Whiteheadian Process and Quantum Theory

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Introduction

Quantum theory has been formulated in several different ways. The original version was 'Copenhagen' quantum theory, which was formulated as a practical set of rules for making predictions about what we human observers would observe under certain well-defined sets of conditions. However, the human observers themselves were excluded from the system, in much the same way that Descartes excluded human beings from the part of the world governed by the natural physical laws.

This exclusion of human beings from the world governed by the physical laws is an awkward feature of Copenhagen quantum theory that is fixed by "Orthodox" quantum theory, which is the form devised by von Neumann and Wigner. This orthodox form treats the entire world as a quantum system, including the brains and bodies of human beings. Some more recent formulation of quantum theory seek to exclude from the theory all reference to the experiences of human observers, but I do not consider them, both because of their technical deficiencies, and because they are constitutionally unequipped to deal adequately with the causal efficacy of our conscious thoughts.[1]

The observer plays a central role in both Copenhagen and Orthodox quantum theory. In this connection, Bohr, describing the 1927 Solvay conference, noted that:

> "…an interesting discussion arose about how to speak of the appearance of phenomena for which only statistical predictions can be made. The question was whether, as to the occurrence of such individual events, we should adopt the

> terminology proposed by Dirac, that we were concerned with a choice on the part of 'nature,' or as suggested by Heisenberg, we should say we have to do with a choice on the part of the 'observer' constructing the measuring instruments and reading their recording."[2]

The point here is that two very different kinds of choices enter into the determination of what happens.

(1) First some particular question must be posed.

(2) Then nature gives an answer to that particular question.

The second kind of choice is described by Dirac as a choice on the part of "nature" as to what the outcome of a given observation will be. For this kind of choice quantum theory gives a statistical prediction: it specifies, for each possible outcome of the observation, the probability for that outcome to appear. This is the famous statistical element in quantum theory.

But that choice of outcome is out of human hands, and it is not the focus of this study.

The first kind of choice is also essential to the quantum process. It is the choice by the experimenter of which aspect of nature he is going to probe. In the context of an experiment being performed by a scientist on some external physical system, this choice by this experimenter of which experiment he will perform is decided by some process going on in the experimenter's mind/brain. In the Copenhagen interpretation that mind/brain process is placed definitely outside the system being investigated. But if, following von Neumann, we take the view that quantum theory ought to cover all physical systems, including human brains, then the system that is determining which question will be put to nature becomes part of the system being studied.

Posing the question

The starting point of this study is the fact that contemporary quantum theory is ontologically incomplete. Two fundamental questions remain unanswered. The theory requires that a sequence of specific questions with 'yes' or 'no' answers be put to nature, whereupon nature promptly delivers an answer, The relative statistical weights of the two possible answers, 'Yes' or 'No,' are then specified by quantum theory. But what is not specified by contemporary quantum theory is:

(1) What determines which questions are put to nature, and

(2) What determines whether the individual answer to a posed question is 'yes' or 'no'?

The objective here is to begin to answer these questions, adhering to the naturalistic principle that the actually occurring experiences "supervene on" the entire history of the physical universe, which is the full history of the evolving quantum state of the universe. However, that condition of supervenience—although it means that given the full physical history, the full experiential history is fixed—does not determine whether our experiences enter as causes, or effects; or as both or neither.

To make the following discussion of these issues clear to physicists I shall use the language and symbols of quantum theory. However, I shall try to explain things in a way that others can understand if they merely regard the symbols I use as pictorial abbreviations of the ideas that I describe.

The (physical) state (of the universe) is represented by the (density operator) *S*. A possible experience is labeled by the letter *e*. The connection of this experience to the mathematical formalism is via the correspondence;

$e \rightarrow P_e$

where P_e is the projection operator

$P_e = SUM_e |i><i|.$

Here SUM_e is over the maximal set of basis states i that are compatible with experience e.

The basic dynamical connection is this: If S is the state of a system before experience e occurs, then the state of the system after this experience occurs is:

$S \rightarrow P_e S P_e$

This change is called the 'reduction of the wave packet': the reduction is to the unique new form that incorporates the restriction imposed by the new knowledge supplied by the experience e, and that introduces no other information into the state.

There is a basic difference in philosophy at this point between the Copenhagen view espoused by Bohr et. al. and the view proposed by von Neumann. Bohr assumed that the state involved in the quantum description is the state of some relatively small system that has been prepared in some specified way by experimenters, and that the projection operator P_e acts in the space associated with that small system. The surrounding world was not represented in the theoretical description except by way of the scientist's specifications, via ordinary language, of the experimental set up. Thus the whole quantum procedure was considered to be merely a procedure that allows scientists to make statistical predictions about what would appear to themselves under those well defined observationally specified conditions. However, the great bulk of the physical world was not represented in the quantum description, except via our descriptions of our experiences. This radical restriction on the scope of science, and of its description of nature, was rejected by Einstein and many others.

Von Neumann adopted the view that one ought to assume that, because measuring devices and human bodies are made up of atoms, the laws of quantum theory, if universal, ought to work also for these physical systems, and hence in principle for the entire physical universe, and that any partial description was artificial. By following through the mathematics of that more global perspective von Neumann showed that one could indeed suppose that the laws of quantum theory applied to the whole physical universe (at least in the non-relativistic approximation, and for the somewhat primitive idea of the make-up of the world that prevailed in the 1930's), and that the projection operator P_e could then be supposed to act on those degrees of freedom of the universe that correspond to the brain of the observer. This transformation $S \rightarrow P_e\, S\, \mathrm{P_e}$ selects out from S, and retains, only those states of the brain that are compatible with the knowledge that constitutes experience *e*.

This procedure allows one to recover, in principle, all the predictions of the technically simpler, but ontologically unsatisfactory, Copenhagen theory. It provides a conception of the universe that is in accord with all the predictions of quantum theory, and is in general accord with the classical idea that there is a causal chain in the physical universe that links the observed event in the external world to the brain of the observer of that event, and that this connection leads—under appropriate conditions of alertness and attention, etc.—to a corresponding mind-brain event of the kind we know.

The only ‘reductions of wave packets’ that are needed in the von Neumann picture, in order to reproduce the predictions of the pragmatic Copenhagen interpretation, are reductions associated with human experiences: these give the increments in ‘our knowledge.’ Of course, it is unacceptably anthropocentric to single out our particular species in a general ontological approach. So I assume that this process in human brains is just a special case of a general natural process. However, I focus here on that special case, because we have direct access to the subjective aspects in that case.

Von Neumann builds into his formulation the demand that a specific question must be posed by invoking his famous "Process 1." To understand this, note that for any *P*, the following identity follows from simple algebra:

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

'Posing of the question' is represented by the von Neumann reduction (i.e., by the von Neumann Process 1):

For some possible experience *e*,

$$S \rightarrow P_e S P_e + (1-P_e) S (1-P_e).$$

The two 'interference' terms, which involve both *P* and *(1-P)*, are dropped.

The first term (after the arrow) is the part of the state *S* that corresponds to the definite outcome 'Yes, experience *e* occurs now!' The second term corresponds to the definite outcome 'No, experience *e* does not occur now.' The other two terms are stripped away by the Von Neumann Process 1.

This action on S defines which question is put to Nature. Nature will then give the answer 'Yes' with probability

$$\mathrm{Tr}\ P_e S / \mathrm{Tr}\ S = SUM_e <i| S |i>/ SUM <i| S |i>.$$

Here *Tr* denotes the trace operation, the sum SUM_e is defined as before, and *SUM* is the sum over all members of the basis set.

Quantum theory makes this definite statistical prediction about which outcome will appear, after the definite question is posed. But it does not specify what the question will be, beyond the requirement that answer 'Yes' must correspond to some identifiable experience. Which question is posed is in the hands of "the observer." This freedom places in the hands of the observer great power to control the course of physical events in his brain, without in any way conflicting with the constraints imposed by the known laws of nature. The argument for this follows.

Light as foundation of being

There are many theoretical reasons for believing that our experiences are correlated mainly to the electromagnetic properties of our brains. Our experiences have a classical character, and the closest connection of quantum mechanics to classical mechanics is probably via the so-called 'coherent states' of the electromagnetic (EM) field.[3] These coherent states integrate a vast amount information about the motions of individual atomic nuclei and electrons; motions that cannot be expected to affect our thoughts except via their integrated activity.

These coherent states are probably the most robust feature of brain dynamics, with respect to perturbations caused by thermal and other noise.[4] I shall not go into more detail here, except to say that the coherent low-frequency part of EM field in the brain can be decomposed approximately into mesoscopic modes each of which behaves like a simple harmonic oscillator. The coherent state description is in terms of this collection of mesoscopic harmonic oscillators. For each such oscillator the ground state is a certain gaussian state in both of its internal variables p and q: $exp\{-qq/2\}$ or $exp\{-pp/2\}$, This gaussian 'cloud of possibilities' is centered at the origin $q=0$ and $p=0$ in both q and p. If one shifts this state so that it is centered at some other point (Q, P), then this center point will move around a circle of fixed radius with constant velocity, which is just the motion in these variables that a classical particle would follow for the simple harmonic oscillator case.

I shall assume that the mind-brain connection is via these coherent states of the EM field, and will examine the effects on the brain of mental action by considering the effects of mental action on these low-frequency mesoscopic coherent states of the EM field in the brain.

Effects of mental action on brain behavior

I first show that, within the framework of quantum theory, the mere choice of which question is asked, can influence the behavior of a system, even when an average is made over the possible answers to the question. This demonstration is intended for physicists and is quite short. Other readers can perhaps get the gist.

The issue is this:

Can $X = \mathrm{Tr}\,[QPSP + Q(1-P)S(1-P)]$ depend on P ?

Take Q = sz, S=(1 + sz) [With sx, sy, and sz the Pauli sigma matrices]

If P = S/2 then X = 2.

If P= (1 + sy)/2 then X=0.

This just confirms, as a matter of principle, that it matters which question is posed—and answered—even if one averages over the possible answers. Thus the gross behavior of a system can depend in principle upon which questions the system is asking, internally, where the gross behavior is obtained by averaging over the answers that nature gives to these questions.

I give two examples of how one's behavior could be influenced in this way, simply by controlling, via one's attention, which question is posed.

The first example is an application of the Quantum Zeno Effect. This effect is well understood, theoretically, and has, at least in a certain sense, been confirmed experimentally.[5] The point is that according to quantum theory a very rapid sequence of posings of the same question 'freezes' the answer: if the answer to the first question is 'yes', then the answer 'yes' will, according to the quantum principles, keep on occurring. Thus the mere fact that the question is asked repeatedly in rapid succession keeps the system in the subspace where the answer is 'yes', even in the face of strong mechanical forces that would quickly take it out of that subspace if the questions were not being asked.

This effect might be connected to the psychological experience that intense concentration on an idea tends to hold that idea in place. For example, if one is holding up some heavy object then intense mental 'focus of attention' on an experience e of willful effort could produce a very rapid sequence of such experiences e, each resulting in a collapse of the wave function associated with the brain to a state compatible with this experience e. The effect would be to guide the evolution of the brain state, holding this idea in place, in spite of strong purely physical forces that would to tend move the brain away from this state.

A second example is this. Suppose we are representing the brain, insofar as its interface with consciousness is concerned, by coherent states of the EM field. This state is a Gaussian state represented by $N\, exp\{-[(q-Q)(q-Q)/2]\}$, where N is a normalization constant.

Suppose I ask the question: Will I find the state to be $N\, exp\{-[(q-Q')(q-Q')/2]\}$? The probability that the answer is 'Yes' is the square of:

$$N^2 \int dq\, \exp\{-[(q-Q)(q-Q)/2]\}\, \exp\{-[(q-Q')(q-Q')/2]\} = \exp\{-[(Q-Q')(Q-Q')/2]\}.$$

For small Q the probability is $(1-(Q-Q')(Q-Q'))$.

Suppose one has a large distance L in Q space, but breaks the distance into n small intervals, for which the above approximation is adequate, and asks the succession of questions: Is the state the Gaussian centered at the end of each of the succession of intervals?

Then the probability, at the end of this process, of finding the state to be the Gaussian centered at L is $(1-(L/n)(L/n)n)$. In the limit of large n this is unity: the mental effort of focusing attention in this way will, with high probability, according to the statistical rules of quantum theory, have changed the state of the brain to this other state in spite of the absence of any tendency for this to happen via action of the Schrödinger equation.

These effects may seem strange. But the point is that there is a loose connection in quantum theory: the physical principles themselves do not specify which question is posed. This opens up the logical possibility that, strictly within the bounds of orthodox quantum theory, our conscious thoughts PER SE could be entering into the mind-brain dynamics in a way reducible neither to purely mechanical effects governed by the Schrödinger equation of motion nor to the random effects of Nature's choices of outcomes, nor to any combination of these two effects. There is a rigorous need for some third process, which I call the 'Heisenberg process', and which selects which question is put to nature. This process is not reducible to the 'Schrödinger process' of evolution between jumps via the Schrödinger equation, or to the 'Dirac process' that selects an answer once the question is posed. Thus in orthodox (vN/W) quantum theory there must be these three process entering into mind-brain dynamics: mind-brain dynamics has a "tripartite causal structure," one component of which is naturally mental or experiential, since it must choose a question that has an experientially recognizable answer.

What determines which question is posed?

What sort of process might one imagine to be filling this logical gap in contemporary quantum theory?

Once one becomes open to the notion that maybe our conscious thoughts have a reality in their own right, it becomes apparent that there is a natural causally efficacious place for them in quantum mind-brain dynamics. The point is that, according to the basic quantum precepts, the occurrence of a conscious thought associated with a quantum system is supposed to cause a reduction of the state of that system to the reduced state that is compatible with the increment in knowledge that constitutes that conscious knowing. In vN/W quantum theory this reduction will be a reduction in the brain state of the person who has the thought. This newly actualized brain state must tend to actualize the functional properties implicit in the conscious thought: it must initiate the brain activities that the thought feels are being initiated. Thus the evolution of this brain state must generate messages going out to various motor centers, if the thought is about generating actions. But, in any case, the Schrödinger evolution must also be generating instructions for the creation of a brain state corresponding to a succeeding thought. However, the natural diffusion caused by the Heisenberg uncertainty will entail that the quantum state actually generated by the brain process will be somewhat fuzzy: a host of possibilities will be created. But this diffusion can be counteracted in part, and the process kept on a focused and intended track, by asking—i.e., attending to the right questions.

We know that often, when we have a thought that initiates an action, we also initiate a monitoring that will test to see whether the action is proceeding as intended. That command to monitor is an instruction to "attend" to some question at some later time. I propose that in general our thoughts issue, as part of their intentional aspect, commands to "attend" in the future to certain questions, and that these directives supply the missing component of the quantum dynamics: THEY pose the particular questions that are put to nature. Then the necessary posings of the questions become an aspect of quantum mind-brain dynamics.

Since the question to be posed is supposed to be of the form "is an experience of such-and-such a kind occurring" it would appear that the question really ought to be part of the mental, rather than physical, side of the mind-brain dynamics. The aspect that makes the mental side essentially different from the physical aspect governed by the Schrödinger equation is that the latter process is mechanical: it is governed by LOCAL causal connections. But conscious thoughts correspond to global properties of brains. They are associated with the action of the operators *P*, and these operators must be non-local because any local projection operator *P* would introduce an infinite amount of energy into the system.

The essential point here is that quantum theory has a lacuna that can very naturally be filled in such a way as to allow our thoughts to exercise real, though not absolute, control over the mechanical aspects of mind-brain dynamics. This bringing of the experiential aspect of nature into the causal structure is very much in line with the ideas of Alfred North Whitehead.

Whitehead and the quantum mind/brain.

It may be useful to expand upon this final point concerning Whitehead. To bring the issue into focus I shall first briefly summarize the main points described above about the connection of mind to brain within quantum physics, and then consider the possible relevance of Whiteheadian thought.

The main point of the above discussion is that the original Copenhagen interpretation of quantum theory placed the human experimenter outside the system that was described in the mathematical language of quantum theory. In that early approach the human experimenter has three roles. The first is as a receptacle for the experiences that are the database of science. The second is to pose to nature a sequence of particular 'Yes–No' questions that nature immediately answers by either returning the experience associated with the answer 'Yes', or by returning no experience. The third role is as a scientist who communicates to his colleagues "what he has done and what he has learned," and thus contributes to the on-going scientific enterprise. Our interest here is in the second role as "the chooser of what question to ask." This choice is not fixed by any laws or processes that are contained in or entailed by Copenhagen quantum theory. This is firstly because Copenhagen quantum theory places the human observer outside the system governed by the quantum laws, which are the only known precise laws. And secondly because in Copenhagen quantum theory the human observer is treated in a practical way, and in practice the choice of which experiment to perform is effectively free: it depends on the observer's intentions and a host of inscrutable and empirically uncontrolled factors.

Von Neumann considered a sequence of different ways of dividing nature into the two parts: the first part is the observed system, which is described in terms of the quantum mathematics, and the second part is the observing system, which is described in terms of human experiences. Von Neumann showed that it made no practical difference which of the various placements of the dividing line between the two parts of nature he used. In each case the choice of which question to put to nature was represented by his "Process 1", which was outside the control of the known physical laws, but was ascribed to the mental processes of the participant/observer. Von Neumann's final placement of the dividing line put all systems composed of atomic constituents and physical fields—such as the electromagnetic and gravitational fields—on the side described in terms of the quantum mathematics, and thus placed only the consciousness of the participant/observer outside the mathematically described physical world. However, there must be a dynamical connection between the mind and the brain: the mind of the observer is obviously connected to what is going on in his brain, and his choice of which questions to put to nature influences his brain in ways controlled in principle by the quantum laws, once the neural correlates of our conscious experiences are known. This connection is via the quantum Zeno effect, which shows explicitly how the choice of questions, and their timings, can influence the course of events in the probed system, which, in this case, is the brain of the participant/observer.

This description summarizes the quantum mechanics of the mind/brain system within the von Neumann formulation of quantum mechanics. It opens the door to the natural incorporation of causally efficacious conscious thoughts into contemporary basic science. But it only opens the door: it does not specify how the brain and the conscious thoughts act together to formulate the necessary questions, and their timings. This is a problem to whose solution Whiteheadian process theory might contribute.

A scientist with physicalist leanings would be prone to try to create some sort of "purely physical process" to produce the needed questions. This would make our conscious thoughts into either redundant side effects, or redescriptions of processes that can be completely described in purely physical terms. But either of these options renders mysterious the fact that experiences exist as the psychological realities that populate our streams of consciousness. The fact that, at least within the Copenhagen and von Neumann approaches, the questions posed are supposed to have experiencable answers means that experiential realities must play some special sort of role in the dynamical processing. But in that case, quite independently of the ultimate truth about the basic nature of these realities, it makes good theoretical sense to take these realities as they are actually are known to us, namely as constituents of human streams of conscious experiences, and weave them into the physical world described by quantum theory in just the way that such experiences fit into the quantum framework, namely as efficacious agents. But they must also conform to philosophical requirements of rational coherence. That establishes the link to Whitehead, whose central endeavor was to create a rationally coherent scheme that weaves experiential-type realities into physical reality by making them integral parts of event-like actual occasions, which are naturally identifiable with the psycho-physical events that are the basic realities of von Neumann's formulation of quantum theory.

The brain is of course the carrier of potentialities generated by the past events. It carries the physical correlates of appetites for various particular resolutions of the conflicting potentialities. While the physicalist might seek to explain the process in purely physical terms, the Whiteheadian approach recognizes the descriptions in terms of potential experiences as valid and useful descriptions of real aspects of nature. It makes use of the huge partial understanding of mind/brain process provided by exploring the structure of human experience itself. Quantum theory does not encourage the idea of taking the physically described aspect of brain process as dynamically complete. It calls for a psycho-physical process of the creation of events that actualize experiencable potentialities.

A central Whiteheadian-type notion is that each actual event must have both an aspect that fixes, experientially and physically, what is taken from the past, and also an aspect that creates experiential and physically manifested potentialities for the future. Each event has an intentionality that does not just take randomly from the past, but rather takes selectively from the past particular potentialities whose actualizations create potentialities for future events that serve some purpose. Quantum theory seems to allow mind/brain events of this kind, and Whiteheadian thought can be viewed as an effort to provide the beginning of an understanding of the structure of such events.

Whiteheadian thought also provides an approach to the question of how one extends quantum dynamics to times and regions where consciousness as we know it is absent. All of nature is composed of actual occasions of the same genus, and thus even primordial events must have aspects that have some kinship to our conscious thoughts.

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