NEUROSCIENCE, ATOMIC PHYSICS, AND THE HUMAN PERSON.

This article is an integration of the contents of three talks and one text that I have prepared and delivered during the past year. They were aimed at four different audiences. The first talk was at a small conference in Philadelphia of scientists who are leading proponents of various diverse efforts to further develop and understand quantum theory. The second talk was at a public event in Switzerland where a number of scientists, and several artists, described to a general audience recent developments aimed at a better understanding the nature of the human person. The third talk was at a conference in Tucson entitled "Quantum Approaches to the Understanding of Consciousness" attended mainly by physicists, psychologists, and neuroscientists. The 'text' was a section of a chapter of a book aimed at neuroscientists. Although the details of these four presentations were different, the essential content was the same: an explanation of the enormous difference in the scientific conception of the connection between mind and brain brought about by the replacement of the essentially seventeenth century classical physical theory of Newton, Galileo, and Descartes by the twentieth century quantum physics of Bohr, Heisenberg, Pauli, and von Neumann.

The orientations of the four presentations were varied. I began my talk in Switzerland with the words:

This talk is about you as a human person.
It is about science's conception of you as a human person.
It is about what makes you different from a machine.
It is about your mind, and how your mind influences your bodily actions.

The talk in Philadelphia began with the words:

This talk has five closely related themes.

1. The most important development in science in the twenty-first century will be a deepening of our understanding of the nature of human beings.

2. The key unsolved question, there, is the nature of the connection between the mind and the brain.

3. Von Neumann's Processes I and II, applied to the human person, constitute genuine causal top-down and bottom-up mind-brain connections, respectively

4. Process I involves "Free Choices."

5. These "Free Choices" Can Influence Brain-Body Behavior.

The talk at Tucson began with:

Neuroscience is an important component of the scientific attack on the problem of consciousness. However, most neuroscientists, viewing our discussions, see only dissent and discord, and no reason to believe that quantum theory has any profound relevance the dynamics of the conscious brain. It is therefore worthwhile, in this first plenary talk of the 2003 Tucson conference on "Quantum Approaches to the Understanding of Consciousness," to focus on the central issue, which is the crucial role of "The Observer," and more specifically, "The Mind of the Observer," in contemporary physical theory. I shall therefore review this radical departure of present-day basic physics from the principles of classical physics, and then spell out some of its ramifications for neuroscience.

The section of the chapter of the book aimed at neuroscientists was part of a chapter describing recent experiments involving the conscious control of emotions, and the large differences in brain activity when a conscious effort is made - or is not made - to suppress the emotional impact of certain visual stimuli. The experiments show strong correlations between data of two distinct kinds: (1), recordings on devices that are measuring physical properties of the brain of a subject, and (2), instructions to those subjects couched in psychological terms pertaining to mental efforts and strategies. The section explains the new modes of understanding and modeling the correlations between data of these two disparate kinds created by the orthodox (von Neumann) quantum theoretic conceptualization of the conscious brain, as contrasted to the classical conceptualization. That section stresses the close similarity between the situations faced by atomic scientists and neuroscientists in their attempts to understand in causal terms the correlations between data described in psychological and physical terms, and how quantum theory provides for bona fide top-down influences of mental actions upon neural processes, and also an operationally and pragmatically simpler theory of the conscious brain that both rests upon and emerges from contemporary physics.

The present article is aimed at all of those audiences, and addresses all of those topics.

I have had to include a few key equations, in order to allow physicists to know exactly what I was saying, but have described in ordinary words what these equations mean. I believe that these symbolic expressions will be helpful to *all* readers, even those who proclaim deep-seated eternal aversion to math.

Before proceeding I should indicate what I mean by the words “mind” and “brain.”

Your *mind* is your stream of consciousness. It consists of your thoughts, ideas, and feelings, and is described in *psychological* or *mental* terms.

Your *brain* is an organ in your body consisting of nerve cells and other tissues, and is described in *physical* terms - in terms of *properties assigned to tiny space-time regions inside your skull.*

Your mind and your brain are obviously related. Your conscious thought can cause your arm to rise. What happens is this: Your conscious intentional effort causes nerve pulses to emanate from your brain, and these pulses cause muscles in your arm to contract, and those contractions cause your arm to rise.

But *how*, according to the basic principles of science, does your conscious thought initiate that chain of bodily events? How does a *mental* action cause *physical* events?

The central theme of all four presentations, and of this article, is the tremendous difference in the scientific understanding of the dynamics of the conscious brain that emerges from orthodox quantum theory, with its essential introduction of the active human agent-participant, as contrasted to classical physics. Although many neuroscientist and neurophilosophers do not explicitly specify that they are assuming the validity of classical physics, which they know to be false in the regime of the behaviors of the ions and molecules that play a key role in the dynamics of the conscious brain, they nevertheless endeavor to conceptualize the dynamics of the conscious brain in essentially classical terms: they have closed their minds to the huge practical and conceptual advantages wrought by the twentieth-century advances in physics. To reveal what they are losing it is helpful first to review the precepts of classical physics.

Classical Physics.

Classical physics is a theory of nature that originated with the work of Isaac Newton in the seventeenth century and was advanced by the contributions of James Clerk Maxwell and Albert Einstein. Newton based his theory on the work of Johannes Kepler, who found that the planets appeared to move in accordance with a simple mathematical law, and in ways wholly determined by their spatial relationships to other objects. *Those motions were apparently independent of our human observations of them*.

Newton assumed that all physical objects were made of tiny miniaturized versions of the planets, which, like the planets, moved in accordance with simple mathematical laws, independently of whether we were aware of them or not. He found that he could explain the motions of the planets, and also the motions of large terrestrial objects and systems, such as cannon balls, falling apples, and the tides, by assuming that every tiny planet-like particle in the solar system attracted every other one with a force inversely proportional the square of the distance between them.

This force was an *instantaneous action at a distance*: it acted instantaneously, no matter how far apart the particles were located.

This feature troubled Newton. He wrote to a friend "That one body should act upon another through the vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it." (Newton 1687: 634) Although Newton's philosophical persuasion on this point is clear, he nevertheless formulated his universal law of gravity without specifying how it was mediated.

Albert Einstein, building on the ideas of Maxwell, discovered a suitable mediating agent: a distortion of the structure of space-time itself. Einstein's contributions made classical physics into what is called a *local theory*: there is no action at a distance. All influences are transmitted essentially by contact interactions between tiny neighboring mathematically described "entities," and no influence propagates faster than the speed of light.

Classical physics is, moreover, *deterministic*: the interactions are such that the state of the physical world at any time is completely determined by the state at any earlier time. Consequently, according to classical theory, the complete history of the physical world *for all time* is mechanically fixed by contact interactions between tiny component parts, together with the initial condition of the primordial universe.

This result means that, according to classical physics, *you are a mechanical automaton*: your every physical action was pre-determined before you were born solely by mechanical interactions between tiny mindless entities. Your mental aspects are *causally redundant*: everything you do is completely determined by mechanical conditions alone, without reference to your thoughts, ideas, feelings, or intentions. Your intuitive feeling that your mental intentions make a difference in what you do is, according to the principles of classical physics, a false and misleading illusion.

Many scientists, philosophers, writers, intellectuals, teachers, and policy makers claim to believe this mechanical conception of human beings, and base policies upon it. They believe that this is what science says, and hence that this is what you must believe.

But this is *not what science says*! It is what *classical physics* says! It is what an essentially seventeenth century precursor to contemporary physical theory says!

There are two ways within classical physics to understand this total incapacity of your mental side - your stream of consciousness - to make any difference in what you do. The first is to consider your thoughts ideas, and feelings to be epiphenomenal *by-products* of the activity of your brain. Your mental side is then a causally impotent sideshow that *is produced*, or *caused*, by your brain, but that generates no reciprocal action back upon your brain. The second way is to contend that your mental aspects are the *very same things* as certain of motions of various tiny parts of your brain.

Problems with the classical-physics idea of the conscious brain.

William James (1890: 138) argued against the first possibility, epiphenomenal consciousness, by arguing that "*The particulars of the distribution of consciousness*, so far as we know them, *points to its being efficacious.*" He noted that consciousness seems to be "an organ, superadded to the other organs which maintain the animal in its struggle for existence; and the presumption of course is that it helps him in some way in this struggle, just as they do. But it cannot help him without being in some way efficacious and influencing the course of his bodily history." James said that the study described in his book "will show us that consciousness is at all times primarily a *selecting agency*." It is present when choices must be made between different possible courses of action. He further mentioned that "It is to my mind quite inconceivable that consciousness should have *nothing to do* with a business to which it so faithfully attends."(1890: 136)

If consciousness has no effect upon the physical world then what keeps a person's mental world aligned with his physical situation: what keeps his pleasures in general alignment with actions that benefit him, and pains in general correspondence with things that damage him, if pleasure and pain have no effect at all upon his actions?

These liabilities of the notion of epiphenomenal consciousness lead many thinkers to turn to the alternative possibility that a person's stream of consciousness is *the very same thing* as some activity in his brain: consciousness is an “emergent property” of brains.

A huge philosophical literature has developed arguing for and against this idea. The primary argument against this “emergent-identity theory” position, *within a classical physics framework*, is that within classical physics the full description of nature is in terms of numbers assigned to tiny space-time regions, and there appears to be no way to understand or explain how to get from such a restricted conceptual structure, which involves such a small part of the world of experience, to the whole. How and why should that extremely limited conceptual structure, which arose basically from idealizing, by miniaturization, certain features of observed planetary motions - and which is now known to be profoundly incorrect in physics - suffice to explain the totality of experience, with its pains, sorrows, hopes, colors, smells, and moral judgments? Why, given the known failure of classical physics at the fundamental level, should that richly endowed whole be explainable in terms of such a narrowly restricted part?

The core ideas of the arguments in favor of an identity-emergent theory of consciousness are illustrated by Roger Sperry’s example of a “wheel.” (Sperry, 1991.) A wheel obviously does something: it is causally efficacious; it carries the cart. It is also an *emergent property*: there is no mention of “wheelness” in the formulation of the laws of physics, and “wheelness” did not exist in the early universe; “wheelness” *emerges* only under certain special conditions. And the macroscopic wheel exercises “top-down” control of its tiny parts. All these properties are perfectly in line with classical physics, and with the idea that “a wheel is, precisely, a structure constructed out of its tiny atomic parts.” So why not suppose “consciousness” to be, like “wheelness”, an emergent property of its classically conceived tiny physical parts?

The reason that consciousness is not analogous to wheelness, *within the context of classical physics,* is that the properties that characterize wheelness are properties that are *entailed,* within the conceptual framework of classical physics, by properties specified in classical physics, whereas the properties that characterize consciousness, namely the way it feels, are not *entailed,* within the conceptual structure provided by classical physics, by the properties specified by classical physics.

This is the huge difference-in-principle that distinguishes consciousness from things that, according to the precepts of classical physics, are constructible out of the particles that are postulated to exist by classical physics.

Given the state of motion of each of the tiny physical parts of a wheel, as it is conceived of in classical physics, the properties that characterize the wheel - e.g., its roundness, radius, center point, rate of rotation, etc., - are specified within the conceptual framework provided by the principles of classical physics, *which specify only geometric-type properties such as changing locations and shapes of conglomerations of particles, and numbers assigned to points in space.* But given the state of motion of each tiny part of the brain, as it is conceived of in classical physics, the properties that characterize a stream of consciousness - the painfulness of the pain, the feeling of the anguish, or of the sorrow, or of the joy - are not specified, within the conceptual framework provided by the principles of classical physics. Thus it is possible, within that classical physics framework, to strip away those feelings without disturbing the physical descriptions of the motions of the tiny parts. One can, *within the conceptual framework of classical physics*, take away the consciousness without affecting the locations and motions of the tiny physical parts of the brain. But one cannot, within the conceptual framework provided by classical physics, take away the wheelness of the wheel without affecting the locations and motions of the tiny physical parts of a wheel.

Because one can, within the conceptual framework provided by classical physics, strip away the consciousness without affecting the physical behavior, one cannot rationally claim that the consciousness is the *cause* of the physical behavior, or is *causally efficacious* in the physical world. Thus the “identity theory” or “emergent property” strategy fails in its attempt to make consciousness efficacious, within the conceptual framework provided by classical physics. Moreover, the whole endeavor to base brain theory on classical physics is undermined by the fact that the classical theory fails to work for phenomena that depend critically upon the properties of the atomic constituents of the behaving system, and brains are such systems: brain processes depend critically upon synaptic processes, which depend critically upon ionic processes that are highly dependent upon their quantum nature. This essential involvement of quantum effects will be discussed in detail in later sections.

The Quantum Approach.

Classical physics is *an approximation* to a more accurate theory - called quantum mechanics - and quantum mechanics makes mind efficacious. Quantum mechanics *explains* the causal effects of mental intentions upon physical systems: it *explains* how your mental effort can produce the brain events that cause your bodily actions. Thus quantum theory converts science's picture of you from that of a mechanical automaton to that of a mindful human person. Quantum theory also shows, explicitly, how the approximation that reduces quantum theory to classical physics completely eliminates all effects of your conscious thoughts upon your brain and body. Hence, from a physics point of view, trying to understand the mind-brain connection by going to the classical approximation is absurd: it amounts to trying to understand something in an approximation that eliminates the effect you are trying to study.

Quantum mechanics arose during the twentieth century. Scientists discovered, empirically, that the principles of classical physics were not correct. Moreover, they were wrong in ways that no minor tinkering could ever fix. The *basic principles* of classical physics were thus replaced by *new basic principles* that account uniformly both for all the successes of the older classical theory and also for all the newer data that is incompatible with the classical principles.

Physical theory was turned inside out.

The most profound alteration of the fundamental principles was to bring the consciousness of human beings into the basic structure of the physical theory. In fact, the whole *conception of what science is* was turned inside out. The core idea of classical physics was to describe the "world out there," with no reference to "our thoughts in here." But the core idea of quantum mechanics is to describe *our activities as knowledge-seeking and knowledge-using agents*. Thus quantum theory involves, basically, not just what is "out there," but also what is "in here," namely "our knowledge." Consciousness is thus introduced into contemporary orthodox physical theory, not as something *whose existence needs to be explained,* but as rather as something whose detailed structure and detailed connection to brain activities needs to be *further* explicated.

Science must bridge the psycho-physical divide.

The basic philosophical shift in quantum theory is the *explicit* recognition that science is about *what we can know*. It is fine to have a beautiful and elegant mathematical theory about an imagined "*really existing physical world out there"* that meets a lot of intellectually satisfying criteria. But the essential demand of science is that the theoretical constructs be tied to the experiences of the human scientists who devise ways of testing the theory, and of the human engineers and technicians who both participate in these test, and eventually put the theory to work. So the structure of a proper physical theory must involve not only the part describing the behavior of the not-directly-experienced theoretically postulated entities, expressed in some appropriate symbolic language, but also a part describing the human experiences that are involved in these tests and applications, expressed in the language that we actually use to describe such experiences to ourselves and each other. Finally we need some "bridge laws" that specify the connection between the concepts described in these two different languages.

Classical physics met these requirements in a rather trivial kind of way, with the relevant experiences of the human participants being taken to be direct apprehensions of various gross behaviors of large-scale properties of big objects composed of huge numbers of the tiny atomic-scale parts. And these apprehensions were taken to be *passive*: they had no effect on the behaviors of the systems being studied. But the physicists who were examining the behaviors of systems that depend sensitively upon the behaviors of their tiny atomic-scale components found themselves forced to go to a less trivial theoretical arrangement, in which the human agents were no longer passive observers, but were *active participants* in ways that contradicted, and were impossible to comprehend within, the general framework of classical physics, *even when the only features of the* *physically described world that the human beings observed were large-scale properties of measuring devices.*

The two-way quantum psycho-physical bridge.

The sensitivity of the behavior of the devices to the behavior of some tiny atomic-scale particles propagates in such a way that the acts of observation by the human observers of *large scale properties of the devices* could no longer be regarded as passive: these acts were assigned a crucial *selective* action. Thus the core structure of the basic general physical theory became transformed in a profound way: the connection between physical behavior and human knowledge was changed from a one-way bridge to a mathematically specified two-way interaction that involves *selections* performed by conscious minds.

This profound change in the principles is encapsulated in Niels Bohr dictum that " in the great drama of existence we ourselves are both actors and spectators." (Bohr, 1963: 15 & 1958: 81) The emphasis here is on "actors": in classical physics we, and in particular our minds, were mere spectators.

This revision must be expected to have important ramifications in neuroscience, because the issue of the connection between mind (the psychologically described aspects of a human being) and brain/body (the physically described aspects of that person) has recently become a matter of central concern in neuroscience.

The Copenhagen formulation.

The original formulation of quantum theory was created mainly at an Institute in Copenhagen directed by Niels Bohr, and is called "The Copenhagen Interpretation." Due to the profound strangeness of the conception of nature entailed by the new mathematics, the Copenhagen strategy was to refrain from making ordinary ontological claims, but to take, instead, a fundamentally pragmatic stance. Thus the theory was formulated *basically* as a set of practical rules for how scientists should go about their tasks of acquiring knowledge, and then using this knowledge in practical ways. Speculations about "what the world out there – apart from our knowledge of it - is really like" were regarded as "metaphysics," and hence outside *real* science.

Copenhagen quantum theory is about the relationships between human agents (called *participants* by John Wheeler) and the systems that they act upon. In order to achieve this conceptualization the Copenhagen formulation separates the physical universe into two parts, which are described in two different languages. One part is the observing human agent and his measuring devices. That part is described in mental terms - in terms of our instructions to colleagues about how to set up the devices, and our reports of what we then learn. The other part of nature is *the system that the agent is acting upon*. That part is described in physical terms - in terms of mathematical properties assigned to tiny space-time regions.

Von Neumann's Process II.

The great mathematician and logician John von Neumann formulated Copenhagen quantum theory in a rigorous way.

Von Neumann identified two very different processes that enter into the quantum theoretical description of the evolution of a physical system. He called them Process I and Process II (Von Neumann, 1955: 418). Process II is the analog in quantum theory of the process in classical physics that takes the state of a system at one time to its state at a later time. This Process II, like its classical analog, is *local* and *deterministic*. However, Process II by itself is not the whole story: it generates physical worlds that do not agree with human experiences. For example, if Process II were the *only* process in nature then the quantum state of the moon would represent a structure smeared out over large part of the sky.

Process I: A dynamical psycho-physical bridge.

To tie the quantum mathematics to human experience in a rationally coherent and mathematically specified way quantum theory introduces *another process*, which Von Neumann calls Process I. It is a *selection* process that is tied to conscious experience, and it is not determined by the micro-local deterministic Process II. It is a selection made by an agent about how he or she will act or attend.

Any physical theory must, in order to be complete, specify how the elements of the theory are connected to human experience. In classical physics this connection is part of a *metaphysical* superstructure: it is not part of the core dynamical description. But in quantum theory this connection of the mathematically described physical state to conscious experiences is part of the essential dynamical structure. And this connecting process is not passive: it does not represent a mere *witnessing* of a physical feature of nature by a passive mind. Rather, the process is active: it injects into the physical state of the system being acted upon properties that depend upon the intention of the observing agent.

Quantum theory is built upon the practical concept of intentional actions by agents. Each such action is expected or intended to produce an experiential response or feedback. For example, a scientist might act to place a Geiger counter near a radioactive source, and expect to see the counter either "fire" during a certain time interval or not "fire" during that interval. The experienced response, "Yes" or "No", to the question "Does the counter fire during the specified interval?" specifies one bit of information. Quantum theory is thus an information-based theory built upon the knowledge-acquiring actions of agents, and the knowledge that these agents thereby acquire.

Probing actions of this kind are performed not only by scientists. Every healthy and alert infant is engaged in making willful efforts that produce experiential feedbacks, and he or she soon begins to form expectations about what sorts of feedbacks are likely to follow from some particular kind of effort. Thus both empirical science and normal human life are based on paired realities of this action-response kind, and our physical and psychological theories are both basically attempts to understand these linked realities within a rational conceptual framework.

The basic building blocks of quantum theory are, then, a set of intentional actions by agents, and for each such action an associated collection of possible "Yes" feedbacks, which are the possible responses that the agent can judge to be in conformity to the criteria associated with that intentional act. For example, the agent is assumed to be able to make the judgment “Yes” the Geiger counter clicked or “No” the Geiger counter did not click. And he must be able to report. “Yes” the counter is in the specified place, or “No” it is not there. Science would be difficult to pursue if scientists could make no such judgments about what they were experiencing.

All known physical theories involve idealizations of one kind or another. In quantum theory the main idealization is not that every object is made up of miniature planet-like objects. It is rather that there are agents that perform intentional acts each of which can result in a feedback that may conform to a certain criterion associated with that act. One bit of information is introduced into the world in which that agent lives, according to whether the feedback conforms or does not conform to that criterion. Thus knowing whether the counter clicked or not places the agent on one or the other of two alternative possible separate branches of the course of world history.

These remarks reveal the enormous difference between classical physics and quantum physics. In classical physics the elemental ingredients are tiny invisible bits of matter that are idealized miniaturized versions of the planets that we see in the heavens, and that move in ways unaffected by our consciousness, whereas in quantum physics the elemental ingredients are intentional actions by agents, the feedbacks arising from these actions, and the effects of our actions on the physical systems that our actions act upon.

Consideration of the character of these differences makes it plausible that quantum theory may be able to provide the foundation of a scientific theory of the human person that is better able than classical physics to integrate the physical and psychological aspects of his nature. For quantum theory describes the effects of a person’s intentional actions upon the physical world, whereas classical physics systematically leaves these effects out.

An intentional action by a human agent is partly an intention, described in psychological terms, and partly a physical action, described in physical terms. The feedback also is partly psychological and partly physical. In quantum theory these diverse aspects are all represented by logically connected elements in the mathematical structure that emerged from the seminal discovery of Heisenberg.

That discovery was that in order to get the quantum generalization of a classical theory one must formulate the theory in terms of *actions.* A key difference between *numbers* and *actions* is that if A and B are two actions then AB represents the action obtained by performing the action A upon the action B. If A and B are actions then, generally, AB is different from BA: the order in which actions are performed matters.

The intentional actions of agents are represented mathematically in Heisenberg's space of actions. Here is how it works.

Each intentional action depends, of course, on the intention of the agent, and upon the state of the system upon which this action acts. Each of these two aspects of nature is represented within Heisenberg's space of actions by an action.

The idea that a "state" should be represented by an "action" may sound odd, but Heisenberg's key idea was to replace what classical physics took to be a "being" by a "doing." I shall denote the action that represents the state being acted upon by the symbol S.

An intentional act is an action that is intended to produce a feedback of a certain conceived or imagined kind. Of course, no intentional act is sure-fire: one's intentions may not be fulfilled. Hence the intentional action puts in play a process that will lead either to a confirmatory feedback "Yes," the intention is realized, or to the result "No", the "Yes" response failed to occur.

The effect of this intentional mental act is represented mathematically by an equation that is one of the key equations of quantum theory. This equation represents, within the quantum mathematics, the effect of the Process I mental action upon the quantum state S of the system being acted upon. The equation is:

$$S \rightarrow S' = PSP + (1-P)S(1-P).$$

This formula exhibits the important fact that this Process I action changes the state S of the system being acted upon into a new state S', which is a *sum* of two parts.

The first part, PSP, represents the possibility in which the experiential feedback called “Yes” appears, and the second part, (1-P)S(1-P), represents the alternative possibility “No”, this feedback does not appear. Thus the intention of the action and the associated experiential feedback are tied into the mathematics that describes the dynamics of the physical system being acted upon.

The action P is important. It represents an action upon the system that is being acted upon by the agent, and it depends on *the intention of the agent*. The action represented by the symbol P, acting both on the right and on the left of S, is the action of eliminating from the state S all parts of S except the “Yes” part. That particular retained part is determined by the intentional choice of the agent. The action of (1-P), acting both on the right and on the left of S, is, analogously, to eliminate from S all parts of S except the “No” parts.

The projection operator P is required to satisfy P = PP. This implies P(1-P) = (1-P)P = 0, which says that the sequence of these two actions, P and (1-P), in either order, leave nothing.

Thus the action P is an action in the space in which the physical system is represented, and it reduces to zero all components that correspond to the “No” response, but leaves intact the components corresponding to the “Yes” response to the intentional action. The action of (1-P) is the analogous action with “Yes” and “No” interchanged. The action of P is the representation of an intentional mental action upon a physically described system.

Notice that Process I produces the *sum* of the two alternative possible feedbacks, not just one or the other. Since the feedback must either be “Yes” or “No = Not-Yes,” one might think that Process I, which *keeps* both the “Yes” and the “No” parts, would do nothing. But that is not correct! This is a key point. It can be verified by noticing that S can be written as a sum of four parts, only two of which survive the Process I action:

$$S = PSP + (1-P)S(1-P) + PS(1-P) + (1-P)SP.$$

This formula is a strict identity. The dedicated reader can easily confirm it by collecting the contributions of the four occurring terms

PSP, PS, SP, and S, and verifying that all terms but S cancel out. This identity shows that the state S can be expressed as a sum of four parts, *two of which are eliminated by Process I.*

But this means that Process I has a *nontrivial effect* upon the state being acted upon: it eliminates the two terms that correspond neither to the appearance of a "Yes" feedback nor to the failure of the "Yes" feedback to appear.

That is the *first key point*: quantum theory has a specific dynamical process, Process I, which specifies the effect upon a physically described system of an *intentional act* by a conscious agent.

Free Choices.

The second key point is this: the agent's choices are "free choices," *in the specific sense specified below.*

Orthodox quantum theory is formulated in a realistic and practical way. It is structured around the activities of human agents, who are considered able to freely elect to probe nature in any one of many possible ways. Bohr emphasized the freedom of the experimenters in passages such as:

> "The freedom of experimentation, presupposed in classical physics, is of course retained and corresponds to the free choice of experimental arrangement for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude." (Bohr, 1958: 73}

This freedom of action stems from the fact that in the original Copenhagen formulation of quantum theory the human experimenter is considered to stand outside the system to which the quantum laws are applied. Those quantum laws are the only precise laws of nature recognized by that theory. Thus, according to the Copenhagen philosophy, *there are no presently known laws that govern the choices* made by the agent/experimenter/observer/participant about how the observed system is to be probed. This choice is*, in this very specific sense*, a "free choice." It is not ruled out that some deeper theory will eventually provide a causal explanation of this "choice."

Probabilities.

The predictions of quantum theory are generally statistical: only the *probabilities* that the agent will experience each of the alternative possible feedbacks are specified. Which of these alternative possible feedbacks will actually occur in response to a Process I action is not determined by quantum theory.

The formula for the probability that the agent will experience the feedback 'Yes' is

Tr PSP/Tr S, where the symbol Tr represents the trace operation. This trace operation means that the actions act in a cyclic fashion, so that the rightmost action acts back around upon the leftmost action. Thus, for example, Tr ABC=Tr CAB =Tr BCA. The product ABC represents the result of letting A act upon B, and then letting that product AB act upon C. But what does C act upon? Taking the trace of ABC means specifying that C acts back around on A.

An important property of a trace is that the trace of any of the sequences of actions that we consider must always give a positive number or zero. Thus this trace operation is what ties the actions, as represented in the mathematics, to measurable numbers.

[The trace operation, and in fact the operation of multiplying together any two operators, is the quantum analog of the classical process of integrating over all of "phase space," giving equal a prior weighting to equal volumes of phase space. Thus the trace operation is in effect a statistical sum over all of the "loose ends" that are not fixed in the expression upon which the trace operation acts.]

Von Neumann's psycho-physical theory of the conscious brain.

The Copenhagen approach separates the world into two parts: "The Observer" which includes the mind, brain, and body of the personal observer together with his measuring devices; and "The System" that this observer is acting upon. "The Observer" is described in psychological terms, whereas "The System" is described in physical/mathematical spacetime terms.

This procedure works very well in practice. However, it seems apparent that the body and brain of the human agent, and his devices, are parts of the physical universe. Hence a complete theory ought to be able to include our bodies and brains in the physically described part of the theory. On the other hand, the structure of the theory depends critically also upon the features that are represented in Process I, and that are described in mentalistic language as intentional actions and experiential feedbacks.

Von Neumann showed that it was possible, without significantly disturbing the predictions of the theory, to shift the bodies and brains of the agents, along with their measuring devices, into the physical world, *while retaining. and ascribing to the mind of the agent, those mentalistically described properties of the agents that are essential to the structure of the theory.* The system acted upon by the mind is the brain. Thus in this von Neumann re-formulation the Process I action is an action of mind upon brain. Hence von Neumann's re-formulation provides us with the core of a science-based dynamical theory of the conscious brain.

It is worthwhile to reflect for a moment on the ontological aspects of Von Neumann quantum theory. Von Neumann himself, being a clear thinking mathematician, said very little about ontology. But he called the mentalistically described aspect of the agent "his abstract 'ego'." (von Neumann, 1955: 421). This phrasing tends to conjure up the idea of a disembodied entity, standing somehow apart from the body/brain. But another possibility is that consciousness is an *emergent property* of the body-brain. Notice that some of the problems that occur in trying to defend the idea of emergence within the framework of classical physical theory disappear when one accepts the validity of quantum theory. For one thing, one no longer has to defend against the charge that the emergent property, consciousness, has no "genuine" causal efficacy, because anything it does is done already by the physically described process, independently of whether the psychologically described aspect emerges of not. In quantum theory the causal efficacy of our thoughts is no illusion: it's the real thing!

Another difficulty with "emergence" in a classical physics context is in understanding how the motion of a set of miniature planet-like objects, careening through space, can *be a painful experience.* But within the quantum framework the basic physical structure, namely the quantum state, is essentially knowledge or information imbedded in space-time. Hence there is no intrinsic problem with the idea that a sudden increment in a person's knowledge should be represented by a sudden jump in the quantum state of his brain. The identification of conscious actions with physical actions is no longer problematic. This is because the old idea of "matter" has been eradicated, and replaced by a mathematical representation of an information-based psycho-physical reality.

In this connection, Heisenberg remarked:

"The conception of the objective reality of the elementary particles has thus evaporated not into the cloud of some obscure new reality concept, but into the transparent clarity of a mathematics that represents no longer the behavior of the particle but rather our knowledge of this behavior." (Heisenberg, 1958)

Conservation of Causality.

The question arises: How can the effect of a psychologically described action be injected into the dynamics of a physically described system without upsetting the causal structure of the latter.

The answer is this: Physicists have discovered an important and unexpected property of nature. It pertains to observable phenomena that depend upon microscopic properties that are *in principle inaccessible to observation.* In such a situation we are *in principle* unable, due to the lack of crucial micro-data, to give a complete causal description of the observable phenomena. However, our principled inability to give a complete causal account of the psychologically described phenomena, due to this inherent gap in the micro-data, can be partially offset by introducing into the theory, *instead of the inaccessible micro-data,* the *psychologically described selection of an action* made upon the system by an agent.

Thus the loss of causal determination at the microlevel, due to the limitations imposed by Heisenberg's uncertainty principle, allows an alternative (statistical) causal account to be achieved by replacing the inaccessible micro-data by empirically available and controllable data about human selections of actions!

This feature discovered in atomic science should be equally importance in neuroscience. That is because the basic problem in neuroscience is essentially the same as the one in atomic physics. In both cases the problem is to provide a causal account of connections between experiences that depend sensitively upon micro-properties that are in principle inaccessible. But quantum theory shows how the principled loss of information at the microlevel can be partially offset by using, instead, the controllable and reportable variables of the intentional actions of human beings. Nature left open a causal gap for us to occupy.

The Quantum Brain.

The quantum state of a human brain is, of course, a very complex thing. But its main features can be understood by considering first a classical conception of the brain, and then folding in some key features that arise already in the case of the quantum state of a single particle, or object, or degree of freedom.

States of a Simple Harmonic Oscillator.

One of the most important examples of a quantum state is the one corresponding to a pendulum, or more precisely, to what is called a "simple harmonic oscillator." Such a system is one in which there is a restoring force that tends to push the center of the object to a single "base point" of lowest energy, and in which the strength of this restoring force is directly proportional to the distance of the center point of the object from this base point.

According to classical physics any such system has a state of lowest energy. In this state the center point of the object lies motionless at the base point. In quantum theory this system again has a state of lowest energy, but the center point is not localized at the base point: it is represented by a *cloudlike* spatial structure that is spread out over a region that extends to infinity. However, the amplitude of this cloudlike form has the shape of a bell: it is largest at the base point, and falls off in a prescribed manner as the distance the center point from the base point increases.

If one were to squeeze this state of lowest energy into a more narrow space, and then let it loose, the cloudlike form would first explode outward, but then settle into an oscillating motion. Thus the cloudlike spatial structure behaves rather like a swarm of bees, such that the more they are squeezed in space the faster they move, and the faster the squeezed cloud will explode outward when the squeezing constraint is released. These visualizable properties extend in a natural way to many-particle cases.

The Double-Slit Experiment.

An important difference between the behavior of the quantum cloudlike form and the somewhat analogous *classical probability distribution* is exhibited by the famous *double-slit experiment*. If one shoots an electron, an ion, or any other quantum counterpart of a tiny classical object, at a narrow slit then if the object passes through the slit the associated cloudlike form will fan out over a wide angle. But if one opens two closely neighboring narrow slits, then what passes through the slits is described by a probability distribution that is not just the sum of the two separate fanlike structures that would be present if each slit were opened separately. Instead, at some points the probability value will be *twice the sum* of the values associated with the two individual slits, and in other places the probability value drops nearly to zero, even though both individual fanlike structures give a large probability value at that place. These *interference* features of the quantum cloudlike structure make that structure logically different from a classical-physics probability distribution, for in the classical case the probabilities arising from the two slits would simply add, due to the fact that, according to classical principles, the particle must pass through one slit or the other, and the fact that some other slit is also open should not matter very much.

Quantum theory deals consistently with this interference effect, and all the other, non-classical properties of these cloudlike structures.

Nerve Terminals, Ion Channels, and the Need to Use Quantum Theory.

Some neuroscientists who study the relationship of consciousness to brain process believe that classical physics will be adequate for that task. That belief would have been reasonable during the nineteenth century, but now, in the twenty-first, it is rationally untenable: quantum theory must in principle be used because the behavior of the brain depends sensitively upon ionic and atomic processes, and these processes involve quantum effects.

To study quantum effects in brains within an orthodox (i.e., Copenhagen or Von Neumann) quantum theory one must use the von Neumann formulation. The reason is that *Copenhagen* quantum theory is formulated in a way that leaves out the quantum dynamics of the human observer's body and brain. But Von Neumann quantum theory takes the physical system S upon which the crucial Process I acts to be the brain of the agent, or some part of the brain. Thus Process I then describes an interaction between a person's stream of consciousness, described in mentalistic terms, and the activity in his brain, described in physical terms. That interaction drops completely out when one passes to the classical approximation. Hence ignoring quantum effects in the study of the mind-brain connection means, according to the basic principles of physics, ignoring the dynamical connection one is trying to study.

One must *in principle* use quantum theory. But there is then the quantitative issue of how important the quantum effects are.

To explore that question we now consider the quantum dynamics of nerve terminals.

Nerve Terminals.

Nerve terminal are essential connecting links between nerve cells. The way they work is quite well understood. When an action potential traveling along a nerve fiber reaches a nerve terminal a host of ion channels open. Calcium ions enter through these channels into the interior of the terminal. These ions migrate from the channel exits to release site on vesicles containing neurotransmitter molecules. The triggering effect of the calcium ions causes these contents to be dumped into the synaptic cleft that separates this terminal from a neighboring neuron, and these neurotransmitter molecules influence the tendencies of that neighboring neuron to “fire.”

The channels through which the calcium ions enter the nerve terminal are called “ion channels.” At their narrowest points they are less than a nanometer in diameter.(Cataldi, 2002). This extreme smallness of the opening in the ion channels has profound quantum mechanical importance. The consequence is essentially the same as the consequence of the squeezing of the state of the simple harmonic operator, or of the narrowness of the slits in the double-slit experiments. The narrowness of the channel restricts the lateral spatial dimension. Consequently, the lateral velocity is forced by the *quantum uncertainty principle* to become large. This causes the cloud associated with the calcium ion to *fan out* over an increasing area as it moves away from the tiny channel to the target region where the ion will be absorbed as a whole, or not absorbed, on some small triggering site.

This spreading of the ion wave packet means that the ion may or may not be absorbed on the small triggering site. Accordingly, the vesicle may or may not release its contents. Consequently, the quantum state of the vesicle has a part in which the neurotransmitter is released and a part in which the neurotransmitter is not released. This quantum splitting occurs at every one of the trillions of nerve terminals.

What is the effect of this *necessary* incursion of the cloud-like quantum character of the ions into the evolving state of the brain?

A principal function of the brain is to receive clues from the environment, to form an appropriate plan of action, and to direct and monitor the activities of the brain and body specified by the selected plan of action. The exact details of the plan will, for a classical model, obviously depend upon the exact values of many noisy and uncontrolled variables. In cases close to a bifurcation point the dynamical effects of noise might even tip the balance between two very different responses to the given clues, e.g., tip the balance between the ‘fight’ or ‘flight’ response to some shadowy form.

The effect of the independent superpositions of the “release” or “don’t release” options, coupled with the uncertainty in the timing of the vesicle release at each of the trillions of nerve terminals will be to cause the quantum mechanical state of the brain to become a smeared out superposition of different macro-states representing different alternative possible plans of action. As long as the brain dynamics is controlled wholly by Process II - which is the quantum generalization of the Newtonian laws of motion of classical physics - all of the various alternative possible plans of action will exist in parallel, with no one plan of action singled out as the one that will actually occur. Some other process, beyond the local deterministic Process II, is required to pick out one particular real course of physical events from the smeared out mass of possibilities generated by all of the alternative possible combinations of vesicle releases at all of the trillions of nerve terminals. That other process is Process I, which brings in the action of the mind of the agent upon his brain.

This explanation of why quantum theory is pertinent to brain dynamics has focused on individual calcium ions in nerve terminals. That argument pertains to the *Process II component* of brain dynamics.

The equally important *Process I component* of the brain dynamics, which brings the mind of the agent into the dynamics, must be analyzed in terms of a completely different set of variable, namely certain *quasi-stable macroscopic degrees of freedom*. These specify the brain structures that enjoy the stability or persistence, and the causal connections needed to represent intentional actions and expected feedbacks.

The states of the brain that will be singled out by the actions P that specify the form of a Process I action will be more like the lowest-energy state of the simple harmonic oscillator discussed above, which tends to endure for a long time, or like the states obtained from such lowest-energy states by spatial displacements and shifts in velocity. Such states tend to endure as oscillating states, rather than immediately exploding. In other words, in order to get the needed stability properties the projection operators P corresponding to intentional actions should be constructed out of *oscillating states of* *macroscopic subsystems of the brain*, rather than out of sharply defined spatial states of the individual particles. The pertinent states will be functionally important brain analogs of a collection of oscillating modes of a drumhead, in which large collections of particles of the brain are moving in a coordinated way that will lead on to further coordinated activity.

In summary, the *need to use quantum theory* in brain dynamics arises from the dispersive quality of *Process II* action at the level of the ionic, and electronic, and atomic components of the brain. Hence *that* analysis is carried out at the individual-particle level. However, the opposing integrative and selective action, Process I, which brings in the mental (i.e., psychologically described) aspect involves a completely different set of variables. Process I is specified by an operator P that singles out a quasi-stable large-scale pattern of brain activity that is the brain correlate of a particular mental intention.

It should be mentioned here that the actions P are *non-local*: they must act over extended regions, which can, and are expected to, cover large regions of the brain. Each conscious act is associated with a Process I action that coordinates and integrates activities in diverse parts of the brain. A conscious thought, as represented by the Von Neumann Process I, effectively grasps as a whole an entire quasi-stable macroscopic brain activity.

Choices of the Process I Actions.

It has been emphasized that the choices of which Process I actions actually occur are "free choices," in the sense that they are not specified by the currently known orthodox laws of physics. On the other hand, a person's intentions surely depend upon his brain. This means that we need to understand the process that determines the choice of P, which, within the framework of contemporary physical theory, is a free choice. In other words, the laws of contemporary quantum theory, although highly restrictive, are not the whole story: there is still work to be done. Hypotheses must be formulated and tested.

According to the theory, each experience is associated with the occurrence of a Process I event. As a simple first guess, let us assume, following a suggestion of Benjamin Libet and other psychologists, that the occurrence of a Process I action is triggered by a "consent" on the part of the agent, and that the rapidity with which consent is given can be increased by "mental effort."

To get a definite model, let {P} be the set of actions P that correspond to possible mental intentions. Then let P(t) be the "most probable P in {P}, where the probability is defined by brain state S(t). In equations this most probable P in {P} would be the P in {P} that maximizes Tr PS(t)P/Tr S(t). The first hypothesis will be that the Process I event specified by P(t) will occur if and only if a "consent" is given at time t.

To make mind efficacious it is assumed that "consent" depends on the *mental realities* associated with P(t), and that "consent" can be given with a rapidity that is increased if the mental evaluation includes a feeling of effort. This simplest model makes the choice of the Process I action dependent both upon the physical state of the agent's brain, and also upon the mental realities associated with that action.

It is assumed, here, that the consent associated with "hearing a nearby clap of thunder" is essentially passive: it will occur unless attention is strongly focused elsewhere. The important input of the mental aspect arises from the *effortful* focusing of mental attention on some intention.

Quantum theory *explains* how such a mental effort can strongly influence the course of brain events. Within the Von Neumann framework this potentially very strong effect of mind upon brain is an automatic consequence of a well-known and well studied feature of quantum theory called The Quantum Zeno Effect.

The Quantum Zeno Effect.

If one considers only passive consents, then it is very difficult to identify any clean empirical effect of this intervention, apart from the production of low-level awareness. In the first place, the empirical averaging over the "Yes" and "No" possibilities tends to wash out all measurable effects. Moreover, the passivity of the mental process means that we have no independent self-controlled mental variable.

But the study of effortful and intentionally controlled attention brings in two empirically accessible variables, the intention and the amount of effort. It also brings in the important physical Quantum Zeno Effect. This effect is named for the Greek philosopher Zeno of Elea, and was brought into prominence in 1977 by the physicists Sudarshan and Misra (1977). It gives a name to the fact that repeated and closely-spaced intentional acts can effectively hold the "Yes" feedback in place for an extended time interval that depends upon the *rapidity at which the Process I actions are happening*. According to our quantum model, this rapidity is controlled by the amount of effort being applied.

This Quantum Zeno Effect is, from a theoretical point of view, a very clean consequence of the Von Neumann theory. It follows from the formula for the transition from the state PSP at time t=0 to the state (1-P)S(t)(1-P) at time t:

(1-P) exp –iHt PSP exp iHt (1-P) = Order t squared.

For small t the expression exp iHt becomes 1 + iHt + Order t squared. Consequently, the terms of zeroth and first order in t on the left side of the above equation are both zero due to the condition P=PP on the projection operator P.

This result entails that by increasing sufficiently the rapidity of the Process I actions associated with a constant (or even slowly changing) operator P, an agent can keep the state S of his or her brain in the "Yes" subspace associated with states of the form PS(t)P.

This "holding-in-place" effect of rapidly repeated observations is known as the Quantum Zeno Effect, and is a macroscopic quantum effect in the conscious brain that is not diminished by the very strong interaction of the brain with its environment.

This result means that if a sequence of similar Process I events occur rapidly [on the time scale of the macroscopic oscillations associated with the associated actions P] then the "Yes" outcome can be held in place in the face of strong Process II mechanical forces that would tend to quickly produce the "No" feedback. Consequently, agents whose efforts can influence the rapidity of Process I actions would enjoy a survival advantage over competitors that lack this feature, for they could maintain beneficial activities longer than their Process I deprived competitors. This gives the leverage needed to link mind to natural selection, and also the leverage needed to allow us to link our mental intentions to our physical actions. For these efforts will then have intention-related physical effects, and his linkage can in principle be discovered, and integrated into behavior by the trial and error learning process mentioned earlier.

Support from Psychology.

A person's experiential life is a stream of conscious experiences. The person's experienced *"self"* is *part* of this stream of consciousness: it is not an extra thing that is outside or apart from the stream. In James's words "*thought is itself the thinker*, and psychology need not look beyond." The "self" is a slowly changing "fringe" part of the stream of consciousness. It provides a background cause for the central focus of attention.

The physical brain, evolving mechanically in accordance with the local deterministic Process II does most of the necessary work, without the intervention of Process I. It does its job of creating, on the basis of its interpretation of the clues provided by the senses, a suitable response. But, due to its quantum nature, the brain necessarily generates an amorphous mass of overlapping and conflicting templates for action. Process I acts to extract from this jumbled mass of possibilities a dynamically stable configuration in which all of the quasi-independent modular components of the brain act together in a maximal mutually supportive configuration of non-discordant harmony that tends to prolongs itself into the future and produce a characteristic subsequent feedback. This is the preferred "Yes" state PSP that specifies the form of the Process I event. But the quantum rules do not assert that this preferred part of the prior state S necessarily comes into being: they assert, instead, that if this process is activated---say by some sort of "consent"---then this "Yes" component PSP will come into being with probability Tr PSP/Tr S.

The rate at which consents are given is assumed to be increasable by mental effort.

The phenomena of “will” is understood in terms of this effortful control of Process I, which can, by means of the Quantum Zeno Effect, override strong mechanical forces arising from Process II, and cause a large deviation of brain activity from what it would be if no mental effort were made.

Does this quantum-physics-based conception of the connection between mind and brain explain anything in the realm of psychology?

Consider some passages from ``Psychology: The Briefer Course'', written by William James. In the final section of the chapter on attention James(1892: 227) writes:

> ``I have spoken as if our attention were wholly determined by neural conditions. I believe that the array of things we can attend to is so determined. No object can catch our attention except by the neural machinery. But the amount of the attention which an object receives after it has caught our attention is another question. It often takes effort to keep mind upon it. We feel that we can make more or less of the effort as we choose. If this feeling be not deceptive, if our effort be a spiritual force, and an indeterminate one, then of course it contributes coequally with the cerebral conditions to the result. Though it introduce no new idea, it will deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away.”

In the chapter on will, in the section entitled ``Volitional effort is effort of attention'' James (1892: 417) writes:

> ``Thus we find that we reach the heart of our inquiry into volition when we ask by what process is it that the thought of any given action comes to prevail stably in the mind.''

and later

> ``The essential achievement of the will, in short, when it is most `voluntary,' is to attend to a difficult object and hold it fast before the mind. ... Effort of attention is thus the essential phenomenon of will.''

Still later, James says:

> ``Consent to the idea's undivided presence, this is effort's sole achievement.''... ``Everywhere, then, the function of effort is the same: to keep affirming and adopting the thought which, if left to itself, would slip away.''

This description of the effect of mind on the course of mind-brain process is remarkably in line with *what had been proposed independently from purely theoretical considerations of the quantum physics of this process*. The connections specified by James are *explained* on the basis of the same dynamical principles that had been introduced by physicists to explain atomic phenomena.

In the quantum theory of mind-brain being described here there are two separate processes. First, there is the unconscious mechanical brain process called Process II. As discussed at length in the book, *Mind, Matter, and Quantum Mechanics* (Stapp, 1993: 150), this brain processing involves dynamical units that are represented by complex patterns of neural activity (or, more generally, of brain activity) that are ``facilitated'' (i.e., strengthened) by use, and are such that each unit tends to be activated as a whole by the activation of several of its parts. The activation of various of these complex patterns by cross referencing---i.e., by activation of several of its parts---coupled to feed-back loops that strengthen or weaken the activities of appropriate processing centers, appears to account for the essential features of the mechanical part of the dynamics in a way that in many cases is not greatly different from that of a classical model, except for the creation of a superposition of a host of parallel possibilities that according to the classical concepts could not exist simultaneously.

The second process, Von Neumann's Process I**,** is a selection process that is tied to intentions, and that is needed in order to separate what is experienced from the continuum of alternative possibilities generated by Process II.

An extended discussion of non-trivial agreement of these features with a large body of recent data from the field of the psychology of attention is described in Stapp (2001)

Quantum theory in Neuroscience.

Scientists in different fields are to some extent free to choose what sort of models or theories they use to organize, explain, understand, and predict the observed features of the data in their field, and to guide their further inquiries. On the other hand, the ideal of *the unity of science* gives precedence to models that mesh with the basic principles of physics, or at least do not contradict them.

On the basis of that ideal the quantum theoretical framework would seem to be superior to the classical one for explaining correlations between psychologically and physically described data. It not only accommodates - and arises from - an adequate account of the physical and chemical processes that underlie brain behavior, but also provides a theoretical framework that has places for the two kinds of data that need to be brought into theoretical concordance, and it also specifies theoretical conditions on the two-way causal connection between these two kinds of data. The concepts of classical physics, on the other hand, are not only known to be inadequate to deal with, for example, the dynamics of ionic motions, but have no natural place for psychologically described data, and no capacity to explain the apparent causal efficacy of willful effort, except as a mysterious illusion arising in connection with conscious realities that are conceptually alien to the concepts of classical physics. Moreover, the causal efficacy of willful effort is eliminated by the approximation that produces classical physics.

To bring these theoretical ideas down to the practical level let us consider the experiments of Ochsner et al. (2002), with particular attention to the following four key questions (posed by neuroscientist M. Beauregard):

1. How does the quantum mechanism work in this case, in comparison to what the classical account would say?

2. How do we account for the rapid changes occurring in large neural circuits involving millions of neurons during conscious and voluntary regulation of brain activity?

3. How does consciousness “know” where and how to interact in the brain in order to produce a specific psychological effect?

4. Is consciousness localized, and, if so, how and in what sense; or does it lie, instead, “outside of space”?

Reduced to its essence the experiments in question consists first of a training phase in which the subject is taught how to distinguish, and respond differently to, two instructions given while viewing emotionally disturbing visual images: ATTEND (meaning passively “be aware of, but not try to alter, any feelings elicited by”) or REAPPRAISE (meaning actively “reinterpret the content so that it no longer elicits a negative response”). The subjects then perform these mental actions during brain data acquisition. The visual stimuli, when passively attended to, activate limbic brain areas and when actively reappraised activate prefrontal cerebral regions. [The succinct formulation in this paragraph is due mainly to Jeffrey Schwartz.]

From the classical materialist point of view this is essentially a conditioning experiment, where, however, the “conditioning” is achieved via linguistic access to cognitive faculties. But how do the cognitive realities involving “knowing,” “understanding,” and “feeling” arise out of motions of the miniature planet-like objects of classical physics, which have no trace of any experiential quality? And how do the vibrations in the air that carry the instructions get converted into feelings of understanding? And how do these feelings of understanding get converted to effortful actions, the presence or absence of which determine whether the limbic or frontal regions of the brain will be activated.

Within the framework of classical physics these connections between feelings and brain activities are huge mysteries. The classical materialist claim is that *someday* these connections will be understood. But the basic question is whether these connections will ever be understood in terms of a physical theory that is known to be false, and that, moreover, results from an approximation that, according to contemporary physical theory, systematically excludes the effect of psychological realities upon physiological realities that these neuropsychology experiments reveal. Or, on the other hand, will the eventual understanding of this linkage accord with causal linkage between mental realities and brain activities that orthodox (Von Neumann) contemporary physical theory entails.

There are important similarities and also important differences between the classical and quantum explanations of the experiments of Ochsner et al. In both approaches the particles in the brain can be conceived to be collected into nerves and other biological structures, and into fluxes of ions and electrons, which can all be described reasonably well in essentially classical terms. However, in the classical description the dynamics is well described in terms of the local deterministic classical laws that govern these classical quantities, insofar as they are precisely defined.

Quantum theory asserts, however, that the condition that these classical quantities be *precisely defined* is unrealistic: Heisenberg's uncertainty principle asserts that this assumption is not justified: one must accept at least some small amount of cloudlike uncertainty. But small uncertainties rapidly grow into larger uncertainties. The discussion of the ionic motions in nerve terminals exemplifies this growth of uncertainty: the state of the brain rapidly fans out into a state that encompasses many possible experiential states.

This incursion into the dynamics of growing uncertainties renders the classical approach basically incomplete: it can never lead to well defined experiential states, except by actually violating the quantum uncertainty principle.

There is a well-known and powerful process in quantum theory that strongly influences this expansion of the state of the brain into a state that encompasses many alternative experiential possibilities. It is called "environmental decoherence." The interactions of the brain with its environment rapidly reduces the state S of the brain into what is called a "mixture." This means that the interference effects between significantly different classically describable possibilities becomes markedly attenuated. That effect is, however, already completely accounted for in the Von Neumann state S of the brain: environmental decoherence is describable within von Neumann's formulation, and it in no way upsets or modifies the Von Neumann theory described here. Indeed, it makes quantum theory more accessible to neuroscientists by converting the complex mathematical concept of a quantum state into a structure that can be visualized as simply a smear of virtual classically conceived states: the quantum state of the brain is effectively transformed by environmental decoherence effects into a continuous smear of classically describable potentialities that becomes converted to a rapid sequence of discrete experiential realities by Process I actions. Thus the quantum brain dynamics becomes much easier to conceive and to describe because the environmental decoherence effect allows classical language and imagery to be validly used in an important way. But environmental decoherence has never been shown to obviate the need for von Neumann's Process I. (Stapp, 2002).

One could, despite violating the quantum laws, try to pursue a quasi-classical calculation. This would be a classical-type computation with the quantum-mandated uncertainties folded in as probability distributions, and with certain classically describable brain states identified as the "neural correlates" of the various possible experiential states. One could then produce, in principle, the same general kinds of statistical predictions that quantum theory would give.

This sort of quasi-classical approach would, in fact, probably give results very similar to quantum theory for situations arising from "passive attention." For in these cases mind is acting essentially as a passive witness, in a way that is basically in line with the ideas of classical physics.

But quantum theory was designed to deal with the other case, in which the conscious action of an agent – to perform some particular probing action - enters into the dynamics in an essential way. Within the context of the experiment by Ochsner et al., quantum theory provides, via the Process I mechanism, an explicit means whereby the mental effort actually causes - by catching and actively holding in place - the prefrontal activation instead of the limbic one. Thus, within the quantum framework, the causal relationship between the mental effort and the observed brain changes is *dynamically* accounted for. Analogous quantum mechanical reasoning can be utilized *mutatis mutandis* to explain the data of Beauregard (2001) and related studies of self-directed neuroplasticity (see Schwartz & Begley, 2002).

The second question is: How do we account for the rapid changes induced by mental effort in large brain circuits?

The answer is that the non-local operator P that represents the intention singles out a large quasi-stable and functionally important brain state that is likely to produce the expected feedbacks. Large functionally effective brain activities are singled out and linked to mental effort through *learning*, which depends upon the fact that the mental efforts, per se, have physical consequences. These discrete macroscopic functional states are singled out from the smear of possibilities by the non-local Process I. Thus quantum theory describes the mathematical machinery that links the mentalistically described intention to the physically described macroscopic state of the brain that implements it.

The third question is: How does consciousness "know" where and how to interact in the brain in order to produce a specific psychological effect?

The answer is that felt intentions, per se, have physical consequences, and thence experiential consequences. Hence an agent can learn, by trail and error, how to select an intentional action that is likely to produce a feedback that fulfills that intention.

The fourth question is: Is consciousness localized, and, if so, how and in what sense; or does it lie, instead, "outside of space"?

Each conscious event is associated with a Process I action that involves an action P that is necessarily non-local, for mathematical reasons. Moreover, the "Yes" part must have the functional properties needed to set in motion the brain-body activity that is likely to produce the intended feed-back experience. Thus each conscious action would, in order to meet these requirements, act over some functionally characterized extended portion of the brain. [In fact, for reasons that go well beyond the scope of this article, this event also induces effects in faraway places: these effects are the causes, within the Von Neumann ontology, of the long-range non-local effects associated with the famous theorem of John Bell (1964).(See Stapp, 2003)]

Ramifications in Neuroscience.

The situations in neuroscience and atomic science are similar. Due to the Heisenberg Uncertainty Principle micro-properties such as the velocities of the ions emerging from narrow ion channels, are in principle unknowable. Thus the computation of the causal behavior of a conscious brain is in principle impossible. Thus just as in atomic physics, and indeed as a direct consequence of the basic principle of atomic physics, there is both room for, and , at least at the practical level, a rational need for, the input of psychologically described data that can according to quantum theory be rationally treated as replacements for the accessible-in-principle micro-properties. According to orthodox quantum theory, the micro-properties postulated by classical physical theory do not exist, but the dynamical gap created by their absence can be partially filled by accepting the psychologically describable and partially controllable data pertaining to conscious human choices about how to act as primary data describing pragmatically independent realities.

The breakdown *in principle* of the possibility a complete bottom-up micro-local causal description opens the door to the quantum psycho-physical description, which consistently combines the bottom-up micro-locally determined Process II with the top-down mentally controlled Process I.

Francis Crick and Christoff Koch have published recently in Nature *neuroscience* a Commentary entitled "A framework for consciousness." (Crick, 2003), They explain that their framework will "not have rigid laws as physics does." But they put forth a ten-fold "point of view for an attack on" the scientific problem of consciousness. Much of their proposal focuses on neuro-anatomical details. But the general features of their framework are in very good agreement with the quantum psycho-physical framework described in Stapp (1993).

C&K explain that they are, in this initial phase of their program, restricting themselves to "attempting to find the neural correlates of consciousness (NCN), in the hope that when we can explain the NCC in causal terms, this will make the problem of qualia clearer." But what does a causal account dealing only with the neural correlates of consciousness say about the causal properties of the conscious realities themselves?

1. *The (unconscious?) homunculus*. C&K speak of the "overwhelming illusion" of the existence of a consciousness homunculus, and suggest that this illusion may "reflect in some way the general organization of the brain." But how do they conclude that the overwhelming intuition that our thoughts can influence our actions is an illusion? The only basis for that allegation is the known-to-be-false classical physical theory. What is the rational basis for denying the validity of this overwhelming intuition, rather than denying the validity of that provably false theory, and accepting, instead, the validated physical theory that validates this overwhelming intuition?

2. *Zombie modes and consciousness*. C&K say "Consciousness deals more slowly with … and takes time to decide on appropriate thoughts and actions." But how can conscious, or conscious decisions, *deal* with anything if only their neural correlates are considered. *Some* property beyond mere correlation is needed for consciousness to be able to deal with anything, or to decide on actions. The quantum psycho-physical theory justifies this causal language.

3. *Coalitions of neurons.* C&K say that the winning coalition "embodies what we are conscious of" and "produces consciousness." But how does a coalition "produce" consciousness, within the framework of classical physics? All that can ever be derived or deduced from the principles of classical physics are combinations of simple mathematical properties imbedded in space-time, and functional properties deducible from them. The concept of "producing consciousness" is not part of classical physics. If one wants to argue that this "production of consciousness" property is an ontological aspect of the classically conceived world that simply is not specified or captured by the classical principles then there is the difficulty that there can be no ontological reality that is even *compatible* with the classical principles. Is it not, therefore, more rational to accept the theory that quantum physicists have already discovered, and extensively studied

and verified, and which, in its orthodox formulation, brings consciousness into the theory in a rationally coherent, causally efficacious, and practically useful manner?

4. *(7)Snapshots.* C&K say, “We propose that conscious awareness (for vision) is a series of static snapshots, with ‘motion’ painted onto them.” “Perception occurs in discrete epochs.” This refers to “awareness” and “perception”, but presumably it must be the NCC that has these discrete epochs. But dynamical discreteness is incompatible with classical physics. However, a series of discrete conscious events is exactly what quantum theory gives. (Stapp, 1993: 158)

5. *(8)Attention and binding.* C&K say “Attention can usefully be divided into two forms: either rapid, saliency driven and bottom-up or slower volitionally controlled and top-down.” The quantum approach *explains* the occurrence of these two kinds of attention, and also binding, as a consequence of the basic laws of physics. The micro-causal Process II is high-speed, saliency-driven, and parallel, whereas the nonlocal, integrative, and effortfully deliberative Process I consists of a *series* of similar actions held in place by the Quantum Zeno Effect.

The quantum psycho-physical theory of the conscious brain is, like quantum theory in general, a *pragmatic* theory. It is set within the framework of communicable descriptions of our intentional actions, and the experiential feedbacks that result from these actions. It justifies *dynamically* our intuition that our psychologically described mental efforts are able to influence our mental and physical behavior in the way that we feel they do. Thus science becomes intelligible: our physical communications are allowed to convey the real knowledge, information, instructions, and meanings that they do in fact carry. They do the job of communicating physically efficacious ideas, rather than being physical vibrations that encode instructions passing between complex biological computers that mysteriously produce, in some presently (and surely eternally) incomprehensible mechanical way, the *illusion* that our thoughts are doing what we think they are doing.

But why should neuroscience bind itself to this essentially seventeenth century approach based on logically inadequate principles and known-to-be-non-existent entities when contemporary physical theory provides a rationally coherent alternative that accords with all the new and old physics data, and brings consciousness into the theory at the foundational level, in tight mathematically controlled coordination with the physically described brain.

Shifting to the quantum psycho-physical approach to the mind-brain problem means switching to a new research posture. The objective is no longer to explain how a classically conceived brain can "produce" or "be" psychologically experienced consciousness. It is rather to elucidate the respective roles of the physically described brain and psychologically described mind in the determination of the content and timings of the stream of conscious Process I actions.

To summarize: Neuropsychological theory is greatly simplified by accepting the fact that brains must in principle be treated quantum mechanically. Accepting that obvious fact means that the huge deferred-to-the-future question of how mind is connected to a classically described brain must, in principle, be replaced by the already partially resolved question of how mind is connected to a quantum mechanically described brain. That shift means adopting the same pragmatic solution that atomic physicists adopted when faced with this *same* problem of accounting coherently for the effects of *mentalistically described human intentional actions upon the physically described systems that those actions act upon.* The benefits of adopting the pragmatic quantum approach may be as important to progress in neuroscience as they were in atomic physics.

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