QUANTUM MECHANICAL APPROACH TO THE CONNECTION BETWEEN MIND AND BRAIN

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ABSTRACT

The current mainstream scientific approach to understanding the connection between mind and brain is based essentially upon the precepts of classical physics. According to those principles, the mind-brain connection is fundamentally bottom-up: mental events are imagined to be determined by physical activities in the brain, and to have no capacity to influence brain activities in ways not traceable to prior physical activities. The possibility of genuine top-down causation originating in the mental realm is excluded. Puzzlements arising from this bottom-up approach are well known. Why do the mental aspects exist at all if every physical event is causally traceable to prior physical events? How can motions of physical particles produce, or become, things so completely unlike themselves as thoughts and feelings? How do the mental and physical aspects of nature stay in alignment during evolution and development if the contents of mental events have no causal efficacy? It is widely recognized that, in spite of huge advances in neuroscience over the past century, this bottom-up approach has produced no significant progress towards bridging the conceptual chasm between mind and matter. Given this stagnation, it is worth noting that the essential change wrought in science early in the twentieth century by the switch from classical mechanics to quantum mechanics is not the introduction of probabilities. It is the introduction of mental aspects of reality into the basic causal structure of our fundamental physical theory, and a concomitant reversal of the classical bottom-up conception of the causal connection between mind and brain to a quantum mechanical top-down conception. This paper argues that in the science-based study of the connection between mind and brain, the bottom-up conception of reality stemming from the work of Isaac Newton needs to be replaced by the top-down conception specified by John von Neumann's quantum theory of measurement.

1. Introduction.

Most contemporary efforts by neuroscientists to understand the connection between the aspects of human beings that we describe in terms of subjective conscious experiences and the aspects that we describe in terms of objective physical properties are heavily influenced by ideas stemming from classical physics. Thus there is almost universal acceptance of the idea that the causal flow in the mind-brain system is bottom-up from physical to mental. Neural activities are believed either *to cause directly*, or perhaps in some way, *even to be*, our thoughts, ideas, and feelings. Some marginal recognition is accorded to the fact that classical physics is known to have been replaced at the fundamental level by quantum mechanics. Thus molecular dynamics is treated quantum mechanically, and the intrusion of statistical physical elements is not ruled out. Yet, in spite of these small concessions, the core idea of classical physics is retained: the mental aspects are regarded as sideshows, somehow generated by, or identical with, the more basic physical aspects.

It is widely recognized that these classical-physics-based attempts to understand the place of mental realities in Nature, and in our lives, remain as frustrated today as they were when Newton's successors stripped our conscious efforts of their intuitively manifest influence upon our physical actions. But quantum mechanics, rigorously applied, radically alters the situation. It has already been demonstrated[1] how a direct application of the basic rules of quantum mechanics, as formulated by John von Neumann[2], explains in a rationally coherent way how a person's conscious intentional efforts, *per se*, can cause his body to act in the consciously intended way. That explanation is rooted in the fact that the founders of quantum mechanics brought the experiential aspects of human experimenters into our basic physical theory in a functionally essential and causally efficacious role. The cited demonstration exploited this foundational change, without being diverted to the related question of whether direct bottom-up actions of brain upon mind are required, or even permitted.

The present paper focuses primarily on that latter question. Section 2 describes the conceptual structure of orthodox quantum mechanics as it pertains to the mind-brain connection. The quantum rules are, of course, formulated in an appropriate mathematical language. But this paper is meant to be understandable to neuroscientists and philosophers, as well as to quantum experts. To this end I refrain here from the use of equations. The mathematical details can be found in other places.[1,3]

Section 3 gives a brief summary of the afore-mentioned demonstration of how quantum mechanics explains voluntary control of bodily actions. In that account certain aspects of the causal connection between mind and brain need not be specified. In particular, it can be left open whether, in addition to the top-down causal actions upon brains specified by von Neumann's quantum mechanical rules, there could be also direct bottom-up action of brain upon mind of the kind that classical mechanics mandates.

Do we need *both* the top-down quantum mechanically described action upon matter---in particular upon our brains---and *also* the direct actions of brains upon thoughts? This question is addressed in Section 4, which contains the meat of this paper. It describes a proposed new understanding of the connection between mind and brain that is based directly upon von Neumann's description of the quantum measurement process. This proposed understanding is called "a purely quantum mechanical ontology" because it answers negatively the question of whether there is, in addition to the top-down causation mandated by quantum mechanics, also a direct bottom-up causation of the kind required by classical physics. This negative answer can be viewed as an application of Occam's razor: direct bottom-up causation is not needed, hence it should be excluded.

Yet there is a far more potent reason to move beyond the classical-physics-based approach to the problem of the mind-brain connection. Neuroscience and philosophy have struggled for years with the mystery of how a physical motion can create (or *be)* a mental reality. By identifying that puzzle as a misleading relic of known-to-be-false early science we take a major step toward achieving a rationally coherent understanding of the mind-brain connection that is fully in accord with our deepest contemporary science. Stripping away the classical blinders allows us to see how the sophisticated quantum measurement process *itself* resolves the long-standing puzzles. It does so by doing exactly what that process is designed to do: enlighten the enquiring mind with the knowledge of physical properties that it actively seeks. This *acquisition of knowledge* is achieved, according to orthodox quantum mechanics, by means of *two top-down actions*, without the need for any direct action of brain upon mind.

This reversal of the direction of causation places the problem of the mind-brain connection in a light very different from the one that has prevailed in science and science-based philosophy for the past three centuries. The scientist/philosopher is no longer faced with the impossible task of explaining how a mechanical motion can become a conscious thought. According to the orthodox quantum mechanical understanding, the physically described universe evolves via the deterministic quantum mechanical equation of motion *during the intervals between* top-down actions upon it that are instigated by inquiring minds. The evolving quantum physical state is a compendium of the knowledge created by these top-down actions. The quantum physical state is not experienced knowledge itself, nor does it directly produce any alteration of any mental reality. In orthodox quantum mechanics all mandated mind-brain causal flow is top-down, and hence the idea that a motion generates or becomes a thought need never arise. Yet all known connections between human knowledge and physical properties seem to be explained without any bottom-up action.

The basic point in all of this is that orthodox quantum mechanics is built conceptually upon the quantum mechanical theory of measurement. That theory brings human agents into the dynamical structure in an essential way. Von Neumann's development of the theory of measurement allows the mental/psychological aspects of the agent to be cleanly separated from his bodily/physical aspects, and then *explains how the agent acquires knowledge* about the physical properties of his brain. Quantum mechanics, in this sense, both supplies, and is built upon, its own epistemology. At its essential core quantum mechanics is a theory of the mind-brain connection in which acquisition of knowledge is achieved without any direct action of the physical upon the mental. If none is added on, then one is left with a theory in which one never encounters the question of how, in a physical world from which all mind-like qualities have been stripped, a physical motion can create, or become, a thought.

As regards the general philosophical setting and scope of this paper, let it be noted that orthodox quantum mechanics accepts, as empirically given, the reality of mental events. The physically described universe that occurs in the theory began as merely a tool useful for understanding empirical correlations among the mental realities. However, the fantastic accuracy of the predictions of the theory suggests that this mathematical/theoretical construct, the quantum state, might be the image in our theory of an actually existing reality.

The present work represents an effort to explore that possibility; it is an effort to move rationally beyond quantum pragmatism to quantum ontology.

Such an exploration can go in many directions, and we must tread lightly on ground where solid empirical data is sparse. However, this paper focuses on an area where high-grade empirical data are abundant, namely the study of relationships between the minds and brains of living human beings.

2. The Conceptual Structure of Orthodox Quantum Mechanics: The Actions of Agents, and the Non-Substantive Nature of the Physical Structure Upon Which These Actions Act.

Quantum mechanics is formulated in a mathematical language. This gives it an operational precision that ordinary language cannot convey. Consequently, its structure can, in one sense, be accurately transmitted only by employing the appropriate formulas. However, describing the structure in a way that exploits the luminous operational clarity of the mathematical equations can tend to blind viewers to the underlying philosophical ideas, which are often unperceived, unappreciated, or suppressed. I shall endeavor here to highlight these ideas, not gloss over them.

Quantum mechanics arose from the efforts of scientists to resolve in a rational and useful way certain conflicts between the principles of classical physics and data from atomic physics. The key breakthrough was Heisenberg's discovery that in a mathematical model that seemed to capture the essence of the quantum features, the quantities x and v---which were supposed to represent the *numbers* that specified, respectively, the location and the velocity of a particle---did not commute: xv was different from vx! But every third-grader knows that the order in which the numbers appear in a product does not matter!

It had been known already for many years that, although it does not matter in which order one performs the actions of *multiplication by numbers*, there are other kinds of actions for which this order does matter. Rotations of a solid object about various axes provide a situation in which the order in which the actions are performed does matter. The replacement of the *numbers* occurring in classical physics by corresponding *actions* was the decisive step. These mathematical actions in the theory are closely related to the physical actions of performing measurements. Thus the replacement of numbers by actions brought crucially into the dynamics the actions of the agents who perform the measurements whose outcomes we observe. The epiphenomenal passive witnesses that constituted our images of ourselves in classical physics---and whose lack of effect upon the physical world has always been so puzzling---were thus replaced in quantum theory by agents who act upon the physically described aspects of nature in a specified way: the agent must first choose a probing action that he intends to perform, then participate in the execution of that action, and finally experience the resulting outcome.

An essential feature of the new picture is the fact that the known laws of the theory do not determine the agent's choice of probing action. In Bohr's words[4]: "The freedom of experimentation … corresponds to the free choice of experimental arrangement for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude." (p. 73); "…our possibilities of handling the measuring instruments allow us to make a choice between the different complementary types of phenomena that we want to study." (p. 51). Thus the theory incorporates, at its pragmatic core, the idea of probing actions that are not determined in any known way by the prior history of the physically described world, but that have, nevertheless, direct effects upon the subsequent course of physically described events.

The effect at the mathematically described physical level of this agent-initiated probing action is called "process 1" by von Neumann. This process specifies a physically defined *effect* whose *cause* is not specified by the quantum mechanical laws. The physical effect of this "freely chosen" probing action is to prepare the physically described system to receive from nature a response to the particular question posed by the probing action.

This picture is elucidated by the orthodox description of the application of quantum theory to scientific practice. According to this description, one must, in order to apply quantum mechanics, divide the physical universe into two parts by a "Heisenberg Cut." Below this cut are placed all those parts of the universe that are to be described in the theoretical language of the quantum mathematics. Above the cut are placed all parts of nature that are to be described in empirical terms---that is, in terms of possible experiences of the agents who are actively probing the part lying below the cut, and observing the outcomes of these probing actions.

Bohr emphasized that the boundary between the part of nature described in terms of empirical-experiential realities and the part described in terms of the theoretical-physical properties can be shifted, within limits. He cited the example of a blind man with a cane; when the cane is loosely held, the boundary between the part of nature experienced as self and the part conceived to be part of the physically described world lies at the interface between hand and cane; but when the cane is firmly held the experienced self extends out to the end of the cane. This variability in the placement of the boundary is allowable within a pragmatic interpretation (which the Copenhagen interpretation of Bohr certainly is) as long as the predictions, which reside in the experiential realm, remain unchanged.

Von Neumann's detailed and mathematically rigorous analysis of the process of measurement allowed him to remove this ambiguity in the positioning of the cut, by shifting into the physically described realm, step by step, all parts of the universe that are conceived to be composed of atomic particles and the physical fields associated with them, and leaving above the cut a residual experiential reality, called by him the "abstract ego".

The *need* in quantum mechanics for this elaborate conceptual structure stems from an important consequence of the conversion mentioned above of numbers to actions. This consequence is the Heisenberg uncertainly principle, which expresses the condition that---in sharp contrast to classical mechanics, where, at each instant of time, both the location and the velocity of every particle have a precise numerical value---in quantum mechanics *no* particle has at *any* time both a precisely defined location and a precisely defined velocity: every quantum state thus involves a smearing out of the values of these properties that in each basic state of classical physical theory are precisely defined.

The combination of this uncertainty principle with the quantum mechanical law of motion, which is a deterministic generalization of the deterministic classical law of motion, greatly expands the problem of the connection between the mentally described and the physically described aspects of nature. In classical mechanics the location and velocity of each particle is presumed to be well defined at some initial time. The law of motion then implies that these values will continue to be well defined at all later times. Thus the physical state is at later times no less describable in terms of possible experiences than it was at early times: there is no loss of experiencibility. But in quantum mechanics, even if one starts with a physical state that is completely compatible with all contemporary human experience, that state will generally evolve into a state consisting of a cloud of potentialities that overlap in such a way as to make the new state completely unintelligible in terms of human experience, *even statistically.* The quantum state of a sensible system generally evolves deterministically into a state of uninterpretable nonsense.

To rescue the situation, and to construct a theory useful in scientific practice, the founders of quantum mechanics brought the experimenter/observer into the dynamics in a particular way. The founders postulated that in order to tie the evolving quantum system to empirical findings, some particular *probing action* must first occur. The simplest form of such a probing action specifies, jointly, one conceivable possible experience and an *associated* physical action upon the existing quantum state. This physical action reduces that existing quantum state (i.e., density matrix) to a sum of two terms: a 'Yes' term that is associated with the specified possible experience and a 'No' term corresponding to the non-occurrence of that possible experience. The mathematics automatically assigns to each of these two alternatives, 'Yes' and 'No', a statistical weight such that the sum of these two weights is unity. Multiple-choice probing actions can be encompassed by repeatedly subdividing the 'No' possibility into a new 'Yes' and 'No'. The key issues are, then, the nature of this association between physical and mental aspects, and the way in which that association enters into the dynamics.

Because the quantum state is represented by a matrix, which has two sides, and the 'Yes' term corresponds to (yes, yes)---a yes condition on both sides---and similarly for the 'No' term, the probing action *reduces* the prior quantum state to a certain part of itself: the (yes, no) and (no, yes) parts are eliminated. This collapse, produced by the probing action, is followed by a *second* collapse, which further reduces the state to either the 'Yes' part or the 'No' part. The choice between the alternative possible responses, 'Yes' and 'No', to the process-1 probing action is called by Dirac "a choice on the part of nature". The prior choice of probing action is called by Heisenberg "a choice on the part of the experimenter".

These names for the two kinds of choices are appropriate for three reasons. The first is the fact that the choice of which experiment is performed is both experienced and spoken of as coming from the experimenter; from his reasons and motivations for performing this particular probing action.

The second reason is that in actual scientific practice one makes continual use of the fact that you, the experimenter, can exercise personal control over which experiment will be performed, whereas the outcome, according to quantum theory, is beyond the control of the experimenter. Nature, not the agent, chooses the response.

The third and more technical reason is that the process-1 action associated with the choice on the part of the *experimenter* is, by virtue of its mathematical structure, “local” in the sense that it has (in the relativistic formulation of the theory) no effect on any quantum mechanical predictions pertaining to observations made in regions that cannot be reached by traveling at the speed of light or less from the region of the probing action; whereas *nature’s* choice of response is “nonlocal” in that it *can* affect such predictions.

Thus there are in orthodox quantum mechanics two kinds of collapses, and they have very different characteristics. The preparatory process-1 reduction is needed to reduce the prior quantum state, whatever it is, to something intelligible. In the simple elementary case, this process-1 reduction is to a sum of two terms. The first ‘Yes’ term is associated with a specified possible experience that might occur in the stream of consciousness of the probing agent. The second term is associated with a null experience---i.e., with no experience in the stream of consciousness of the probing agent. Logically subsequent to this process-1 action there will be the follow-up ‘choice on the part of nature’. It will choose either the ‘Yes’ or the ‘No’ term, in compliance with the statistical weights prescribed by the theory.

The currently known laws provide no information about which probing action the probing agent will choose---no information about which of the possible experiences that conceivably might appear in agent’s stream of consciousness will actually be put forth to be either accepted or rejected by nature’s choice This leaves open the central question, to which we will return later, of what determines the choice of the probing action.

In summary, the situation is this: In classical mechanics the physically described world is conceived to be the fundamental, self-sufficient reality. A *rational* connection of this self-sufficient physical world to experiential realities is essentially unattainable, because there is no reason within the classical conception of physical reality for conscious thoughts to exist at all. Mental realities must simply be added *ad hoc*. But at least there is no outright contradiction between what is considered to physically exist, and what we perceive.

Yet classical physics is fundamentally wrong: it cannot accommodate the empirical facts. The replacement theory, quantum theory, may seem odd in several ways, but its most important and critical feature is this: the deterministically evolving quantum state of the universe would, if allowed to evolve unchecked, become unintelligible in perceptual terms. The place in nature of the physically described universe is therefore, according to the orthodox theory, changed from that of a *self-sufficient basic reality*---of a substance---to that of *a compendium of the information implanted into it by psycho-physical events of two kinds*: (1), purposeful probing actions, considered to be chosen and performed by mindful agents; and (2), responses to these probing actions, considered to be randomly chosen by "nature". Each probing action specifies, jointly, a particular set of alternative *possible* experiences, and for each of these possible experiences (or null experience in the case of 'No') an *associated action* that, if it were to be performed, would reduce the prior physical state to the part of itself that is *compatible* with that experience.

But only one of these possibilities is actualized. "Nature" makes the choice between the possibilities defined/created by the agent's probing action! Nature's response to this probing action is represented either by the entry into the mind of the probing agent of *one* of the possible experiences, conjunctively with the reduction of the prior quantum state to the part of itself that is compatible with this particular experience; or by the entry of *no* experience, and a reduction of the prior physical state to its 'No' part.

This is a general description of the sophisticated structure that allows orthodox quantum mechanics to make valid statistical predictions about correlations between experiences of human agents. The need for this special apparatus, described under the title "quantum theory of measurement" stems, as already emphasized, from the fact that the uncertainty principle, coupled with the deterministic law of motion, renders the quantum state generally unintelligible in terms of human experience. Intelligibility is achieved, according to the orthodox view, only with the aid of an active participation on the part of the *mental* aspect of the observer.

3. How Conscious Intent Can Cause Intended Bodily Action.

All of us run our lives on the regularly confirmed expectation that our conscious intentional effort will reliably produce, in connection with certain "mentally controllable" bodily actions, the intended experiential feedback. Our judicial system and social institutions rest on the idea that intentional mental effort, applied with sufficient will power, can normally override our mechanical tendencies, even though, from the perspective of classical physics, this capacity of mind must be deemed illusory, since according to that view all physical actions are totally under the control of mechanical processes.

As explained above, orthodox quantum mechanics says that the physically described world evolves in the physically deterministic way only *between* intrusions of top-down actions related to events in the minds of agents. These intrusions originate causally in our "free choices"---in choices that are not controlled by any currently known laws.

This arrangement provides a rational opening for conscious effort to be, *itself,* causally effective in controlling certain bodily actions. Consider some possible physical action, such as writing a big letter S" on the blackboard. Performing this single conceived action will require a temporally coordinated sequence of nerve signals to various muscles. It is plausible that there is some pattern of neurological activity that contains the sequencing information, and that will, if held in place for a sufficiently long period of time, cause the arm to move in the needed way. Let this pattern be called the "template for action S". The agent, by virtue of trial and effort learning, will have learned what mental intent, if sufficiently focused upon, will tend to produce this intended action. If conscious intent to perform this action can generate *a sufficiently rapid sequence* of probing actions whose process-1 'Yes' aspect is the actualization of this template for action, then by virtue of the quantum Zeno effect[5], the template for action can be held in place despite the normal dissipative physical tendencies, and the consciously intended bodily action will therefore tend to occur.

The mathematical details of this process have been described elsewhere.[1,3]
The reason for briefly mentioning it here is merely to bring forward this paradigmatic example of top-down influence of mental intent upon bodily actions that quantum mechanics so neatly explains, and thereby to rehabilitate the pervasive intuition that is the conceptual foundation of our purposeful lives, but that has been widely branded as an "illusion" by physicalist philosophers and scientists, namely the idea that mental effort can influence bodily behavior.

It is worth mentioning that the model discussed above, which involves holding in place by mental effort a "static" template for action, is easily generalized to one in which the mental intention is continuously evolving, in response to a more fluid dynamical context. The quantum Zeno effect is equally effective in this case in holding the physical state in the one specified by the evolving probing action. The mathematical details are given in reference 6.

4. A Purely Quantum Mechanical Ontology.

Compactly stated, the situation is this:

Orthodox quantum mechanics is based on the concept of mathematically described *physical states.* These states evolve in accordance with a deterministic law of motion, except at the times of the occurrences of *psycho-physical events.* In the original 'Copenhagen' interpretation, the physical states were considered to be the states of systems that were rather small on the human scale. But the analysis of the process of quantum measurement by John von Neumann allowed the concept of physical state to be extended to include the physical state of the universe. States of smaller systems, such as brains, can be extracted from the state of the universe, and an action upon a brain state is also an action upon the state of the universe.

The earlier physics, classical physics, had stemmed from a modification of the ideas of René Descartes. Descartes proposed that our understanding of nature be based on the notion that nature is divided into two realms, the mental and the physical, which interact only within (human) brains. The *physical* aspects are characterized, basically, by ascribing mathematical properties to points in the space-time continuum, whereas the *mental* aspects are supposed to be qualities of the kind that occur in our streams of conscious experiences; things like our thoughts, perceptions, memories, and feelings. Isaac Newton created the foundations of classical physics by proposing, in effect, that a full causal structure could be obtained by considering the physical aspects alone. He, or in any case his successors, assumed that our minds have no effects on the course of physical events: the physical realm was considered to be causally closed within itself.

That drastic assumption---which appears to be directly contradicted by the continually re-confirmed empirical evidence that our mental efforts can, under normal conditions, strongly influence our actions---was revoked by quantum mechanics. In order to accommodate the twentieth-century empirical data the founders of quantum mechanics brought the actions of human agents back into the dynamics in an explicit way, specified by the quantum theory of the measurement process.

Von Neumann's analysis of the process of measurement allowed the psychologically described mental aspects of the agent to be cleanly separated, conceptually, from the agent's physically described body and brain. His analysis allowed there to be, as with Descartes, a clean conceptual separation between the psychological and physical aspects of nature. The temporal evolution of the physical state is a deterministic process controlled exclusively by the physical aspects, except at certain moments when this smooth development is interrupted by an abrupt *psycho-physical event*. Each such event is either *a probing action* or *a response* to a probing action. Each elementary probing action is a Yes/No type query, and it is considered to be instigated by the mental aspect of an agent. The response, either 'Yes' or 'No', is considered to be selected by "Nature", in concordance with a statistical rule specified by the theory.

Each elementary probing action mandated by the quantum mechanical theory of the process of measurement and observation is associated with *a single specified possible experience*, which conceivably *might* occur in the mind of the probing agent. The physical aspect of the probing action is called "process 1" by von Neumann. It reduces the prior physical state of the brain of the agent to a sum of two parts: a 'Yes' part, and a 'No' part. The 'Yes' part is the part of the prior physical state of the brain that is *compatible with* the specified experience, whereas the complementary 'No' physical part is not associated with any experience.

Nature's response is imagined to be tied to some sort of random element. However, that element is not part of the physical world, as that world is represented in the theory. It is this *external random element* that Einstein alluded to when he said, by way of criticism of the orthodox theory, that "God doesn't play dice with the universe." Nature's choice, as it is understood from the orthodox point of view, is like picking out a marble in a completely unbiased way from a large collection of indistinguishable marbles, each of which, unbeknownst to the picker, has been assigned to one of the two options, 'Yes' or 'No'. Nature's choice is in this sense "top-down".

The same can be said of the agent's choice of probing action: the action is action by the *mind* of the agent upon the *brain* of the agent. No part of the orthodox quantum formalism explains why this choice is what is, except that Bohr's words "free choice" and "a choice between" do give an impression that the choice is not fixed by a mechanical process. Nevertheless, one may easily fall prey to classical thinking, and unreflectively accept the prevailing opinion that a physical brain process must produce the choice, despite the fact that quantum mechanics neither requires this, nor in any way suggests it.

What is certainly true is that the top-down choice of probing action *does link together* the specified possible mental event and an associated process-1 physical action. Nature's logically subsequent top-down choice between 'Yes' and 'No' then either actualizes this possible mental event *in conjunction with the linked physical action*, or, alternatively, produces no mental event at all. In the case of a 'Yes' response, a *correlation* between mind and brain is thus created, without there being any direct action of brain upon mind.

This reversal of the direction of the causation, from bottom-up to top-down, constitutes an enormous theoretical boon: it relieves us of the need to explain how a physically described brain could produce something so completely unlike itself as a mental event. Each mental element is now conceived to be created, not by a brain process, but rather by a mental process that, acting from within a mental realm, can instigate a probing action and receive back a response that provides it with knowledge about the physical properties of the system that it is probing. Thus we are led, via von Neumann's analysis of the measurement process, to the idea of two dynamical realms, a mental realm described in psychological terms, and a physical realm described in physical terms, with the interactions between these two realms being limited to the two kinds of top-down interactions that constitute, together, the fundamental process of quantum measurement. This quantum measurement process is specifically designed to account, within the conceptual framework of quantum mechanics, for the acquisition by the probing agent of *knowledge* about the physical properties of the physical system that it is probing.

In view of this great achievement of quantum mechanics---namely the accounting, in a rationally coherent way, for the observed correlations between mind and brain---it becomes completely reasonable, from a scientific perspective, to accept the solution of the mind-brain problem offered by quantum mechanics, rather than clinging to the extremely problematic concepts based on an early physical theory that is not only now known to be false, but that, moreover, *rules out* the existence of the efficacious top-down connections that are central to the orthodox quantum mechanical understanding of the dynamics of the mind-brain connection.

The "top" in these top-down connections are of two kinds. For nature's response the "top" represents a choice that generally has global physical consequences. For a von Neumann process-1 action the "top" is described in mental terms, and is prima facie *mental* in character. In actual scientific practice the origin of the choices of the process-1 actions are considered to arise from the scientist's mentality: from his reasons, motives, and aims. There is no suggestion, within the theory, that these choices arise as consequences of the deterministic laws that are the quantum analogues of the deterministic laws of classical physics. Indeed, they definitely do not arise from these laws, but supply inputs (determinations) that go beyond what these deterministic laws supply: they partially specify collapses of the states generated from earlier conditions by these laws. There is no rational basis within quantum theory for assuming or postulating that these top-down process-1 actions really stem from, or are determined by, the physically described aspects. With respect to the process-1 actions, the "top" means, at least within the structure of the theory, *basically mental*!

This mental realm might contain incipient thoughts that never rise to the level of a consciously remembered thought: the mental realm could include subconscious or unconscious aspects that are mental in nature but not consciously remembered. A person's stream of consciousness could be held together not directly by the physical brain, as classical physics would have it, but rather by what William James calls the "fantastic laws of clinging" that cause associated thoughts to hang together. A mental dynamics is suggested that associates thoughts with other thoughts, and that can, under certain circumstances, act upon appropriately structured physical systems. From this quantum perspective, the causal structure of the mind-brain connection that is tacked ad hoc onto classical mechanics---which itself leaves mental aspects completely out---is essentially upside down.

A basic underlying issue, now, is memory: how are our memories, beyond those of the "specious present", stored? How are my memories of what I was experiencing yesterday, when I went out to dinner with an old friend, stored? Are they stored directly as mental things that can be recalled *as such*, or are they stored as something of a different order---stored in physical brain traces that can later somehow call forth, from that non-mental realm, mental reproductions of the mental originals?

A priori, either option is possible. But, given the world view of classical physics, the answer is clearly that retention is accomplished by the formation of brain traces! Classically, all causation is understood to be carried forward basically by the physical properties, with any mental sidebar being a mysteriously parallel supernumerary.

But if the precepts of quantum physics apply then the argument goes the other way. In orthodox quantum mechanics the brain is the *recipient* of the known actions, not the instigator, so if these top-down actions are doing the job then the retention should be in the mental realm, in order that the retained information can affect later bodily behavior.

This leads to the idea that mental happenings are retained in mental form, ready to become, in the context of an ongoing mental process, parts of a later mental event, instead of being reduced purely to brain traces, and then later, upon recall, being created anew as reconstituted mental realities.

According to this view, each agent's mental structure is an evolving mental reality that carries a full memory structure. This mental structure is controlling, via top-down actions, the agent's bodily actions in the way discussed in the preceding section. This mental structure is continually probing the (awake or sleeping) brain for tiny clues that can alert it to the fact that something of interest might be going on. That is, it is postulated that, in addition to all of the probing actions that are being directly instigated by the ever-changing flux of ideas that are at the forefront of the agent's conscious mental life, there is an ever-active (unconscious) monitoring activity: a collection of probing actions such as "Has there been a sudden change in noise level?" "In pain signals?" "In pangs of hunger?" "In visual brightness?" The existence of such a continual monitoring process is needed to alert the intelligent process to physical happenings that require more detailed attention.

According to this quantum mechanical model, the *causal origins* of the choices of upcoming probing actions *lie in a mental realm*, not in the physically described brain.

We all know how fast things can be sorted out by twenty highly intelligent questions! My presumption, here, is that the mental realm has developed a probing strategy that produces acquisition of knowledge sufficient to account for the knowledge that we actually do acquire, via our probing actions, about physical properties.

According to this view, the complex physical structure of the quantum-mechanically-described brain contributes what such a physical structure can provide, when acting in full compliance with the laws of quantum physics, and hence responding both to all of the physical input from its physical past. coming via the Schroedinger-equation-controlled deterministic process, and also to the inputs from the mental realm. This melding of the mental and physical aspects of nature is achieved in just the way specified by the quantum theory of measurement.

What is being suggested here, therefore, is a shift of the science-based conception of "self" to one that is in essential accord with our human intuition of what we are. This conception is profoundly different from the classical-physics-based conception, which appears, from the more accurate quantum perspective, to be causally-upside-down.

It is worth emphasizing that the correspondence between mental events and their neural correlates need not be injected by primal fiat. It can be established by trial and error learning! Whether we are performing a physical action or experiencing a perception, the situation is essentially the same. The human psyche is able to exert a host of efforts, but at birth the mind knows not which effort corresponds to which feedback. Yet with trial and error experience the mind can come to recognize that certain efforts, if they produce any feedback at all, produce always essentially the same feedback. Thus no pre-ordained correspondence is needed between the 'feeling of effort that elicits a physical probing action' and the 'possible acquisition of knowledge' that this action generates. Trial and error learning of this kind depends upon the fact that the causal connection is top-down: the free input variable is the mental intent!

This quantum approach allow us to escape the materialism entailed by classical physics without flipping over to idealism: the reconciliation of the psychological and the physical is achieved in the precisely way specified by the quantum theory of measurement, which is a rational construct expressly designed to allow our minds to acquire *knowledge* of physical properties in rational accord with both the known laws of physics, and scientific actual practice.

A certain prevailing confidence among neuroscientists that quantum effects can be ignored in the context of the mind-brain problem has been bolstered by a paper in Nature[7] by Christof Koch and Klaus Hepp, who argue that quantum considerations are not pertinent to this issue. Their argument was, however, directed essentially at the particulars of the approach pursued by Penrose and Hameroff, which depends critically upon the maintenance of long-range quantum coherence in thinking brains. The present work carefully avoids any implicit or explicit use of such effects. The Koch-Hepp arguments have, consequently, no bearing on the application of the more fundamental features of quantum mechanics under consideration here.[8]

Science seeks empirical evidence to decide between theories. But, as noted by Sir Karl Popper, the classical materialist position is probably unfalsifiable, due to its promissory character: explanations of the data are claimed to be consequences of some yet-to-be-discovered solution to the mystery of the workings of the bottom-up mind-brain connection. Yet this mystery need have a no solution, for it arises within the context of a theory that is known to be false. So the materialist position remains perpetually viable because the addition that is needed to complete, namely a rational explanation of how physical motions become conscious thoughts, it is something that does not exist.

The advance from classical mechanics to quantum mechanics rests on a theory of measurement and observation that, according to the analysis by von Neumann, constitutes a radical restructuring of the science-based conception of the mind-brain connection. This radical restructuring is all about *fixing the problems raised by Newton's severance of the mind-brain connection postulated by Descartes.*

The final science-based theory of the mind-brain connection must, of course, be reconciled with the profound changes wrought by the shift from empirically inadequate classical theory to empirically adequate quantum theory. This shift is erected upon the uncertainty principle, which, by breaking the rationally closed physically deterministic conception imposed by the classical approximation, opens the way to a rationally coherent conception of an interactive mind-brain connection. In view of the generally acknowledged failure of the three-century effort to rationally understand the mind-brain connection within the framework of the classical approximation, it should, I think, be evident to all that the more rational science-based approach to this problem should be based upon the empirically validated quantum mechanical conception that naturally incorporates mind, rather than upon the invalidated classical approximation that, as a matter of principle, leaves mind out.

The task of science is to connect empirical evidence to theoretical ideas. Thus an adequate theoretical framework needs to have a place for the human experiences that constitute the primary empirical data, and it must provide an understanding of how these experiences are connected to the physical aspects of the theory. Quantum mechanics does both: classical mechanics does neither, and is, consequently, an incomplete theory: it needs to be augmented by a theory that connects the physical aspects that it purports to describe by a yet-to-be-invented theory that specifies how the physical and mental aspects of nature are connected to each other.

Quantum mechanics fills this need not by simply adding some specified superstructure to a rationally complete physical base. Instead, it fills this need by exploiting the uncertainty principle, which opens a 'causal gap' that allows the physical and mental aspects of nature to hang together in a rationally coherent way.

What is called for, ideally, is a theory that incorporates in a rationally coherent way *all* of the empirical successes of classical physics, yet provides both the room for, *and a need for*, mental realities. Orthodox quantum mechanics meets these requirements. The opposing idea that one can erect a rationally coherent understanding of the mind-brain connection upon a classical theory that enforces a known-to-be-false determinist principle that eliminate both the rational need for mind to exist, and the possibility that it can actually do anything not already done by the physical aspects, must be regarded, from a well-informed rational point of view, as highly unlikely to succeed.

All arguments in favor of "materialism" based either on the demand that the theory be compatible with the basic laws of physics, or upon demonstrations of the adequacy of mechanical explanations of various empirical findings, are actually arguments in favor of the proposed quantum ontology. For that ontology is in complete accord with the basic laws of physics, insofar as they are known today, and conforms to the classical mechanical ideas insofar as the uncertainty effects are small, whereas any "materialist" explanation based on classical physics violates the known laws of physics, and violates them in a way that eliminates the quantum uncertainty principle, which is precisely the physical principle that allow us to be endowed with capacities beyond those possible for the mechanical automata that pre-twentieth-century science proclaimed us to be.

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[Response to Koch and Hepp.
Not published by Nature on numerous “policy” grounds.]
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