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CONSCIOUSNESS AND THE PROBLEM OF QUANTUM MEASURMENT

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Abstract

A variant of the von Neumann-Wigner Interpretation is proposed. It does not make use of the familiar language of wave functions and observers. Instead it pictures the state of the physical world as a vector in a Fock space and, therefore not, literally, a function of any spacetime coordinates. And, rather than segregating consciousness into individual points of view (each carrying with it a sense of its proper time), this model proposes only unitary states of consciousness, *Q*(t), where *t* represents a fiducial time with respect to which both the state of the physical world and the state of consciousness evolve. States in our world's Fock space are classified as either 'admissible' (meaning they correspond to definite states of consciousness) or 'inadmissible' (meaning they do not). The evolution of the state vector of the world is such as to always keep it restricted to 'admissible' states. Consciousness is treated very much like what Chalmers calls an "M-Property." But we try to show that problems with the quantum Zeno effect do not arise from this model.

Keywords: Consciousness, Quantum Measurement, M-Properties, Quantum Zeno Effect.

Introduction.

The relationship between consciousness and quantum mechanics has long been discussed in a serious context. Schrödinger (1), Wigner (2), and von Neumann (3) were, early on, most associated with these lines of investigation. And Everett's Relative State Interpretation is very much about our states of consciousness. Still, it seems that little effort has gone into developing mathematical formalisms appropriate to the description of this relationship. Perhaps this is because mental states seem to be mathematically indefinable. The von Neumann-Wigner idea has never been very popular with physicists, who mostly hold to somewhat Instrumentalist views; the wave function collapses because macroscopic, complicated, things like detectors cannot exist in superposed states. How big macroscopic things are, or how complex something must be to be complicated, are questions left largely to the imagination.

Recognizing that *conscious states* never seem to exist in superposition, Chalmers (4) has introduced the very clever idea of M-properties. These properties cannot exist in superposition. He takes consciousness to be such a property and assigns it an operator (which we will designate M) that measures it and projects states– he treats consciousness very much like an ordinary physical observable. The present work tries to extend this idea and resolve some of the apparent problems it engenders. Particular attention is given to the quantum Zeno effect.

States of the World.

Designate the state of the physical world as $|\Psi(t)>$. Such states are to be understood as vectors in a Fock space. Basis vectors in this space are constructed from the vacuum state $|0>$ by the repeated application of creation operators appropriate to the various kinds of particles that inhabit our universe. The parameter *t* recognizes that this state evolves with respect to a fiducial time that we can identify with a particular Lorentz frame. It is essential to recognize that $|\Psi(t)>$ is *not* a function of the spatial coordinates (x, y, z). We will work in the Dirac Interaction Picture. Here we regard our Fock space as built using the creation operators appropriate to free, non-interacting particles and write $i\,\partial_t\ |\Psi(t)> \ = \ H'\ |\Psi(t)>$ where H' is the Hamiltonian describing the interactions amongst these particles. The complete Hamiltonian for the system is written H = $H_0 + H'$. Every effort will be made *not* to express anything in terms of 'wave functions.' It has been recognized that this concept is problematic since the inception of quantum field theory (5). $|\Psi(t)>$, in fact, describes the entire world without making arbitrary distinctions between observers, detectors, and things detected.

States of Consciousness.

Suppose that, at any time t, the conscious state of the universe can be designated as $Q(t)$. $Q(t)$ describes the *qualia*– the totality of sensations experienced by any and all consciousness anywhere at that time; that could include physicists recording a quantum measurement or worms tasting sugar in a pond on a distant planet. We will try not to make particular distinctions between various "observers." Proceeding in analogy to quantum mechanics we suppose that there are 'states of consciousness' and that these states can be represented as vectors in our Fock space. There acts upon this space a non-linear 'consciousness pseudo-operator'– $\mathbb{C}$– which has the property that, for some of these vectors,

1) $\mathbb{C}\ |C_i> = Q_i\ |C_i>$.

The $|C_i>$ constitute something like eigenvectors of $\mathbb{C}$– they correspond to what we will call *definite states of consciousness*. By this we mean that Q_i specifies a unique and unambiguous state of awareness possessed by the totality of sentient observers. Now it is immediately clear what a strange sort of "operator" $\mathbb{C}$ is. We are accustomed to seeing c-numbers as eigenvalues, maybe a few other things, but sensations? We assign $\mathbb{C}$ no explicit time dependence. Any state that is not an eigenstate of $\mathbb{C}$ will be called a mixed state. Definite states of consciousness are admissible states in this theory. Mixed states are inadmissible and cannot be allowed to occur. (By writing things this way it might appear that we regard the Q_i and $|C_i>$ as constituting discreet, denumerably infinite sets. This is, of course, not the case. Both are, properly, to be regarded as continua as is the set of inadmissible states. This notation is just simpler to work with.)

There should be no segregation of consciousness into any set of individual observers. We will just designate it $Q(t)$. This will prevent us from trying to describe the world in terms of separable and independent "wave functions," one for your brain, my brain, or other things; it would be difficult having to make sense of trillions of independent consciousness operators. While it is true that we seem to experience our individual conscious states independently, we have to argue that this apparent separateness is merely an illusion born of facts like "I" can remember my memories but not "yours." And "I" can experience my sensation of blue but not "yours." These facts are indisputable, and surely interesting. But they only obscure matters if we wish to study the problem at hand. And we do not want to be misinterpreted as proposing anything mystical here. The important point is mathematical—we will regard consciousness (in its totality) as something that can be indexed by a *single* parameter t. (This also disposes of the Wigner's Friend paradox.)

If $\mathbb{C}$ is to be regarded as any sort of operator at all (in the normal mathematical sense) we could well encounter difficulties. Consider $<\Psi_a|\mathbb{C}|\Psi_b>$ supposing that Ψ_a and Ψ_b are eigenstates of $\mathbb{C}$ corresponding to two different qualia states Q_a and Q_b. Imagine $\mathbb{C}$ to be Hermitian—like a normal measurement operator should be. Now, unless qualia are strange and behave, effectively, like zero, we would have to conclude that Ψ_a and Ψ_b must be orthogonal. This would prove fatal (*vide infra*). We would be much better off denying $\mathbb{C}$ the status of any kind of operator, calling it a pseudo-operator instead. If Ψ_a and Ψ_b have different qualia

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eigenvalues we can say little about their linear combinations. Are these mixed states? Are they eigenstates corresponding to Q_a or Q_b or some completely different qualia state? Who knows? A very important point to bear in mind is that two state vectors, in this theory, do not have to be orthogonal in order to correspond to completely different qualia eigenvalues. We will, somewhat carelessly, use the terms 'eigenvector' and eigen-space' in connection with $\mathfrak{C}$ but it should never be thought that we mistake it for a real operator.

Regarding the nature of the $|C_i>$s one thing is obvious; they are highly degenerate with respect to the Q_i. It would, for instance, make no difference to the overall state of consciousness whether an electron had been created in a region with no observers. And we must recognize a sort of null state of consciousness—a state where there just aren't any sentient observers at all. (The state vector a few seconds after the big bang would correspond to such a state. So would many others.) So we must picture our Fock space as broken up into many separate subspaces, some with a particular Q_i that designates the unique conscious experience corresponding to it, and others corresponding to no definite experience at all.

The time variable that appears in $|\Psi(t)>$ and $Q(t)$ requires a comment. As it pertains to the former case it causes no problems with relativity since the equations that determine the evolution of $|\Psi(t)>$ are, themselves, relativistically invariant—t only represents an arbitrary choice of Lorentz frame. $Q(t)$ might cause a problem, however. By choosing not to regard consciousness as broken up into separate observers (each of which needing to be assigned its own proper time) we have more-or-less forced ourselves to select a particular set of space-like hypersurfaces to designate the various 't's. Now perhaps because consciousness is a non-material sort of thing such a violation of relativity is permissible—we can't be sure how physics treats non-material things. But it is essential that we construe $Q(t)$ in such a way as to end up with no *physical* violations of relativity.

The Evolution of these States with Time.

Taking no account of consciousness we could picture $|\Psi(t)>$ evolving according to $i\,\partial_t\,|\Psi(t)> = H'(t)\,|\Psi(t)>$ where H' designates the interaction operator for our world. ($H'(t) = \int \mathcal{H}'(x,t)\,d^3\boldsymbol{x}$ where $\mathcal{H}(x,t)$ is the corresponding Hamiltonian density operator). We assume normal ordering. All operators and state vectors are being represented in the Dirac Interaction Picture. There would, in consequence, exist a unitary operator, $U(t_2, t_1)$, having the property that $|\Psi(t_2)> = U(t_2, t_1)\,|\Psi(t_1)>$. Let us imagine the world at time t_1 being in a definite state of consciousness. Now the $|C_i>$ are in no necessary way eigenstates of the Hamiltonian. So things could quickly evolve into a situation where we have some probability of finding the conscious state of the world in any of quite a number of configurations. But this is never what we seem to experience; our common awareness appears unconfused and composed of a well-defined succession of qualia. Reality will only tolerate definite states of consciousness– that is to say $|\Psi(t)>$ must *always* lie within one of the eigenspaces of $\mathfrak{C}$.

We can arrange for this to happen by amending the previous equation for the time-evolution of $|\Psi(t)>$ to also require $\mathfrak{S}\,|\Psi(t)> = |\Psi(t)>$ where $\mathfrak{S}$ is a (non-linear) operator having some interesting properties:

2) If $|\Psi(t)>$ is an eigenstate of $\mathfrak{C}$ it does nothing. The state is completely unaffected.

3) If $|\Psi(t)>$ is not an eigenstate of $\mathfrak{C}$ it will look at all the amplitudes $<C_i|\Psi(t)>$ for every existing $<C_i|$ (that is to say every eigenstate of $\mathfrak{C}$). It will square these amplitudes and, using these values as *relative* probabilities,

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convert |Ψ*(t)*> into one of the $|C_i>$ at random.

𝕾 functions as a projection operator taking mixed states (with respect to ℭ) into definite states of consciousness. We give up the idea of a unitary time-evolution operator. Such an operator has an inverse. We cannot go backwards in time according to 𝕾 since the decision how to go forward is made at random. This imparts a natural directionality to time. $𝕾^2$ = 𝕾 and 𝕾 has no explicit time dependence. Since |Ψ*(t)*> is always an eigenstate of ℭ we may write ℭ |Ψ*(t)*> = *Q(t)* |Ψ*(t)*>. The qualia-state is assumed independent of phase so, if |Ψ*(t)*> corresponds to a particular Q_i, $e^{i\theta}$ |Ψ*(t)*> will correspond to it also. We suppose that ℭ |0> = ϕ |0> where ϕ designates the null state of consciousness.

As a matter of practical fact, I tend to believe that |Ψ*(t)*> usually evolves rather seamlessly, and without great need for 𝕾, passing more-or-less continuously from one eigenstate of ℭ into another. (But experimental physics can easily complicate things.)

It is worthwhile to consider the difference between the present idea and Chalmers' M-property theory. Chalmers appears to regard his M-operator (which measures consciousness) as behaving like any standard measuring operator in textbook quantum mechanics. It seems to play an active role in projecting the state into one of its eigenstates. Since the M-property here is the qualia state of the system it plays a role somewhat analogous to that of our C. But for us C plays not so much an active as a "permissive" role– it distinguishes admissible state vectors from inadmissible ones. Here is a picturesque metaphor: We are accustomed to thinking of the Fock space in which our reality lives as something like an infinitely extended, infinite-dimensional block of Cheddar cheese. We, instead, picture it more like a block of Swiss cheese– it is full of holes. The cheese contains the state vectors that represent definite states of consciousness. The holes contain the mixed states. Ordinarily |Ψ*(t)*> evolves, under the action of U, so as to remain inside the cheese. 𝕾 does nothing at all. But sometimes (perhaps due to the intervention of experimental physicists) it tries to move into one of the holes. At the instant it does this 𝕾 corrects the situation by projecting it back into the cheese. But 𝕾 is a rather lazy operator. $| < \Psi_1 | \Psi_2 > |^2$ is a sort of measure of how similar two state vectors are. If they are identical it is 1. If they are quite different it is zero or very small. 𝕾 tries to project the errant state into the most similar states available in the cheese. Hence the Born rule. (I suppose it might have elected to do things differently. But that is just how physics works.) This idea would run into serious trouble if the state vector were to evolve into a |Ψ*(t)*> that existed in the "cheese" but was about to enter a "hole" if |Ψ*(t)*> was orthogonal to *every other* $|C_i>$. 𝕾 would have no choice but to project the state back into itself and reality would hang up there forever. Since the universe seems to have been evolving successfully for about 14 billion years, we assume that our "Swiss cheese" is so densely packed with $|C_i>$s that this situation never arises.

It might be objected that our "fiducial time" violates relativity by introducing a preferred Lorentz frame. It does do this, of course, but only in relation to qualia. We are Property Dualists and do not think that qualia are, in any sense, physical things. We believe that they can violate relativity as much as they want provided that no physically observable contradictions of relativity result. Since we have assigned consciousness only a permissive (as opposed to active) role, we do not see a problem here. I think it would be very difficult to use this idea to construct any *physical* experiment that would show a violation of relativity. (But it is hard to prove a negative.)

The Anatomy of a Measurement.

Consider a very simple experiment in which an electron is sent through a Stern-Gerlach apparatus. It can be prepared as either spin-up or spin-down or in any superposition of these states. If it comes in spin-up it always veers up and strikes a detector that causes a light, originally blue, to shine green. If it is down it goes the other way and a red light is triggered. This device, the electron whose spin it measures, and an observer, constitute a physical universe described by |Ψ*(t)*>. The conscious states of this universe, we will imagine, belong to this single observer whose only possible states of awareness are 1) seeing a green color, 2) seeing a red color, or 3) seeing a blue color. So the space in which the conscious state of the universe is a vector contains three subspaces– one corresponding to each of the above possibilities. These are the eigenspaces defined by $\mathfrak{C}$. Since this world is simple we think that we can get away with describing it in a simple manner. Let us describe its initial state as |Ψ(0)> = |+, B> where + says that our electron is spin-up. 'B' simply says that the rest of the measurement system (observer and all) are in their initial state. $\mathfrak{C}$|Ψ(0)> = B |Ψ(0)> since we imagine the light is blue before any measurement is made. When the spin-up electron is detected at t_d |Ψ(0)> evolves into |Ψ(t_d)> which we can write as |+, G>. $\mathfrak{C}$|Ψ(t_d)> = G |Ψ(t_d)> meaning that this new state is an eigenvector corresponding to the qualia 'seeing a green color.' (If the election had been spin-down we would have ended up with a red qualia and a state |-, R>.) If things happen to start out as (|+, B> + |-, B>)/$\sqrt{2}$ our system will, obviously, evolve into a superposition of states which is no longer an eigenvector of $\mathfrak{C}$. Since, according to the above-mentioned principle, reality cannot tolerate any state that is not an eigenstate of $\mathfrak{C}$ it is necessary that $\mathfrak{S}$ project |Ψ(t_d)> into either |+, G> or |-, R> with 50% probability. Let us make it clear that no wave function collapses. Instead, a state vector |Ψ(t)>– which is *not* a function of the spatial coordinates (x, y, z)– tries to evolve into a state (in Fock space) where it no longer resides entirely within a particular C_i but rather exists as a superposition of 'red' and 'green' qualia states. $\mathfrak{S}$ immediately corrects this by projecting |Ψ*(t)*> back into only one of the two *definite* states of consciousness available to it.

There is something a little awkward about such a phenomenon. And it is not obvious that adjoining consciousness to the problem by way of $\mathfrak{S}$ does much to improve things. Everett elects to throw out $\mathfrak{S}$ and freely allow non-definite states of consciousness. These are, presumably, able to sort themselves out into separate, conscious worlds. Clever as the Relative-State Interpretation is, it suffers from a serious problem. Suppose that the electron is sent out in such a state that the green light should illuminate 99% of the time and the red one only 1%. I know perfectly well that, in situations like this, I will see the green light almost all the time. But one cannot be "just a little bit conscious." One either is or one isn't. If there are two conscious "observers"– one seeing green and one seeing red– there ought, really, to be a 50/50 chance of "my" being either. In fact, there does not seem to be a satisfactory solution to this inconsistency (6). For this reason we will want to reject the Everett Interpretation and not burden ourselves with the uneconomical existence of realities we can have no contact with or knowledge of.

The Quantum Zeno Effect.

Since $\mathfrak{S}$ measures the state vector constantly (7) a concern may arise regarding the quantum Zeno effect (8); if the state is always being observed can it really ever go from blue to green or red? This problem has been discussed carefully by Chalmers in his consideration of M-properties.

Consider a spin-up electron moving through the Stern-Gerlach apparatus but still far from the detector. |Ψ*(t)*> will, of course, be changing. But it will always remain one of the many B eigenstates and $\mathfrak{S}$ will affect it in no way. As the electron moves along toward the detector, a very frequent measurement of its position might, indeed, stop it somewhat from moving. But a very frequent measurement of the blueness of the light will not affect its motion whatsoever. (It is true that |Ψ*(t)*> changes discontinuously at t_d. But this is not strange. It is just a consequence of the simplistic way in which we imagined our experiment.)

At t_d it encounters the measuring device. |Ψ*(*t_d*)*> is now an eigenstate of $\mathfrak{C}$ having a green qualia. Throughout this entire process $\mathfrak{S}$, for all its observing, *has done not a single thing to the state vector*. Now, if the electron had been in a superposed state when it hit the detector, $\mathfrak{S}$, at t_d, would have immediately projected things into either of the two possible outcomes. But, still there is no Zeno effect to be noticed in the process. Why? $\mathfrak{S}$ measures things all the time but, as things proceed along here, |Ψ*(t)*> *always* remains an eigenstate of $\mathfrak{C}$.

Now real measurements do not, of course, occur instantaneously. Perhaps the devil is in the details. Say the electron is spin-up. Set t_d = 0 and suppose that the measurement is complete at Δt. Suppose Δt is very small and that we can approximate the state vector's evolution as linear. We can write |Ψ*(t)*> ≈ [(1 - t/Δt) Ψ_B + (t/Δt) Ψ_G]/N (where N is just for normalization). Are these intervening states mixed, as they would have to be in Chalmers' theory? We can't say. Maybe, as long as t < Δt/2, the state is still a blue eigenstate. At exactly Δt/2 it becomes a green one. (|Ψ*(t)*> may change continuously but *Q(t)* might not for all we know. I do not think we can even say what continuity means for qualia.) Or, maybe, after t = 0, it takes a little time (Δt) for the blue light's filament to cool down and for the red one's to heat up? At t = Δt/2 the observer would be seeing both some blue and red light. Perhaps this is what is going on. Anyway, we can easily construe $\mathfrak{C}$ in such a way as to have no problems with Zeno. Things are very different if we consider (|+, G> + |-, R>)/$\sqrt{2}$, the state that would try to arise if we sent a half-up/half-down electron into our apparatus. There is plainly no way for this state to be anything but mixed. It will immediately be projected back into the "cheese." This would happen the moment |Ψ*(t)*> tried to enter the "hole."

As a general matter, say that |Ψ*(*t_d*)*> is just about to enter a "hole." <Ψ*(*t_d*)*|Ψ*(*t_d*)*> = 1 at this time so it might seem as if $\mathfrak{S}$ would have to project it back into itself. Not at all. Suppose there was another eigenstate of $\mathfrak{C}$, |Φ>, that was such that <Φ |Ψ*(*t_d*)*> = .999. This is altogether possible and |Φ> might even correspond to an entirely different qualia eigenstate than |Ψ*(*t_d*)*>. There would now be an almost equal probability of projection into either state. (There might even be 1000 such Φ-type eigenstates!) This would be impossible if $\mathfrak{C}$ were an actual Hermitian operator since, then, the |C_i> would constitute a complete orthonormal basis for the Fock space. But we are proposing nothing of the sort and the various squared amplitudes must be interpreted as *relative*, not absolute, probabilities.

Chalmers' problem stems from his taking M literally as a Hermitian operator. He appears to reason somewhat as follows: If |Ψ*(0)*> is an eigenstate of M corresponding to the blue qualia and M measures the state vector at t = ϵ it will find it almost entirely in |Ψ*(0)*>. In particular, at ϵ << τ_Z (where τ_Z is the Zeno time for the system (8)), |Ψ*(ϵ)*> = mostly |Ψ*(0)*> + small bit |orthogonal state>. He seems to assume that this orthogonal state could not correspond to a blue qualia so that if M measured 'blue' at ϵ it would project the state vector right back into |Ψ*(0)*> and nothing else. This is certainly not the case in our theory (and not necessarily in his either since the orthogonal state could be a blue eigenstate too). But for |Ψ*(ϵ)*> to correspond to a 'green' qualia state (*vide supra*) would be impossible in his theory since < Ψ*(0)*|Ψ*(ϵ)*> is not going to be very different from 1 and |Ψ*(ϵ)*> cannot therefore have a different qualia eigenvalue than |Ψ*(0)*> assuming M is Hermitian. Of course, this is not a problem for our theory. We allow two eigenstates corresponding to different qualia eigenvalues to be non-orthogonal.

A bigger problem both Chalmers' theory and this one might seem to face is why the quantum Zeno effect can be demonstrated at all; it is, indisputably, a real thing. Excited beryllium ions have been prevented from decaying by pulsing them frequently with light to detect if they are still in their original state (9). This is a perfectly valid experiment since measuring the ion as excited completely precludes *any* possibility of its being decayed. But the rate of testing of the ion (as fast as 250 times/sec) greatly exceeds what any human brain could consciously process. It appears that human consciousness cannot be affecting the ion. Is the detector supposed to be conscious too?

We need to consider this process more carefully. For simplicity let us suppose the detector makes only two measurements, one at T and one at 2 T. T is very small relative to the rate of decay. Initially the ion is in its undecayed state (U) and the detector is still in its initial state (I). We will write its state vector as |U, I>. At time T the first measurement is made. Consciousness notices nothing and nothing projects. But the detector records its activities on a strip of magnetic tape. The state is now α |U, I, I> + β |D, I, A> (where A means the detector has registered a decay and $\alpha >> \beta$). At 2 T another measurement is made. The state now becomes α^2 |U, I, I, I> + α β |D, I, I, A> + β |D, I, A, A>. Everything, the tape included, is still in superposition. Now consciousness looks at it. It wants to know the probability of finding |U, I, I, I> i.e. that the particle has not decayed. This is $|\alpha^2|^2$ which is exactly what it would have been had the measurements actually projected (collapsed) the state. Had that been the case the probability of U at T would be $|\alpha|^2$ and at 2 T it would be $|\alpha|^4$ which is the same as that obtained above. The decay is inhibited just as Zeno would have it. Although they might seem to do nothing, the measurements have altered the trajectory of the state vector through our Fock space. If they had not been performed the system would have evolved differently.

Conclusion.

By replacing wave functions with states in Fock space, |Ψ*(t)*>, we have created an interpretive picture that is in better agreement with the view adopted by physics since the inception of modern field theory in the 1950s. A price to be paid for this "better agreement" is the acceptance of a unitary view of consciousness in which the idea of individual observers is ignored. Peculiar as this may seem, it does not bring with it any observable consequences. But it allows us to refer to an instantaneous consciousness-state (qualia-state) of the universe as *Q(t)*. We have to do this if we want to put such a state into relation with |Ψ*(t)*>. Central to the success of this approach is the realization that C is, in fact, not an operator in any quantum mechanical sense; rather, it is a 'classifier' that sorts the |Ψ*(t)*>s into admissible and inadmissible states. This theory preserves a role for consciousness in quantum measurement but a slightly different one from that it plays in M-property theory.

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4) Chalmers, D. J., *Consciousness and its Place in Nature*, Sec. 9, in *Philosophy of Mind: Classical and Contemporary Readings* (Oxford, 2002). See also https://www.tubule.coma/watch?v=DIBT6E2GtjA.

5) Wave functions are , generally, taken to be functions of a particle's location in spacetime. In free field theory it easy to express a universe consisting of only one particle with a definite momentum k as $a_{\boldsymbol{k}}^{\dagger}|0\rangle = |\mathbf{k}\rangle$. If we attempt to restrict this "particle" to a single point, let us say x = 0 at t = 0, by representing $|\Psi(0)\rangle$ as $\sum_{\boldsymbol{k}} e^{i\boldsymbol{k}\boldsymbol{x}} |\mathbf{k}\rangle$, a so-called Newton-Wigner state, we have a chance of finding the particle infinitely far away at the slightest future time– seeming to violate relativity. If we try to formulate things in a relativistically invariant way by representing $|\Psi(0)\rangle$ as $\sum_{\boldsymbol{k}} \frac{1}{\sqrt{2\omega_k}} e^{i\boldsymbol{k}\boldsymbol{x}} |\mathbf{k}\rangle$ then we end up with a situation where the states of two particles, localized at different places are no longer orthogonal (see Teller, P. (1995), *An Interpretive Introduction to Quantum Field Theory*, Princeton University Press).

6) Chalmers (Chalmers, D. J. (1996), *The Conscious Mind*. Oxford University Press) defends the Everett idea by means of arguments that try to show that superpositions of states will automatically organize themselves into separate (we would say definite) conscious experiences. The present writer does not see how these arguments resolve the "relative probabilities" problem. This matter has been analyzed in a recent paper (Byrne, A and Hall, N., *Chalmers on Consciousness and Quantum Mechanics*, http://web.mit.edu/abyme/www/Conc&QM.html).

7) While the simplest way to think of continuous measurement is just to imagine an infinite number of von Neumann measurements being performed infinitely quickly there are other, and more subtle, ways of looking at the problem. See Schulman, L. S. *Physical Review A*, 1509 (1998).

8) For an excellent recent review of the quantum Zeno effect see Pascazio, S. arXiv 1311.6645v1.pdf (2013).

9) Itano, W., Heinzen, D., Bollinger, J., Wineland, D. *Physical Review A*, 2295 (1990).