QUANTUM PHYSICS IN NEUROSCIENCE AND PSYCHOLOGY: A NEW MODEL WITH RESPECT TO MIND/BRAIN INTERACTION

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Short abstract

Neuropsychological research on the neural basis of behavior generally posits that brain mechanisms fully suffice to explain all psychologically described phenomena. Terms having intrinsic experiential content (e.g., "feeling," "knowing" and "effort") are not included as causal factors because they are deemed irrelevant to the causal mechanisms of brain function. However, principles of quantum physics causally relate mental and physical properties. Use of this causal connection allows neuroscientists and psychologists to more adequately and effectively investigate the neuroplastic mechanisms relevant to the growing number of studies of the capacity of directed attention and mental effort to systematically alter brain function.

Long abstract

The cognitive frame in which most neuropsychological research on the neural basis of behavior is conducted contains the assumption that brain mechanisms *per se* fully suffice to explain all psychologically described phenomena. This assumption stems from the idea that the brain is made up entirely of material particles and fields, and that all causal mechanisms relevant to neuroscience must therefore be formulated solely in terms of properties of these elements. One consequence of this stance is that psychological terms having intrinsic mentalistic and/or experiential content (terms such as "feeling," "knowing" and "effort) have not been included as primary causal factors in neuropsychological research: insofar as properties are not described in material terms they are deemed irrelevant to the causal mechanisms underlying brain function. However, the origin of this demand that experiential realities be excluded from the causal base is a theory of nature that has been known to be fundamentally incorrect for more than three quarters of a century. It is explained here why it is consequently scientifically unwarranted to assume that material factors alone can in principle explain all causal mechanisms relevant to neuroscience. More importantly, it is explained how a key quantum effect can be introduced into brain dynamics in a simple and practical way that provides a rationally coherent, causally formulated, physics-based way of understanding and using the psychological and physical data derived from the growing set of studies of the capacity of directed attention and mental effort to systematically alter brain function.

Key words: attention, brain, consciousness, mental effort, mind, neuropsychology, neuroscience, quantum physics, self-directed neuroplasticity.

1. Introduction

The introduction into neuroscience and neuropsychology of the extensive use of functional brain imaging technology has led to a major conceptual advance pertaining to the role of directed attention in cerebral functioning. On the empirical side the identification of brain areas involved in a wide variety of information processing functions concerning learning, memory and various kinds of symbol manipulation has been the object of a large amount of intensive investigation (See Toga & Mazziotta 2000). As a result neuroscientists now have a reasonably good working knowledge of the role of a variety of brain areas in the processing of complex information. But, valuable as these empirical studies are, they provide only the data for, not the answer to, the critical question of the causal relationship between the psychologically described information and the central nervous system (CNS) mechanisms that process this information. In the vast majority of cases investigators simply assume that measurable properties of the brain are the only factors needed to explain, at least in principle, all of the types of information processing that are experimentally observed. This privileging of physically describable brain mechanisms as the core, and indeed final, explanatory vehicle for the processing of every kind of psychologically formulated data is, in fact, the foundational assumption of almost all contemporary biologically based cognitive neuroscience.

It is becoming increasingly clear, however, that there is at least one type of information processing and manipulation that does not readily lend itself to explanations that assume that all final causes are subsumed within brain, or more generally, CNS mechanisms. The cases in question are those in which the conscious act of willfully altering the mode by which experiential information is processed itself changes, in systematic ways, the cerebral mechanisms utilized. There is a growing recognition of the theoretical importance of applying experimental paradigms that employ directed mental effort in order to produce systematic and predictable changes in brain function (e.g., Beauregard et al. 2001; Ochsner et al. 2002). These wilfully induced brain changes are generally accomplished through training in the cognitive reattribution and attentional recontextualization of conscious experience. Further, an accelerating number of studies in the neuroimaging literature significantly support the thesis that, again, with appropriate training and effort, people can systematically alter neural circuitry associated with a variety of mental and physical states that are frankly pathological (Schwartz et al. 1996; Schwartz 1998; Musso et al. 1999; Paquette et al. 2003). A recent review of this and the related neurological literature has coined the term "self-directed neuroplasticity" to serve as a general description of the principle that focused training and effort can systematically alter cerebral function in a predictable and potentially therapeutic manner (Schwartz & Begley 2002).

From a theoretical perspective perhaps the most important aspect of this line of empirical research is the direct relevance it has to new developments in our understanding of the physics of the interface between mind/consciousness and brain. Until recently virtually all attempts to understand the functional activity of the brain have been based entirely on principles of classical physics that have been known to be fundamentally false for three quarters of a century. A basic feature of that classical conception of the world was that all causal connections were carried by, and were completely explainable in terms of, direct interactions between material realities. This truncated view of causation is not entailed by the current principles physics, which provide a far more adequate and useful foundation for the description and understanding the causal structure of self-directed neuroplasticity. The superiority of contemporary physics in this context stems from two basic facts. First, terms such as "feeling," "knowing" and "effort," because they are intrinsically mentalistic and experiential, cannot be described exclusively in terms of material structure. And second, mentalistic terminology of precisely this kind is critically necessary for the design and execution of the experiments in which the data demonstrating the core phenomena of self-directed neuroplasticity are acquired and described. Thus the strictly materialistic principles of causation to which one is restricted by the form of classical physics enforce a causal gap between the neurological and psychological parts of the data of self-directed neuroplastic phenomena. On the other hand, physics, as it is currently practiced, utilizes quantum principles that, as we shall explain in detail, fully allow for the scientific integration of mentalistic and neurophysiological terminology. These principles provide for logically coherent rational explanations that are entirely capable of accounting for the causal mechanisms necessary to understand the rapidly emerging field of self-directed neuroplasticity.

In order to explicate the physics of the interface between mind/consciousness and brain, we shall in this article describe in detail just how the quantum mechanically based causal mechanisms work, and show why it is necessary in principle to advance to the quantum level to achieve an adequate understanding of neurophysiology during volitionally directed activity. The reason, basically, is that classical physics is an approximation to the more accurate quantum theory, and this approximation eliminates the causal efficacy of our thoughts that is manifested in these experiments.

The theoretically important point is that classical physics, and the associated doctrine of materialism, fail to coherently explain self-directed neuroplastic phenomena, while the quantum mechanical principles that causally integrate mentalistic and physicalistic data clearly and explicitly do. Because experientially based language is not logically reducible to classical materialist terminology, yet such mentalistic language is a logical pre-requisite for the design, execution, and description of volitionally directed neuroplastic phenomena, the attempt to explain such phenomena in solely materialist terms must be abandoned as a matter of principle: the logical structure of materialism is inadequate in these cases. In the light of the causal structure of quantum physics, as described in some detail in later sections of this article, the case for giving brain mechanisms a privileged position as the sole cause of our conscious efforts, and of their consequences, has become radically atheoretical and ungrounded in reason.

Let us be entirely clear about the sort of neuroscientific reasoning that remains coherent, given the structure of modern physics, and, contrastingly, the types of assertions that should now be viewed as merely the residue and cultural baggage of a materialistic bias stemming from superceded physical concepts. Entirely acceptable are **correlational analyses** concerning the relationship between mentalistic data and neurophysiological mechanisms. Examining the qualitative and quantitative aspects of brain function, and doing detailed analyses of how they relate to the data of experience, obtained through increasingly sophisticated means of psychological investigation and subject self-report analysis (e.g., the entire Sep/Oct 2003 issue of Journal of Consciousness Studies, Volume 10, Number 9-10, is dedicated to these issues), can now be seen as being both completely in line with fundamental physics, and also the core structure of neuropsychological science. To a significant degree this is already the case. However, what is not justified is the assumption that all aspects of experience examined and reported are necessarily causal consequences solely of brain mechanisms that are in principle observable. The structure of modern physics entails no such conclusion. This is particularly relevant to data from first person reports concerning active willfully directed attentional focus, and especially to data regarding which aspects of the stream of conscious awareness a subject chooses to focus on when making self-directed efforts to modify and/or modulate the quality and beam of attention. In such cases the deep structure of orthodox quantum physics implies that the investigator is not justified in assuming that the focus of attention is determined wholly by brain mechanisms that are in principle completely well defined and mechanically determined. Effort itself can justifiably be taken to be a primary variable whose complete causal origins may be untraceable in principle, but whose causal efficacy can be regarded as real.

The quantum mechanical principles that causally integrate mental and physical phenomena, which are separately taken to be to be both indispensable and irreducible, provide a rationally coherent foundation for modern neuroscience and neuropsychology.

2. Practical and theoretical aspects of self-directed neuroplasticity

The cognitive frame in which neuroscience research, including research on cerebral aspects of behavior, is generally conducted contains within it the unstated assumption that brain mechanisms *per se*, once discovered, are fully sufficient to explain whatever phenomenon is being investigated. In the fields of neuroimaging this has led to experimental paradigms that primarily focus on changes in brain tissue activation as primary dependent variables used to explain whatever behavioral changes are observed --- including ones understood as involving essentially cognitive and emotional responses. As long as one is investigating phenomena that are mostly passive in nature this may well be fully justified. A person is shown a picture depicting an emotionally or perhaps a sexually arousing scene. The relevant limbic and/or diencephalic structures are activated. The investigator generally concludes that the observed brain activation has some intrinsic causal role in the emotional changes reported (or perhaps, the hormonal correlates of those changes). All is well and good, as far as it goes. And all quite passive from the experimental subject's perspective --- all that's really required on his or her part is to remain reasonably awake and alert, or, more precisely, at least somewhat responsive to sensory inputs. But when, as happens in a growing number of studies, the subject makes an active response aimed at systematically *altering* the nature of the emotional reaction --- for example by actively performing a cognitive reattribution --- understanding the data solely from the perspective of brain-based causal mechanism can be severely limiting and counterproductive. This is especially so when one is investigating how to develop improved methods for altering the emotional and cerebral responses to significantly stressful external or internally generated stimuli.

Simply stated, the prevailing prejudices, unsupported by contemporary physics, about the respective causal roles of neurophysiological and mentalistic variables seriously limits the scope and utility of the present matter-based theory of conscious-brain activity. While one may immediately grant that that these two types of variables are quite intimately related, and that complete clarity concerning their respective role in any given human action can be difficult (and sometimes even impossible), the fact remains that the serious investigator of human neuropsychology must make a concerted effort to sort out the differences. This is especially so when the phenomena under investigation are value-laden, i.e., involve the possibility of making choices and decisions about how to respond to sensory phenomena.

In the case of studying clinical phenomena such as psychological treatments and their biological effects the distinction between mind and brain (or, if one prefers, mentalistic and neurophysiological variables) becomes absolutely critical. That's because if one simply assumes the most common generic belief of our era of neuroscience research, namely that all aspects of emotional response are passively determined by neurobiological mechanisms, then the possibility of developing genuinely effective self-directed psychological strategies that cause real neurobiological changes becomes, in principle, impossible. The clinician thus becomes locked, as it were, into at least the implicit view that the psychological treatment of ailments caused by neurobiological impairments is not a realistic goal.

There is already a wealth of data arguing against this view. For instance, work in the 1990's on patients with obsessive compulsive disorder demonstrated significant changes in caudate nucleus metabolism and the functional relationships of the orbitofrontal cortex-striatum-thalamus circuitry in patients who responded to a psychological treatment utilizing cognitive reframing and attentional refocusing as key aspects of the therapeutic intervention (for review see Schwartz & Begley 2002). More recently work by Beauregard and colleagues (Paquette et al. 2003) have demonstrated systematic changes in the dorsolateral prefrontal cortex and parahippocampal gyrus after cognitive-behavioral therapy for spider phobia, with brain changes significantly related to both objective measurements and subjective reports of fear and aversion. There are now numerous reports on the effects of self-directed regulation of emotional response, via cognitive reframing and attentional recontextualization mechanisms, on cerebral function (e.g., Beauregard et al. 2001; Lévesque et al. 2003; Ochsner et al. 2002 ; Paquette et al. 2003 ; Schwartz et al. 1996).

Indeed, the brain area generally activated in all the studies done so far on the self-directed regulation of emotional response is the prefrontal cortex, an area of the brain also activated in studies of cerebral correlates of willful mental activity, particularly those investigating self-initiated action and the act of attending to one's own actions (Spence & Frith 1999; Schwartz & Begley 2002). There is however one aspect of willful mental activity that seems particularly critical to emotional self-regulation and seems to be the critical factor in it's effective application --- the factor of focused dispassionate self-observation that, in a rapidly growing number of clinical psychology studies, has come to be called mindfulness or mindful awareness (Segal et al. 2002)

The mental act of clear-minded introspection and observation, variously known as mindfulness, mindful awareness, bare attention, the impartial spectator, etc. is a well-described psychological phenomenon with a long and distinguished history in the description of human mental states (Nyanaponika 2000). The most systematic and extensive exposition is in the canonical texts of classical Buddhism preserved in the Pali language, a dialect of Sanskrit. Because of the critical importance of this type of close attentiveness in the practice of Buddhist meditation some of it's most refined descriptions in English are in texts concerned with meditative practice (although it is of critical importance to realize that the mindful mental state does not require any specific meditative practice to acquire, and is *certainly not* in any sense a "trance-like" state). One particularly well-established description, using the name bare attention, is as follows:

> "Bare Attention is the clear and single-minded awareness of what actually happens *to* us and *in* us at the successive moments of perception. It is called 'Bare' because it attends just to the bare facts of a perception as presented either through the five physical senses or through the mind . . . without reacting to them." (Nyanaponika 1973, p.30)

Perhaps the essential aspect of mindful observation is that you are just watching, observing all facts, both inner and outer, very calmly, clearly and closely.

A working hypothesis for ongoing investigation in human neurophysiology, based on a significant body of preliminary data, is that the mental action of mindful awareness specifically modulates the activity of the prefrontal cortex. Because of the well established role of this cortical area in the planning and willful selection of self-initiated responses (Spence & Frith 1999; Schwartz & Begley 2002) the capacity of mindful awareness, and by implication all emotional self-regulating strategies, to specifically modulate activity in this critical brain region has tremendous implications for the fields of mental health and related areas.

The major theoretical issue we are attempting to address in this article is the failure of classical models of neurobiological action to account for *all* of the mechanisms that are operating when human beings utilize self-directed strategies for the purpose of modulating emotional responses and their cerebral correlates. Specifically, the assumption that all aspects of mental activity and emotional life are ultimately explicable solely in terms of micro-local deterministic brain activity, with no superposed effects of mental effort, is neither rationally reconcilable with the basic data of psychological observation nor entailed by modern physics. The simple classical model must in principle be replaced by the physically more accurate and certainly more functionally useful concept that the role played by the mind when observing and modulating one's own emotional states is an intrinsically active and efficacious process, one in which mental action is *affecting* brain activity and not merely being affected by it. One key reason for the necessity of this change in perspective is the fact that recognition of the active character of the mind in emotional self-regulation is needed both to subjectively access the phenomena, and to objectively describe what is subjectively happening when a person directs his or her inner resources to the challenging task of modifying emotional responses. It takes *effort* for people to do this. That is because it requires a redirection of the brain's resources away from lower level limbic responses and toward higher level prefrontal functions --- and this does not happen passively. Rather, it requires willful training and directed effort. It is semantically inconsistent, clinically counter productive, and to insist that these kinds of brain changes be viewed as being solely an intra-cerebral "the physical brain changing itself" type of action, because essential features of the activity are not describable solely in terms of material brain mechanisms.

Furthermore, as we will see in detail in the following sections of this article, orthodox concepts of contemporary physics are ideally suited to a rational and practical understanding of the action of mindful self-observation on brain function. Classical models of physics, which view all action in the physical world as being ultimately the result of the movements of material particles, are now seriously out of date, and no longer should be seen as providing the only, or necessarily the best, paradigm for investigating the interface between mind/consciousness and brain.

Does it make scientific good sense to try to understand the process of self-directed neuroplasticity solely in terms of brain mechanisms?

For at least one quite straightforward reason it seems clear that it does not. That reason is that it is intrinsically impossible to explain and describe to real people the techniques they must learn to perform and strategies required to initiate and sustain self-directed neuroplastic changes without using language that contains instructions about what to do with your mind, i.e., without using terms referring to mental experience, words like: feeling, effort, observation, awareness, mindfulness and so forth. When people practice self-directed activities for the purpose of systematically altering patterns of cerebral activation they are attending to their mental and emotional *experiences*, not merely their limbic or hypothalamic brain mechanisms. And while no scientifically oriented person denies that those brain mechanisms play a critical role in generating those experiences, precisely what the person is training himself to do is to willfully *change* how those brain mechanisms operate --- and to do that absolutely requires attending to mental experience *per se*. It is in fact the basic thesis of self-directed neuroplasticity research that the *way* in which a person directs his attention, e.g., mindfully or unmindfully, will affect both the experiential state of the person and the state of their brain.

The very acquisition of the skills required in order to change the brain, especially in the attempt to alleviate stressful and/or patholological conditions, requires understanding what it means to observe mindfully etc., and learning those skills cannot be accomplished via the sole use of neurobiological terminology --- the language of mental experience must of necessity be utilized. A growing body of research informs us that when people learn to systematically alter their emotional and/or behavioral responses to stressful stimuli it modulates the activity of the prefrontal cortex, among other areas. But to merely say to someone "Now modulate your prefrontal cortex," just like that, is not in and of itself a meaningful use of language. This is so because in the absence of some kind of learning and/or training process that in principle *must* use of the language of personal experience, it is intrinsically impossible for any real living person to know *how to* modulate their prefrontal cortex. For experimental subjects to actually learn and operationalize the skills and techniques necessary for the collection of the data that demonstrate the phenomena of self-directed neuroplasticity *requires* the use of mind-based experiential language. The assertion that a science of self-directed action could possibly be elaborated within a purely materialist framework is neither semantically coherent nor entailed by the principles of modern physics.

People can certainly learn how to be mindful, and when they do it changes brain function in very beneficial ways. But to effect and accomplish those brain changes requires the language of mental experience and activity in basic and irreducible ways --- it can never be accomplished solely by the use of brain-based language. This straightforward fact tells us that the language of neurobiology will never be sufficient for the effective self-regulation of brain activity. The language of the active mind is an absolute logical requirement. As we will now see, contemporary physical theory contains a prepared place for the needed causal intervention in brain activity of conscious volition.

3. 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 observed them of 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 the particles were apart. 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.

There are two possible ways within classical physics to understand this total incapacity of your mental side (i.e., mental processes and consciousness) to make any difference in what you do. The first way 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 *produces* no reciprocal action back upon your brain. The second way is to contend that each or your conscious experiences --- each of your thoughts, ideas, or feelings --- is the *very same thing* as some pattern of motion of various tiny parts of your brain.

4. Problems with classical physics

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 mental processes and consciousness have 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 mind and consciousness lead most thinkers to turn to the alternative possibility that a person's mind and stream of consciousness are *the very same thing* as some activity in his brain: mind and consciousness are "emergent properties" 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, 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 mind and consciousness are illustrated by Roger Sperry's example of a "wheel." (Sperry 1992) 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 mind and consciousness to be, like "wheelness", emergent properties of their classically conceived tiny physical parts?

The reason that mind and consciousness are 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 conscious mental processes, 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 mind and consciousness from things that, according to 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 the 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 while leaving intact the properties that enter into that theoretical construct, namely the locations and motions of the tiny physical parts of the brain and its physical environment. 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 mind and consciousness without affecting the physical behavior, one cannot rationally claim, within that framework, that mind and consciousness are the *causes* of the physical behavior, or are *causally efficacious* in the physical world. Thus the “identity theory" or "emergent property" strategy fails in its attempt to make mind and 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 a later section.

5. The Quantum approach

Classical physics is *an approximation* to a more accurate theory - called quantum mechanics - and quantum mechanics makes mind and consciousness efficacious. Quantum mechanics *explains* the causal effects of mental intentions upon physical systems: it explains how your mental effort can influence the brain events that cause your body to move. 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 connection between mind/consciousness and brain 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.

The most profound alteration of the fundamental principles was to bring the mind and 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 human agents*, and *the knowledge that we thereby acquire*. Thus quantum theory involves, basically, what is "in here," not just what is "out there."

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 a *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 pertinent to 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 gross behaviors of large-scale properties of big objects composed of huge numbers of the tiny atomic-scale parts. These apprehensions --- of, for example, the perceived location and motion of a falling apple, or the position of a pointer on a measuring device --- 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 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. 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 bridge. This revision must be expected to have important ramifications in neuroscience, because the issue of the connection between mind/consciousness (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.

This 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 any ontological claims, but to take, instead, an essentially 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 is really like" were discouraged.

The most 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 and 1958: 81) The emphasis here is on "actors": in classical physics we were mere spectators.

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. This extended "agent," which includes the devices, 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 "see," or otherwise consciously experience. 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. Thus Copenhagen quantum theory brings "doing science" into science. In particular, it brings a crucial part of doing science, namely our *choices* about how to probe physical systems, directly into the causal structure. And it describes the non-trivial effects of these choices upon the systems being probed.

This approach 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, and hence that a complete theory ought to be able to describe also our bodies and brains in physical terms. On the other hand, the structure of the theory depends critically also upon aspects of reality described in mentalistic language as our intentional probing actions and the resulting experiential feedbacks.

The great mathematician and logician John Von Neumann reformulated the theory in a rigorous way that allows the bodies and brains of the agents, along with their measuring devices, to be placed in the physically described world, *while retaining those* *mentalistically described properties of the agents that are essential to the causal structure of the theory.* It is this von Neumann formulation that provides a natural science-based account of how your mental intentions influence the activities of your brain and body.

Von Neumann identifies two very different processes that enter into the quantum theoretical description of the evolution of a physical system. He calls them Process 1 and Process 2 (Von Neumann 1955: 418). Process 2 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 2, like its classical analog, is *local* and *deterministic*. However, Process 2 by itself is not the whole story: it generates "physical worlds" that do not agree with human experiences. For example, if Process 2 were, from the time of the Big Bang, the *only* process in nature, then the quantum state of the moon would represent a structure smeared out over large part of the sky, and each human body-brain would likewise be represented by a structure smeared out continuously over a huge region.

To tie the quantum mathematics to human experience in a rationally coherent and mathematically specified way quantum theory invokes *another process*, which Von Neumann calls Process 1.

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 human experiences is placed *within the causal 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 projects into the physical state of the system being acted upon properties that depend upon the choices made by the 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/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 attempting 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. 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 or may not 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 scrutiny, whereas in quantum physics the elemental ingredients are intentional actions by agents, the feedbacks arising from these actions, and the effects of these actions upon the physically described states of the probed systems.

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 mind-brain interaction that is better able than classical physics to integrate the physical and psychological aspects of human nature. For quantum theory injects the choices made by human beings into basic causal structure, in order to fill a logical need, and it specifies the effects of these choices upon the physically described systems being probed. Classical physics systematically eliminates these physical effects of our conscious actions, hence seems ill-suited to be the foundation of a rational understanding of the connection between the psychologically and physically described aspects of nature.

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 a satisfactory quantum generalization of a classical theory one must replace various numbers in the classical theory by *actions* (operators). 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 two different actions then generally AB is different from BA: the order in which actions are performed matters. But for numbers the order does not matter: AB=BA.

The difference between quantum physics and its classical approximation resides in the fact that in the quantum case certain differences AB-BA are proportional to a number measured by Max Planck in 1900, and called Planck's constant. Setting those differences to zero gives the classical approximation. Thus quantum theory is closely connected to classical physics, but is incompatible with it: certain nonzero quantities must be replaced by zero to obtain the classical approximation.

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 did not occur.

The effect of this intentional mental act is represented mathematically by an equation that is one of the key components of quantum theory. This equation represents, within the quantum mathematics, the effect of the Process 1 action upon the quantum state S of the system being probed. The equation is:

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

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, (I-P)S(I-P), represents the alternative possibility “No”, this feedback does not appear. Thus an effect of the probing action is injected into the mathematical description of the physical system being acted upon.

The operator P is important. The action represented by 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 choice made by the agent. The symbol I is the unit operator, which is essentially multiplication by the number 1, and the action of (I-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.

Notice that Process 1 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 1, 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 made quite clear by noticing that S can be written as a sum of four parts, only two of which survive the Process 1 action:

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

This formula is a strict identity. The dedicated reader can quickly verify 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 is a sum of four parts, *two of which are eliminated by Process 1.*

But this means that Process 1 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 causal process, Process 1, which produces a nontrivial effect of an agent's action upon the physical description of the system being examined.

5.1. 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 about how the observed system is to be probed. This choice is*, in this very specific sense*, a "free choice."

5.2. Probabilities

The predictions of quantum theory are generally statistical: they specify, for each of the alternative possible feedbacks, only the *probability* that the agent will experience that feedback. Which of these alternative possible feedbacks will actually occur in response to the Process 1 probing 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. This trace operation is what ties the actions, as represented in the mathematics, to measurable numbers.

Von Neumann generates his form of quantum theory by recognizing that Process 1 describes an influence of a mentalistically described aspect of reality upon a physically described aspect, and by expanding the physically described part to include the brain that is connected to the mentalistically described stream of consciousness. Thus Process 1 represents, in the end, a dynamical influence of the mind of an agent upon his own brain

But if the agent is *free* to choose which action to take, and if the *intention* of that action, represented by P, affects the state being acted upon, then the agent's free mental choice of intention influences the state S being acted upon, which in Von Neumann quantum theory is his or her brain.

This is the important conclusion: Orthodox (Von Neumann) quantum theory has a Process 1 action that: (1) is needed to tie the theory to human experience, (2) is not determined by the known laws, and (3) produces a specified effect on the state of the brain of the agent.

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 this idea of emergence within the framework of classical physical theory disappear if one uses quantum theory. For one thing, there is no longer a need to defend against the charge that the emergent properties, mind and consciousness, have 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! A conscious choice has physically described effects that are not determined by the local deterministic Process 2 that is the generalization of the laws of classical physics.

Another difficulty with "emergence" in a classical physics context is to understand how the motion of a set of miniature planet-like objects, careening through space, can *be a painful experience*. Classical physics is *a postulated conceptual structure* into which is placed only mindless bits of mathematically characterized structure. From this restricted conceptual base there is no natural way to go beyond it to the world of conscious experiences. But quantum theory, although it has a mathematical analog of the physical world of classical physics, has a basically different ontological structure. This analog of the physical description of classical physics is tied to experiential realities in a way that has caused physicists to call it a representation, not of material substance, but rather of "our knowledge," or of "information," or of "potentialities for events to occur." For example, Heisenberg said:

"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)

The essential point, here, is that gulf between mind and matter that characterizes classical physics is bridged by quantum theory: the psychologically and physically described aspects of nature become understood as *two interacting parts of a nonmaterial causally connected whole.*

This reconciliation of the physically and psychologically described aspects of nature that was needed in atomic physics should be important also in neuroscience and neuropsychology. That is because the basic problem in neuroscience and neuropsychology is essentially the same as the basic problem in atomic physics. It is the problem of linking, in a practically useful and testable way, the space-time-based mathematical description of a physical system to the psychologically described aspects of a probing and observing agent. The problem in both cases, and in science in general, is to link, in practically useful ways, the psychological language that we use to communicate the content of our experiences to others, and to ourselves, to the mathematical language of physics and physiology. Matter-based classical physics provides no scientifically adequate conceptual linkage between these two languages, but agent-based quantum physics does.

The quantum state of a human brain is a very complex thing. But its main features can be understood by considering first a classical conception of the brain, and then incorporating some key features that arise already in the case of the quantum state associated with single degree of freedom, which could be the quantum analog of the center point of some large or small object.

5.3. States of a simple harmonic oscillator

One of the most important examples of a quantum state is that of a pendulum, or more precisely, 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: the location of the center point 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. However, it should be emphasized that the “swarm of bees” analogy cannot be pushed too far, because the cloud like structure refers, in the simple one-particle case, to *one single particle* ---e.g., to one calcium ion --- isolated from all others. The different parts of the cloud that represents this *one single calcium ion* , seem to be repelling each other, in the case of the squeezed state.

5.4. 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. This is analogous to the initial explosion of the tightly confined swarm of bees. 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 almost *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 a single particle --- because in the classical case the probabilities arising from the two slits would simply add, due to the facts that, according to classical principles, the particle must pass through one slit or the other, and that the presence of the other opening should not matter much.

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

5.5. Nerve terminals, ion channels, and the need to use Quantum Theory

Some neuroscientists who study the relationship of mind and 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 large 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 1 acts to be the brain of the agent. Thus Process 1 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 connection between mind/consciousness and brain 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 consider the quantum dynamics of nerve terminals.

Nerve terminal are essential connecting links between nerve cells. The way they work is 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 sites on vesicles containing neurotransmitter molecules. A 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 et al. 2002). This extreme smallness of the opening in the ion channels has profound quantum mechanical implications. 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 "release" or "don't release" options at each of the trigger sites, 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 cloud of different macroscopic possibilities representing different alternative possible plans of action. As long as the brain dynamics is controlled wholly by Process 2 - 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 be experienced.

Some process beyond the local deterministic Process 2 is required to pick out one experienced 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. This other process is Process 1. It brings in a *choice* that is not determined by any currently known law of nature, yet has a definite effect upon the brain of the chooser. The choice must pick an operator P, and also a time *t* at which P acts. The effect of this action is to change the state *S(t)* of the brain, or of some large part of the brain, to $PS(t)P + (I-P)S(t)(I-P)$.

The action P cannot act at a *point* in the brain, because a point action would dump a huge (in principle infinite) amount of energy into the brain, which would then explode. The operator P must therefore act non-locally, over a potentially large part of the brain.

To obtain a satisfactory theory the *Process 1* part of brain dynamics must involve a completely different set of variable. The pertinent variables are not the coordinates of the various individual calcium ions, but rather certain *quasi-stable macroscopic degrees of* *freedom*. The associated brain structures must enjoy the stability, endurance, and causal connections needed to bring into being the intended experiential feedbacks.

These structures are likely to be more like the lowest-energy state of the simple harmonic oscillator discussed above, which is stable, or like the states obtained from such lowest-energy states by spatial displacements and shifts in velocity. These states tend to endure as oscillating states, rather than immediately exploding. In other words, in order to get the needed causal structure the projection operators P corresponding to intentional actions ought to be constructed out of *oscillating states of macroscopic subsystems of the brain*, rather than out of the states of the individual particles. The states associated with Process 1 would then be functionally important brain analogs of collections of oscillating modes of a drumhead, in which large assemblies of particles of the brain are moving in a coordinated way that will lead on, via the mechanical laws, to further coordinated activities.

The brain process that is actualized by the transition $S(t) \rightarrow PS(t)P$ is the neural correlate of the psychological intended action. It is the brain's template for the intended action.

5.6. Choices of the Process 1 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 laws of physics. On the other hand, a person's intentions surely depend upon his brain. This means that the laws of contemporary orthodox quantum theory, although restrictive and important, are not the whole story. There is work to be done: hypotheses that fill in the missing details need to be formulated and tested.

It is useful to classify Process I events as either "active" or "passive." The *passive* Process I events are considered to occur automatically, in accordance with some brain-controlled rule, with little or no involvement of conscious effort. The *active* Process I events are intentional and involve effort.

Consciousness probably contributes very little to brain dynamics, compared to the contribution of the brain itself. To minimize the input of consciousness, and in order to achieve testability, we propose to allow mental effort to do nothing but increase the "density of attention", which is a measure of the *rapidity* of the sequence of Process 1 events. This allows mental effort to have *some* influence on brain activities that are largely controlled by the brain itself.

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

5.7. The Quantum Zeno effect

If one considers only passive events, then it is very difficult to identify any empirical effect of Process 1, apart from the occurrence of awareness. In the first place, the empirical averaging over the "Yes" and "No" possibilities tends to wash out all effects that depart from what would arise from a classical statistical analysis that incorporates the uncertainty principle as simply lack of knowledge. Moreover, the passivity of the mental process means that we have no empirically controllable variable.

But the study of effortfully controlled intentional action 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 model, this rapidity is controlled by the amount of effort being applied.

This Quantum Zeno Effect is, from a theoretical point of view, an unambiguous mathematical consequence of the Von Neumann theory. This effect was first identified *theoretically*, and the theoretical predictions were later confirmed in many experimental contexts. The first confirmations were in the realm of atomic and molecular physics.

Consider an atom that has absorbed a photon of energy. That energy has kicked one of the atom's electrons into what's called a higher orbital, kind of like a super-massive asteroid kicking Mercury into Venus's orbit, and the atom is said to be "excited." But the electron wants to go back where it came from, to its original orbital, which it can do if the atom releases a photon. When the atom does so is one of those chance phenomena, like when a radioactive atom will decay: the atom has some chance of releasing a photon (and allowing the electron to return home) within a given period of time. Physicists can measure whether the atom is still in its initial state or not. If they carry out such measurements repeatedly and rapidly, physicists have found, they can keep the atom in its initial state. This is the Quantum Zeno Effect: such a rapid series of observations locks a system into that initial state. The more frequent the observations of a quantum system, the greater the suppression of transitions out of the initial quantum state. Taken to the extreme observing continuously whether an atom is in a certain quantum state keeps it in that state forever. For this reason, the Quantum Zeno Effect is also known as the watched pot effect ("A watched pot never boils," according to the old adage). The act of rapidly probing the quantum system freezes it in a particular state, preventing it from evolving as it would if we weren't peeking. Actively observing a quantum system can suppress certain of its transitions to other states.

How does it work? Consider this experiment. An ammonia molecule consists of a single atom of nitrogen and three atoms of hydrogen. The arrangement of the four atoms shifts over time because all the atoms are in motion. Let's say that at first the nitrogen atom sits atop the three hydrogens, like an egg nestled on a tripod (The nitrogen atom has only two options, to be above or below the trio. It cannot be in between.). The wave function that describes the position of the nitrogen is almost all concentrated in this configuration; that is, the probability of finding the nitrogen at the apex is nearly 100 percent. Left to its own devices, the wave function would shift as time went by, reflecting the increasing probability that the nitrogen atom would be found below the hydrogens. But before the wave function shifts, we make an observation. The act of observation causes the wave function (which, again, describes the probability of the atom being in this place or that one) to collapse from several probabilities into a single actuality. This is all standard quantum theory, the well-established collapse of the wave function following an observation.

But something interesting has happened. "The wave function has ceased oozing toward the bottom," as Sudarshan and his colleague Rothman explained (1998) "it has been 'reset' to the zero position. And so, by repeated observations at short intervals, . . . one can prevent the nitrogen atom from ever leaving the top position." If you rapidly and repeatedly ask a system, *are you in this state or are you not?,* by making observations designed to ascertain whether or not the nitrogen atom is where it began, the system will not evolve in the normal way. It will become, in a sense, frozen. An answer of “Yes” to the posed question [in this case: Is the nitrogen atom on top?] will become fixed and unchanging. The state will be forced to stay longer within the realm that provides a “Yes” answer.

Quantum Zeno has been verified experimentally many times. One of the neatest confirmations came in a 1990 study at the National Institute of Standards and Technology. There, researchers measured the probability that beryllium ions would decay from a high-energy to a low-energy state. As the number of measurements per unit time increased, the probability of that energy transition fell off; the beryllium atoms stayed in their initial, high-energy state because scientists kept asking them, “So, have you decayed yet?” The watched pot never boiled. As Sudarshan and Rothman concluded, "One really can stop an atomic transition by repeatedly looking at it."

This effect is a very special case of the general fact that if a sequence of similar Process 1 events occur rapidly [on the time scale of the macroscopic oscillations associated with the “Yes” state picked out by P] then the “Yes” outcome can be held in place in the face of strong Process 2 mechanical forces that would tend quickly to produce the “No” feedback. This means that agents that can influence the rapidity of non-local Process 1 actions upon their own brains could enjoy a survival advantage over competitors that lack this capacity, for they could sustain beneficial brain activities longer than competitors who do not exploit this feature of the quantum laws. This gives the leverage needed to link quantum selection to natural selection. It would be advantageous for species to evolve in ways that would exploit this survival-enhancing possibility offered by the quantum laws of nature. But is there any empirical evidence that the various species, and man in particular, have actually evolved in a way that exploits this quantum possibility?

6. 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 2 can do most of the necessary work of the brain. It can do the job of creating, on the basis of its interpretation of the clues provided by the senses, a suitable response, which will be controlled by a certain pattern of neural or brain activity that acts as a *template for action*. But, due to its quantum nature, the brain necessarily generates an amorphous mass of overlapping and conflicting templates for action. Process 1 acts to extract from this jumbled mass of possibilities some particular template for action. This is the preferred "Yes" state PSP that specifies the form of the Process 1 event. But the quantum rules do not assert that this "Yes" part of the prior state S *necessarily* comes into being. They assert, instead, that if this Process 1 action is triggered---say by some sort of "consent"---then this "Yes" component PSP will come into being with probability Tr PSP/Tr S, and that the "No" state will occur if the "Yes" state does not occur.

If the rate at which these "consents" occur is assumed to be increasable by conscious mental effort, then the causal efficacy of "will" can be understood. Conscious effort can, by activation of the Quantum Zeno Effect, override strong mechanical forces arising from Process 2, and cause the template for action to be held in place longer than it would if the rapid sequence of Process 1 events were not occurring. This sustained existence of the template for action can cause that action to occur.

Does this quantum-physics-based conception of the origin of the causal efficacy of "Will" accord with the findings 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 introduces 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 will on the course of mental-cerebral processes 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. Thus the whole range of science, from atomic physics to mind-brain dynamics, is brought together in a single rationally coherent theory of an evolving cosmos that consists of a physical reality that is constituted not of matter but of an action-based reality that determines propensities or tendencies for Process 1 events to occur, and within which conscious agents could naturally evolve in accordance with the principles of natural selection.

In view of this general concordance with psychology and natural selection the quantum approach cannot be rationally considered to be a radical innovation. The radical approach would be to reject contemporary physics, which seems to be able to account in a natural way for the efficacy of our mental efforts, in favor of a known to be fundamentally false theory whose failure to accommodate or rationally explain the apparent causal efficacy of consciousness has been the source of enormous philosophical difficulty and debate for more than three hundred years.

In the quantum theory of mind/consciousness-brain being advocated here there are two separate processes. First, there is the unconscious mechanical brain process called Process 2. As discussed at length in the book, *Mind, Matter, and Quantum Mechanics* (Stapp 1993/2003: 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 often is not greatly different from that of a classical model, except for the appearance of a host of parallel possibilities that according to the classical concepts cannot exist simultaneously.

The second process, Von Neumann's Process 1**,** is needed in order to select what actually happens from the continuum of alternative parallel possibilities generated by Process 2.

Process 1, which is connected to conscious awareness and to what actually happens, has itself two modes. The first involves mere passive consent, and temporally isolated events; the second involves mental effort, and a rapid sequence of Process 1 events that bring importantly into play the Quantum Zeno Effect. The first mode involves passive processing, and can exploit the massively parallel processing capacities of Process 2, whereas the second mode involves an effortfully sustained rapid linear sequence of Process 1 events.

Active Process 1 intervention has, according to the quantum model described here, a distinctive form. It consists of a sequence of intentional actions, the rapidity of which can be increased with effort. Such an increase in Attention Density, defined as an increase in the number of observations per unit time, can bring into play the Quantum Zeno Effect, which tends to hold in place both those aspects of the state of the brain that are fixed by the sequence of intentional actions, and also the felt intentional focus of these actions. Attention Density is not controlled by any physical rule of orthodox contemporary quantum theory, but is taken both in orthodox theory and in our model to be subject to subjective volitional control. This concordance of atomic physics and neurodynamics is the core of our model.

6.1. Application to the psychology of attention

A huge amount of empirical work on attention has been done since the nineteenth century writings of William James. Much of it is summarized and analyzed in Harold Pashler's 1998 book "The Psychology of Attention." Pashler organizes his discussion by separating perceptual processing from post-perceptual processing. The former covers processing that, first of all, identifies such basic physical properties of stimuli as location, color, loudness, and pitch, and, secondly, identifies stimuli in terms of categories of meaning. The post-perceptual process covers the tasks of producing motor actions and cognitive action beyond mere categorical identification. Pashler emphasizes [p. 33] that "the empirical findings of attention studies argue for a distinction between perceptual limitations and more central limitations involved in thought and the planning of action." The existence of these two different processes with different characteristics is a principal theme of Pashler's book [pp. 33, 263, 293, 317, 404].

A striking difference that emerges from the analysis of the many sophisticated experiments is that the perceptual processes proceed essentially in parallel, whereas the post-perceptual processes of planning and executing actions form a single queue. This is in line with the distinction between "passive" and "active" processes. The former are essentially one-shot Process 1 events, whereas the "active" processes involve effort-induced rapid sequences of Process 1 events that can saturate a given capacity. This idea of a limited capacity for serial processing of effort-based inputs is the main conclusion of Pashler's book. It is in accord with the quantum-based model, supplemented by the condition that there is a limit to how many effortful Process 1 events per second a person can produce.

Examination of Pashler's book shows that this quantum model accommodates naturally all of the complex structural features of the empirical data that he describes. He emphasizes [p. 33] a specific finding: strong empirical evidence for what he calls a central processing bottleneck associated with the attentive selection of a motor action. This kind of bottleneck is what the quantum-physics-based theory predicts: the bottleneck is precisely the single linear sequence of mind-brain quantum events that Von Neuman quantum theory is built upon.

Pashler [p. 279] describes four empirical signatures for this kind of bottleneck, and describes the experimental confirmation of each of them. Much of part II of Pashler's book is a massing of evidence that supports the existence of a central process of this general kind.

The queuing effect is illustrated in a nineteenth century result described by Pashler: mental exertion reduces the amount of physical force that a person can apply. He notes that ``This puzzling phenomena remains unexplained." [p. 387]. However, it is an automatic consequence of the physics-based theory: creating physical force by muscle contraction requires an effort that opposes the physical tendencies generated by the Schroedinger equation (Process 2). This opposing tendency is produced by the quantum Zeno effect, and is roughly proportional to the number of bits per second of central processing capacity that is devoted to the task. So if part of this processing capacity is directed to another task, then the applied force will diminish.

The important point here is that there is in principle, in the quantum model, an essential dynamical difference between the unconscious processing carried out by the

Schroedinger evolution, which generates via a local process an expanding collection of classically conceivable possible courses of action, and the process associated with the sequence of conscious events that constitutes a stream of consciousness. The former are not limited by the queuing effect, because all of the possibilities develop in parallel, whereas the latter do form elements of a single queue. The experiments cited by Pashler all seem to support this clear prediction of the quantum approach.

This bottleneck is not automatic within classical physics. A classical model could easily produce, simultaneously, two responses in different modalities, say vocal and manual, to two different stimuli arriving via two different modalities, say auditory and tactile: the two processes could proceed via dynamically independent routes. Pashler [p. 308] notes that the bottleneck is undiminished in split-brain patients performing two tasks that, at the level of input and output, seem to be confined to different hemispheres. This indicates that the non-local operator P probably involves, in some important way, activities in the brain stem, and hence could naturally be involved in the evolution of the species.

An interesting experiment mentioned by Pashler involves the simultaneous tasks of doing an IQ test and giving a foot response to a rapidly presented sequence of tones of either 2000 or 250 Hz. The subject's mental age, as measured by the IQ test, was reduced from adult to 8 years. [p. 299] This result supports the prediction of quantum theory that the bottleneck pertains to both `intelligent' behavior, which requires conscious processing, and selection of motor response.

Another interesting experiment showed that, when performing at maximum speed, with fixed accuracy, subjects produced responses at the same rate whether performing one task or two simultaneously: the limited capacity to produce responses can be divided between two simultaneously performed tasks. [p. 301]

Pashler also notes [p. 348] that ``Recent results strengthen the case for central interference even further, concluding that memory retrieval is subject to the same discrete processing bottleneck that prevents simultaneous response selection in two speeded choice tasks."

In the section on ``Mental Effort" Pashler reports that ``incentives to perform especially well lead subjects to improve both speed and accuracy", and that the motivation had ``greater effects on the more cognitively complex activity". This is what would be expected if incentives lead to effort that produces increased rapidity of the events, each of which injects into the physical process, via quantum selection and reduction, bits of control information that reflect mental evaluation.

Studies of sleep-deprived subjects suggest that in these cases ``effort works to counteract low arousal". If arousal is essentially the rate of occurrence of conscious events then this result is what the quantum model would predict.

Pashler notes that ``Performing two tasks at the same time, for example, almost invariably... produces poorer performance in a task and increases ratings in effortfulness." And ``Increasing the rate at which events occur in experimenter-paced tasks often increases effort ratings without affecting performance". ``Increasing incentives often raises workload ratings and performance at the same time." All of these empirical connections are in line with the general principle that effort increases the rate of conscious events, each of which inputs a mental evaluation and a selection or focussing of a course of action, and that this resource can be divided between tasks.

Additional supporting evidence comes from the studies of the effect of the conscious process upon the storage of information in short-term memory. According to the physics-based theory, the conscious process merely actualizes a course of action, which then develops automatically, with perhaps some occasional monitoring. Thus if one sets in place the activity of retaining in memory a certain sequence of stimuli, then this activity can persist undiminished while the central processor is engaged in another task. This is what the data indicate.

Pashler remarks that "These conclusions contradict the remarkably widespread assumption that short-term memory capacity can be equated with, or used as a measure of, central resources."[p.341] In the theory outlined here short-term memory is stored in patterns of brain activity, whereas consciousness is associated with the selection of a sub-ensemble of quasi-classical states. This distinction seems to account for the large amount of detailed data that bears on this question of the connection of short-term-memory to consciousness. [pp. 337-341]

Deliberate storage in, or retrieval from, long-term memory requires focused attention, and hence conscious effort. These processes should, according to the theory, use part of the limited processing capacity, and hence be detrimentally affected by a competing task that makes sufficient concurrent demands on the central resources. On the other hand, “perceptual'” processing that involves conceptual categorization and identification without conscious awareness should not interfer with tasks that do consume central processing capacity. These expectations are what the evidence appears to confirm: ``the entirety of...front-end processing are modality specific and operate independent of the sort of single-channel central processing that limits retrieval and the control of action. This includes not only perceptual analysis but also storage in STM (short term memory) and whatever may feed back to change the allocation of perceptual attention itself." [p. 353]

Pashler speculates on the possibility of a neurophysiological explanation of the facts he describes, but notes that the parallel versus serial distinction between the two mechanisms leads, in the classical neurophysiological approach, to the questions of what makes these two mechanisms so different, and what the connection between them is [p.354-6, 386-7].

After analyzing various possible mechanisms that could cause the central bottleneck, Pashler [p.307-8] says ``the question of why this should be the case is quite puzzling.'' Thus the fact that this bottleneck and its basic properties seems to follow automatically from the same laws that explain the complex empirical evidence in the fields of classical and quantum physics means that the theory has significant explanatory power.

These features of the phenomena can perhaps be explained by some classical-physics-based model. But the naturalness of such an explanation is obstructed by the absence from classical physics of the notion of conscious effort, or of the causal efficacy of conscious thoughts, or of the change-inhibiting effect of a rapid sequence of conscious events. These consciousness-connected features would have to be injected into the consciousness-free causal structure of classical theory, rather than being directly supplied --- in a specific form --- by the causal structure of fundamental physical theory.

7. Mental action in neuropsychological experiments

The quantum model is better suited to the analysis of neuropsychological data than models based on the classical approximation. For, just as in the treatment of atomic systems, the quantum approach brings the *phenomenologically described data* directly into the dynamics, in place of microscopic variables that are in principle unknowable. Quantum theory injects directly into the causal structure the phenomenal descriptions that we human beings use in order to communicate to our colleague the empirical facts. It thereby specifies a useful and testable causal structure, while evading the restrictive classical demand that the causal process be “bottom up”--- i.e., expressible in terms of local mechanical interactions between tiny mindless entities. The Heisenberg Uncertainty Principle renders that ideal *unachievable in principle*, and the banishment of that microlocal "bottom up" determinism opens the door to the quantum alternative of injecting the phenomenologically described realities directly into the causal structure in the way that is both allowed by and described by contemporary physical theory.

To illuminate this approach we consider its application to the experiments of Ochsner et al. (2002), with particular attention to the following four questions:

1. How does the quantum approach work in this specific 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? O,r does it lie, instead, "outside of space"?

Reduced to its essence the experiment 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.

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 question is whether these connections will ever be understood in terms of a physical theory that is known to be false, and that, moreover, is false in ways that, according to contemporary physical theory, systematically exclude the causes of the correlations between the psychological and physiological aspects of the mind/consciousness-brain system that these neuropsychology experiments demonstrate. 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 approach the dynamics must in principle be describable in terms of the local deterministic classical laws that govern these classical quantities. The problem of classical-physics-based neuroscience is then to reconcile the neuropsychological data with a conception of causation that gives mind and consciousness no explicit role.

The quantum approach is fundamentally different. In the first place the idea that all causation is *fundamentally mechanical* is dropped as being prejudicial and unsupported either by direct evidence or by contemporary physical theory. The quantum model of the human person is essentially dualistic, with one of the two components being described in psychological language and the other being described in physical terms. The empirical/phenomenal evidence coming from subjective reports is treated as data pertaining to the psychologically described component of the person, whereas the data from objective observations, or from measurements made *upon that person,* are treated as conditions on the physically described component of the person. The causal connection between these two components is the connection specified by the quantum laws.

The physical description will, for reasons spelled out below, be essentially a classical description, smeared out to accommodate the uncertainty principle. This smeared out cloud will evolve, under the action of Process 2, essentially in accordance with the laws of classical physics. There is no significant departure at this point from classical physics, smeared out to accommodate the uncertainty principle. But the fanning out of the possibilities generated by Process 2 will be controlled by a sequence of Process 1 events. Each such event trims back the possibilities to keep them in line with the experiences of the person.

Many of these events will be passive, controlled largely by the dynamics that contemporary quantum theory has not yet specified. But the *effects* of these events are specified. When no effort is applied the evolution of the body/brain will be roughly in accord with the principles of classical physics. But important departures from the classical prediction can be caused by effortful focus of attention. This effort can cause a pattern of neural activity that is a template for action to be held in place for an extended period. And this will tend to cause the specified action to occur. In the Ochsner experiments the effort of the subject to "reappraise" *causes* the "reappraise" template to be held in place, and the holding in place of this template *causes* the suppression of the limbic response. These causal effects are consequences of the quantum equations of motion. Thus the "subjective" and "objective" aspects of the data are tied together by quantum laws that directly specify the causal effects of the choices made by the subject, without prejudice pertaining to exactly how these choices come about.

Quantum theory was designed to deal with the 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 1 mechanism, an explicit means whereby the successful effort to "rethink feelings" actually causes - by catching and actively holding in place - the prefrontal activations critical to the experimentally observed deactivation of the amygdala and orbitofrontal cortex. The resulting *intention-induced modulation* of limbic mechanisms that putatively generate the frightening aversive feelings associated with passively attending to the target stimuli is the key factor necessary for the achievement of the emotional self-regulation seen in the active cognitive reappraisal condition. Thus, within the quantum framework, the causal relationship between the mental work of mindfully reappraising and the observed brain changes presumed to be necessary for emotional self-regulation is *dynamically* accounted for. Furthermore, and crucially, it is accounted for in ways that fully allow for communicating to others the means utilized by living human experimental subjects to attain the desired outcome. The classical materialist approach to these data, as detailed earlier in this chapter, by no means allows for such effective communication. Analogous quantum mechanical reasoning can of course 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 corresponds to the action that singles out a large quasi-stable and functionally effective *template for action* that tends to produce the intended feedback. If the "Yes" answer is selected by nature then a monitoring of the activity of the brain would reveal a rapid emergence from the background "noise" of the held-in-place template for action associated with P, followed by the actions instigated and guided by that template.

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

Large intention-controlled functionally effective brain activities are singled out and linked to mental effort through *learning*, which depends upon the fact that mental efforts can have direct physical consequences. A "Yes" outcome actualizes such a functional state. Quantum theory thus provides the mathematical machinery for causally connecting psychologically described intentions to the physically described macroscopic states of the brain that implements them. No comparable psycho-physical linkage is provided by classical physics.

The fourth question is: Are mind and consciousness localized, and, if so, how and in what sense? Or, do they 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. 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 formulation, of the long-range effects associated with an important non-locality theorem of John Bell (1964), and a generalization due to Stapp (2003).

Each Process 1 event changes in a specified way the state of the system that is being acted upon, or probed. This change can affect, for example, the energy of the observed system. If the action is a measurement of the energy of the probed system then the “Yes” response will single out one possible energy value, or perhaps a collection of possible energy values. However, the statistical laws of quantum theory ensure, in this case of a measurement of energy, that the weighted statistical average over all possible outcomes leaves the average unchanged and independent of exactly which possible energy values are included in “Yes” and which are included in “No.” In more general cases this ‘average energy’ of the observed system can be changed by the probing action.

If the effect of the “inquiry” is to say “Yes” to a collection of temporarily oscillatory states of parts of the brain, as is likely to be the case, then the effect on the average energy could be virtually undetectable. In any case, the change is only a selection of one possibility *for that probed system* from among a mass of allowed possibilities. Because the energy of the full system is conserved during the Process 2 dispersion of the cloud of possibilities there will be a strong tendency for the selection of an energy state of the probed subsystem of the brain to be compensated for by correlated energy changes in other parts of the brain and its environment.

The question of whether the psychologically described properties are inside or outside of space is a hold-over from classical Cartesian thinking. The quantum model is dualistic in the practical sense that there is a Process 1 “Choice” that is the direct descendant of the pragmatic Copenhagen philosophy’s conscious *choice on the part of the observer*. However, what is instantiated in the space-time structure is *knowledge*, not matter. Psychologically described properties are the grist from which the mathematical structure in space is constructed. It makes no ontological sense to separate mind from the spatial structure that is both built out of it, and that gives it the stability and form needed to define the changes that it effects.

8. Answers to objections

Several objections have been raised to the idea of applying quantum theory to a warm, wet, noisy brain that is interacting strongly with its environment. The following seven objections are addressed in this section:

1. The interaction of the brain with its environment will produce strong "decoherence" effects that will effectively eliminate the quantum properties and reduce brain dynamics to classical dynamics.

2. Quantum effects may indeed be important at the level ions, but these effects cannot significantly influence the functioning of the brain, given the temperature at which it operates.

3. From a functional neurophysiological point of view, large neural circuits (not neurons or ionic channels) constitute the most elementary units of the brain. At this macroscopic level, classic physical effects apply, not quantum effects

4. "The effort of attention is the essential phenomenon of will." But 'will' can influence mind processes other than attention that are too rich and complicated to be represented by a binary (Yes or No) system response.

5. "Large intention-controlled functionally effective brain activities are singled out and linked to mental effort through learning." But what about cases where a subject accomplishes the task the first time?

6. How can a theory that makes conscious choices dynamically important deal with the universe before the existence of life, and with biological evolution?

7. Quantum physicists do not agree on what is the correct interpretation of quantum theory. Should not the rest of us wait until physicists have put their own house in order, before trying to apply quantum theory outside atomic physics?

Understanding the answers to all of these questions depends on understanding clearly the answer to the first.

It is known that the interaction of the brain with the environment *enormously* curtails the interference effects that are characteristics of quantum physics. This effect reduces the brain to a *nearly* classically describable system. But the effect --- exploited in the quantum approach described above --- of a person’s conscious choices upon the state of his physical brain is a strictly quantum effect. So one might surmise that the strong suppression of the quantum interference effects would strongly suppress also the effect of conscious choices upon the state of the brain. But that conclusion does not follow.

The reason that the conclusion does not follow is easy to see. The state of the brain is represented by the operator S = S(t). It is often called the density matrix, and can by pictured as a square array of numbers <x|S|x’>, where x specifies a set of possible locations of for each of the particles in (some part of) the brain, and x’ specifies another possible set of locations. This density matrix is obtained by “averaging” over all the other degrees of the universe. Hence it depends only on the two variables x and x’. According to orthodox (Von Neumann) quantum theory this matrix of values contains all the physical information about the brain system that can be obtained by doing measurements or observations solely upon that brain. And it contains all of the effects due to the interactions of that brain system with its environment.

The effect of those interactions is to cause all of the numbers $\langle x|S|x'\rangle$ to become very small unless x is very close to x'. This means that all interferences effects involving contributions from two appreciably different possible classically conceived brain states will be severely suppressed. This means that all quantum effects like those exploited by quantum computers can be expected to be strongly suppressed. This fact constitutes a very powerful objection to all attempts to apply quantum mechanics to human brains in a way that depends on such interference effects.

The effect of the environment is also to reduce the equation of motion for those values of $\langle x|S|x'\rangle$ where x and x' are nearly the same to essentially the classical equation. Thus if the probability distribution $\langle x|S(t)|x\rangle$ has a "bump" in a certain place then the motion of this bump will very closely approximate what a classical calculation would give. This is the basis of the claim that the effects of the interaction with the environment will reduce brain dynamics to classical dynamics.

But those considerations are just the preliminaries to the main story. The Heisenberg uncertainty principle is not undone by the interaction with the environment. One still obtains a quantum state $\langle x|S(t)|x'\rangle$ that satisfies the uncertainty conditions, *not some particular value of x*, which is what classical physics would give. This distribution will contain contributions corresponding to many different experiences 'e'. Thus the basic interpretational problem is still unresolved: "How is some particular experience picked out from the blur of possibilities?" This question brings one back to the essential core of quantum theory, which is Von Neumann's Process 1. This process picks an experience e, and hence a projection operator P(e), which if activated rapidly brings in the Quantum Zeno Effect. This effect *disrupts the classically predicted changes of* $\langle x|S(t)|x\rangle$ that the decohence effects leave untouched.

The decoherence effects leave those classical motions of the probabilities $\langle x|S(t)|x\rangle$ essentially unaffected because these motions are governed by the values of $\langle x|S(t)|x'\rangle$ where x and x' are very nearly the same. This is the basis of the claim that the effect of the interaction with the vacuum preserves the classical limit. *But the Quantum Zeno Effect produces violations of those classical equations that the decoherence effects leave alone,* even though the decoherence effects do severely curtail interference effects for values of x and x' that are appreciably different. So the bottom line is that The Quantum Zeno Effect that follows from the application of Von Neumann's rules can strongly effect the *nearly* classical states produced by the very strong environmental decoherence effect! The environmental decoherence produces nearly classical states that would evolve in the absence of Process 1 events in close conformity to the classical laws, but whose evolution would be strongly affected by a sufficiently rapid sequence of Process 1 events.

The answer to objection 2, about the effects of heat, is a corollary to the answer about the effects of the environment. The effect of heat is an effect of the environment, and the same considerations apply.

The third objection is:

> From a functional neurophysiological point of view, large neural circuits (not neurons or ionic channels) constitute the most elementary units of the brain. At such a macroscopic level, classic physical effects apply, not quantum effects

The answer to objection number one was directly about large structures in the brain. If no Process 1 event occurs then the uncertainties at the ionic level automatically expand in the course of time to uncertainties in the large structures. It is these *latter* uncertainties that correspond to the uncertainties in experiences that the Process 1 event resolves. The quantum uncertainties at the ionic level cannot be confined to the ionic level, even in a classical statistical description.

Objection 4 is:

> "The effort of attention is the essential phenomenon of will." But 'will' can influence mind processes other than attention that are too rich and complicated to be represented by a binary (Yes or No) system response.

According to the theory, each conscious experience, no matter how complex, corresponds to the actualization of a state PS(t)P, and the features specifically brought out by the suppression by P of the alternatives that would conflict with the experience are the neural correlates of the experience. Some idea of the complexity of this correlate is gained by noticing that if some large set of oscillating states of various weights are actualized, then a complexity comparable to --- and actually far transcending --- that of the sound of a symphony orchestra can be achieved. The discussion in Sections (6.6) and (6.5) of Stapp (1993/2003) gives a glimpse into the sort of complexity that is naturally encompassed by the model, both at the individual event level, and by a sequence of such binary events. The "Yes" result corresponds to the actualization of a normally very rich and complex structure created as a possible response to a complex stimulus impacting on a brain created by a long period of evolution followed perhaps by a long lifetime of study and reflection.

Objection 5 is:

> "Large intention-controlled functionally effective brain activities are singled out and linked to mental effort through learning." But what about cases where subjects accomplish the task the first time?

A repertoire of functional actions are learned by trial-and-error effort. These are the basic links between the psychological and physical realms. The process of creating these links is comparable in physics to the calibration of measuring devices. One must get started by finding out some primary linkages between how the probing devices are constructed and what they can tell us about and do to the world outside us. But latter on we can achieve our ends by putting together known elements in complex ways without needing to learn by trial and error how the complex combination will behave.

Objection 6 is:

> How can a theory that makes conscious choices dynamically important deal with the universe before the existence of life, and with biological evolution?

Conscious choices are dynamically important in systems such as human brains. But even in these systems there are “passive” Process 1 events which are essentially automatic. During biological evolution the “active” Process 1 events involving mental effort can be assumed to become increasingly significant as brains evolve that are increasingly able to exploit the dynamical possibilities imbedded in the structure of the quantum laws of motion.

The present article has focused on neuropsychology and human subjects, where the issue is the integration of the psychologically described data with the physically described properties of the brain. We have endeavored to provide a model that depends minimally upon the yet-to-be discovered details of the passive process, which is empirically more difficult to study because we lack the (at least partially) controllable variables associated with effort and intention. However, pursuing the general approach developed here one is led to the phenomena of plausible reasoning. Human beings appear to be able to arrive (sometimes) at reasonable conclusions on the basis of data that is insufficient to determine unique definite conclusions. And they do so efficiently. This "reasoning" process somewhat resembles conscious reasoning, so it appears that brain process might support something that could be considered to be a natural predecessor to conscious thought.

There is growing interest in computer science in replacing mechanistic algorithms with software agents that interact with an environment and are able to draw inferences and execute plans to achieve goals. The new paradigm replaces deterministic logic with plausible reasoning based on probability, and Bayesian inference. T. S. Lee and David Mumford (2003) have applied these ideas successfully to the visual cortex. One of the present authors (HPS) is working with K. Laskey to develop a quantum version of a system that performs plausible reasoning by using Bayesian inference and exploiting the Quantum Zeno Effect. This would appear to be the reasonable next step in the development of the model proposed here in the direction of pre-conscious processes.

Objection 7 is:

> Quantum physicists do not agree on what is the correct interpretation of quantum theory. Should not the rest of us wait until physicists have put their own house in order, before trying to apply their theory outside atomic physics?

The disagreements are at the ontological level. All physicists agree at the pragmatic level on how to connect the mathematical formulas to the empirical findings. The practical rules in the realm of atomic physics are the ones formulated in the mid-1920 by Heisenberg, Pauli, Born, Bohr and others. They are the rules of Copenhagen quantum theory. But there are many ways of trying to devise an ontology that will lead to these rules. The towering virtue of the Copenhagen approach is that it evades dependence upon these speculations, and provides useful testable rules, and even understanding, provided that understanding is about the likely empirical feedbacks to the alternative possible ways that we might choose to act.

This pragmatic approach was extended by Von Neumann from atomic physics to neuroscience by shifting the boundary between 'probee' and 'prober' from between atomic system and measuring device, which is where it was drawn in Copenhagen quantum theory, to between the physically described brain and empirically described choices and responses. Von Neumann created the foundation for a *pragmatic approach* to neuroscience that *encompasses* the pragmatic Copenhagen approach to atomic physics, and extends it to the realm of neuroscience. Von Neumann's formulation, like the Copenhagen formulation, brings in a process, Process 1, that is not controlled by the Schroedinger equation, which is the local deterministic quantum generalization of the classical laws. This lack of mechanical determinism opens a causal gap that is filled in practice, without conflicting with any other law of contemporary physics, by injecting directly into the dynamics choices made by the observer about how he or she will act upon the system being probed The theory then entails a certain dependence of the behavior of the probed physically described system upon how the agent chooses to probe it. The existence of this choice-controlled effect is strikingly confirmed by the empirically verified Quantum Zeno Effect, which can cause an atom to remain in an excited state longer than normal by increasing the frequency of the probing events. The same equations applied in the Von Neumann formulation to the behavior of a brain--- which is the Von Neumann analog of the system being directly probed --- entail a dependence of brain behavior upon "attentional density," i.e., the frequency at which the Process 1 events occur.

If one moves to an ontological level, then one can pose the question "what it is that controls the attentional density." Is it an 'individual soul', or a 'global consciousness,' or a rather mindless process that 'causes' consciousness? Orthodox contemporary quantum mechanics gives no answer this question. However, it does have a natural and causally efficacious place for the empirically controllable variable "density of directed attention." This parameter plays the causal role in brain dynamics that William James assigned to "Volition" or "Effort of attention."

The most prominent alternatives to the orthodox (Copenhagen/Von Neumann) approach to quantum theory are the pilot-wave model of David Bohm (1952) and the many-worlds approach of Hugh Everett III (1957). Both attempt to eliminate the intervention of the psychologically described conscious observer, and his or her choices, in favor of a mathematically described process based on mathematically defined localized properties.

One failing of the Bohm pilot-wave model is that, in spite of intense efforts, it has never been generalized from its original non-relativistic form to cover the premier quantum theory, quantum electro-dynamics. The Von Neumann approach, on the other hand, has been extended from its original non-relativistic form to cover general relativistic quantum field theory (Tomonaga 1946; Schwinger 1951).

Bohm (1986, 1990) recognized that mind and consciousness need to be brought in. But his method of doing so involved equating conscious essentially to an infinite tower of realities, each of which was guided by the one above it. This complexity vitiates the great virtue of his original model, its simplicity. Consequently, it is unlikely that the Bohm approach will be as testable and useful in neuroscience as Von Neumann's theory. Moreover, the complexity of Bohm's theory of consciousness, with its infinite tower, undercuts the main thrust of the original model, which was to eliminate the non-algorithmic intrusion of "the observer" into the dynamics. If the choices made by the observer do play a complex dynamical role, as even the Bohm model now suggests, then it is scientifically advantageous to introduce these choices into the dynamics the most direct possible way. That is what Von Neumann's Process 1 does.

Most careful readers of Von Neumann's work are initially led to the attractive idea of eliminating his mysterious Process 1, and letting the dynamics be controlled wholly by Process 2. This idea jumps out of Von Neumann's work because he focuses largely on "ideal measurements" in which an interaction with a fixed device specifies the projection operator P that corresponds to a distinctive experiential feedback (or specifies, perhaps, a *set* of P's that correspond one-to-one to a *set* of distinguishable outcomes). Since each of the possible outcomes corresponds to a separate possible branch of reality that, for all practical purposes, never interferes with any of the others, one can assume that all of the possibilities exist "in parallel," with the consciousness associated with each branch unaware of the other branches, but somehow assigned the appropriate statistical weight. This leads to a many-worlds conception of reality.

But focusing on one fixed ideal measurement eliminates the problem that Process 1 was introduced to resolve: what fixes that ideal measurement? The solution that immediately comes to mind is to let "the environment" play the role played in Von Neumann quantum theory by the consciously choosing agent. But the details of such an approach have never been completely worked out Stapp (2002). The problem is that if the dynamics is controlled exclusively by Process 2 then any possible device would be part of a smeared out continuum of possibilities, and it has never been shown how a discrete set of P's corresponding to distinctive experiences can emerge from this continuum by means of Process 2 alone. In practice the cognitive scientists who contemplate, for example, quantum computation must in the end introduce the agent-controlled devices, in place of the smeared out collection of possibilities that an unrestricted Process 2 would generate.

Thus the initial promises of the pilot-wave and many-worlds alternatives have not been borne out, and they would appear in any case to be far less useful in neuroscience than Von Neumann's theory.

The other prominent quantum approach is the gravity/microtubule model of Roger Penrose and Stuart Hameroff (1996). That theory, like the present one, is built upon Von Neumann's Process 1. But it ties the timing of Von Neumann's Process 1 events to gravity rather than directly to the psychological concepts of William James, and to the empirically reportable and largely controllable variables of the psycho-physical and psycho-neural experiments. Also, it requires a strong persistence of macroscopically extended quantum interference effect in a warm, wet brain that is strongly interacting with its environment. Most physicists find the claim that such interference could persist under these conditions to be unrealistic. A principle virtue of the model proposed here is that it does not depend on any macroscopic interference effect.

These considerations argue for the conclusion that although other interpretations of quantum theory have indeed been advanced, they have liabilities that make them less attractive than Von Neumann's as a testable and useful model of the mind-brain connection.

9. Conclusions and summary

The philosophy of materialism has no basis in contemporary physics. There is no support in current fundamental physics for the notion that the physical world is made out of, or even contains, what Isaac Newton (1721) called "solid, massy, hard, impenetrable movable particles," or that our conscious thoughts are patterns of motions of such entities. There is also no basis in physics for the idea that every thought is *caused* purely by local mechanical processes, or that our conscious thoughts merely *seem* to be causing our bodily actions. On the contrary, contemporary orthodox physical theory provides no mechanically deterministic cause for our conscious choices, yet allows these conscious choices to influence physical behavior. And it instantiates the causally efficacious mathematical properties of nature in a structure that is ontologically more like information, knowledge, or potentiality for information-changing events to occur, than like the material substance postulated by classical physics.

The benefits of adopting the pragmatic quantum approach could be as important to progress in neuroscience and neuropsychology as they were in atomic physics. It allows the deferred-to-the-future question of how mind and consciousness are connected to classically described brain to be replaced by the partially answered question of how mind and consciousness are connected to quantum mechanically described brain. This switch allows the psychological data of psycho-physical and neuropsychological experiments to be treated as descriptions of the causally efficacious *psychological part* of contemporary pragmatic dualistic physical theory. Mind and consciousness are no longer coerced into being an aspect of a mechanical approximation that systematically strips them of their causal power.

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