function could be regarded as an external influence, and the Quantum Universe would then no longer be isolated. Is it possible to think of the Quantum Universe being entangled with God? The nature of this entangled state would be very difficult to define, but it would necessarily draw the Quantum Universe into an intimate, multi-dimensional

34 Vaidman, L. *op. cit.* (37).

relationship with God. God would be entangled with every conceivable eigenstate of the Universal Wave Function. One model of imagining this entanglement would be analogous to Lockwood's splitting minds interpretation.[35] With each interaction of the mind with the Universal Wave Function, the mind splits into orthogonal determinate states, each state perceiving the state of the world relative to its state. In a similar way, God would relate to the Universal Wave Function in an infinite number of determinate states, each relative to the eigenstate of the Universal Wave Function with which it is entangled. God could then be thought of as existing as a superposition of different determinate states, brought into being through the interaction with the Quantum Universe. The implication of this interaction is that the Universal Wave Function splits God, just as in Lockwood's interpretation, the world splits the mind, and that each world would effectively have its own version of God.

But unlike a quantum system, there are strong arguments in the Christian tradition for rejecting any idea that God exists in superposition. For example, Aquinas, following a long Christian tradition, asserts that God is simple.[36] Divine simplicity, according to Aquinas, follows from his immutability, his individuality, and his non-dependency, all of which are due to God's existing as pure being.[37] From this point of view, an entangled state of God and the Quantum Universe cannot be thought of as dividing God, but implies that God is wholly present to each and every branch of the Quantum Universe. If this argument were pressed, we would have to accept that although every world relates to the same God and is a creation of God, not every world would be created good, as our world is considered in Genesis chapter one. Indeed, there will be some worlds in which there will be a superabundance of evil and suffering, and others where there will be no life at all. In the Christian tradition, creation is good because the creator is the greatest good. In the Quantum Universe, God would be responsible for all worlds, good, evil and amoral. It is hard to argue that a good God created many worlds that are evil, or in which life is incapable of emerging, so that one at least will be good. The problem of evil is multiplied many times over in the Quantum Universe.

A further property of the Universal Wave Function is that it is deterministic. Quantum indeterminism only applies within a branch, and is a subjective perspective from within that branch. From a global perspective, perhaps we would say from a Divine perspective, indeterminism has no place. Everything that can happen will happen in one branch of the Quantum Universe or another. From a perspective within a branch, what happens may appear miraculous, but from the Divine perspective it is part of the deterministic evolution of the Universal Wave Function. God cannot therefore be thought of as acting in a special way, either within a branch, or with respect to the Quantum Uni-

35 Lockwood, M. *op cit.* (27).
36 Thomas Aquinas *Summa Theologica*, 1a, 3,1; 1a, 3,2; 1a, 3,3.
37 Davies, B. *Aquinas*, Continuum (2002), pp. 54–61.

verse as a whole. If God created it as a deterministic system, then he would contradict his own laws by so acting.

History

The Universal Wave Function, according to Everett, evolves deterministically by a process of branching, in which all possible eigenstates exist in orthogonal relative states. In this scheme, history, understood as an irreversible consequential sequence of events, is at most a relative concept, only applicable within a specific branch, and related to the memory structure of the eigenstate of the observer relative to that branch. History therefore does not carry an objective meaning, independent of the observer or person who is telling the history. The telling of the history will have only a subjective significance, because there will be any number of alternative histories relative to the infinite number of branches, or worlds or minds that actually exist. The fundamental challenge here to Christian theology is how we even begin to speak about salvation history or divine purpose, and especially the incarnation, in any absolute sense. Do the determinate events of the incarnation have meaning or consequences other than within the branches that succeed the one in which those events determinately occurred? Or is salvation history unique to the world that we inhabit, and do other worlds have different divine purposes and possibly none?

If salvation history is unique to our world within the Quantum Universe, the experience of good and evil, and of human suffering, and the divine revelation and sense of meaning that inform our theological understanding would also be relative to the world we inhabit. To reach beyond the limitations of our knowledge or experience of other worlds, theological reflection must engage with imagination, drawing upon art and literature,[38] in order to explore God in the Quantum Universe. Inevitably, such theological understanding would be highly speculative.

It-from-Bit

If Hugh Everett III took as his starting point the sufficiency of the wave function of an enclosed isolated system in giving a complete account of the dynamics of the system (his Process II), John A. Wheeler takes as the basis for his discussion of the nature of reality a quotation from Niels Bohr: 'No elementary phenomenon is a phenomenon until it is a registered phenomenon.'[39]

For Wheeler it is the notion of measurement that is central to quantum mechanics, corresponding to von Neumann's Process I. Measurement is to do

38 See, for example, Philip Pullman, *His Dark Materials*, Scholastic 1997. One of Pullman's influences is William Blake, whose imagination also roves through a many-layered universe.
39 Quoted in Wheeler, J.A. 'Law without law (1979 – 1981)', in Wheeler J.A. and Zurek, W.H. (eds) *Quantum Theory and Measurement*, Princeton: Princeton University Press (1983), pp. 182–213.

with the registering of a phenomenon, and need not involve a conscious human observer. It is the irreversible event of registering that transforms potentiality into actuality. The wave function, so often thought of as the real subject matter of quantum mechanics, really sets out all the possibilities that might be the case, whereas the act of measurement selects just one of these possibilities and renders it actual. In quantum mechanics, the process of turning potentiality into actuality is formalised as a stochastic process, and the precision of quantum mechanics lies not in predicting with certainty what will be the outcome of a measurement, but in setting out the probability of a certain outcome occurring.

The nature of measurement of a quantum system is like posing a question. There is a choice of questions that may be asked of a system and a particular question is asked by the particular way a measuring device is set up. For Penrose[40] all measurements in quantum physics can be put in the form of yes-no questions; questions that have simple binary answers, which in actual experiments are to do with whether or not a particular phenomenon has been registered.

Wheeler draws out the analogy between the ways a computer works and the binary information – the 'bits' of information – gained in the process of measurement of the quantum system as the answers to the questions that are posed to it. The main difference between the two is the predictability of a computer compared to the stochasticity of quantum measurement, but, Wheeler suggests, 'it is not unreasonable to imagine that information sits at the core of physics, just as it sits at the core of a computer…The universe and all that it contains ('it') may arise form the myriad yes-no choices of measurement (the 'bits').'[41]

Delayed Choice

How does the idea of It-from-Bit work? Wheeler[42] gives the example of observing light from a distant quasar, with an intervening galaxy between it and earth, of which there is at least one example.[43] Light, sent out in different directions from the quasar, is brought together again by the gravitational field of the galaxy, so that the two pathways of light reach the earth together, giving the appearance of two stellar objects. Wheeler compares this situation to that of

40 Penrose, R. *op. cit.* (21), pp. 282–286
41 Wheeler, J.A. *op. cit.* (16) p. 340.
42 Wheeler, J.A. 'Delayed choice experiments and the Bohr-Einstein dialogue', in Wheeler, J.A. *At Home in the Universe*, AIP Press (1994), pp. 112-131; J. A. Wheeler, 'Genesis and observership', in Wheeler, J.A. *At Home in the Universe*, AIP Press (1994), pp. 23-46; J. A. Wheeler, 'It from bit', in Wheeler, J.A. *At Home in the Universe*, AIP Press (1994), pp. 295-312.
43 *ibid*. Wheeler cites the example of quasars 0957 + 561 A,B, which were once thought to be two distinct objects, but are now thought to be one object producing two images because of a gravitational lens effect due to a galaxy situated between the quasar and earth.

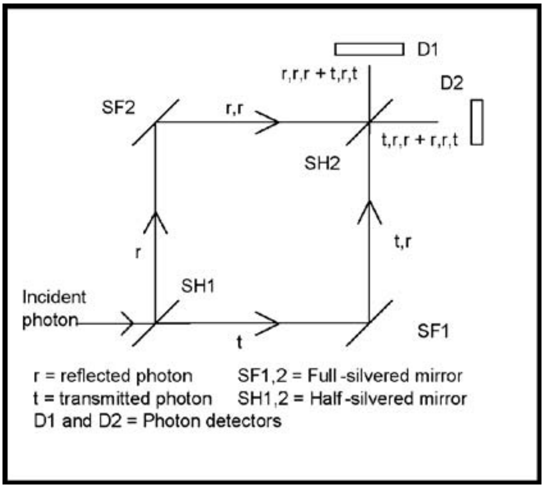

Figure 1: Two-path thought experiment.

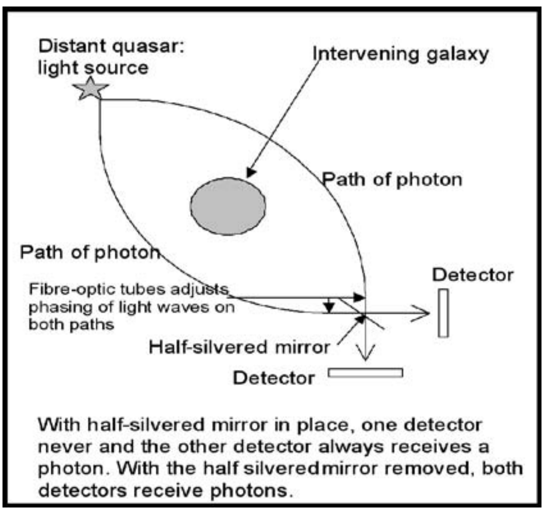

Figure 2: Delayed-choice thought experiment with light from a distant quasar.

the two-path thought experiment (Figure 1),[44] with the galaxy in the place of the two full silvered mirrors (Figure 2). In passing, it is interesting to note that the same experiment is used to support the Many Worlds interpretation.[45] This is a good example of the way evidence from quantum physics is open to differing interpretations.

44 For accounts of this experiment, see: Penrose, R. *op. cit.* (21), pp. 260-263; Albert, D.Z. *op. cit.* (5); Barratt, J.A. *op. cit.* (20), pp. 8-11.
45 Deutsch, D. *op. cit.* (6), p. 205.

In the two-path experiment, a half-silvered mirror (S_{H1} in Figure 1) is set precisely at 45° to a parallel beam of monochromatic light. Transmitted light travels to a fully-silvered mirror (S_{F1}) where it is reflected to a second half silvered mirror (S_{H2}) and reflected light travels to another fully-silvered mirror (S_{F2}) where it is reflected to the second half-silvered mirror, the path of both the transmitted and reflected light being equal in length. Light detectors (D_1 and D_2) are placed beyond the second half-silvered mirror. Classically, it may be thought that half of the photons are transmitted and half reflected, but this view breaks down when the intensity of the beam is reduced so that one photon is incident at a time. In the classical picture, the photon would be considered as either being transmitted or reflected, and therefore not in a superposition of pathways. It would then be expected to follow one of the determinate routes through the apparatus, and being either transmitted or reflected at the second half-silvered mirror, would be registered by each detector in about half the trials.

In quantum mechanics, it is supposed that the photon is in a superposition of following the transmitted pathway and the reflected pathway after interacting with the first half-silvered mirror. If we also assume a phase change of a quarter (an arbitrary amount for simplicity, and a property of the mirrors) at each instance of reflection, then the superposed pathways of the photon can be described as follows:

1) At S_{H1} incident photon proceeds to
'transmitted' plus 'reflected, with a quarter phase change'.

2a) At S_{F1} 'transmitted' proceeds to
'transmitted, reflected, with a quarter phase change'.
2b) At S_{F2} 'reflected with a quarter phase change' proceeds to
'reflected, reflected, with a half phase change'.

3a) At S_{H2} 'transmitted, reflected with a quarter phase change' proceeds to
'transmitted, reflected, transmitted, with a quarter phase change' plus
'transmitted, reflected, reflected, with a half phase change'.
3b) At S_{H2} 'reflected, reflected with a half phase change' proceeds to
'reflected, reflected, transmitted, with a half phase change' plus
'reflected, reflected, reflected, with a three quarter phase change'.

4a) The 'transmitted, reflected, reflected, with a half phase change' and the 'reflected, reflected, transmitted, with a half phase change' will emerge from S_{H2} in phase, will constructively interfere and will therefore be registered by D_2.
4b) The 'transmitted, reflected, transmitted, with a quarter phase change' and the 'reflected, reflected, reflected, with a three quarter phase change' will emerge from S_{H2} exactly half out of phase, will destructively interfere and will therefore not be registered by D_1.

Wheeler then supposed that after the photon has left the source, and before it arrives at the second half-silvered mirror, the experimenter may have a change of mind about the experimental set up, and decide to remove the second half-silvered mirror. He called this a delayed choice experiment. In this case detector 1 would detect a photon that is transmitted and then reflected, and detector 2 again would detect one that is reflected and then reflected. No interference will then occur, and it will appear as if a photon has determinately travelled on one path or another, rather than in a superposition of both paths. Changing the experimental set-up after the photon has left the light source shows that the result is dependent on the actual observation that is made.

When the quasar with an intervening galaxy is observed, what is actually recorded would depend similarly on the choice of the way the apparatus is set up. If the half-silvered mirror is not included in the experimental set-up, there will be no interference and both detectors may register the arrival of a photon, which we may infer will have travelled either on one side of the galaxy or on the other side. Alternatively, the photon may be registered after it has passed through the half-silvered mirror. If the relative phasing of the light waves on each path is arranged accordingly, destructive interference will prevent one of the detectors from receiving the photon, and constructive interference will result in the other detector receiving the photon (see Figure 2). In this case, the photon will be in a superposition of travelling on the two paths either side of the galaxy. The light from the quasar would have taken many thousands of years to reach the earth, and our decision as to how to measure the light, whether through a half-silvered mirror or not, would be made as the photon has nearly completed its journey.

The choice of which measurement is made determines what can be said about the pathway of the light photons, whether one has travelled by one path or both paths. The observer, Wheeler maintains, is inescapably involved in bringing about that which is observed. The observer-participant is involved in what Wheeler describes as an elementary act of creation, in which a phenomenon is brought into actuality by the act of observation. Until that moment it cannot be said to be a phenomenon at all. If a different observation is made a different phenomenon occurs, and 'we have come no closer to penetrating to the untouchable interior of the phenomenon'.[46]

In the case of the observation of the quasar, choice of measurement determines 'what the photon shall have done after it has already done it'.[47] Wheeler does not mean that through the observation the observer determines what the past actually is, as if the past is somehow created out there retrospectively, but that in fact the past has no existence independent of the observation. The registering of the phenomenon is the way that a process that began at some time in the past is brought to completion. From the observation and recording of such phenomenon the observer-participant constructs the past. For Wheeler,

46 Wheeler, J.A. *op. cit.* (47), p. 123.
47 Wheeler, J.A. *op. cit.* (44).

observership is to do with the macroscopic registering of phenomena, and is not necessarily confined to human observers. I take human observership to be a special case that is particularly relevant theologically.

Reality and Acts of Creation

Wheeler describes reality in these terms: 'What we call reality consists of a few iron posts of observation between which we fill in by an elaborate papier mâché construction of imagination and theory.'[48]

The iron posts of observation are quite solid in that they are actual quantum events amplified so that they leave a permanent record. These events amplified are irreversible, which gives each one a unique function in building up the construct of reality. To explain what he means here, Wheeler tells the story of a variant of a game of Twenty Questions.[49] Normally the group that is asked the questions decides on a word that has to be deduced by the questioner in twenty or fewer questions. But in the variant of the game, no word is actually chosen. The only rules are that the questions must be only yes-no questions, and that the answers must be consistent with each other. At the end of the game the questioner thinks of a word that is also consistent with all the answers, and that is defined by them.

In a similar way, reality is constructed out of the billions of bits of information gained through irreversible acts of observation, both those that have been already registered and those that will be registered in the future. Reality can thus be thought of as emerging out of the interaction between the observer and the observed, and is dependent upon the questions that are asked of the world. In his variant of Twenty Questions without a chosen word, the word that emerges will be different according to the set of questions that are asked. However, as the questioning proceeds, the choice of the next question becomes more and more limited in order to maintain the rule of consistency. There is then an interaction between what is in the process of emerging and the questioner, so that the emergent word to some extent determines the question to be asked. The result is a participatory universe. In the game, the word emerges out of the questions and answers. A different series of questions will have resulted in a different word, and in a similar way, the involvement of the observer in the measurement process will contribute to the nature of reality that is constructed.

For Wheeler, reality is a loop: physics (that is, what is out there in the universe) gives rise to observer-participancy; observer-participancy gives rise to information; information gives rise to physics. The loop is a self-excited circuit,

48 *ibid.*
49 Wheeler, J.A. 'Beyond the black hole', in Wheeler, J.A. *At Home in the Universe*, AIP Press (1994), p. 287.

which enables the universe to self-synthesise:

> Beginning with the big bang, the universe expands and cools. After eons of dynamic development it gives rise to observership. Acts of observer-participancy, via the mechanism of the delayed choice experiment, in turn give tangible 'reality' to the universe not only now but also back to the beginning. To speak of the universe as a self-excited circuit is to imply once more a participatory universe.[50]

Wheeler almost avoids any discussion of objects in the world. He constructs reality out of the iron posts of bits of information without any particular reference to whatever the information refers to. However, in the above quotation, he assumes that such reference is made. In his model of the universe as a self-excited circuit he suggests that acts of observation have origins that are prior to the observation, whether in the transmission of light from a distant quasar, or in the events of the big bang. The realisation of their intelligibility has to wait for the act of observation and the reading of its information. Wheeler's It-from-Bit proposal cannot be supported without affirming the existence of the origins of the observations that furnish the bits of information.

In the self-excited circuit there are then three points at which original creative acts enable the circuit to function. The first of these, observer-participancy, Wheeler describes as elementary acts of creation. These acts of observer-participancy could not take place if observership were not present. Wheeler discusses the emergence of observership with respect to the anthropic principle:[51] Human observers exist in the universe because the universe is the way it is; but equally, for Wheeler, the universe is the way it is because of observer-participancy. Observership, on this reasoning, is something that has been written in to the story of the Universe from the beginning, and its emergence is an integral part of its creation. The emergence of observership is thus the second creative act in the self-excited circuit, and the third is the bringing into existence of the physical universe with all its potentiality and energy that enables it to emerge. For Wheeler, the reality of the physical universe depends on the acts of observer-participancy. The bits of information gained through observer-participancy make communication possible, and give intelligibility to the Universe that only exists potentially up to this point.

Construction of Meaning or Co-Creation?

In Wheeler's participatory universe, intelligibility and meaning give substance and purpose to reality, and he ascribes a central and indispensable role in the construction of meaning to subjects who are able to communicate with one another. The meaning that is constructed is a shared meaning, which is

50 Wheeler, J.A. *op. cit.* (44).
51 Wheeler, J.A. *op. cit.* (49), pp. 36 – 38.

expressed in human culture, religion and social institutions. Theologically, the question is whether intelligibility and meaning are therefore totally human constructs, as would be argued, for example by Cupitt.[52] God-talk is then a way of expressing our meaning for our world, and we have no authority for asserting more than that. Wheeler's It-from-Bit process suggests that this construction of meaning would apply not only to religious faith, but also to the very structure of our reality.

Alternatively, we may think of the creative acts whereby the universe comes into being as co-creative acts between the creator and the universe. The notion of co-creation has tended to focus particularly on the role of humankind as stewards of creation. However the biblical concept is rather parochial and anthropocentric. If we can speak of co-creation within Wheeler's It from Bit proposal, we would need to extend the concept from this parochial, human-centred notion, to one in which different elements of the universe are engaged in co-creation with each other and with God in its own becoming.

A number of theologians[53] have suggested that quantum indeterminism, as an irreducible element of natural law, implies divine self-limitation. If quantum events are truly probabilistic, then even the divinity could not have foreknowledge, because that would contravene the very laws he has brought into being. The universe would then be truly open to all future possibilities, and its course could not be predetermined either by the divinity working through natural law or through special divine action. In Wheeler's It-from-Bit proposal, divine power and foreknowledge would also be limited, not so much by indeterminism, but by the very emergence of the actual universe as a self-excited circuit.

In discussing the role of observership in the creation of the Universe, Wheeler refers to the legend in the Midrash[54] where God first reminds Abraham that without him, Abraham would not exist. Abraham's reply also suggests the role that the observer-participant has in the creation of the universe: 'Yes, Lord, but also you would not be known if it were not for me.'[55] Here, both God and Abraham act on each other to create each other. Abraham exists because God made him in the first instance, but in making an autonomous being God is capable of being known, and being known is also in a process of coming into being. In a similar way, the creation of a participatory universe is an act of co-creation.

Irrespective of quantum indeterminism, the divinity would then work through influence and co-operation rather than through sovereign power and

52 See, for example: Cupitt, D. *Only Human*, SCM (1986).
53 See, for example: Peacocke, A.R. *Theology for a Scientific Age* (enlarged edition), SCM (1993), pp. 121 – 123.
54 Wheeler, J.A. *op. cit.* (49).
55 *ibid*.

absolute will. The outcome of the creative process would not be fixed in advance, and would involve the risk that a less desirable outcome would result. The divine role would then be described more appropriately not in the language of power and supremacy, but in the language of love.[56]

Concluding Remarks

By working with these two contrasting interpretations of quantum theory and taking them seriously, I hope to have shown that the interpretation matters to our self-understanding and our theological insight. The difference between the Everettian and Wheeler's approaches, according to Clayton,[57] is fundamentally to do with the place ascribed to the subject. The Everettian is keen to avoid giving emphasis to the role of the subject in bringing about an ontological change in the physical universe, and thus to re-establish the objective physical world as the basis of explanation, as it is in classical mechanics. In contrast, Wheeler's It-from-Bit proposal is radically subject centred, and thereby takes seriously the subject as an irreducible part of the universe. The different theological scenarios that I have sketched depend on the view of reality from which we start. If future scientific discovery would be able to help us decide between the many interpretations of quantum theory, perhaps we could then decide between the different theological scenarios. But in the absence of such discoveries we have the delight, or the dilemma, whichever way we see it, of being able to explore many theological paths with equal vigour.

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56 Vanstone, W.H. *Love's Endeavour, Love's Expense*, DLT (1977); Peacocke, A.R. *op. cit.* (57), pp. 123 – 124.
57 Clayton, P. 'Tracing the lines: constraint and freedom in the movement from quantum physics to theology', in Russell, R.J., Clayton, P., Wegter-McNelly, K., Polkinghorne, J. (eds.) *Scientific Perspectives on Divine Action Volume 5*, Vatican Observatory Publications (2001), pp. 211 – 234.

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