# The Role of Evolution in the Formation of Consciousness

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## Abstract

It is argued that the principles of classical physics are inimical to the development of an adequate science of consciousness. The problem is that insofar as the classical principles are valid consciousness can have no effect on the behavior, and hence on the survival prospects, of the organisms in which it inheres. Thus within the classical framework it is not possible to explain in natural terms the development of consciousness to the high-level form found in human beings. In quantum theory, on the other hand, consciousness can be dynamically efficacious: quantum theory does allow consciousness to influence behavior, and thence to evolve in accordance with the principles of natural selection. However, this evolutionary requirement places important constraints upon the details of the formulation of the quantum dynamical principles.

## The Inadequacy of Classical Mechanics as the Basis for a Science of Consciousness

Every major advance in science has involved an important conceptual development, and the incorporation of consciousness into physics should be no exception. The mapping out of the empirical correlations between brain activity and consciousness will certainly contribute in an important way to our understanding of the mind/brain system, but there must also be conceptual progress on the theoretical problem of how to bring consciousness into concordance with the principles of physics.

Rational analysis of this problem hinges on one central fact: classical mechanics does not entail the existence of consciousness. Classical mechanics neither requires, demands, nor allows one to predict with certainty, the existence of (phenomenal) experience. The full content of nature, as it is represented in classical mechanics, resides in the locations and motions of particles, and the values and rates of change of local fields. There is nothing within the classical physical principles that provides a basis for deducing how a physical system "feels" – for deducing whether it is happy or sad, or feels agony or delight. There is no phenomenal hook or toehold within classical mechanics itself that can permit one to deduce, logically, simply from the principles of classical mechanics alone, the assured validity of assertions about the experiential aspects of nature. This is not a matter of lack of imagination, or inability to conceive new possibilities. It is a matter of basic principle. There is no basis within the principles of classical mechanics for a logical proof of the existence of a "feeling" because classical mechanics is a rationally closed conceptual system whose principles supply no more than is needed to determine the motions of particles and fields from the prior dispositions of these same variables themselves. This dynamical connection is established within a narrow mathematical framework that never refers to any phenomenal (i.e., psychological or experiential) quality.

Since classical mechanics is dynamically complete, with respect to all the variable with which it deals, namely the so-called "physical" variables, one has, with respect to the phenomenal elements of nature, four options:

1. Identify the phenomenal elements with certain properties or activities of the physical quantities.
2. Say that these phenomenal elements are not identically the same as any physical property or activity, but are companions to certain physical properties or activities, and that their presence in no way disrupts the classical dynamics.
3. Accept some combination of (1) and (2).
4. Accept that phenomenal elements do affect the dynamics, rendering classical dynamics invalid.

The first three options are scientifically indistinguishable, and they share the common feature that the classical dynamical principles do not logically determine whether the proposed connection of the physical variables to our felt experiences, or to the analogous feelings in members of other species, is valid or not. So the connection to physical parameters of something so basic to science as our experienced knowledge of what is going on about us is not logically entailed by the basic dynamical laws. Consequently, the feelings that we experience become appendages whose existence could, from a logical point of view, be denied without violating the posited classical laws. The phenomenal aspects of nature would be, in this sense, epiphenomenal: the classical dynamical principles could be completely valid without the feelings that we experience being present in nature at all.

It is very likely true that any physical system that is built and behaves in certain ways will also be conscious, and that this tight relationship between behavior and felt experience arises naturally out of the essential nature of the actual physical substrate. But the existence of such a connection would not mean that this tight relationship is a logical consequence of the principles of classical mechanics. On the contrary, it would mean rather that the principles of classical mechanics are incomplete because they fail to entail the existence of this naturally occurring aspect of nature, and are, moreover, necessarily false unless consciousness is epiphenomenal.

The epiphenomenal character of consciousness implied by classical mechanics cannot be reconciled with the naturalistic notion that consciousness evolved due to the survival advantage it conferred: epiphenomenal properties confer no survival advantage. Hence if the classical principles were taken to govern the dynamical process of nature then the presence in human beings of highly developed consciousness would be a double mystery: the basic dynamical principles would neither entail the existence of the phenomenal realities that populate our experiential realms, nor, given their existence, allow any natural dynamical explanation of how they could have evolved to this high state from simpler forms.

These considerations would be very destructive of the naturalistic program of science were it not for the fact that classical mechanics has already been found, by purely physical considerations, to be basically incorrect: it does not describe correctly the empirically observed properties of physical systems. This failing is not merely a slight inaccuracy. To get an adequate theoretical foundation for a description of physical processes the entire logical structure of classical mechanics had to be abandoned at the foundational level. It was replaced by a radically different logical structure that allows our experiences to play a key logical and dynamical role.

## Quantum Mechanics and Consciousness

The successor of classical mechanics is called quantum mechanics. The basic change is to a mathematical description that effectively converts the atomic particles to something of a radically different ontological type. In the new theory the “particles” can no longer be imagined to be tiny material objects of the kind encountered in everyday life, but merely smaller. They become more like nonlocalized elements of an information network, or of a knowledge structure. This ontological change infects everything made up of atomic constituents (and fields), and hence the entire physical world. Thus the basic conceptual problem that the founders of quantum theory had to solve was how, in the face of this dissolution of the substantive universe of classical mechanics, to find some new foundational structure upon which to base an adequate new physics.

Their solution was pragmatic and epistemological. No matter what the world “out there” is really like, our direct experiences of it are just what they were before the quantum character of nature was discovered: they are of the same kind that they were when classical mechanics seemed adequate. Given this empirical fact, that “our experiences of the world” are “classically describable,” in the sense that we can describe them as if they were experiences of a world that accords at the macroscopic level with the concepts of classical physics, one can take experiences of this kind to be the foundational elements upon which to build the new science. Thus the founders of quantum theory constructed the new physics as a theory of statistical correlations between experiences of this kind: the basic realities of the new physical science became these “classically describable” experiences, and the physical world became an information network that connected these classically describable experiential realities to each other in a mathematically specified statistical way.

The important thing about this new conception of basic physical theory, in the context of the mind/brain problem, is that the experiential things are no longer left out. Rather they have moved to a central position. Thus we are no longer forced to graft the experiential aspects of nature into a physical theory that has no natural place for them, and that moreover excludes from the outset any possibility of their playing an irreducible dynamical role. Furthermore, since the elemental ingredients of the theory are information and knowledge, rather than material objects resembling little rocks, we are no longer faced with the ontological puzzle of how to build consciousness out of something so seemingly unsuited to the task as a collection of tiny rocks hurtling through space. On the contrary, in quantum theory the rock-like aspects of nature arise from certain mathematical features that inhere in idea-like qualities.

## Quantum Ontologies

The original “Copenhagen” interpretation of quantum theory eschewed ontology: it made no attempt to provide a description of nature itself, but settled for a system of rules describing statistical correlations between our experiences (i.e., between our classically describable experiences of the world). Physicists have, by now, devised essentially three ontological pictures that could produce the same statistical connections as the earlier pragmatic system of rules. These ontologies are Everett’s One-World/Many-Minds ontology, Bohm’s Pilot-Wave ontology, and the more orthodox Wavefunction-Collapse ontology associated with the names of Heisenberg, von Neumann, and Wigner. To get the essential point of what consciousness can do it will be useful to describe briefly the essential features of these three ontologies.

In all three ontologies a key component of nature is the quantum state vector. This is a basic element in the quantum theory, and it can be represented in various equivalent ways. In the simplest way one decomposes it into components corresponding to various numbers of “particles” of various kinds, where the word “particle” initially means just that there is a set of three variables x, y, and z, and a "mass," and perhaps a few other (spin) variables for each such "particle." Then, for example, the component of the state vector corresponding to N spinless particles would be a function of 3N variables, namely the three variables x, y, and z for each of the N particles. This function is called the "wave function" of the N particles: it can be imagined to be something like a wave, or set of ripples, on a pond, where the different locations on the "pond" are specified now not by just two variables, as for an ordinary pond, but rather by 3N variables. This "wave," or set of ripples, evolves in time under the control of the Schroedinger equation, which causes the wave to propagate over this 3N-dimensional "pond." The essential feature of this propagation is that there is a tendency for the wave continually to divide further and further into ever finer separate branches that are narrowly focused and move off in different directions in the 3N-dimensional space. Each such branch corresponds, roughly, to a different classically describable possibility. For example, one such branch might correspond to the dead version of Schroedinger's notorious cat, whereas another branch would describe the alive version. The various separate branches become far apart on the 3N-dimensional pond, and hence come to evolve independently of each other: each branch quickly comes to evolve in almost exactly the way that it would evolve if the various branches from which it is diverging were not present at all. On the other hand, various branches that are far apart and independently evolving in 3N-dimensional space could be sitting right on top of each other if one were to project these branches down onto the ordinary 3-dimensional space that we seem to inhabit: the independently evolving dead and alive cats could be confined, as far as appearances are concerned, to the same small 3D cage.

The basic interpretational question in quantum theory is how to comprehend these many co-existing "branches" of the universe, only one of which we ever observe.

I think almost every physicist who starts to think diligently about this question is led first (on his own if he has not already heard about it) to a natural interpretation that Everett [1957] first described in detail. This is the idea that, because the Schroedinger equation is the quantum mechanical analog of Newton's equations, which were supposed to govern the evolution of the universe itself, the physical world should have a really existing component corresponding to each of the branches generated by the Schroedinger equation. Since each of these branches evolves essentially independently of every other one, the realm of consciousness associated with each branch of the wave function of a person's brain must be dynamically independent of the realms of consciousness associated with every other branch. Thus each conscious observer should be aware only of the classically describable world that corresponds to the branch of the universe (as specified by the wave function) that contains the corresponding branch of his brain: the branches of the wave function of his brain that are parts of other branches of the universe should correspond to differently independently evolving realms of experience, namely to realms of experience corresponding to these other "classically describable" branches of the universe.

The existence of these essentially independently evolving branches of the wave function follows directly from the basic equations of quantum mechanics, and thus seems reasonable from a physicist's point of view, even though it leads to the strange idea that the complete reality is a super-world that is populated with a plethora of really existing ordinary-worlds, only one of which is represented in any individual realm of consciousness.

The logical simplicity of this model is undermined, however, by a logical difficulty. It has to do with the statistical predictions that are the heart of quantum theory. The quantum evolution in accordance with the Schroedinger equation causes each branch generally to divide into sub-branches, and quantum theory assigns to each sub-branch a relative statistical weight, and gives to this relative statistical weight an empirical meaning. This meaning entails that if a person finds himself to be on a branch then the probability that he will subsequently find himself to be on a particular sub-branch will be specified by the aforementioned relative statistical weight of that sub-branch. Thus if a sub-branch has a very low relative statistical weight, according to the theory, then quantum theory predicts that the chance is very small that a person who experiences himself at one moment to be on the original branch will later experience himself to be on that sub-branch.

In order to provide a basis for this notion of probability one must have something that can belong to one branch OR another. In the above discussion this something was a realm of consciousness: each realm of consciousness is considered to belong to some particular branch, not to all branches together. However, in the state vector, or its representation by a wave function, all of the branches are conjunctively present: a toy boat might be sitting on one branch OR another branch, but the pond itself has this ripple AND that ripple, AND that other ripple, etc. Thus, in order to deal with probabilities one is forced to introduce something that is logically different from the quantum state or wave function that the basic principles of quantum mechanics provide. This move constitutes the introduction of a new kind of ontological element: the theory becomes essentially dualistic, in contrast to the monistic structure of classical mechanics. Consciousness is a new kind of thing that, quite apart from its phenomenal character, has mathematical properties different from those of the "physical" part of nature represented by the wave function.

Once it is recognized that the realms of consciousness are not simply direct carryovers from the quantum state, but must have essentially different logical properties, it appears that it would be more parsimonious and natural to have, for each person, a single realm of consciousness that goes into a single branch rather than having to introduce this new kind of ontological structure that, unlike the wave function, divides *disjunctively* into the various branches. This option produces a one-mind variation of Everett's many-minds interpretation. The one-mind version has been promoted by Euan Squires [1990].

David Bohm [1952, 1993] solves this "AND versus OR" problem by introducing in addition to the quantum state, or wave function, not consciousness but rather a classical universe, which is represented by a moving point in the 3N-dimensional space. Bohm gives equations of motion for this point that cause it to move into one of the branches OR another in concordance with the quantum statistical rules, for a suitable random distribution of initial positions of this point. Thus Bohm's theory is also dualistic in the sense of having two ontological types, one of which, the quantum state, combines the branches conjunctively, and the other of which, the classical world, specifies one branch OR another.

The great seeming virtue of Bohm's model is that, like classical mechanics, it is logically complete without bringing in consciousness. But then any later introduction of consciousness into Bohm's model would, from a logical point of view, be gratuitous, just as it is for classical mechanics: consciousness is not an integral and logically necessary part of the theory, but is rather a dangling epiphenomenal appendage to a theory whose chief virtue was that, like classical mechanics, it was logically and dynamically complete without consciousness.

Bohm's model is, moreover, nonparsimonious: it is burdened with a plethora of empty branches that evolve for all eternity even though they have no influence on the motion of the classical world. Squire's model has a similar defect: it has a plethora of empty (of consciousness) branches that evolve for all eternity, but have no effect on anyone's experiences. Everett's many-minds interpretation is nonparsimonious for the opposite reason: it has for each individual human being, John Doe, a plethora of minds only one of which is needed to account for the empirical facts. It is the presence of these superfluous elements in each of these interpretations that causes many physicists to turn away from these "unorthodox" interpretations.

The most parsimonious theory is the Bohr/Heisenberg/von-Neumann/Wigner wave-function-collapse model. This model:

1. Accepts Bohr's view that our experienced knowledge is an appropriate reality upon which to build physical theory.
2. Accepts Heisenberg's view that transitions from potentiality to actuality are a basic component of nature.
3. Accepts von Neumann's identification of these transitions with abrupt changes of the quantum state of the universe.
4. Accepts Wigner's proposal (attributed by Wigner to von Neumann) that our conscious experiences are associated with brain events that actualize new quantum states.

This association of the experiential events upon which Bohr based the whole theory with brain events that are just special cases of the general collapse events of Heisenberg and von Neumann brings closure to the theory, and produces a natural basis for a science of consciousness.

This model is more parsimonious than the others because the state of the universe becomes a representation of a set of potentialities, and hence the state vector, bringing them into concordance with the new knowledge actualized by the event. The experienced knowledge that an adequate physical theory must accommodate and explain is thus brought explicitly into the theory, rather than being left in some ineffable limbo, and the quantum state remains always in concordance with the potentialities for the next event, rather that being burdened with “empty branches” that no longer have any bearing on our experiences. The theory thus retains much of the pragmatic thrust of the original Copenhagen interpretation, but brings into the theoretical description the brains that are the physical substrates of our experienced knowledge.

Large physical objects are at the same time both entities in their own right, parts of the world that envelop them, and also constructs fabricated from their atomic constituents. In a naturalistic science one expects thoughts and other experiences to have analogous properties. So a central problem is to understand, within the context of our basic physical theory, namely quantum mechanics, how our thoughts and other experiences can be both whole entities, and yet also constructs built out of elemental components.

How do our complex thoughts come to be parts of nature? There is the notion of Platonic ideals according to which the ideal forms are somehow eternal. But it is more in line with the naturalistic program of science to try to understand complex thoughts as being constructed by some natural process out of more elemental forms. Indeed, the naturalistic program leads us to try to explain how our complex thoughts are built up by natural processes associated with our complex brains.

In any proof, or theorem, or theory, one can only get out what one puts in, in some form or another. So consciousness cannot come out of a theoretical or computational model of the mind/brain unless at least the seeds of consciousness are put in. It would be contrary to the naturalistic program of science to put full-blown complex thoughts or experiences directly into the conception of the mind/brain at the outset. But one must put in seeds that can bloom into our conscious thoughts in the physical environment of our brains. Classical mechanics has no such needs, but the foregoing description of the Bohr/Heisenberg/von Neumann/Wigner collapse interpretation of quantum mechanics suggests that an appropriately constituted informational model that implements the mathematical structures that quantum phenomena has revealed to us could contain the requisite seeds of consciousness.

## The Seeds of Consciousness

I have argued above that classical mechanics does not entail the existence of consciousness. The reason was that classical mechanics does not contain any reference to psychological qualities, and hence there is no way that one can deduce from the principles of classical mechanics alone that any activity that classical mechanics entails is necessarily accompanied by a psychological activity. But what is it that causes some scientists to resist the temptation to just sweep away the problem of consciousness by simply asserting baldly that certain functional physical activities simply *are* psychological activities?

One reason to resist is that this is a bald assertion: it is a claim that is not entailed by the dynamical principles. One can define a thundercloud to be angry when its electrical potential is high relative to the earth, or nearby clouds, and justify this definition by pointing out that an angry cloud is, by virtue of the dynamical principles, likely to have a destructive outburst, which is a sign of anger. But making this definition does not mean that an angry thundercloud feels like you feel when you are angry. There is no way to deduce from the classical dynamical principles anything about how a thundercloud "feels," even though one can "deduce," on the basis of this definition, that it is angry.

The situation is entirely different if one accepts that quantum mechanics is the appropriate physical theory for explaining natural phenomena. As already pointed out, the most parsimonious quantum ontology is the Bohr/Heisenberg/von Neumann/Wigner Wavefunction-Collapse model, and conscious experiences are already woven into the fabric of that theory. They were placed there not to provide the basis for a theory of consciousness, but rather to provide a basis for rationally coherent and practically useful physical theory that accommodates the experimental evidence pertaining to the basic qualities of the physical stuff of nature. The core insight of Bohr and his colleagues was that since the key mathematical elements of the practical calculations were representations of structures that seemed more akin to ideas than to material substance the theory should be pragmatic and epistemological, and built around our experienced knowledge, rather than around the classical notion of matter. This core idea is retained: conscious events, and their images in the mathematical representation of nature, become key logical, dynamical, and epistemological elements of the theory. An experience is neither a companion of, nor claimed to be identical to, a certain physical activity that seems profoundly different from itself, namely a collection of tiny rock-like objects hurtling through space in some way. Rather it is identified as a certain contraction of an idea-like structure to more compact and cohesive structure. Such a contraction is naturally akin to a thought in the following respects: it selects and brings into being a certain cohesive idea-like reality, and it grasps as an integral unit an information structure that is extended over a large spatial region.

## Collapse Conditions and the Evolution of Consciousness

The purpose of this section is to bring out some conditions that are imposed by the demand that consciousness must evolve naturally in accordance with the principles of natural selection, and hence in coordination with the survival advantage that consciousness can confer upon organisms that possess it.

Within the Bohr/Heisenberg/von Neumann/Wigner framework, conscious process has an image in the physicists' description of nature. This process is represented by a sequence of collapse events that directly controls the evolution of the physical system. The basic problem in tying this causally efficacious conscious process to survival advantage is that in a first approximation quantum mechanics and classical mechanics, though conceptually very different, give essentially the same predictions about many physical quantities: it takes well controlled experiments to establish the corpuscular character of light, or the wave character of atomic particles. But to the extent that classical mechanics is adequate to explain our physical behavior, consciousness can be regarded as unnecessary, and hence unable to confer survival advantage. Thus to study the survival advantages conferred by consciousness it is necessary to consider behavioral features that cannot be accounted for by classical mechanics, but that depend critically upon effects of the collapse events that are, in this theory, the physical images of conscious events.

Most of the extant analyses bearing on this problem have been carried out within the general context laid down by von Neumann in his study of the measurement problem. The main condition in these studies is that the process being studied corresponds to a "good measurement." This entails that the wave function of the full system must divide during the process of "measurement" into several well separated branches, such that within each branch some macroscopic variable, dubbed the "pointer" variable, will be confined to a small region, and such that the various small regions associated with the various branches will be non-overlapping. The collapse is supposed to occur after this separation has occurred, and is achieved by restricting the pointer variable to the region corresponding to some selected one of these branches, with the relative frequencies of the branches – selected in a long run of similar experiments – conforming to a specified statistical rule, namely the Born rule.

Within this "good measurement" context the predictions derived from the Bohr/Heisenberg/von Neumann/Wigner collapse model will be no different from those derived from David Bohm's deterministic model, which has no collapses, and hence no effect of consciousness. The point is that Bohm's model is designed to give the same predictions as the orthodox Copenhagen rules in these "good measurement" cases, and it does so without bringing in either collapses or efficacious consciousness.

This is a key point: insofar as the collapses in the brain occur only under "good measurement" conditions, and in accordance with the Born rule, it will be difficult if not impossible to obtain any effect of consciousness, per se, upon the survival prospects of the organism. This is because the evolution would not differ significantly from Bohm's statistical model that gives the same statistical results without involving or invoking the notion of consciousness.

Conversely, however, if the collapses in the brain occur under conditions other than those of a "good measurement" then the collapses, which in this theory are images of thoughts and feelings, can in principle enter into the dynamics in ways that would lead to a natural evolution of consciousness.

Note that the pertinent point here is not a difference between classical mechanics and quantum mechanics, per se. The issue is the role of consciousness. No one doubts that quantum theory should be used where it differs from classical mechanics, but that fact is not directly relevant to the consciousness issue. For the Bohm model can account for much of quantum phenomena without ever mentioning either consciousness or collapses. The Bohr/Heisenberg/von Neumann/Wigner formulation does bring consciousness per se into the dynamics in a natural and dynamically efficacious way. But if this dynamical effect does not produce, as regards survival prospects, departures from what the Bohm formulation predicts then one cannot rationally assert that consciousness per se is having any effect on survival.

The only way I can see to make the predictions of the Bohr/Heisenberg/von Neumann/Wigner collapse model depart from the predictions of the Bohm model is to say either that the collapses in brains occur sometimes under conditions that do not conform to "good measurements," or that under these conditions the Born rule can sometimes fail, or to say that the Bohm model does not apply to the real world, which many involve complexities such as "strings," super-symmetries, quantum gravity, etc. that could render Bohm's model inapplicable.

The situation, therefore, is this. Naturalistic science requires the existence of our complex human consciousness to be explained, in the sense that we should be able to see how its presence and form could emerge in conjunction with the evolution of bodily forms as a consequence of the survival advantages that it confers upon organisms that possess it. Insofar as classical mechanics is taken to be the basic mechanics, the existence of human consciousness could never be explained in this sense. This is because the classical principles do not specify how consciousness enters: one can vary at will one's idea of how consciousness is connected to the physical properties of some organism, and even hold it to be absent altogether from that organism's life, without contradicting the principles of classical mechanics. On the other hand, consciousness does enter efficaciously into the Bohr/Heisenberg/von Neumann/Wigner formulation of quantum mechanics, so this conception of the basic dynamical theory does provide at least a toehold for a possible naturalistic explanation of the evolution of consciousness. For in this theory, consciousness is tied tightly to the causally efficacious collapse process. But invoking quantum mechanics does not automatically provide a natural explanation for the evolution of consciousness. The mind/brain dynamics depends critically upon the details of how the collapse process operates in the brain. In the simplest sort of scenario, the dynamics would be indistinguishable from what could be predicted by Bohm's model, which involves no collapses and no consciousness. So if the naturalistic program is to succeed then the collapse process in human brains must be more complex than what the simplest possible quantum scenario would yield.

One approach would be that of Roger Penrose and Stuart Hameroff. This depends upon the existence of difficult-to-achieve long-range quantum coherence effects that extend through a large part of the brain. Moreover, Penrose ties this model to Platonic ideals, which are not intrinsically tied to physical structure, but are rather more free-floating and prior to their physical embodiments. Naturalistic science, on the other hand, would have each thought tied intrinsically to some physical substrate, such as a brain.

Some technical foundations of a naturalistic approach to these questions are given in two earlier versions [Stapp, 1996a,b] of the present paper, which did not meet the space limitations imposed on contributions to these proceedings. The key point of those papers is that if the "good measurement" condition is lifted, and the collapses are taken to be collapses to patterns of neurological activity of the kind identified in Stapp [1993] as a brain images of thoughts, but without demanding that these patterns be disjoint from similar but slightly different patterns (specified by slightly earlier or later, or stronger or weaker, pulses on some neurons), then there can be a significant speed-up – as compared to classically described or Bohm-described processes – of brain processes that are searching for abductive solutions to typical problems that organisms must face in their struggle for survival. It is just this "speed-up" that can confer survival advantage.

## References


Bohm, David. (1952). "A suggested interpretation of quantum theory in terms of 'hidden' variables, I and II." *Physical Review* 85, 166-193.

Bohm, David and Hiley, B. (1993). *The Undivided Universe: An ontological interpretation of Quantum Theory*. Rutledge, London.

Everett, Hugh III. (1957). "Relative state interpretation of quantum mechanics." *Reviews of Modern Physics* 29, 463-62.

Stapp, H.P. (1993). *Mind, Matter, and Quantum Mechanics*. Springer Verlag, Heidelberg, New York.

Stapp, H.P. (1996a). *Chance, Choice and Consciousness: A Causal Quantum Theory of the Mind/Brain*.

Stapp, H.P. (1996b). *Science of Consciousness and the Hard Problem*.

Squires, E. (1990). *The Conscious Mind in the Physical World*, Adam Hilger, Bristol.

Von Neumann, J. (1932). *Mathematical Foundations of Quantum Mechanics*. (English Translation, 1955). Princeton University Press, Princeton, NJ.

Wigner, E. (1967). "Remarks on the Mind-Body Problem." *Symmetries and Reflections*. Indiana University Press, Bloomington.