QUANTUM MEASUREMENTS AND THEIR PLACE IN NATURE

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Abstract

A variant of the von Neumann-Wigner Interpretation is proposed. Problems arising from the quantum Zeno effect are addressed as we have described previously. We do, however, offer some new and, perhaps, unexpected observations. We are accustomed to thinking of wave function collapse as occurring consequent to laboratory measurements. We speculate that, whatever physical correlate of consciousness exists within the brain, it is quantum mechanical in the sense that a brain, left to itself, would eventually decohere into a state no longer compatible with its conscious functioning. Wave function collapse returns it to a state compatible with consciousness. Indeed, this may be its important reason for occurring. A universe without it simply could not play host to conscious brains. The fact that it also prevents us from encountering "absurd" situations in the laboratory is merely a fortunate dividend. Whenever a quantum measurement is made the universe's future history splits into a number of possibilities. This number may be very large or infinite. And we believe consciousness plays a vital role in this happening. A "conscious" universe where quantum measurements are being made allows for an enormous number of equally acceptable world-histories. An "unconscious" one, always evolving in a unitary fashion, allows for only one. If we assume that the decision as to which world-history is the *real* one (i.e. this one) is made at random we see that the universe is overwhelmingly more likely to be "conscious" than not.

Keywords: Consciousness, Quantum Measurement, von Neumann-Wigner Interpretation, Quantum Zeno Effect.

Introduction and Preliminaries.

In the 1930s von Neumann and Wigner (1) proposed an interpretation of quantum mechanics that assigned consciousness a central role in the collapse of the wave function. While never very popular with physicists, it remains an idea worth considering. Suppose we perform a quantum measurement on an electron. If its spin is up along some axis a green light is triggered. If it is down a red light turns on. If it is in a superposed spin state we might expect to see a 'green-red' light. Wigner called this situation "absurd" and we are inclined to agree with him. To avoid this the system collapses into either an up-green state or a down-red state according to the Born rule. In 2013 Chalmers and McQueen (2) sharpened this idea by introducing the notion of m-properties. There exists an m-operator that is very like a normal Hermitian measurement operator. Systems that are in eigenstates of this operator correspond to definite qualia-states. Others (like the 'green-red' state) correspond to mixed and "absurd" states of consciousness. The latter are excluded and the system collapses so as to avoid them.

We pause, briefly, to discuss a point of nomenclature. We express things in the language of quantum field theory (3) instead of that of non-relativistic quantum mechanics. This may be a bit unfamiliar to some readers. We do this for several reasons. Firstly, no one seriously thinks that non-relativistic quantum mechanics is any "real" theory of anything. It is a simple approximation that makes it easier to discuss simple things, like electrons and their spins, as if they were isolated systems (which, of course, they are not). Real quantum measurements also involve a physical detector and, if we are right, brains (and consciousness) too. And it provides a very convenient language with which to discuss these matters. We work in the Dirac Interaction picture (4) since this is best suited to our purposes. We designate the state of the physical world as $|\Psi(t)\rangle$. Such states are to be understood as vectors in a Fock space. They are always normalized to 1. 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. 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. Let us 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. Every $|\Psi(t)>$ will, thus, correspond to a particular $Q(t)$. But, following von-Neumann and Wigner, we assume that $|\Psi(t)>$ must always correspond to a *definite* qualia state. We will deem such $|\Psi(t)>$s *'admissible.'* Other ones, corresponding to "absurd" indefinite or mixed states of consciousness, are regarded as *'inadmissible.'* $|\Psi(t)>$ can never enter into such a state. If it tries, through unitary evolution, to do this it is immediately projected into an admissible state (*vide infra*).

The m-property theory runs into trouble with the quantum Zeno effect (5) and Chalmers and McQueen quickly became aware of this. (See also (6).) They (7) have, more recently, modified their theory to allow superposed states undergoing measurement to persist as superposed for just a short time and to a limited extent. They will still collapse. But they do so slowly enough to circumvent Zeno. They also couch their theory in terms of Integrated Information Theory.

We took a different approach to the Zeno problem (8). We rejected any analogy between consciousness and von Neumann measurement operators. Consciousness, instead, functions as a kind of "classifier" that divides all the possible $|\Psi(t)>$s into admissible and inadmissible ones. We do not suggest that the relationship between $Q(t)$ and $|\Psi(t)>$ is, in any sense, continuous. Consider two state vectors, $|\Psi_a>$ and $|\Psi_b>$, which are very similar but not identical. $|<\Psi_a|\Psi_b>|^2 = 1 - \epsilon$. One might think that, for a small enough (but non-zero) ϵ, the qualia states corresponding to the two vectors would, necessarily, be the same. But we do not think this. If we did we would, once again, end up with a Zeno problem. Rather, we think they might correspond to completely different qualia or one might even be inadmissible and the other admissible.

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. ($H'(t) = \int \mathcal{H}'(x, t)\, d^3\mathbf{x}$ where $\mathcal{H}'(x, t)$ is the corresponding Hamiltonian density operator.) But $|\Psi(t)>$ must *always* remain admissible. 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:

1) If $|\Psi(t)>$ is admissible it does nothing. The state is completely unaffected.

2) If $|\Psi(t)>$ is not admissible it will look at all the amplitudes $<\Psi_a|\Psi(t)>$ for every admissible $<\Psi_a|$. It will square these amplitudes and, using these values as *relative* probabilities, convert $|\Psi(t)>$ into one of the $|\Psi_a>$ at random.

$\mathfrak{S}$ functions as a projection operator taking mixed states into definite states of consciousness. $\mathfrak{S}^2 = \mathfrak{S}$ and $\mathfrak{S}$ has no explicit time dependence. The qualia-state is assumed independent of phase so, if $|\Psi(t)>$ corresponds to a particular $Q(t)$, $e^{i\theta}\,|\Psi(t)>$ will correspond to it also. We suppose that there are (admissible) null states of consciousness. |0> would, of course, correspond to one of these. A state consisting of only a single electron would too. Indeed, such states are probably a great deal more common than those corresponding to actual sensations.

We have discussed this matter previously (8). (We mention one additional restriction we must place upon $\mathfrak{S}$ – it cannot project a state into one where the expectation value of the stress-energy tensor operator would be changed outside the future light cone of the measurement event. This would result in physical information (something that affects spacetime geometry) being sent faster than light. This matter is discussed extensively in (9) but does not figure much in this paper.)

We offer 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 inadmissible mixed states. Ordinarily $|\Psi(t)>$ evolves in a unitary manner so as to remain inside the cheese. $\mathfrak{S}$ 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 $\mathfrak{S}$ corrects the situation by projecting it back into the cheese. But $\mathfrak{S}$ is a rather lazy operator. $| < \Psi_a | \Psi_b > |^2$ is a 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. $\mathfrak{S}$ tries to project the errant state into the most similar states available in the cheese, hence the Born rule. We might be concerned, since there will be null states (e.g. the basis vectors of our Fock space) that are not absolutely orthogonal to our newly errant state, that the quantum measurement might abolish consciousness from the universe. But this would entail changes to the spacetime geometry outside the future light cone of the measurement event. We do not have anything to worry about.

We illustrate the difference between our approach and that of Chalmers and McQueen by considering an example from their recent paper. It concerns the emergence of the first conscious animal in the universe. This could be a sort of problem for them since for $|\Psi(t)>$ to evolve instantaneously from a null state to a (presumably orthogonal) conscious one would seem impossible. They resolve this difficulty by supposing that $|\Psi(t)>$ can evolve into a superposition of a conscious and an unconscious state and remain that way long enough so that, eventually, consciousness comes about through repeated wave function collapses. We, on the other hand, have no such problem. $|\Psi(t)>$ can very happily evolve (unitarily) from an admissible null state to a conscious one since the two do not have to be at all orthogonal.

(We mention another thing: We speak of our Fock space basis vectors as discreet, denumerable, things rather than constituting a continuum – such would be the case if the universe were a giant periodic box. We do not think we live in a box. But this is a much more convenient way of describing things.)

Brains as Detectors.

Most physicists would probably rather believe that it is a property of their instrumental detectors that refuses to exist in some kinds of superpositions. Perhaps it is their size or complexity? But rocks can be fairly large and complex too. It is hard to see how they collapse wave functions. Also, how to explain the fact that, when wave functions do collapse, they always seem collapse in such a manner that consciousness remains in a definite state and does not wander into an absurd one? If consciousness is nothing more than an epiphenomenal "innocent bystander" this seems peculiar. And, since quantum measurements, as we understand them, appear to require the intervention of experimental physicists, would the universe have to wait for billions of years for animals to develop quantum mechanics, bubble chambers, and photomultiplier tubes before wave functions could collapse at all? Maybe. But, this too, seems somewhat peculiar.

We explore a different possibility. We do believe in psychophysiological parallelism – we think there are physical brain processes (embodied in $|\Psi(t)>$) that correlate with our qualia states. Suppose these processes are exquisitely sensitive to some, irreducibly quantum mechanical, effects of the brain's structure or function.

Essentially, the brain is a sort of quantum computer (albeit completely different from any that have been constructed in laboratories). Various candidates (e.g. microtubules (10), catecholaminergic neurotransmission (in a possible sense) (11), Integrated Information Theory (7)) have been proposed. We have no specific suggestion. But we note that most such processes are likely to be sensitive to quantum decoherence. The brain is a "warm, wet, noisy environment." This represents a serious problem for the designers of quantum computers and for, at least, the microtubule hypothesis as well (12).

Let us consider a very simple universe – one where $|\Psi(t)>$ describes only a single, conscious, brain floating in a nutrient bath and experiencing qualia. $|\Psi(t)>$ begins in an admissible state. But it might very well decohere (through unitary evolution) into an inadmissible one. At the moment this tries to happen $\mathfrak{S}$ projects it back into an admissible state as described above. It may then evolve smoothly until it, again, begins to decohere. $\mathfrak{S}$ will then project it once more. Whether this decoherence sets in every femtosecond, every day, or every year we cannot say. But, if this view is correct, $\mathfrak{S}$ exists not so much to clean up the results of Stern-Gerlach experiments and such as it does to *enable* conscious brains to function as workable quantum computers. $\mathfrak{S}$ is not simply a consequence of consciousness but, also, an *absolute precondition for consciousness*. A universe without $\mathfrak{S}$ might be able to accommodate very simple animals, assuming their unconscious brains functioned at a completely classical level. But it could never generate interesting, conscious, animals. This observation does not depend on the exact manner in which $\mathfrak{S}$ accomplishes its task. It could, for instance, function in the manner Chalmers and McQueen suggest and be just as effective in protecting $|\Psi(t)>$ from decoherence. (It is unfortunate that we have, apparently, not been able to manufacture a conscious quantum computer. If we could $\mathfrak{S}$ would, presumably, take care of its decoherence problems!)

Why Consciousness?

As far as we know, the universe began with a brief moment of inflation during which $|\Psi(t)>$, living in the Fock space of the Standard Model, became populated with the enormous number of elementary particles we now see. This could, presumably, have happened in any number of ways depending on the nature of the inflaton field and the manner of its transition from its false vacuum to its true one. So our universe could have begun in a great many initial states. We will designate these $|\Psi_i(\epsilon)>$ (where ϵ is the very small time over which the inflation occurred). We assume they are all admissible null states. We expect that many of these initial states would be completely inconsistent with the emergence of consciousness – they might give rise to universes that were too hot or cold or dense or diaphanous or homogeneous or inhomogeneous to ever permit the formation of stars and planets. No conscious life could ever evolve. But some (one, at least) must have been such as to allow for this. We know that because we are, obviously, here. We will call the first set 'sterile' and the other 'fertile.'

Now sterile and fertile initial conditions would evolve quite differently. The former would simply evolve from one admissible null state to another to another forever. $\mathfrak{S}$ would do nothing. Each would give rise to a single world-history $|\Psi_i(t)>$. In a fertile universe conscious animals would, eventually, appear and start making quantum measurements. Every time this happened the world-history would diverge into a (probably often infinite) number of new, possible, branches. In time, each of these will branch still further. As $t\to\infty$ the probabilities of the various results of the measurements will converge to the values predicted by Quantum Mechanics. Suppose our branches come about through repeatedly performing a quantum measurement that has a 60% chance of giving a 'green' result and a 40% chance of a 'red' one. Any acceptable branch will, in the limit, be found to contain 1.5 times as many 'green' nodes as 'red' ones. And, if we look at sections of a branch, we will usually find more sequences like ...GGGGG... than ...RRRRR... . An infinite sequence of all Gs would not constitute a valid world-history since it would not satisfy the predictions of Quantum Mechanics.

We will introduce a new pictorial metaphor. The world-history deriving from a sterile initial condition would look like a single, infinitely long, blade of grass – it would never branch at all. One deriving from a fertile initial condition would look like a dense, complicated, *bush*. It would consist of infinitely many world-histories each being perfectly consistent with the laws of physics. And not all fertile $|\Psi_i(\epsilon)>$ are created equal. Some may be very conducive to the evolution of consciousness – in these many quantum measurements would take place. Others might give rise to only a few conscious animals and these might die out quickly. We would end up with a bush in either case. In the second case the bush would be small and sparse. In the first, it would be a great deal "bushier."

Now we think there is one, and only one, real world-history. But we also suspect that sterile initial conditions must be far more common than fertile ones. (It is easier to design a watch that does not work than it is to design one that does.) But we are conscious.

We could make an appeal to Anthropic Principles here. But we will do something completely different. For lack of any reason to think otherwise, let us assume that the real universe is picked at random. This is the very simplest way things could be. After all, any world-history will satisfy the laws of physics equally well. It is then overwhelmingly likely that the one picked will belong to a bush and not be a blade of grass. In fact, it is overwhelmingly likely to belong to the bushiest part of the bushiest bush possible given the laws of physics. If what we have said so far is correct, our universe is overwhelmingly likely to have evolved from the most fertile initial condition possible. Thus we do not have to regard the existence of consciousness in Nature as happy accident or the result of Divine Intervention or some Anthropic Principle. Rather, it is just an ineluctable, statistical, consequence of the way things work. And this conclusion is, also, fairly robust. Perhaps we are wrong about how $\mathfrak{S}$ works. Maybe it works like Chalmers and McQueen say or in some other way. But, if it branches world-histories, we will still end up with bushes and blades of grass. Or, perhaps, Everett is right. In this case all conscious world-histories would be conscious. "We" would still be vastly more likely to find "ourselves" in a bushy branch on a bushy bush rather than elsewhere.

Conclusion.

We have tried to provide a variant of the von Neumann-Wigner Interpretation that circumvents the quantum Zeno effect and provides a reasonable description of physics. Some readers, at least, will find several of our assumptions rather counterintuitive. That two $|\Psi>$s could be arbitrarily close to one another (but not identical) and correspond to altogether different qualia states is, perhaps, the strangest thing we have said. But that state vectors in Fock space correlate with qualia at all is strange and corresponds to nothing else we know from physics. We are not sure how seriously we can take our intuitions in such a peculiar situation. At any rate, it is the price we pay for avoiding the Zeno problem. Other readers may dislike the fact that we consider all possible world-histories to be equally good candidates for reality. But they *are* all equally good. They all satisfy the laws of Quantum Mechanics. Some readers might say that our interpretation is perfectly fine except that consciousness and qualia need to be demoted to the status of epiphenomena and replaced by some purely physical property or process. We would, however, hate to do this. We like the von Neumann-Wigner approach because it gives us an obvious reason for $\mathfrak{S}$; I intuitively understand why I cannot experience a 'green-red' qualia. If there are purely physical properties or processes that cannot exist in superposition for an equally obvious reason it is incumbent upon the reader to tell us what they are.

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