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On Quantum Theories of the Mind *

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Abstract

Replies are given to arguments advanced in this journal that claim to show that it is to nonlinear classical mechanics rather than quantum mechanics that one must look for the physical underpinnings of consciousness.

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In a paper with the same title as this one Alwyn Scott (1996) has given reasons for rejecting the idea that quantum theory will play an important role in understanding the connection between brains and consciousness. He suggests that it is to nonlinear classical mechanics, not quantum mechanics, that we should look for the physical underpinnings of consciousness. I shall examine here all of his arguments, and show why each one fails.

Scott contrasts, first, the linearity of quantum theory with the nonlinearity of certain classical theories, and notes the complexities induced by the latter. Thus he asks: "Is not liquid water essentially different from gaseous hydrogen and oxygen?" Of course it is! And this difference is generated, according to quantum field theory, by certain nonlinearities in that theory, namely the nonlinearities in the coupled *field equations*. These field equations (or, more generally, Heisenberg equations) are the direct analogs of the coupled nonlinear equations of the corresponding classical theory, and they bring into quantum theory the analogs of the classical nonlinearities: these nonlinearities are in no way obstructed by the linearity of the *wave equation*.

To understand this point it is helpful to think of the equation of motion for a classical statistical ensemble. It is linear: the sum of two classical statistical statistical ensembles evolves into the sum of the two evolved ensembles. This linearity property is a trivial consequence of the fact that the elements of the ensembles are imaginary copies of one single physical system, in different contemplated states, and hence they do not interact with one another. Thus in classical statistical mechanics we have both the (generally) nonlinear equations for coupled *fields*, and also the (always) linear equation for a certain statistical quantity.

Similarly, in quantum field theory we have both the (generally) nonlinear field equations for the coupled *fields*, and also the (always) linear wave equation for a certain statistical quantity, the *wave function*. The fact that a group of several atoms can behave very differently from how they would behave if each one were alone is a consequence of the nonlinearity of the field equations: this nonlinearity is not blocked by the linearity of the wave equation.

This blurring of the important distinction between the completely compatible linear and nonlinear aspects of quantum theory is carried over into Scott's discussion of solitons. The nonlinear field equations make the parts of this configuration of fields hang together indefinitely, and never spread out like a wave, as could be verified by doing experiments that probe its 'togetherness' by making several measurements simultaneously at slightly separated points: the various simultaneously existing parts of the soliton never move far apart. There is no conflict between this stability of the soliton and the linearity of the quantum mechanical wave equation. The wave function for the *center-of-mass of the soliton* does eventually spread out in exactly the way that *a statistical ensemble* consisting of the *centers of the solitons* in an ensemble of freely moving solitons (of fixed finite extension) would do: the spreading out of the *wave function* of the center-of-mass of a soliton just gives the diffusion analogous to the spreading out of a statistical ensemble of superposed *centers of mass*, due to the distribution in this ensemble of velocities of these centers of mass: the extended object itself, the soliton, does not spread out; its parts are held together by a nonlinear effect that can be attributed to the nonlinearity of the field equations.

This obscuring by Scott of the important conceptual distinctions between the two very different aspects of the soliton associated with the linear and nonlinear aspects of quantum theory creates, I think, a very false impression of some significant deficiency of quantum theory with regard to the manifestation of the analogs in quantum theory of nonlinear classical effects. No such deficiency exists: the atoms of hydrogen and oxygen do combine, according to quantum theory, to form water.

Failure carefully to follow through this conceptual distinction is the root of the failures of all of Scott's arguments.

Scott emphasizes the smallness of the spreading of the wave function of the center-of-mass of Steffi Graf's tennis ball. That situation involves the motion of a large massive object, the tennis ball, relative to, say, a baseline on a large tennis court.

A pertinent analogous situation in the brain involves the motion of a calcium ion from the exit of a microchannel of diameter 1 nanometer to a target trigger site for the release of a vesicle of neuro-transmitter into the synaptic cleft. The irreducible Heisenberg uncertainty in the velocity of the ion as it exits the microchannel is about 1.5 m/sec, which is smaller than its thermal velocity by a factor of about 4×10^{-3}. The distance to the target trigger site is about 50 nanometers. So the spreading of the wave packet is of the order of 0.2 nanometers, which is of the order of the size of the ion itself, and of the target trigger site. Thus the decision as to whether the vesicle is released or not, in an individual instance, will have a large uncertainty due to the Heisenberg quantum uncertainty in the position of the calcium ion relative to the trigger site: the ion may hit the trigger site and release the vesicle, or it may miss the trigger site and fail to release the vesicle. These two possibilities, yes or no, for the release of this vesicle by this ion continue to exist, in a superposed state, until a "reduction of the wave packet" occurs. Thus, if there is a part of the wave function that represents a situation in which a certain particular *set of vesicles* are released, due to the relevant calcium ions having been captured at the appropriate sites, then there will be other nearby parts of the wave function of the brain in which some or all of the relevant captures do not take place—because, for this part of the wave function, some of the calcium ions miss their target—and hence the corresponding vesicles are not released.

This means, more generally, in a situation that corresponds to a very large number N of synaptc firings, that until a reduction occurs, all of the 2^N possible combinations of firings and no firings will be represented with comparable statistical weight in the wave function of the brain/body and its environment. Different combinations of these firings and no firings can lead to very different macroscopic behaviours of the body that is being controlled by the this brain, via the *highly nonlinear* neurodynamics of the brain. Thus the collapse effectively chooses between very different possible macroscopic bodily actions.

I do not suggest that the mechanism just cited, involving the diffusion of the calcium ions in the nerve terminals is the *only* sources of significant differences between the macroscopic consequences of the quantum and classical descriptions of brain dynamics, for many other possible effects have been identified by quantum physicists interested in brain dynamics. But this effect is directly computable, whereas some of the others depend on complex factors that are not yet under theoretical control, and hence could be challenged as questionable. But this effect pertaining to calcium ions in nerve terminals gives very directly a reason for the the inappropriateness of the example of Steffi Graf's tennis ball: the relevant scales are enormously different. Because of this the huge difference in scales, the consequences of the Heisenberg uncertainty principle, and the subsequent collapses that they entail, are irrelevant to the outcome of the tennis match, but are critical to the bodily outcome of a brain activity that depends on the action at synapses.

Scott now lists a number of reasons for believing that quantum theory is not important in brain dynamics in a way that would relate to consciousness. However, as I shall now explain, none of these arguments has any relevance to the issue, which hinges on a putative connection between conscious thoughts and quantum reduction events.

The point is this. The quantum reduction/collapse events mentioned above are, according to orthodox Copenhagen quantum theory, closely tied to our conscious experiences. I believe that all physicists who suggest that consciousness is basically a quantum aspect of nature hold that our conscious experiences are tied to quantum collapses. The motivation for this belief is not merely that it was only by adopting this idea that the founders of quantum theory were able to construct a rational theory that encompassed in a unified and logically coherent way the regularities of physical phenomena in both the classical and quantum domains. The second powerful motivation is that this association seems provide a natural physical basis for the unitary character of our conscious experiences. The point is that quantum theory demands that the collapse of the wave function represent in Dirac's words "our more precise knowledge after measurement". But the representation of the increase in knowledge associated with say, some perception, would be represented in the brain as the actualization, as a whole unit, of a complex brain state that extends over a large part of the brain. Collapse events of some kind are necessary to make ontological sense out of orthodox-type quantum theory, and these events can never be pointlike events: they must have finite extension. But once they are in principle non-pointlike, they need not be tiny, and can quite naturally extend over an entire physical system. The natural and necessary occurrence in quantum theory of these extended holistic macroscopic realities that enter as inseparable and efficacious units into the quantum dynamics—and which, according to the physical theory itself, are associated with sudden increments in our knowledge—seems to put the physical and psychological aspects of nature into a much closer and more natural correspondence with each other in quantum theory than in classical mechanics, in which every large-scale thing is, without any loss, completely decomposable, both ontologically and dynamically, into its tiny parts.

Scott's first reason for claiming quantum theory to be unimportant to mind pertains to the speading of wave packets in molecular dynamics. That effect was just considered, and the crucial spreading of the calcium ion wave packets in nerve terminals was shown to be large compared to the ion size, contrary to Scott's estimate.

Scott then considers a subject he has worked on: polarons. He says the the effect of the quantum corrections is to degrade the global coherence of the classical polaron. But this "degrading" is not just some fuzzying-up of the situation: it is the very thing that is of interest and importance here. In the case of a body/brain this "degrading" is, more precisely, the separation of the wave function into branches representing various classical describable possibilities. However, only one of these classical possibilities is experienced in the mind associated with this body/brain. Quantum theory in its present form is mute on the question of which of these possibilities is experienced: only a statistical rule is provided. But then what is it that *undoes* this huge (in our case) degrading that the linear wave equation generates. It is not the classical nonlinearities, for the quantum analogs of these nonlinearities are built into the part of the quantum dynamics that *creates* the superposition of the classically describable possibilities: they are built into the Schroedinger equation. A collapse, which is the putative physical counterpart of the conscious experience, is a different effect that does not enter into the Schroedinger equation. Nor does it enter at all into the classical approximation to quantum theory. In that approximation there are no Heisenberg uncertainties or indeterminacies, and hence no collapses, and hence from the persective of the encompassing and more basic quantum theory, no physical counterparts of our conscious experiences.

His next two points concern the difficulty of maintaining "quantum coherence" in a warm, wet brain. The brain is a complex structure with built-in energy pumps. The question of whether or not long-range quantum coherence could be maintained is difficult to settle theoretically. Some explorations have been made (Vitiello, 1995), but the matter is not yet settled. On the other hand, my theory yields important quantum effects that are not wiped out by decohence effects and that could lead to the evolution of a dynamically efficacious consciousness in coordination with evolution of brains without requiring any long-range quantum coherence (Stapp, 1997a,b).

Scott's next item is the theory for the propagation of an action potential along a nerve fiber. He points out that this propagation is well described by the classical Hodgkin-Huxley equation. But even among neuroscientists who accept classical mechanics as an adequate foundation for brain dynamics there is a recognition that although in some situations the parallel processing structure produces reliable and essentially deterministic behaviors of groups of neurons, in spite of the essentially stochastic character of the the distribution of individual pulses on the individual neurons, in other cases there are long-range correlations in the timings of pulses. One can expect in cases where thermal and other classical fluctuation effectively cancel, in such a way as to give reliable and deterministic behaviors, that the quantum effects associated with collapses will probably have no major macroscopic consequences. But in cases where long-range correlations of pulse timings arise, the precise details of these timings must be controlled in part by stochastic variables even in a completely classical model that generallly conforms to, say, the Hodgkin-Huxley equation. In these more delicate situations there is ample room for the large-scale effects associated with quantum collapses of brain-wide quantum states to play a decisive dynamical role *within* the framework of possibilities compatible with the classical Hodgkin-Huxley equations. Indeed, the actualization of global brain states would be expected produce fine-tuned global regularities that classical mechanics could not account for.

Scott's final point is about Schroedinger's cat. He says the Schroedinger equation cannot be constructed because the cat does not conserve energy. But the usual assumption in these studies of the quantum mind-brain is that quantum theory is universally valid, in the sense that the Schroedinger equation is the equation of motion for the entire universe, in absence of collapse events. Partial systems are defined by integrating over the other degrees of freedom, and their energies are not conserved.

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