QUANTUM MECHANICAL THEORIES OF CONSCIOUSNESS

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Abstract

Quantum mechanical theories of conscious are contrasted to classical ones. A key difference is that the quantum laws are fundamentally psychophysical and hence can provide a dynamical explanation of the causal effect of conscious effort on neural processes, while the law of classical physics, being purely physical, cannot. The quantum approach explains detailed findings in psychology, and impacts on neuroscience.

Introduction

Isaac Newton initiated in the seventeenth century an approach to understanding nature that, with important contributions from Clerk Maxwell and Albert Einstein, developed into what is called classical mechanics. That theory is now known to be fundamentally incorrect. It was replaced around 1926 by a profoundly different theory called quantum mechanics. A principal conceptual difference between classical mechanics and its quantum successor is that the former is exclusively physical whereas the latter is essentially psychophysical. In particular, classical mechanics is theory of a material physical world conceived to be completely specified by numbers assigned to points in space and time, and to be, moreover, dynamically complete, in the sense that the behavior of these numbers for all times is completely specified by laws and initial conditions that involve only these numbers themselves. Contrastingly, orthodox quantum mechanics brings into the dynamics certain experiential elements that can have large causal effects in the physical world yet are not entailed by currently known laws of physics.

This entry of causally efficacious conscious experiences into contemporary physics has led some quantum physicists to believe that an adequate scientific theory consciousness must be quantum mechanical. This view has been challenged by some nonphysicists, who argue that quantum theory deals with microscopic atomic-level processes whereas consciousness is associated with macroscopic neuronal processes, and that the concepts of classical physics provide an adequate understanding of such macroscopic systems.

That argument is not valid. Quantum mechanics deals with the observed *macroscopic* behaviors of systems, in cases where those behaviors depend sensitively upon the properties of the atomic-level constituents of the physically described aspects of the world. Brains are such systems: their behaviors depend strongly upon the effects of, for example, the ions that flow into nerve terminals. Computations show that the quantum uncertainties in the ion-induced release of neurotransmitter molecules at the nerve terminals are large (Stapp, 1993, p.133, 152). These uncertainties propagate in principle up to the macroscopic level. But then the psychophysical laws of quantum physics can come into play, and produce dynamical effects of mental effort on brain behavior.

No comparable derivation from the principles of classical physics is possible because, in the first place, no occurrence of any psychologically described reality is *entailed* by the dynamically complete classical laws. Hence there is no possibility of *actually deducing* anything pertaining to conscious experiences from the laws of classical physics. In the second place, classical mechanics is an *approximation* to quantum physics, and in this approximation the cloudlike domains of physical uncertainty *within which the quantum causal effects of mental effort operate* shrink down to classical-type trajectories of zero uncertainty, rendering conscious effort necessarily devoid of those causal effects that the unapproximated theory can entail.

The entry into quantum dynamics of experiential elements, and in particular of our conscious choices, is rendered possible by the effective elimination from quantum mechanics of the classical concept of material substance. Quantum theory retains the core feature of classical physics, namely a structure of mathematical quantities assigned to points in space and time. But the dynamical role and behavior of this structure is greatly altered. The mathematical structure represents no longer a classically conceived material universe but rather an *informational structure* that represents the *knowledge* associated with psychophysical events that have already occurred, and also *objective tendencies* (propensities) for the occurrence of future possible psychophysical events. This conceptual revision is heralded by the famous pronouncement of Heisenberg (1958):

> The conception of 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 particles but rather our knowledge of this behavior.

The aim of this chapter is to explain briefly, in plain words, how this enormous change came about, how it works, and how this altered conception of the role of consciousness in physics impacts on psychology and neuroscience.

Copenhagen quantum mechanics

Quantum mechanics was initiated by a discovery made by Max Planck in 1900. Planck was studying the distribution over frequencies of the radiant energy emitted from a tiny hole in hollow container. Classical physics gave clear predictions about the dependence of this energy distribution upon the temperature of the container, but those predictions did not match the empirical facts.

Planck found that the empirical data could be accounted for if he assumed that the radiant energy associated with each given frequency was concentrated in units, or quanta, with the amount of energy in a unit being directly proportional to the frequency of the radiation that carried it. The constant of proportionality was measured by Planck, and is called Planck's constant.

This discovery was followed by a flood of empirical data that tested various predictions of classical physics that depended sensitively on the classical conception of such things as electrons and electro-magnetic radiation. The data revealed fascinating mathematical structures, which seemed to involve Planck's constant, but, like Planck's data, was essentially incompatible with the classical materialist conception of the world.

Many of the best mathematicians of the generation, men such as Hilbert, Jordan, Weyl, von Neumann, Born, Einstein, Sommerfeld, and Pauli, struggled to unravel this mystery, but it was not until 1925 that the key step was made. Heisenberg found that correct predictions could be obtained if one transformed classical mechanics into a new theory by a certain "quantization" procedure. This procedure replaced the *numbers* that specified the structure of the classically conceived material universe by *actions*. Actions differ from numbers in that the ordering of numerical factors does not matter---2 times 3 is the same as 3 times 2---whereas the order in which two actions are applied can matter.

This replacement of numbers by actions is the mathematical foundation of quantum mechanics. But an adequate physical theory requires more than just mathematical rules. It requires also a conceptual framework that allows certain mathematical statements to be tied to human experiences. In classical mechanics the interpretive framework that ties the mathematics to experience does not disturb the mathematics. It *envelopes* the mathematical structure *but does not affect it*. The basic idea of the classically conceived connection between the physically and psychologically described aspects of nature is a carry-over from the planetary dynamics that was the origin of classical mechanics: the locations of the centers of objects are regarded as being directly experiencable, without producing any effects on those objects. But in quantum mechanics the numbers that in classical mechanics represent, for example, the location of a material object are replaced by actions. These actions are associated with *the process of acquiring information* or knowledge pertaining to the location of that object, and this action normally affects the state that is being probed. Thus the act of acquiring knowledge about the object becomes enmeshed in a non-classical way with the state of the object being examined.

This elimination of the numbers that were imagined to specify the physical state of the material world, and their replacement by actions associated with the acquisition of knowledge, raises huge philosophical difficulties. The needed conceptual adjustments were worked out principally by Bohr, Heisenberg, Pauli, and Born. The center of this activity was Bohr's institute in Copenhagen, and the conceptual framework created by these physicists is called The Copenhagen Interpretation.

A key feature of the new philosophy is described by Bohr:

> In our description of nature the purpose is not to disclose the real essence of phenomena but only to track down as far as possible relations between the multifold aspects of our experience. (Bohr, 1934, p.18)

> ...the appropriate physical interpretation of the symbolic quantum mechanical formalism amounts only to prediction of determinate or statistical character, pertaining to individual phenomena appearing under conditions defined by classical physics concepts. (Bohr, 1958, p.64).

The references to `"classical physics concepts" is explained as follows:

> ...it is imperative to realize that in every account of physical experience one must describe both experimental conditions and observations by the same means of communication as the one used in classical physics. (Bohr, 1958, p.88),

> The decisive point is to recognize that the description of the experimental arrangement and the recording of observations must be given in plain language suitably refined by the usual physical terminology. This is a simple logical demand since by the word "experiment" we can only mean a procedure regarding which we are able to communicate to others what we have done and what we have learnt (Bohr, 1958, p 3)

Bohr is saying that scientists do in fact use, and must use, the concepts of classical physics in communicating to their colleagues the specifications on how the experiment is to be set up, and what will constitute a certain type of outcome. He in no way claims or admits that there is an actual reality out there that conforms to the precepts of classical physics.

But how can one use jointly and consistently these two mutually inconsistent mathematical structures? This is the problem that the Copenhagen Interpretation solves, at least for all practical purposes.

The Copenhagen solution is to divide nature into two parts. One part is the observing system, including the bodies, brains, and minds of the human beings that are setting up the experimental situations and acquiring, via the experiential feedbacks, increments in knowledge. This observing part includes also the measuring devices. This observing system is described in ordinary language refined by the concepts of classical physics. Thus the agent can say "I placed the measuring device in the center of the room, and one minute later I saw the pointer swing to the right." The agent's description is a description of what he does---of what probing actions he takes---and of the experienced consequences of his actions.

The other part of nature is the system being probed by the classically conceived and described observing system. This probed system is described in the symbolic language of quantum mathematics.

In classical physics the classical concepts are asserted to be applicable in principle right down to the atomic level, but according to the quantum precepts the quantum mathematical description must be used where ever the classical approximation is not justified.

The separation between the two parts of nature is called the Heisenberg cut. Above the cut one uses experience-based classical descriptions, while below the cut one uses the quantum mathematical description.

The cut can be moved from below a measuring device to above it. This generates two *parallel descriptions* of this device, one classical and the other quantum mechanical. The quantum description is roughly a continuous smear of classical-type states. The postulated theoretical correspondence, roughly, is that the smeared out mathematical quantum state specifies the *statistical weights* of the various alternative possible classically described experiencable states. The predictions of the theory thereby become, in general, statistical predictions about possible experiences described in the conceptual framework of classical physics.

There is, however, a fly in the ointment. In order to extract statistical predictions pertaining to possible experiences, a specific kind of question must be physically posed. The question must have a *countable* set of experientially distinct alternative possible answers. "Countable" means that the answers can be placed in one-to-one correspondence with the whole numbers 1, 2, 3, ….or with some finite subset of these numbers. But the number of possible classically describable possibilities is not countable: there is a continuous infinity of such possibilities. Yet before any statistical consequence can be drawn from the theory, some definite question with a countable set of empirically distinct alternative possible answers must be physically posed.

The mathematical structure of the theory does not specify what this question is, or even put statistical constraints on what it might be. Thus the mathematical theory is dynamically incomplete on three counts: it fails to specify which question will be posed, when it will be posed, and which answer will then appear. The theory does assign a statistical weight (probability) to each of the alternative possible answers to the physically posed question.

Von Neumann emphasized the need for the process of posing a particular question by calling it Process 1, and distinguishing it from the very different

Process 2, which is the mathematically specified evolution of the quantum state in accordance with the rules specified by the quantization procedure.

How does orthodox Copenhagen quantum theory resolve this basis problem?

It resolves it by adopting a pragmatic stance. Copenhagen quantum theory is regarded as a procedure that provides predictions about the likely classically describable experiential consequences of the alternative possible probing actions that experimenters can choose to institute. Within that pragmatic framework the human agent is free to choose which experiment (probing action) he or she will perform. Thus it is normally a consciously chosen action by an experimenter/agent that resolves the basis problem.

This resolution of the basis problem has the effect of allowing our conscious choices to be causally efficacious in the physically described world Our conscious choice of how we will act---which question we will pose---determines *the set of possible experiential feedbacks*. Under certain circumstances, which will be described later, a person's conscious choices about which questions to pose, and when to pose them, can, *by virtue of the quantum laws themselves,* strongly influence the behavior of the system being probed!

Bohr often emphasized this crucial element of freedom:

> 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, p.73).
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> "To my mind there is no other alternative than to admit in this field of experience, we are dealing with individual phenomena and that 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. (Bohr, 1958, p. 51).

These quotes highlight the fact that Process 1 is determined within the framework of contemporary physics not by the known mathematical laws but rather by a free choice made by a conscious agent.

Von Neumann's Extension

Von Neumann first expressed Copenhagen quantum mechanics in a mathematically rigorous form, and then showed that the Heisenberg cut could be pushed all the way up, so that the bodies and brains of the agents are treated quantum mechanically. This placement of the cut does not eliminate the need for Process1. It merely places the physical aspect of the Process 1 psychophysical event in the brain of the conscious agent. The psychologically described aspect, identified as the conscious choice, is still needed to specify Process 1. The carrier of this psychological element is called by von Neumann (1955, p. 421) the "abstract ego".

Bohr emphasized that the laws of quantum theory should continue to be valid in biological systems, but that the latitude introduced by the severe constraints upon observation imposed by the demands of sustaining life could permit such concepts such as "teleology" and "volition" to come *consistently* into play. (Bohr, 1958, p.10, p.22)

It should be noted that quantum theory does not *explain why conscious exists*. It accepts that we human beings are conscious, and then creates a conceptual framework that links our conscious thoughts in a scientifically useful way to a mathematical generalization of classical physics.

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Psychophysical events

In classical physics the universe, and every subsystem of it, evolves continuously. In quantum theory the analogous evolutions are *usually* continuous, and specified by Process 2, which is the "quantized" version of the laws of motion of classical physics. But according to orthodox von Neumann quantum theory this continuous mechanically controlled evolution is occasionally interrupted by a Process 1 event. Each Process 1 event has two coordinated aspects. One describes a conscious experience; the other describes an associated change in a physical state. The conscious experience is a choice to act in a way that is intended to bring into being intended experiential feedbacks. For example, an experimenter may choose to first set a Polaroid lens at a certain angle and then attend to the visual sensation that results from looking through the lens at the source of a photon that will soon be emitted. If he experiences the expected confirmation about the setting, then whether he experiences or not a visual sensation as he looks at the source through the lens will give him a new bit of knowledge about the photon, about his brain, and about the content of his stream of consciousness. Von Neumann showed how it is

> …possible to describe the extra-physical process of subjective perception as if it were in reality in the physical world---i.e., to assign to its parts equivalent physical processes in the physical world. (Von Neumann, 1955, p.419)

For example, choosing to set the lens in a certain way, and then to attend to the visual sensation, will probably be followed by an experience of the lens being set in place, and then, perhaps, by the visual sensation of "seeing the photon". Within this context the visual sensation is *equivalent*, for the purposes of computing probabilities, to a certain mathematical *action* on the quantum state of the photon, or, equivalently, on the quantum state of the agent's brain. A theoretical equivalence is thereby established, *within the quantum theoretical* *framework*, between the visual sensation of seeing the photon and an associated physical action that brings into existence a certain state of the photon or, equivalently, that brings into being *the neural correlate of the visual experience of seeing the photon*. The empirical predictions of the pragmatic theory are based squarely on these psychophysical events.

The main differences between the quantum treatment and the analogous classical treatments are, first, that the “extra-physical process of subjective perception”, with its image in the mathematical/physical description, are core parts of quantum theoretical structure; and, second, that the quantum dynamics features a process, Process 1, that enters importantly into the dynamics, but is not selected or caused by any yet-known law.

In contemporary quantum physics the choices of which probing actions to make, and when to make them, are, as just emphasized, not specified by the known laws of nature. They are treated as “free variables”, controlled by conscious choices made by agents. Although these choices are not determined by the quantum laws, they do exert upon the brain of the agent effects that are determined by the quantum laws. The situation is thus just the reverse of the one in classical physics, where it is generally assumed that the psychological happening is somehow determined by the brain state---presumably by some extra psychophysical law that supplements the usual physical ones---but that this psychological reality exerts no influence back upon the brain, whose behavior is already completely determined by the physically described variables acting in accordance with the usual physical laws

The fact that the conscious choices are not determined by the known laws yet can influence neural processing opens the way to an understanding of the apparent power of mental volitional effort to control brain, hence bodily processes. If one postulates that the rapidity with which probing actions take place can be increased by conscious effort then the dynamical effect of conscious effort will, if sufficiently strong, be to *hold in place, against the mechanical effects of Process 2*, the neural correlate of the idea of the intended feedback.

This quantum effect is an application at the level of the brain of the well known quantum Zeno effect, which is a theoretically well, understood and well verified consequence of quantum theory. (Misra, 1977: Itano, !990) Quantum theory is able, therefore, to give to conscious choices both freedom from mechanical coercion and yet a capacity to influence neural behavior in a way that tends to bring intended experiences into the stream of consciousness. The details are described in Stapp (1999, 2001) and in Schwartz, Stapp, and Beauregard (2003, 2004).

Comparison to psychological findings

The dynamical effect of the volition-induced high rapidity of the Process 1 probing actions is exactly in line with the description of the effects of volition described by William James (1892). In the section entitled *Volitional effort is effort of attention* he 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. (p, 417)
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> The essential achievement of will, in short, when it is most 'voluntary,' is to attend to a difficult object and hold it fast before the mind. (p.417).
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> Everywhere, then, the function of effort is the same: to keep affirming and adopting the thought which, if left to itself, would slip away. (p.421)

James apparently foresaw, on the basis of his efforts to understand the mind-brain connection, the implied eventual downfall of classical mechanics. He closed his book with the prophetic words

> …and never forget that the natural-science assumptions with which we started are provisional and revisable things. (p.433)

A lot has happened in psychology since the time of William James, but these developments support James's idea of the holding-attention-in-place action of volition. Much of the recent empirical and theoretical work pertaining to attention is summarized in Harold Pashler's book *The Psychology of Attention* (Pashler, 1998). Pashler concluded that the evidence indicates the existence of two distinct kinds of mental processes, one that appears not to involve volition, and that allows several perceptual processes to proceed in parallel without significant interference, and one that does involve volition and that includes planning and memory storage. This latter process seems to involve a linear queuing effect with limited total capacity. The properties of the volition-driven process appear to be completely in line with the idea that volition is associated with a linear sequence of Process 1 events that can hold in place, by means of the quantum Zeno effect, the pattern of neural activity that will tend to bring into being the intended effects. This details of how this works are spelled out in the references cited at the end of the preceding section.

Impact on Neuroscience

An application in neuroscience is to the work of Ochsner et.al. (2001) on the cognitive control of emotion. Subjects are trained how to cognitively re-evalutea emotional scenes. When they then consciously choose to cognitively re-evaluate emotion-laden visual scenes that they are viewing the activity of their brains as determined by fMRI measurements shifts from limbic to prefrontal. The influence of volitional conscious choices on brain activity is thus empirically exhibited.

How does a shift to a quantum mechanical theory of consciousness impact upon scientific practice pertaining to experiments of this kind?

Within a classical approach the conscious choices are incidental to the causal chain. Hence a causal description would involve a causal connection between *the physical causes of the feeling* of conscious effort and the seeming effect of that effort. But quantum considerations suggest that when difficult choices are involved the quantum uncertainties will block *in principle* any causal explanation of that kind. It suggests an alternative approach in which the conscious choices to apply effort are treated as free variables, the only allowed effect of which is to hold in place the neural correlate of the effort, which is the pattern of neural activity that if held in place long enough will tend to bring into being, eventually, the intended experiential feedback.

The classical and quantum approaches thus involve fundamentally different understandings of the causal underpinnings of mind-brain behavior, and hence lead to different research programs to test and fill in the details of the competing models.

The only objections to this quantum approach to mind-brain dynamics that I know of are the claims of some nonphysicists that the principles of classical physics are completely adequate for an understanding of the mind-brain connection, in spite of their being fundamentally false, and independent of mind, and the somewhat similar contention of some physicists that the pragmatic approach should be replaced by an ontological one in which consciousness plays no causative role. Neither of these objections claim an actual *error* in the pragmatic quantum approach. Both claim, rather, the superiority of an alternative approach in which our thoughts have no influence on physical activity, and purely physical determinism prevails. Orthodox contemporary quantum theory provides a rational physics-based foundation for the opposing view that mind really matters.

There are several alternative quantum theories of consciousness, but all of them start with von Neumann's work. The considerations described above rest completely on the basic von Neumann framework. I describe next some proposals that introduce some more controversial and unconventional ideas.

The Penrose-Hameroff Theory

Roger Penrose and Stuart Hameroff (Hameroff & Penrose, 1996) have proposed a quantum theory of consciousness that brings together three exciting but controversial ideas. The first pertains to the still-to-be-worked-out quantum theory of gravity. The second involves the famous incompleteness theorem of Gödel. The third rests upon the fairly recently discovered microtubular structure of neurons.

Penrose proposes that the abrupt changes of the quantum state that are associated with conscious experiences are generated by the qravitational effects of particles of the brain upon the structure of space-time in the vicinity of the brain. Ordinarily one would think that the effects of gravity *within the brain* would be too minuscule to have any significant effect on the functioning of the brain. But Penrose and Hameroff come up with an estimate of typical times associated with the gravitational effects that are in the tenth of a second range associated with conscious experiences. This fuels the speculation that the abrupt changes in the quantum state that occur in quantum theory are caused not by the entry of thoughts into brain dynamics, but by quantum effects of gravity.

But then why should thoughts or consciousness be involved at all?

Two reasons are given. Penrose uses Gödel's incompleteness theorem to argue that mental processing cannot be wholly mechanical or algorithmic. The argument takes hundreds of pages (Penrose, 1986, 1994) and has been attacked by many qualified critics. (e.g., Putnam, 1994). It is fair to say that it has not passed the usual demands made upon mathematical and logical arguments. But the argument claims that both mental processing and the gravitational effects are non-algorithmic, and that the latter could therefore provide in a natural way the non-algorithmic element needed for the former

The second connection of the proposed gravitational effect with consciousness is that the estimated time associated with the gravitational effect was based on the presumption that the components of the brain critical to consciousness were functioning microtubules. Data pertaining to loss of consciousness under the influence of various anesthetic agents indicate that the proper functioning of microtubules is necessary for consciousness. But many things are *necessary* for consciousness, so this argument that the gravitational effect is connected consciousness via microtubules is not compelling. *.*

A serious objection to the Penrose-Hameroff theory has been raised by Max Tegmark (2000) The Penrose-Hameroff theory requires that the critical microtubular state be a *coherent* quantum state that extends over a macroscopic region in the brain. Normally one expects any macroscopic coherence of a quantum state in a warm wet brain to be destroyed almost immediately. Tegmark estimates the duration of coherence to be on the order of 10^{-13} seconds, which is far smaller than the one tenth of a second associated with consciousness. Hagen, Hameroff, and Tuszynski (2002). have claimed that Tegmark's assumptions should be amended, so that the decohence time becomes 10^{-4} seconds, and they suggest that the needed factor of a thousand can be made up by biological factors. In any case, the need to maintain macroscopic quantum cohererence in a warm wet brain is certainly a serious problem for the Penrose-Hameroff model.

It might be mentioned here that in the von Neumann model described in the preceding sections quantum decoherence is an important *asset,* because it allows the quantum state of the brain to be understood as essentially a smeared out statistical ensemble (i.e., collection) of essentially classically conceived states, which, however, can interact with neighboring members of the ensemble in a way that preserves the quantum Zeno effect. This quasi-classical conceptualization of the quantum state of the brain allows non-physicists to have a relatively simple understanding of the mind-brain system.

The Eccles-Beck approach

An early quantum approach to the mind-brain problem was made by John Eccles (1990) who emphasized the entry of quantum effects into brain dynamics in connection with effects at nerve terminals. However, instead of building directly on the quantum rules and the profound conceptual relationships between quantum and classical mechanics he introduced a conscious biasing of the quantum statistical rules. This actually contradicts the quantum rules, thereby upsetting the logical coherency of the whole scheme. In a later work with Beck (2003) he retained the quantum rules, while introducing quantum uncertainties at the nerve terminals that can play the same role that they do in the standard approach described earlier. This brings the model into accord with the standard model described above, in regard to this technical point. However, Eccles added a superstructure involving conscious "souls" that can exist apart from physical brains. That suggestion goes beyond the ideas described here.

Other Theories

Several quantum theories of consciousness have been proposed. All are outgrowths of von Neumann's formulation. The differences in these proposals are mainly at the level of technical physics. I have focused here on the over-riding general issues of why quantum theory should be relevant to consciousness in the first place, and how the switch to quantum physics impacts upon the question---important in neuroscience, psychology, and philosophy---of the neural effects of volitional effort.

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