BRAINS AS QUANTUM MECHANICAL SYSTEMS – A NEW MODEL

Chris Allen Broka
2002 Granemore St. Las Vegas, NV 89135
(chris.broka@gmail.com)

Abstract

We consider the possibility that the brain functions in the manner of a conscious quantum computer. The processes that instantiate its consciousness – the physical correlates of consciousness – are suggested to be fundamentally quantum mechanical in nature rather than classical. This idea is by no means new. But specific physical models are hard to come by; it is not obvious what kind of *physical* process might give us something like qubits. The Hameroff-Penrose Microtubule Hypothesis is one example. We begin by approximating a synapse as a small, parallel plate capacitor. We find that the classical electromagnetic energy stored in such a synapse corresponds closely to the spacing of energy levels we would obtain were the capacitor to be quantized. Considering each synapse to be an independent oscillator, we can define something like a Fock space in which the quantum state of the brain is to be represented. We designate the state vector in this space $|\Omega(t)>$. Some $|\Omega(t)>$ correspond to definite states of consciousness and are deemed 'admissible.' The others correspond mixed and indefinite qualia states. These are deemed 'inadmissible.' State vectors collapse so as to preclude the occurrence of inadmissible states.

Keywords: Brains as Quantum Computers, Quantum Measurements, von Neumann-Wigner Interpretation, Synapses.

Introduction.

The author ([1], [2], [3]) has recently advanced a variant of the von Neumann-Wigner Interpretation of Quantum Mechanics [4]. We work in the language of field theory where the state of the entire universe, at time *t*, $|\Psi(t)>$, is a vector in the Fock space of the Standard Model. Consciousness is, here, assigned the role of "classifier." Some $|\Psi(t)>$s are classified as admissible. The others are inadmissible. We gave a simple example where an electron is passed through a Stern-Gerlach apparatus. If it comes in spin-up a green light is triggered. If it is down we get a red light. A conscious observer watches all of this. Were the electron to come in in a superposed spin-state unitary evolution would have our observer seeing a 'green-red' qualia. Wigner called this situation "absurd" and we call it inadmissible. $|\Psi(t)>$ can never enter into such a state. To ensure that it does not we introduce a new operator – $\mathfrak{S}$ – and demand that $\mathfrak{S}\,|\,\Psi(t)> \;=\; |\Psi(t)>$ always. If $|\Psi(t)>$ is admissible $\mathfrak{S}$ does nothing. If it is not, $\mathfrak{S}$ looks 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.

This takes care of the "absurd" 'green-red' qualia. But we wondered whether $\mathfrak{S}$ might not perform another – and more important – function. Let $|\Psi(t)>$ describe a simple universe consisting of a single conscious brain that is experiencing qualia. Suppose, further, that the brain instantiates its consciousness through a physical mechanism that it, in one way or another, quantum mechanical in nature – it does not behave as a totally classical system. $|\Psi(t)>$ starts out in an admissible state. But the brain is a warm, wet, noisy environment. It may be that, as $|\Psi(t)>$ evolves unitarily, interaction with the environment begins to carry it into an inadmissible state no longer compatible with consciousness or its functioning as a workable "quantum computer." $\mathfrak{S}$ then projects it back into an admissible state. It then evolves unitarily with no trouble until, after a while, it tries to, once again, become inadmissible. We (rather loosely) described this process as quantum decoherence. There are not a great many *physical* theories of brains as quantum computers and we used, as an example, the Hameroff-Penrose Microtubule Hypothesis [5]. Tegmark [6] has calculated that their model would decohere in about 10^{-13} -

10^{-20} sec. This is quite rapid relative to the time-scales normally associated with conscious processes. We did not, ourselves, propose any physical model of the brain as a quantum computer. But we will try to do so here.

The Independent Oscillator Model.

We begin by approximating a synapse as a capacitor consisting of two circular, parallel, plates of radius R separated by a gap of width d. (In real synapses these are about 0.5 μm and 30 nm, respectively.) This system is studied in every introductory course on electromagnetism. Between the plates is a potential difference φ. There will be a uniform electric field ($-\varphi/d$) between the plates. Assume this oscillates. A circulating magnetic field ($\frac{1}{2c^2}\, r\, \partial_t\, E$) will be induced between the plates. As this changes, a correction will be introduced into the electric field. This will, in turn, induce a new correction to the magnetic field. We could carry this process on indefinitely and end up with an electric field that depended on the radius as a Bessel J_0 function. We will not, however, do this. We will drop all but the original (homogeneous) electric field and its first-order magnetic correction. As long as the potential is not varying quickly, we are justified in doing this. As a practical matter, potentials in synapses do not change much over time-scales of about 10^{-4} sec. Given the dimensions of a typical synapse, the higher-order corrections drop to zero very quickly. We can now write a Hamiltonian for our synapse which reads:

1) $\int \frac{\epsilon_0}{2}\left(E^2 + c^2 B^2\right) dV = \frac{\mu}{2}\,\varphi_{,t}{}^2 + \frac{\mu\,\alpha^2}{2}\varphi^2$ where $\mu = \frac{\pi R^4 \epsilon_0}{8 c^2 d}$ and $\alpha = \frac{\sqrt{8}\; c}{R}$.

We have a classical harmonic oscillator with resonant frequency α. Of course, we do not know over what range φ oscillates. It would oscillate quickly, however; $\alpha \approx 2 \text{ X } 10^{15}\ \text{sec}^{-1}$.

We now make a very interesting observation: Guessing that we should try to quantize our model we look at $\hbar\,\alpha$ (the energy of a quantized excitation of our oscillator) and compare it to the total classical energy in our synapse which is equal to $\frac{\epsilon_0}{2}\frac{\pi R^2}{d}\varphi_{\max}{}^2$ where $\varphi_{\max}$ is the greatest classical potential difference achieved by our oscillator. If the latter is vastly greater than the former, we know we are *not* dealing with a quantum mechanical problem. Equating the two gives us $\varphi_{\max} \approx 40$ mV. This is exactly similar to the potential differences typically seen in real synapses. Action potentials, for instance, are generally about 70 mV in magnitude (although they can be somewhat larger or smaller). We could, I suppose, write this off as a strange coincidence. But we could, also, suspect that Nature has engineered this result carefully and for a purpose.

We will proceed to quantize our system. We re-write our Hamiltonian as:

2) $\mathcal{H} = \frac{1}{2\mu}\, p^2 + \frac{\mu\,\alpha^2}{2}\varphi^2$.

p and φ are, now, to be interpreted as operators where $[\varphi, p] = i\,\hbar$. This leads to a wave function for φ:

3) $\psi(\varphi,\ t) = \sum_n c_n\, \psi_n\,(\varphi,\ t)$ where the $\psi_n\,(\varphi,\ t)$ are the familiar energy eigenstates for a quantized harmonic oscillator.

We are no longer interested in the classical physics and are, certainly, not trying to suggest that there is a classical φ in the synapse that oscillates ~ 10^{15} times a sec. That would be ridiculous. $\psi(\varphi, t)$ simply tells us the likelihood of finding a particular value of φ were it to be measured. And this will affect how the brain functions.

Let us imagine a scenario in which there is an action potential propagating down our axon towards a synapse that is in $\psi(\varphi)$. We envision action potentials as purely classical things. When it arrives at the synapse it must decide what to do. Since it is a classical object it will have to perform a quantum measurement to determine the value of φ. If it finds a very small value, things go on as usual. Suppose its potential difference is large enough to allow it to fire the synapse and proceed down the next neuron. But suppose it measures a φ that is large and opposite in sign. The net potential difference would then be reduced. The action potential may find itself unable to fire the synapse and will stop there. Or, suppose the action potential is too small to fire the synapse by itself. But it might find that φ is large and of the same sign. It then might be able to fire the synapse and proceed on its way. The value it finds for φ is, of course, determined randomly. The overall effect is to introduce an element of randomness into the process of neurotransmission. Some strong action potentials will, sometimes, fail to cross a synapse although we would expect them to. Some weak ones might get across although we would expect them not to.

When a measurement is performed and φ found to be φ_0, the wave function of the synapse will want to collapse into a state with no uncertainty in φ. The uncertainty in p would then be infinite. The state of the synapse would instantly evolve into one where there would be an equal probability of a new measurement giving *any* result for φ (even physically impossible ones). This situation is almost as "absurd" as the 'green-red' qualia. We suppose that, for the animal in question, this would correspond to an indefinite, mixed, state of consciousness. Let $\{\psi_a(\varphi)\}$ denote the set of all admissible $\psi(\varphi)$s. $\mathfrak{S}$ would project the (inadmissible) state into one of the $\psi_a(\varphi)$ with a relative probability given by $|\psi_a(\varphi_0)|^2$. Here we encounter a real example where $\mathfrak{S}$ does, in fact, function to allow the brain to continue its quantum mechanical operations (although quantum decoherence is not involved). There are thought to be up to 10^{15} synapses in a human brain. If each synapse encounters an action potential 10 times a second, $\mathfrak{S}$ would have to project the system every 10^{-16} sec. We also mention that several other models have been proposed that try to impute quantum mechanical properties to synapses ([7], [8]).

Admissible and Inadmissible States.

At any given time each synapse will be in a state described by a set of numbers $\{c_n\}$ as above. There are about 10^{15} synapses in a human brain so the "Fock space" here is 10^{15}-dimensional. Call the state vector $|\Omega(t)\rangle$. It is this vector that we propose corresponds to our qualia-state. We have already encountered an example of an inadmissible state above. But this cannot be the whole story. Consider the Stern-Gerlach experiment described earlier. If the electron is $|+\rangle$ the brain ends up in an admissible state, $|\Omega_G\rangle$, that corresponds to seeing a green qualia. If the electron is $|-\rangle$ we end up in $|\Omega_R\rangle$. If the electron comes in superposed we end up, by unitary evolution, in a sum of our two admissible states. But this would represent the 'green-red' qualia and, of course, be inadmissible.

The Evolution of Consciousness.

Whatever the process underlying consciousness, Evolution seems to have put a great deal of effort into optimizing it. It must confer a powerful benefit upon the animal possessing it. What could this be? At first glace it might be hard to see how what we have proposed would be useful at all. As mentioned, it leads to a certain randomization of neurotransmission and this might appear to be detrimental. But suppose there were a primitive animal in which a particular stimulus resulted in the firing of a synapse between neurons A and B. This, in turn, leads to a behavior and an outcome. If the brain were a completely classical system this behavior would always result from the stimulus. But, if we are right, on some random occasions the synapse will fail to fire. The result would be a different behavior and outcome. If the different outcome was favorable the brain would "notice" this and be inclined to weaken or delete the synapse so as to ensure that the favorable outcome always occurred. Or suppose the different outcome was unfavorable. The brain would try to strengthen the synapse or, perhaps, create more synapses between A and B to make sure that the unfavorable outcome never occurred again. The animal will, therefore, have *learned* something. We think the advantage of our proposed model lies in its ability to allow the animal to (randomly) experiment with a wider range of behaviors than would otherwise be possible. Learning would take place and the animal's survival chances would be improved.

Conclusion.

In [3] we speculated that the brain functions as a sort-of quantum computer and that $\mathfrak{S}$ may be necessary for this to be possible. We mentioned the Microtubule Hypothesis but were unable to offer any model of our own. We have now provided one.

By far the strongest evidence suggesting that our model might be on the right track comes from the "coincidental" agreement between the classical energy stored in our capacitor-like synapse and the quantum mechanical spacing of the energy levels obtained by quantizing it. This is a truly remarkable result and hints at some very clever evolutionary design-work. Neurons, given their small size and metabolic limitations, probably, have more-or-less to function with potential differences of about 40 mV. It is hard to see how they could generate hugely greater potentials. This being the case, were the radius of the synapse to be ten times larger than it is, the synaptic cleft would have to be 30 μm wide for our "coincidental" equality to hold. Neurotransmitters would be unable to diffuse across it quickly or in significant concentrations. If the radius were ten times smaller, the synaptic cleft would have to be narrower than an atom.

References.

[1] Broka, C. A. *Consciousness and the Problem of Quantum Measurement.* arXiv:1911.01823 (2019).

[2] Broka, C. A. *Gravitation and the Problem of Quantum Measurement.* arXiv:2010.14965 (2020).

[3] Broka, C. A. *Quantum Measurements and Their Place in Nature.* Philsci-Archive.pitt.edu/21677 (2023).

[4] Schrödinger, E. *The Present Situation in Quantum Mechanics. Naturwissenschaften* **23** (49); 807 (1935); Wigner, E. P. *Remarks on the Mind-Body Question.* In: I. J. Good, "The Scientist Speculates," (London, Heinemann, 1961); von Neumann, J. *The Mathematical Foundations of Quantum Mechanics* (1932).

[5] Hameroff, S., Penrose, R. *Consciousness in the Universe: a Review of the 'Orch OR' theory. Phys Life Rev.* **11** (1), 39 (2014). doi: 10.1016/j.plrev.2013.08.002.

[6] Tegmark, M. *The importance of quantum decoherence in brain processes*. *Physical Review E*. **61** (4),

4194, (2000). doi: https://doi.org/10.1103/PhysRevE.61.4194.

[7] Beck, F., Eccles, J. C. *Quantum aspects of brain activity and the role of consciousness. Proc. Natl. Acad. Sci. USA*. **89** (23), 11357 (1992). doi: 10.1073/pnas.89.23.11357.

[8] Georgiev, D. D., Glazebrook, J. F. *The quantum physics of synaptic communication via the SNARE protein complex. Prog. Biophys. Mol. Biol.* **135**, 16 (2018). doi: 10.1016/jpbiomol/bio.2018.01.006.