Appendix A
Proof that Information Must Sometimes be Transferred Faster Than Light

Strengthening Bell's Theorem by Removing the Hidden-Variable Assumption

In the context of correlation experiments involving pairs of experiments performed at essentially the same time in very far-apart experimental regions Einstein famously said [22]:

> But on one supposition we should in my opinion hold absolutely fast: 'The real factual situation of the system S2 is independent of what is done with system S1 which is spatially separated from the former.'

This demand is incompatible with the basic ideas of standard (Copenhagen/Orthodox) quantum mechanics, which makes two relevant claims:

(1) Experimenters in the two labs make "local free choices" that determine which experiments will be performed in their respective labs. These choices are "free" in the sense of not being pre-determined by the prior history of the physically described aspects of the universe, and they are "localized" in the sense that the physical effects of these free choices are inserted into the physically described aspects of the universe only within the laboratory, and during the time interval, in which the associated experiment is being performed.

(2) These choices of "what is done with the system" being measured in one lab can (due to a measurement-induced global collapse of the quantum state) influence the outcome of the experiment performed at very close to the same time in the very faraway lab.

This influence of '*what is done*' *with* the system being measured in one region upon the outcome appearing at very nearly the same time in a very faraway lab was called "spooky action at a distance" by Einstein, and was rejected by him as a possible feature of "reality".

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John Bell's Quasi-classical Statistical Theory

Responding to the seeming existence in the quantum world of "spooky actions", John Bell [23] proposed a possible alternative to the standard approach that might conceivably be able to reconcile quantum spookiness with "reality". This alternative approach rests on the fact that quantum mechanics is a statistical theory. We already have in physics a statistical theory called "classical statistical mechanics". In that theory the statistical state of a system is expressed as a *sum* of terms, each of which is a possible *real physical state* λ of the system multiplied by a probability factor.

Bell conjectured that quantum mechanics, being a statistical theory, might have the same kind of structure. Such a structure would satisfy the desired properties of "locality" and "reality" (local realism) if, for each real physical state λ in this sum, the relationships between the chosen measurements in the two regions and the appearing outcomes are expressed as product of two factors, with each factor depending upon the measurement and outcome in just one of the two regions. The question is then whether the statistical properties of such a statistical ensemble can be consistent with the statistical predictions of quantum mechanics.

Bell and his associates proved that the answer is No! They considered, for example, the empirical situation that physicists describe by saying that two spin-1/2 particles are created in the so-called spin-singlet state, and then travel to the two far-apart but nearly simultaneous experimental regions. The experimenter in each region freely chooses and performs one of the two alternative possible experiments available to him. Bell et. al. then prove that the predictions of quantum mechanics cannot be satisfied if the base states λ satisfy the "factorization property" demand of "local realism". A theory satisfying this demand is called a "local hidden-variable theory" because the asserted underlying "reality" is described by variables that cannot be directly apprehended.

Two Problems with Bell's Theorems

Bell-type theorems, if *considered as proofs of the logical need for spooky actions in a theory that entails the predictions of quantum mechanics*, have two problems. The first is that the theorems postulate a "reality" structure basically identical to that of classical statistical mechanics. Bell's theorems then show that imposing "locality" (factorizability for each fixed λ) *within this classical-type reality structure* is incompatible with some predictions of quantum mechanics. But that result can be regarded as merely added confirmation of the fact that quantum mechanics is logically incompatible with the conceptual structure of classical mechanics. Simply shifting to a classically conceived "statistical" level does not eliminate the essential conceptual dependence on the known-to-be-false concepts of classical physics.

The second problem is that the condition of "local realism" is implemented by a "factorization" property, described above, that goes far beyond Einstein's demand for no spookiness. In addition to the non-dependence of outcomes in a region upon *"what is done"* in the faraway region "local realism" entails also what Shimony calls "outcome independence". That condition goes significantly beyond what Einstein demanded, which is merely a non-dependence of the factual reality (occurring outcome) in one region on *the choice of experiment performed in the faraway region*. "Outcome independence" demands that the outcome in each region be independent also of the *outcome* in the other region.

That property, "*outcome independence*", is not something that one wants to postulate if a resulting incompatibility with predictions of quantum mechanics is supposed to entail the existence of spooky actions at a distance!

That unwanted independence assumption is not a just a minor fine point. Consider the simple example of two billiard balls, one black, one white, shot out in opposite directions to two far-apart labs. This physical example allows—given the initial symmetrical physical state—the outcome in one region to be correlated with the *"outcome"* appearing in the other region, without any hint of any spooky action at a distance": a "black" ball in one region entails a "white" ball in the other, and vice versa, without any spooky action. Hence Bell's theorems do not address—or claim to address—the key question of the compatibility of Einstein's demand for no spookiness with the predictions of (relativistic) quantum mechanics. Bell's theorems are based on the stronger assumption of local hidden variables.

Bell's theorems (regarded as proofs of the need for spooky actions) are thus deficient in two ways: they bring in from classical (statistical) mechanics an alien-to-quantum-mechanics idea of "reality"; and they assume, in the process of proving a contradiction, a certain property of "outcome independence" that can lead to a violation of quantum predictions without entailing the lack of spookiness that Einstein demanded.

The question thus arises whether the need for spooky interactions can be proved simply from the validity of some empirically well validated predictions of standard quantum mechanics, without introducing Bell's essentially classical "hidden variables"? The answer is "Yes"!

The Proof

The following proof of the need for "spooky actions" places no conditions at all on any underlying process or reality, beyond the macroscopic predictions of quantum mechanics: it deals exclusively with connections between macroscopic measurable properties. This change is achieved by taking Bell's parameter λ to label, now, the different experiments in a very large set of simultaneously performed similar experiments, rather than the different possible basic microscopic states λ of the statistical ensembles. The ontology thereby becomes essentially different, though the mathematics is similar. The macroscopic experimental arrangements are the ones already described above.

In the design of this experiment the physicists are imagining that a certain initial macroscopic preparation procedure will produce a pair of tiny invisible (spin 1/2) particles in what is called the singlet state. These two particles are imagined to fly out in opposite directions to two faraway experimental regions. Each of these experimental regions contains a Stern-Gerlach device that has a directed preferred axis that is perpendicular to the incoming beam. Two detection devices are placed to detect particles deflected either along this preferred axis, or in the opposite direction. Each of these two devices will produce a visible signal (or an auditory click) if the imagined invisible particle reaches it.

The location of the individual detector is specified by the angle ϕ of the directed preferred axis such that a displacement along that particular direction locates the detector. Clearly, the two detectors in the same experimental region will then be specified by two angles ϕ that differ by 180°. For example, if one detector is displaced "up" ($\phi = 90°$) then the other is displaced "down" ($\phi = -90°$). The angle $\phi = 0$ labels in both regions a common deflection to the right: e.g., along the positive x axis in the usual x-y plane.

Under these macroscopic experimental conditions, quantum theory predicts that, if the detectors are 100% efficient, and if, moreover, the geometry is perfectly arranged, then for each created pair of particles—which are moving in opposite directions to the two different regions—exactly one of the two detectors in each region will produce a signal (i.e., "fire"). The key prediction of quantum theory for this experimental setup is that the fraction *F* of the particle pairs for which the detectors that fire in the first and second regions are located at angles ϕ_1 and ϕ_2, respectively, is given by the formula

$$F = (1 - Cosine(\phi_1 - \phi_2))/4.$$

In the experiment under consideration there are two alternative possible experiments in the left-hand lab, and two alternative possible experiments in the right-hand lab, making $2 \times 2 = 4$ alternative possible pairs of experiments. For each single experiment (on one side) there are two detectors, and hence two angles ϕ. Thus there are altogether $4 \times 2 \times 2 = 16$ F's.

I take the large set of similar experiment to have 1000 experiments. Then the fractions F of 1000 are entered into the 16 associated boxes of the following diagram.

In Fig. A1, the first and second *rows* correspond to the two detectors in the *first* possible set-up in the left-hand region. The third and fourth rows correspond to the two detectors in the *second* possible set-up in the left-hand region. The four *columns* correspond in the analogous way to the detectors in the right-hand region. The arrows on the periphery show the directions of the displacements of the detectors associated with the corresponding row or column.

For example, in the top-left 2-by-2 box if the locations of the two detectors (one in each region) that fire together are both specified by the same angle, $\phi_1 = \phi_2$,

	↑	↓	↗	↙
↑	0	500 A	73	427 B
↓	500	0	427	73
→	250	250 D	73	427 C
←	250	250	427	73

Fig. A1 Matrix of transition probabilities described in the text

then, because *Cosine 0 = 1*, each specified pair of detectors will *never* both fire together: if one of these two specified detectors fires, then the other will not fire. If ϕ_1 is some fixed angle and ϕ_2 differs from it by 180° then, because *Cosine 180°* = *−1*, these two specified detectors will, under the ideal measurement conditions, fire together for *half* of the created pairs. If ϕ_1 is some fixed angle and ϕ_2 differs from it by 90° then these two specified detectors will fire together for $^1/_4$ of the pairs. If ϕ_1 is some fixed angle and ϕ_2 differs from it by 45° then these two specified detectors will fire together, in a long run, for *close to 7.3%* of the pairs. If ϕ_1 is some fixed angle and ϕ_2 differs from it by 135° then these two specified detectors will fire together, in a long run, for *close to 42.7%* of the created pairs.

I have listed these particular predictions because they are assumed to be valid in the following proof of the need for near-instantaneous transfer of information between the two far-apart, but nearly simultaneous, experimental space-time regions. These particular predictions have been massively confirmed empirically.

The second assumption is “localized free choices”. The point here is that physical theories make predictions about experiments performed by experimenters with devices that detect or measure properties of the systems whose properties are being probed by these devices. The theory entails that the various settings of the devices will correspond to probe-associated properties of the system being probed.

Of course, in an actual situation these specified parts of the experimental setup are all parts of a universe that includes also the experimenter and whatever the experimenter uses to actually fix the experimental settings. Such a "choosing" part of the universe *could*, however, *conceivably* causally affect not only to the setting of the associated measuring device but, say, via the distant past, also other aspects of the experiment. Those unsuspected linkages via the past could then be responsible for systematic correlations between the empirical conditions in the two regions—correlations that are empirically dependent on which experiments are chosen and performed but are empirically independent of how the experimental setups are chosen.

In view of the limitless number of ways one could arrange to have the experimental setup specified, and the empirically verified fact that the predictions are found to be valid independently of *how* the setup is chosen, it is reasonable to assume that the choices of the experimental setups can be arranged so that they are not systematically connected to the specified empirical aspects of the experiment except via these choices of the experimental setup. This is the assumption of "localized free choices." It is needed to rule out the (remote) possibility that the choice of the setup is significantly and systematically entering the dynamics in some way other than as just the localized fixing of the experimental setup.

Suppose, then, that we have the two far-apart experimental regions, and in each region an experimenter who can freely choose one or the other of two alternative possible experimental set-ups. Suppose we have, in a certain region called the source region, a certain mechanical procedure to which we give the name "creation of N individual experimental instances, where N is a large number, say a thousand. At an appropriate later time the experimenters in the two regions make and implement their "localized free choices" pertaining to which of the two alternative possible experiments will be set up in their respective experimental regions. At a slightly later time each of the two experimenters looks at and sees, in each of the N individual instances, which one of his two detection devices has fired, and then records the angle ϕ that labels that detector, thereby recording the outcome that occurs in that individual instance.

There are altogether two times two, or four, alternative possible experimental setups. Figure A1 gives, for each of these four alternative possible setups, the number of individual instances, from the full set of 1000, that produce firings in the pair of detectors located at the pair of angles ϕ specified along the left-hand and top boundaries of the full diagram. For example, the four little boxes in the first two rows and the first two columns correspond to the case in which the experimenter in the left-hand region sets his two detectors at "up" ($\phi_1 = 90°$) and "down" ($\phi_1 = -90°$), while the experimenter in the right-hand region sets his two detectors also at "up" ($\phi_2 = 90°$) and "down" ($\phi_2 = -90°$). In this case the expected distribution (modulo fluctuations) of the thousand instances is 500 in the box in which $\phi_1 = 90°$ and $\phi_2 = -90°$ and the other 500 in the box in which $\phi_1 = -90°$ and $\phi_2 = 90°$.

The fluctuations become relatively smaller and smaller as N get larger and larger. So I will, for simplicity, ignore them in this discussion and treat the predictions to be exact already for N = 1000.

The two experimental regions are arranged to be essentially simultaneous, *very* far apart, and very tiny relative to their separation. These two regions will be called the “left” and “right” regions.

The “no-essentially-instantaneous-transfer of information about localized free choices” assumption made here is that, no matter which experiment is performed in a region, the outcome appearing there is independent of which experiment is freely chosen and performed in the faraway region. This means, for example, that if the experiment on the right is changed from the case represented by the left-hand two columns to the case represented by the right-hand two columns, then the *particular set* of 500 instances—from the full set of 1000—that are represented by the 500 in the top row second column get shifted into the two boxes of the top row in the second two columns.

More generally, a change in the experiment performed on the right shifts the individual instances—in the set of 1000 individual instanced—horizontally, in the same row; whereas a change in the experiment performed on the left shifts the individual instance vertically. The Fig. A1 then shows how, by a double application of the “no FTL condition”, a subset of the set of 500 instances occupying box A gets shifted via box B to box C, which must then contain at least 427 − 73 = 354 of the original 500 instances in A. However, the applying of the two changes in the other order, via D, demands that the subset of instances in A that can be in C can be no greater than 250. That is a contradiction. Thus one cannot maintain simultaneously both the general rule of no FTL transfers of information and four very basic and empirically confirmed predictions of quantum mechanics.

In more detail the argument then goes as follows. Let the pairs (individual instances) in the ordered sequence of the 1000 created pairs be numbered from 1 to 1000. Suppose that the actually chosen pair of measurements corresponds to the first two rows and the first two columns in the diagram. This is the experiment in which, in each region, the displacements of the two detectors are “up” and “down”. Under this condition, quantum theory predicts that for some particular 500-member subset of the full set of 1000 individual instances (created pairs) the outcomes conform to the specifications associated with the little box labeled A. The corresponding 500 member subset of the full set of 1000 positive integers is called Set A. This Set A is a particular subset of 500 integers from set {1, 2, …,1000}. The first 4 elements in Set A might be, for example, {1, 3, 4, 7}.

If the local free choice in the right-hand region had gone the other way, then the prediction of quantum mechanics is that the thousand integers would be distributed in the indicated way among the four little boxes that lie in one of the first two rows and also in one of the *second* two columns, with the integer in each of these four little boxes specifying the number of instances in the subset of the original set of 1000 individual instances that lead to that specified outcome. Each such outcome consists, of course, of a pair of outcomes, one in the left-hand experimental region, and specified by the row, the other in the right-hand experimental region and specified by the column.

If we now add the Locality Condition, then the demand that the macroscopic situation in the left-hand region be undisturbed by the reversal of the localized free choice made by the experimenter in the (faraway) right-hand region means that the set of 500 integers in Set A must be distributed between the two little boxes standing directly to the right of the little box A. Thus the Set B, consisting of the 427 integers in box B, would be a 427 member subset of the 500 integers in Set A.

The above conclusions were based on the supposition that the actual choice of experiment on the left was the option, represented by the top two rows and the leftmost two columns in Fig. A1. However, having changed the choice in the right-hand region to the one that is represented by the *rightmost* two columns—the possibility of which is which is entailed by Einstein's reference to a dependence on "what is done with" the faraway system—we next apply the locality hypothesis to conclude that changing the choice on the left must leave the outcomes on the right undisturbed. That means changing the top two rows to the bottom two rows, leaving the integers that label the particular experiment in the set of 1000 experiments in the same column. This means that the 427 elements in the box B must get distributed among the two boxes that lie directly beneath it. Thus box C must include at least $427 - 73 = 354$ of the 500 integers in Set A.

Repeating the argument, but reversing the order in which the two reversals are made, we conclude, from exactly the same line of reasoning, that box C can contain no more than 250 of the 500 integers box A, Thus the conditions on Set C that arise from the two different possible orderings of the two reversals are contradictory!

A contradiction is thus established between the consequences of the two alternative possible ways of ordering these two reversals of localized free choices. Because, due to the locality hypothesis being examined, no information about the choice made in either region is present in the other region, no information pertaining to the order in which the two experiments are performed is available in either region. Hence nothing pertaining to outcomes can depend upon the relative ordering of these two space-like separated reversals of the two choices.

This argument uses only macroscopic predictions of quantum mechanics—without any conditions on, or mention of, any micro-structure from whence these macroscopic properties come—to demonstrate the logical inconsistency of combining a certain 16 (empirically validated) predictions of quantum mechanics with the locality hypothesis that for each of the two experimental regions there is no faster-than-light transfer to the second region of information about macroscopically localized free choices made in the first.

The Bell's theorem proofs are rightly identified as proofs of the incompatibility of "local realism" with the predictions of quantum mechanics. But "local realism" brings in both alien-to-quantum-theory classical concepts and also an "outcome independence" condition whose inclusion nullifies those theorems as possible proofs of the need for spooky actions at a distance. Both of these features are avoided in the present proof.

As regards Einstein's reality condition, namely that the no-spooky-action condition pertains to the "real factual situation" one must, of course, use the quantum conception of the "real factual situation", not an invalid classical concept. In ontologically construed orthodox quantum mechanics (in the contemporary relativistic quantum field theory version that I use) the "real factual situation" evolves in a way that depends upon the experimenter's free choices and nature's responses to those choices. The no-spooky-action condition is a condition on these choice-dependent real factual situations—namely outcomes observed under the chosen conditions—that is inconsistent with certain basic predictions of the theory. That is what has just been proved. In classical mechanics there are no analogous free choices: the physical past alone uniquely determines the physical present and future.

The Einstein idea of no spooky actions involves comparing two or more situations only one of which can actually occur. This is the kind of condition that occurs in modal logic considerations involving "counterfactuals". But here this modal aspect does not bring in any of the subtleties or uncertainties that plague general modal logic. For in our case the specified condition is a completely well defined and unambiguous (trial) mathematical assumption of the non-dependence of a nearby outcome upon a faraway free choice between two alternative possible probing actions. The proof does not get entangled with the subtle issues that arise in general modal logic. Everything is just as well defined as in ordinary logic.

In this proof there is no assumption of a "hidden variable" of an essentially classical kind lying "behind" the ontologically construed orthodox quantum theory. The phenomena are rationally understandable in terms of an evolving quantum state of the universe that represents "potentialities for experiences" that evolve via a Schrödinger-like equation punctuated by an ordered sequence of psycho-physical events each of which is an observer's personal experience accompanied by a "collapse of the quantum state of the universe" that brings that evolving state into conformity with the observer-initiated experience of that observer.

The bottom line is that, given the validity of some basic macroscopic predictions of quantum mechanics, there is no way that the macroscopic phenomena can conform to the predictions of quantum mechanics without allowing violations of the general notion that the information about the local free choices cannot get essentially instantaneously to faraway regions and affect outcomes appearing in those regions.

Appendix B
Graphical Representation of the Argument

The argument in Appendix A was expressed in words and equations. For many purposes it is useful, for arguments involving an ordered sequence free choices or decisions, to have a graphical representation of the alternative possibilities

The argument in Appendix A is based on statements of the form:

> If measurement M is performed and the outcome is O, then if, instead of M, the measure M' were to be performed, then the outcome would be O'.

Statements of this kind make sense in classical physics. An outcome O of M could, within some theoretical framework, give some information about the state of the world before the measurement M was performed, and this information could entail that O' would occur if M' were to be performed. For example, the outcome of the first experiment could give information about the previously unknown or unspecified velocity of a particle entering the experimental region, and this added information could allow the outcome O' of M' to be predicted. The connection between the two alternative possible situations is a consequence of the conjectured structure of the reality lying behind the observable phenomena. It is therefore a condition on the real existence of that conjectured structure.

The argument in Appendix A involves only macroscopic choices of measurements and outcomes, and a conjectured no-faster-than-light condition. These things are all classically understandable, and the argument can be represented graphically.

Statements of this kind can be definitely true or definitely false in the context of a physical theory that has logically consistent laws that allow the "free choices" between which of several alternative possible experiments is performed to be treated as free variables. Copenhagen and orthodox quantum mechanics are theories of this kind.

Logical reasoning is aided by having a "mechanical" way of checking the truth or falsity of statements. Then all competent users of the logic can agree on the truth or falsity of the propositions.

Robert Griffiths [13] has invented such a "mechanical" procedure for validating reasoning of this kind. It is a graphical procedure. It involves a tree graph that, reading from left to right, has branches that "branch" at branch points into more branches. Some branch points represent the occurrence of events where a choice must be made between two (or more) alternative possible experiments. Other

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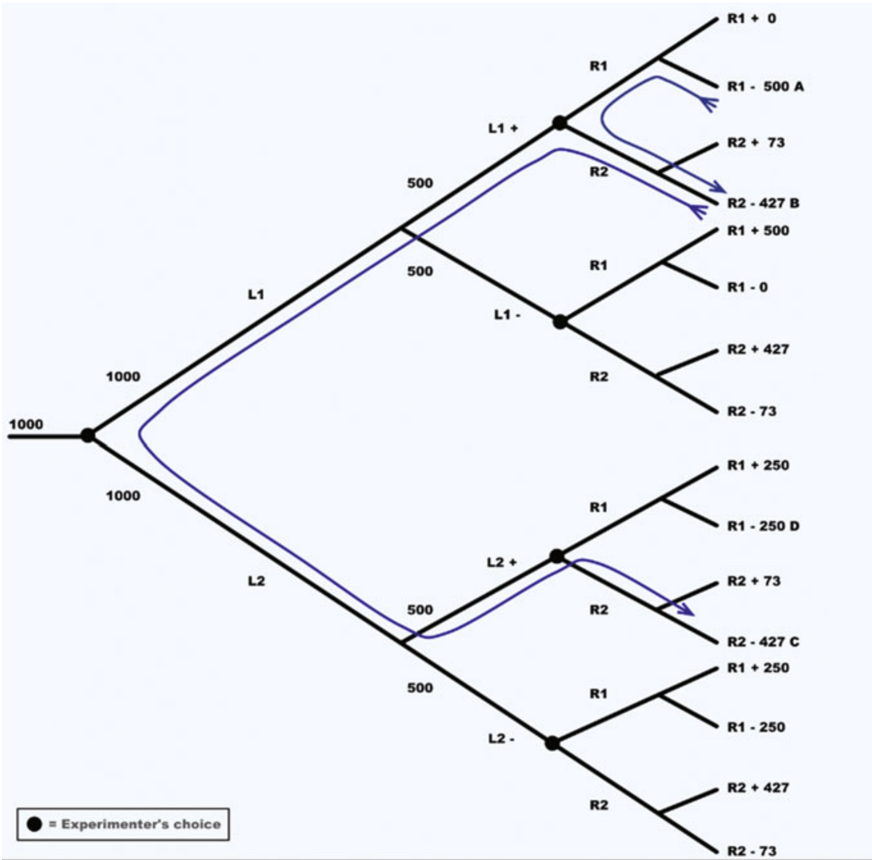

Fig. B1 The Griffiths Diagram Corresponding to the part of the argument given in Appendix A in which the reversal R1 to R2 in region R precedes the reversal L1 to L2 in region L

branch points represent events where some particular outcome of some particular experiment must be chosen (by nature).

If, as in our case, there are two far-apart experimental regions, then the full graphical part that represents the possible events in the later region must be hooked onto each of the branches representing an outcome in the first region, in order for the graph, reading from left to right, to represent, without prejudice stemming from the no-faster-than-light conjecture at issue, the temporal order of the macroscopic events.

Griffiths allows graphs that include branch points corresponding to microscopic (invisible) events, but I exclude all such points and consider only visible events. For the argument in Appendix A explicitly precludes all reference to such imagined events.

Figures B1 and B2 give the graphical representations of the two parts of the argument in Appendix A. The part of the graph that corresponds to the part of the

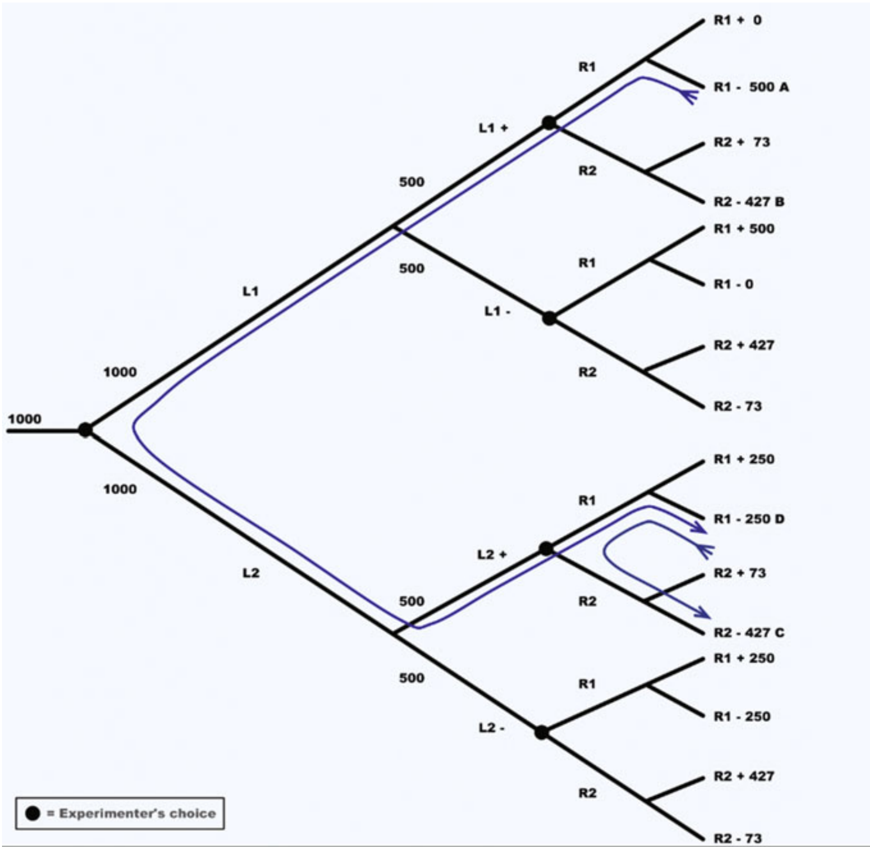

Fig. B2 The Griffiths Diagram Corresponding to the part of the argument given in Appendix A in which the reversal L1 to L2 in region L precedes the reversal R1 to R2 in region R

process labeled L (for left-hand region) stands to the left of the parts labeled R (for right-hand region). The left-to-right ordering in the graph corresponds to increasing time. Thus the L part of the physical process is earlier than the R part.

The argument in Appendix A involves two different orderings of the reversals. So one might consider a second graph with the L-R ordering reversed. But a key requirement of Griffiths' formalism is that a valid argument must be expressed by using only one single graph. So, within Griffiths' theory, the reasoning in Appendix A must be justified by using only one single graph. Consequently, the two parts of the argument must use the same graph. The superposed thinner lines in the two diagrams represent the propositions in the two parts of the argument.

Figure B1 represents the case in which the reversal from experiment R1 to experiment R2 comes first. Keeping track of the 500 elements of Set A under this reversal, which leaves everything in region L unchanged, we see that 427 of the 500 elements a Set A go to Set B. Next comes the reversal L1 to L2 in region L, with the experimenter's choice of R2 in region R left unchanged. We are interested in how many of the 500 elements in set A end up in set C, which corresponds to L2+. These must come from the 427 elements in set B. Because at most 73 of these 427 elements can go to R2+, at least 427 − 73 = 354 must end up in set C. This is just a diagrammatic representation in the pertinent Griffiths graph of the first half of the argument given in Appendix A.

Figure B2 represents the second half of the argument given in Appendix A, the part in which the first reversal is the reversal of L1 to L2 with the choice in region R of R1 held fixed. Starting again with the 500 elements in set A, but now tracing first back to the experimenter's choice between L1 and L2, and then forward along the other branch, L2, and following the L2+ branch that leads to branch D. Only 250 0f the original 500 instances in Set A end up in D. Then the reversal of R1 to R2 keeping the choice in region L of L2 unchanged allows at most 250 of the elements in Set A to be in Set C. This conclusion conflicts with the conclusion associated with Fig. B1, which was that at least 354 elements of set A are contained in set C. Thus the conclusion deduced in Appendix A by using the common-sense understandings of the meanings of the words is confirmed within Griffiths' graphical representation of the structure of counterfactual reasoning, restricted now to visible macroscopic events.

A variation of this argument based on experiments of the kind proposed by Julian Hardy has been described in [14, 15, 16, 17, 18, 19]. The argument given above is the one given earlier in [18], here spelled out in greater detail.

Appendix C
Reply to Sam Harris on Free Will

Sam Harris's book "Free Will" is an instructive example of how a spokesman dedicated to being reasonable and rational can have his arguments derailed by a reliance on prejudices and false presuppositions so deep-seated that they block seeing science-based possibilities that lie outside the confines of an outmoded world view that is now known to be incompatible with the empirical facts.

A particular logical error appears repeatedly throughout Harris's book. Early on, he describes the deeds of two psychopaths who have committed some horrible acts. He asserts: "I have to admit that if I were to trade places with one of these men, atom for atom, I would be him: There is no extra part of me that could decide to see the world differently or to resist the impulse to victimize other people."

Harris asserts, here, that there is "no extra part of me" that could decide differently. But that assertion, which he calls an admission, begs the question. What evidence rationally justifies that claim? Clearly it is not empirical evidence. It is, rather, a prejudicial and anti-scientific commitment to the precepts of a known-to-be-false conception of the world called classical mechanics. That older scientific understanding of reality was found during the first decades of the twentieth century to be incompatible with empirical findings, and was replaced during the 1920s, and early 1930s, by an adequate and successful revised understanding called quantum mechanics. This newer theory, in the rationally coherent and mathematically rigorous formulation offered by John von Neumann, features a separation of the world process into (1), a physically described part composed of atoms and closely connected physical fields; (2), some psychologically described parts *lying outside the atom-based part*, and identified as our thinking ego's; and (3), some psycho-physical actions attributed to nature. Within this empirically adequate conception of reality there *is* an extra (non-atom-based) part of a person (his thinking ego) that can resist (successfully, if willed with sufficient intensity) the impulse to victimize other people. Harris's example thus illustrates the fundamental errors that can be caused by identifying honored science with nineteenth century classical mechanics.

Harris goes on to defend "compatibilism", the view that claims both that every physical event is determined by what came before in the physical world and also that we possess "free will". Harris says that "Today the only philosophically

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respectable way to endorse free will is to be a compatibilist—because we know that determinism, in every sense relevant to human behavior, is true".

But what Harris claims that "We know" to be true is, according to quantum mechanics, not known to be true.

The final clause "*in every sense relevant to human behavior*" is presumably meant to discount the relevance of quantum mechanical indeterminism, by asserting that quantum indeterminism is not relevant to human behavior—presumably because it washes out at the level of macroscopic brain dynamics But that idea of what the shift to quantum mechanics achieves is grossly deficient. The quantum indeterminism merely opens the door to a complex dynamical process that not only violates determinism (the condition that the physical past determines the future) at the level of human behavior, but allows mental intentions that are not controlled by the physical past to influence human behavior in the intended way. Thus the shift to quantum mechanics opens the door to a causal efficacy of free will that is ruled out by Harris's effective embrace of false nineteenth science.

Appendix D
The Paranormal and the Principle of Sufficient Reason

This book has been an exposition of what I call "Realistically construed orthodox quantum mechanics". That name is intended to mean the conception of reality most naturally concordant with the "pragmatic" interpretation offered by the founders (Heisenberg, Schrödinger, Born, Dirac, Bohr, and Pauli), as mathematically formulated by John von Neumann and subsequently converted during the late 1940s (principally by Tomonaga, Schwinger, and Feynman) into contemporary Relativistic Quantum Field Theory, RQFT.

It might be objected that this orthodox theory is deficient because it does not encompass the widely reported paranormal phenomena. On the other hand, many scientists believe that those phenomena, which, by definition, are incompatible with the generally accepted contemporary physical theory, ought not be considered to be "science" because, by and large, the papers reporting them have not been published in the most prestigious scientific journals, ostensibly because of defects in their methods and procedures.

One exception to that publication criterion is a recent (2012) paper in the Journal of Personality and Social Psychology by Cornell psychologist Daryl J. Bem. However, I show in this appendix how Bem's data, which *appears* to require backward-in-time (retro-causal) effects forbidden by the strictly orthodox RQFT can be explained without any actual backward-in-time action by passing from this "strictly orthodox" theory to a modified "quasi-orthodox" version which, unlike the orthodox theory, enforces "The principle of sufficient reason". This principle asserts that every definite happening must have some definite reason to be what it is, rather than something else. This principle seems, from a general scientific point of view, to be rational and reasonable: it bans the possibility that a definite value of a physical property can just suddenly "pop out of the blue", which is what the strictly orthodox theory effectively demands when it specifies that nature makes strictly random yet perfectly definite choices. The reasonable question is: "What principle or process separates this chosen value from the un-chosen ones, in the (assumed to be single) observed universe?"

It turns out that Bem's data can be accommodated by replacing the "strictly-orthodox" theory by a "quasi orthodox" theory that upholds the principle of sufficient reason. In the quasi-orthodox theory nature's choices are not random, hence lacking a sufficient reason to be what they are, but are assumed to have

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sufficient reasons that entail a biasing of nature's choices in favor of choices that advance the personal values of the subjects in these experiments who are posing the questions pertaining to matters of interest to themselves.

In the Bem experiment these pertinent choices occur at the very end of the experimental instance, and hence later in time than another "independent" choice made by the subject-observer at the beginning of the experimental instance. However, a biasing of the later choice biases *records of the past*, due to the difference between the actual and effective past discussed in Chap. 7. Thus, on the basis of the recorded data that survive the collapses, the experimenter will conclude that the earlier choice was biased. That is because the records that survive the final collapse will not include the records residing in the branch of reality that was created at the moment the device made the macroscopic random choice of which picture to present to the subject, but that nature later (biasly) chose not to actualize.

To explain this possibility in more detail, I include (intact) in this appendix a paper that I prepared in 2012 but never submitted to a journal. It shows that the retro-causal actions seemingly found by Bem can be avoided by replacing the "irrational" strictly orthodox dependence of nature's choice of response to the subject's probing actions upon "pure chance" by a meaningful choice that depends on values residing in that person's "ego". That biasing of the statistical weight of a choice made by nature at the *tail end* of the experimental instance effectively biases, via the quantum collapse, the weighting of the "effective" past that precedes that collapse without there being any actual backward-in-time action.

Quasi-Orthodox Quantum Mechanics and the Principle of Sufficient Reason

Abstract The principle of sufficient reason asserts that anything that happens does so for a reason: no definite state of affairs can come into being unless there is a sufficient reason why that particular thing should happen instead of something else. This principle is usually attributed to Leibniz, although the first recorded Western Philosopher to use it was Anaximander of Miletus. The demand that nature be rational, in the sense that it be compatible with the principle of sufficient reason, conflicts with a basic feature of contemporary orthodox physical theory, namely the notion that nature's responses to the probing actions of observers be determined by pure chance, and hence on the basis of absolutely no reason at all. This injection of "irrational" pure chance can be deemed to have no fundamental place in reason-based Western science, and it has been criticized by Einstein, among others. It is argued here that in a world that conforms to the principle of sufficient reason, the usual quantum statistical rules will naturally emerge at the pragmatic level, in cases where the reason behind Nature's choice of response is unknown, but that the usual statistics can become biased in an empirically manifest and apparently retrocausal way when the reason for the choice is empirically identifiable. It is shown here that some recently reported high profile experimental results that violate the principles of contemporary physical theory can be rationally and simply explained if nature's supposedly random choices are sometimes slightly biased in a way that depends upon the emotional valence of the observer-experiences that these choices create.

Introduction

An article recently published by the Cornell psychologist Daryl J. Bem [24] in a distinguished psychology journal has provoked a heated discussion in the New York Times [25]. Among the discussants was Douglas Hofstadter who wrote that: "If any of his claims were true, then all of the bases underlying contemporary science would be toppled, and we would have to rethink everything about the nature of the universe."

It is, I believe, an exaggeration to say that if any of Bem's claims were true then "all of the bases underlying contemporary science would be toppled" and that "we would have to rethink everything about the nature of the universe". In fact, all that is required is a relatively small change in the rules, and one that seems even more reasonable and natural than the usual rules, within the broad general framework of rational Western science. The major part of the required rethinking was done already by the founders of quantum mechanics, and cast in more rigorous form by John von Neumann [26], more than seventy years ago.

According to the ordinary precepts of *classical* mechanics, once the physically described universe is created, it evolves continuously in a deterministic manner that is completely fixed by mathematical laws that depend always and everywhere only on the evolving local values of physically described properties. There are no inputs into the dynamics that go beyond what is specified by those physically described properties. Here *physically described properties* are properties that are specified by assigning mathematical properties to space-time points, or to very tiny regions, independently of whether they are presently being experienced by any biological or other experiencing entity. These properties are thereby distinguished from properties that are described directly in terms of *actually experienced* thoughts, ideas, or feelings. Within that classical mechanical framework of physics the increasing experienced knowledge of human beings and other biological agents enters only as an *output* of the physically described evolution of the universe: experiential aspects of reality that go beyond the purely physical aspects play no role in the algorithmically determined mechanistic evolution of the universe, except perhaps at its birth.

This one-way causation from the physical aspects of nature to the empirical/epistemological/mental aspects has always been puzzling: Why should experienced "knowledge" exist at all if it cannot influence anything physical, and hence be of no use to the organisms that possess it. And how can something like an "idea", seemingly so different from physical matter, as matter is conceived of in classical mechanics, be created by, or simply *be*, the motion of physical matter?

The basic precepts of classical mechanics are now known to be fundamentally incorrect: they cannot be reconciled with a plenitude of empirical facts discovered and verified during the twentieth century. Thus there is no reason to demand, or believe, that those puzzling properties of the classically conceived world must carry over to the actual world, which conforms far better to the radically different precepts of quantum mechanics.

The founders of quantum theory conceived their theory to be a mathematical procedure for making practical predictions about future empirical/experiential findings on the basis of present empirical knowledge. According to this idea, quantum theory is basically about the evolution of knowledge. This profound shift is proclaimed by Heisenberg's assertion [27] that the quantum mathematics "represents no longer the behavior of the elementary particles but rather our knowledge of this behavior", and by Bohr's statement [28] that "Strictly speaking, the mathematical formalism of quantum mechanics merely offers rules of calculation for the deduction of expectations about observations obtained under conditions defined by classical physics concepts."

The essential need to bring "observations" into the theoretical structure arises from the fact that physical evolution via the Schrödinger equation, which is the quantum analog of the classical equations of motion, produces in general not a single evolving physical world that is compatible with human experience and observations, but rather a mathematical structure that corresponds to a smeared out mixture of increasingly many such worlds. Consequently, some additional process, beyond the one generated by the Schrödinger equation, is needed to specify the connection is between the physically described quantum state of the universe and experienced empirical reality.

This important connectivity is alien to the concepts of classical physics. Those concepts arose from—or were at least heavily reinforced by—the conceptual miniaturization of the celestial objects of astronomy and the solid terrestrial objects of normal observation. In those two regimes we, the observers, stand effectively apart from the system being observed and—under the conditions of the applicability of that classical physical theory—have no appreciable influence upon the behavior of the observed system. The classical concept of "the physical system" was thereby divorced from the concept of "being observed".

This classical separability the physical from the mental is not altered by miniaturization. However, there is no rational reason why this separability feature of the classical conceptualization of the physical world should continue to be useful or applicable when the brains of *we the observers* become included in what is being described physically. But how does scientific theory advance in a well-defined and useful way beyond the classical notion of mind-brain disjunction? How can science bring these two disparate kinds of descriptions together in a rationally coherent manner?

The founders of quantum mechanics achieved a profound advance in our understanding of nature when they recognized that the mathematically/physically described universe that appears in our best physical theory represents *not* the world of material substance contemplated in the classical physics of Isaac Newton and his direct successors, but rather a world of "*potentia",* or "*weighted possibilities",* for our future acquisitions of *knowledge* [29]. It is not surprising that an adequate scientific theory designed to allow us to predict correlations between our shared empirical findings should incorporate, as orthodox quantum mechanics does: (*1*), a natural place for *"our knowledge",* which is both all that is really known to us, and also the empirical foundation upon which science is based; (*2*), an account of the process by means of which we acquire our *knowledge* of certain physically described aspects of nature; and (*3*), a statistical description, at the pragmatic level, of relationships between various features of the growing aspect of nature that constitutes "our knowledge".

What is perhaps surprising is the ready acceptance by most western-oriented scientists and philosophers of the notion that the element of chance that enters quite reasonably into the *pragmatic* formulation of physical theory, in a *practical* context where many pertinent things may be unknown to us, stems from an occurrence of raw pure chance at the underlying *ontological* level. Ascribing such capriciousness to the underlying basic reality itself would seem to contradict the rationalist ideals of Western Science. From a strictly rational point of view, it is, therefore, not unreasonable to examine the mathematical impact of tentatively accepting, *at the basic ontological level*, Einstein's dictum that: "God does not play dice with the universe", and thus to attribute the effective entry of pure chance at the practical level to our lack of knowledge of the *reasons* for the supposedly random choices that enter into the quantum dynamics to be what they turn out to be.

These supposedly random choices enter quantum mechanics only through certain "choices on the part of nature". These choices determine which of the potentialities generated by the mechanistic Schrödinger equation are actualized and experienced. The tentative assumption, here, is that the seeming randomness of these choices arises from the incompleteness of our knowledge of the conditions that determine what these choices will be, but that sufficient reasons for these choices do exist, and a proper task of science is to find out what some of these reasons are.

Implementing the Principle of Sufficient Reason

I make no judgment regarding the technical correctness of the purported evidence for the existence of the reported retrocausal phenomena. That I leave to the collective eventual wisdom of the scientific community. I am concerned here rather with essentially logical and mathematical issues, as they relate to the apparent view of some commentators that scholarly articles reporting the existence of retrocausal phenomena should be banned from the scientific literature, essentially for the reason articulated in the New York Times by Douglas Hofstadter, namely that the actual existence of such phenomena is irreconcilable with what we now (think we) know about the structure of the universe. But is it actually true that the existence of such phenomena would require a wholesale abandonment of basic ideas of contemporary physics.

That assessment is certainly not valid, as will be shown here. A limited, and intrinsically reasonable, modification of the existing orthodox quantum mechanics is sufficient to accommodate the reported data. Hence banning the publication of such works would block a possible important advancement in science that would constitute an empirically small but conceptually important correction to contemporary mainstream science. The issue in question is the validity of Einstein's opinion that the randomness invoked by orthodox quantum mechanics is not a fundamental feature of reality itself.

In order for science to be able to confront effectively purported phenomena that violate the prevailing basic theory, what is needed, or at least helpful, is an alternative theory that retains the empirically valid predictions of the currently prevailing theory, yet accommodates in a rationally coherent way the claimed new phenomena.

If the example of the transition from classical physics to quantum physics can serve as an illustration, in that case we had a beautiful theory that had worked well for 200 years, but that was incompatible with the new data made available by advances in technology. However, a new theory was devised that was closely connected to the old one, and that allowed us to recapture the old results in the appropriate special cases, where the effects of the nonzero value of Planck's constant could be ignored. The old formalism was by-and-large retained, but readjusted to accommodate the fact that properties that according to ordinary classical ideas were described by *numbers* that specified the actual numerical values of the properties, were represented at a more basic level by *actions,* which were related to the *measurement processes* by means of which the numerical values were empirically ascertained. Thus the active process by means of which *we find out about* certain pertinent numbers was brought explicitly into the dynamical theory. This restructuring that brings into the heart of the theory our actions of performing the measurements that produced the increments in our knowledge that constituted our empirical findings is closely tied to *a rejection of a basic classical presupposition*, namely the idea that basic physical theory should properly be primarily about connections between physically described material events, with experiential ramifications an inessential addendum. The founders of quantum theory insisted, in direct contrast, that their more basic physical theory was essentially pragmatic—i.e., was directed at predicting practically useful connections between empirical (i.e., experienced) events [30].

This original pragmatic Copenhagen QM was not suited to be an ontological theory, because of the movable boundary between the aspects of nature described in *classical* physical terms and those described in *quantum* physical terms. It is certainly not ontologically realistic to believe that the pointers on observed measuring devices are built out of *classically* conceivable electrons and atoms, etc. The measuring devices, and also the bodies and brains of human observers, must be understood to be built out of quantum mechanically described elements. This is what allows us to understand and describe many observed properties of these physically described systems, such as their rigidity and electrical conductance. The aspects of quantum mechanics that describe our observations is more accurately called a description of the experiential aspects, which can make use of classical concepts as aids to our descriptions of our experiences.

Von Neumann's analysis of the measurement problem allowed the quantum state of the universe to describe the entire physically described universe: everything that we naturally conceive to be built out of atomic constituents and the fields that they generate. This quantum state is described by assigning mathematical properties to space-time points (or tiny regions). There is a deterministic law, the Schrödinger equation, that specifies the mindless, essentially mechanical, evolution of this quantum state. But this quantum mechanical law of motion generates *a huge continuous smear of worlds of the kind that we actually experience.* For example, as Einstein emphasized, the position of the pointer on a device that is supposed to tell us the *time* of the detection of a particle produced by the decay of a radioactive nucleus, evolves, under the control of the Schrödinger equation, into a *continuous smear of positions corresponding to all the different possible times of detection*; not to a single position, which is what we observe [31]. And the unrestricted validity of the Schrödinger equation would lead, as also emphasized by Einstein, to the conclusion that the moon, as it is represented in the theory, would be smeared out over the entire night sky, until the first observer of it, say a mouse, looks.

How do we understand this huge disparity between the representation of the universe evolving in accordance with the Schrödinger equation and the empirical reality that we experience?

An adequate physical theory must include a logically coherent explanation of how the mathematical/physical description is connected to the experienced empirical realities. This demands, in the final analysis, a theory of the mind-brain connection: a theory of how our idea-like knowings are connected to our evolving physically described brains.

The micro-macro separation that enters into Copenhagen QM is actually a separation between what is described in quantum mechanical physical terms and what is described in terms of *our experiences*—expressed in terms of our everyday concepts of the physical world, refined by the concepts of classical physics [28, Sect. 3.5].

To pass from *quantum pragmatism* to *quantum ontology* one can treat all *physically described* aspects quantum mechanically, as Von Neumann did. He effectively transformed the Copenhagen pragmatic version of QM into a potentially ontological version by shifting the brains and bodies of the observers—and all other physically described aspects of the theory—into the part described in quantum mechanical language. The entire physically described universe is treated quantum mechanically, and *both our knowledge*, and *the process by means of which we acquire our knowledge about the physically described world,* are elevated to essential features of the theory, not merely postponed, or ignored! Thus certain aspects of reality that had been treated superficially in the earlier classical theories—namely "our knowledge" and "the process by means of which we acquire our knowledge"—were now incorporated into the theory in a detailed way.

Specifically, each acquisition of knowledge was postulated to involve, first, a "choice of probing action executed by an observing agent", followed by "a choice on the part of nature" of a response to the agent's request (demand) for this particular piece of experientially specified information.

This response on the part of nature is asserted by orthodox quantum mechanics to be controlled by *random chance*, by *a throw of nature's dice*, with the associated probabilities specified purely in terms of physically described properties. These "random" responses create a sequence of collapses of the quantum state of the universe, with the universe created at each stage concordant with the new state of "our knowledge".

If Nature's choices conform strictly to these orthodox statistical rules then the results reported by Bem cannot be accommodated. However, if nature is not capricious—if God does *not* play dice with the universe—but Nature's choices have sufficient reasons, then, given the central role of "our knowledge" in quantum mechanics, it becomes reasonable to consider the possibility that Nature's choices are not completely determined in the purely mechanical way specified by the orthodox rules, but can be *biased* away from the orthodox rules in ways that depend upon the character of the knowledge/experiences that these choices are creating. The results reported by Bem can then be explained in simple way that elevates the individual "choices on the part of nature" from "choices that are determined by absolutely nothing at all", to "choices that arise from relevant conditions that include the experienced emotions of biological agents."

In classical statistical physics such a biasing of the *statistics* would not produce the appearance of *retrocausation*. But in quantum mechanics it does! The way that the biasing of the forward-in-time quantum causal structure leads to *seemingly* "retrocausal" effects will now be explained.

Backward in Time Effects in Quantum Mechanics

The idea that choices made now can influence what has already happened needs to be clarified, for this idea is, in some basic sense, incompatible with our idea of the meaning of time. Yet the empirical results of Wheeler's delayed-choice experiments [32], and the more elaborate delayed-choice experiments of Scully and colleagues [33] are saying that, *in some sense*, what we choose to investigate now can influence what happened in the past. This backward-in-time aspect of QM is neatly captured by an assertion made in the recent book "The Grand Design" by Hawking and Mlodinow: "We create history by our observations, history does not create us" [34].

How can one make rationally coherent sense out of this strange feature of QM?

I believe that the most satisfactory way is to introduce the concept of "process time". This is a "time" that is different from the "Einstein time" of classical deterministic physics. That classical time is the time that is joined to physically described space to give classical Einstein space-time. (For more details, see my chapter in "Physics and the Ultimate Significance of Time" SUNY, 1986, Ed. David Ray Griffin. In this book three physicists, D. Bohm, I. Prigogine, and I, set forth some basic ideas pertaining to time [35].)

Orthodox quantum mechanics features the phenomena of collapses (or reductions) of the evolving quantum mechanical state. In orthodox Tomonaga-Schwinger relativistic quantum field theory [36, 37, 38], the quantum state collapses not on an advancing sequence of constant time surfaces (lying at a sequence of times $t(n)$, with $t(n + 1) > t(n)$, as in non-relativistic QM), but rather on an advancing sequence of *space-like surfaces* $\Sigma(n)$. (For each n, every point on the spacelike surface $\Sigma(n)$ is spacelike displaced from every other point on $\Sigma(n)$, and every point on $\Sigma(n + 1)$ either coincides with a point on $\Sigma(n)$, or lies in the open future light-cone of some points on $\Sigma(n)$, but not in the open backward light-cone of any point of $\Sigma(n)$.)

At each surface $\Sigma(n)$ a projection operator $P(n)$, or its complement $P'(n) = I - P(n)$, acts to reduce the quantum state to some part of its former self!

For each surface $\Sigma(n)$ there is an associated "block universe", which is defined by extending the quantum state on $\Sigma(n)$ both forward and backward in time via the unitary time evolution operator generated by the Schrödinger equation. Let the index n that labels the surfaces $\Sigma(n)$ be called "process time". Then for each instant n of process time a "new history" is defined by the backward-in-time evolution from the newly created state on $\Sigma(n)$.

This new "effective past" is the past that smoothly evolves *into the future the quantum state (of the universe) that incorporates the effects of the psycho-physical event that just occurred.* As far as current predictions about the future are concerned it is *as if* the past were the "effective past": the former *actual* past is no longer pertinent because it fails to incorporate the effects of the psycho-physical event that just occurred.

In orthodox QM each instant of process time corresponds to an "observation": the collapse at process time n reduces the former quantum state to the part of itself that is compatible with the increased knowledge generated by the new observation. This sequential creation of a sequence of new "effective pasts" is perhaps the strangest feature of orthodox quantum mechanics, and the origin of its other strange features.

The *actual* evolving physical universe is generated by the always-forward-moving creative process. It is forward-moving in the sense that the sequence of surfaces $\Sigma(n)$ advances into the future, and at each instant n of process time some definite, never-to-be-changed, psycho-physical events happens. But this forward-moving creative process generates in its wake an associated sequence of effective pasts, one for each process time n. *The conditions that define the effective past associated with process time n change the preceding effective past imposing a "final" condition that represents what happened at process time n.* It is this "effective past" that evolves directly into the future, and is the past that, from a future perspective, has smoothly evolved into what exists "now". The actual past is not relevant to a history of the universe that starts from now and looks back, and projects smoothly into the immediate future.

The "histories" approach to quantum physics focuses attention on histories, rather than the generation of the profusion of incompatible possibilities. Both the effective past and the history associated with process time *n* depend upon which experiment is performed at time *n*, and in quantum mechanics that choice of which experiment is performed at process time *n* is not determined by the quantum state at process time *n*: it depends upon the agent's "free choice" of which probing action to initiate, where the word "free" specifies precisely the fact that this choice on the part of the agent is not determined by the known laws of nature.

Two key features of von Neumann's rules are mathematical formalizations of two basic features of the earlier pragmatic Copenhagen interpretation of Bohr, Heisenberg, Pauli, and Dirac. Associated with each observation there is an initial "choice on the part of the observer" of what aspect of nature will be probed. This choice is linked to an empirically recognizable possible outcome "Yes", and an associated projection operator $P(n)$ that, if it acts on the prior quantum state ρ, reduces that prior state to the part of itself compatible with the knowledge gleaned from the experiencing of the specified outcome "Yes".

The process that generates the observer's choice of the probing action is not specified by contemporary quantum mechanics: this choice is, *in this very specific sense*, a "free choice on the part of the experimenter." Once this choice of probing action is made and executed, then, in Dirac's words, there is "a choice on the part of *nature"*: nature randomly selects the outcome, "Yes" or "No" in accordance with the statistical rule specified by quantum theory. If Nature's choice is "Yes" then $P(n)$ acts on the prior quantum state ρ, and if nature's answer is "No" then the complementary projection operator $P'(n) = I - P(n)$ acts on the prior state. Multiple-choice observations are accommodated by decomposing the possibility "No" into sub-possibilities "Yes" and "No".

Mathematical Details

The description of orthodox quantum mechanics given above is a didactic equation-free account of what follows from the equations of quantum measurement theory. Some basic mathematical details are given in this section.

The mathematical representation of the dynamical process of measurement is expressed by the two basic formulas of quantum measurement theory:

$$\rho(n+1)_Y = \frac{P(n+1)\rho(n)P(n+1)}{Tr(P(n+1)\rho(n)P(n+1))},$$

and

$$<P(n+1)>_Y = Tr(P(n+1)\rho(n)P(n+1)) = Tr(P(n+1)\rho(n)).$$

Here the integer *"n"* identifies an element in the global sequence of probing "measurement" actions. The symbol $\rho(n)$ represents the quantum state (density matrix) of the observed physical system (ultimately the entire physically described universe, here assumed closed) immediately *after* the *nth* measurement action; $P(n)$ is the (projection) operator associated with answer *"Yes"* to the question posed by the *nth* measurement action, and $P'(n) = I - P(n)$ is analogous projection operator associated in the same way with the answer *"No"* to that question, with *"I"* the unit matrix. The formulas have been reduced to their essences by ignoring the unitary evolution *between* measurements, which is governed by the Schrödinger equation.

The expectation value $<P(n + 1)>_Y$ is the normal orthodox probability that nature's response to the question associated with $P(n + 1)$ will be *"Yes",* and hence that $\rho(n + 1)$ will be $\rho(n + 1)_Y$. In the second equation I have used the defining property of projection operators, $PP = P$, and the general property of the trace operator: for any X and Y, $Tr(XY) = Tr(YX)$. (The trace operation Tr is defined by: $Tr(M)$ = Sum of the diagonal elements of the matrix M).

Of course, one cannot know the density matrix ρ of the entire universe. The orthodox rules tell us to construct a "reduced" density matrix by taking a partial trace over the degrees of freedom about which we are ignorant, and renormalizing. This eliminates from the formulas the degrees of freedom about which we are ignorant.

The trace operation is the quantum counterpart of the classical integration over all of phase space. The classical operation is a summation that gives equal a priori weighting to equal volumes of phase space. That is the weighting that is invariant under canonical transformations, which express physical symmetries. The quantum counterparts of the canonical transformations are the unitary transformations, which leave the trace unchanged. Thus the orthodox trace rules are the rational way to give appropriate weights to properties about which we have no knowledge, namely by assuming that properties related by physical symmetries should be assigned equal a priori weights.

All this is just orthodox quantum mechanics, elaborated to give a rationally coherent ontological account compatible with the standard computational rules and predictions [39].

But the assumption that nature gives equal weights to properties that we, in our current state of scientific development, assume should be given equal weights, does not mean that nature itself must give such properties equal weight. Two states of the brain that are assigned equal statistical weight by the orthodox trace rule may be very different in the sense that one corresponds to a meaningful, coherent, pleasing experience and the other does not. Classical mechanics postulates that experiential qualities, per se, can make no difference in the flow of physical events. But, since quantum mechanics places experiences in a much more central role than classical mechanics, there is no rationally compelling reason to postulate in quantum mechanics that nature, in the process of choosing outcomes of empirical questions posed by agents, must be oblivious to the experiential aspects of reality. That issue should be settled by empirical findings, not by classical-physics-based prejudice.

Consider a situation in which: (*1*), an agent (the participant) observes a property that corresponds to a projection operator *P*; and (*2*), a dynamically independent random number generator (*RNG*) creates either the property represented by the projection operator *Q*, or the property represented by the complementary property $Q' = (I - Q)$. Suppose at some time after these properties have been created they are still confined to two different systems that have never interacted, so that $PQ = QP$, and $\rho = \rho(P)\ \rho(Q)$. Then the probability of getting the answer (*PYes*), given that (QYes) occurs, is:

$$Trace\, PQ\rho/Trace\, Q\rho = Tr\, P\rho(P)/Tr\, \rho(P),$$

which is independent of *Q*: the probability of *P* does not depend on what the dynamically independent *RNG* does.

Suppose, now, the two systems interact later, beginning at time *t*, then the propagation to a final later time *t'*, at which time an observable corresponding to projection operator *R* is measured. The predicted statistical correlation between the outcomes of the measurements associated with *P* and the outcomes of measurements associated with *Q* will now normally depend upon whether the outcome of the final measurement is the *"Yes"* associated with projection operator *R*, or the *"No"* associated with the projection operator $(I - R)$. But the orthodox rules ensure that if one sums the contributions from *R* and $(I - R)$, using the weights prescribed by those orthodox rules, then this dependence on R will drop out. If, on the other hand, the probabilities of nature's choices between *R* and $(I - R)$ differ from the orthodox ones, then, after Nature's biased choice, the theory predicts observable correlations between the outcomes of the measurements of *P* and *Q*: the outcomes of these measurements that are predicted to be *un*correlated by orthodox quantum mechanics will now be predicted to be correlated. This change in the predictions arise from the contributions of some extra weighted histories brought in by Nature's biased choice, and the absence of some other weighted histories.

Applications to Bem's Experiments

All nine of Bem's experiments have the following general form: First, in each instance in a series of experimental instances, the participant is presented with some (in most cases emotionally neutral) options, and picks a subset of these options as 'preferred'. These preferences are duly recorded. *Later*, for each instance, an emotional stimulus is applied to the participant. The stimulus, and the way it is applied to the participant, is determined by some random number generators (RNGs). These RNGs are, according to both classical and quantum ideas, dynamically independent of the participant's earlier actions. But Bem's empirical result is that the probability that an option is preferred by the participant at the earlier time depends upon choices made later by the RNGs.

This finding seems to suggest that either the believed-to-be dynamically independent RNGs are being influenced in a mysterious and complex way by the participant's earlier actions; or the participant's earlier actions are being affected in a complex retrocausal (backward-in-time causal) way by the choices made by RNGs.

The kinds of actions made by the participant, and by the RNGs, vary greatly over the nine experiments. But, from a quantum standpoint, one single presumption explains all of the reported results, and explains them all in a basically forward-in-time causal way, without any mysterious influence of the participant's choice of preference on the RNGs. This presumption is that the choices on the part of nature, which are essential elements of orthodox quantum mechanics, are slightly biased, relative to the orthodox quantum statistical rules, in favor of the actualization of positive feelings in the mind of the participant, or, in other cases, against the actualization of negative feelings.

For example, in the first Bem experiment the participant is shown two similar screens, L and R, and is told that behind one screen lies a picture, and behind the other lies the image of a blank wall. S/he is instructed to choose a "preferred" screen, P (either L or R) behind which s/he *feels* the picture lies. *After* the participant's preference P, either L or R, is recorded, a first random number generator, RNG1, chooses a "target" screen T (either L or R), and assigns a *picture* to target screen T, and an image of a blank wall to the other screen. A second random number generator, RNG2, decides, with equal probabilities, whether the picture will be "Erotic" or "Neutral" (The stimulus type S is either E or N). What has been determined by the RNGs to lie behind the preferred screen P is then shown to the participant.

Bem's empirical result is that the participants choose, more often than orthodox quantum mechanics (or classical statistical mechanics) predicts, the screen behind which *will lie* an erotic picture, but prefers L and R with equal probability if RNG2 chooses a "neutral" picture.

If the well-tested random number generators are working as they normally do then this empirical result would appear to be a case of retrocausation (causal action backward in time): the choices made *later* by the two RNGs are influencing the subject's *earlier* choice between L and R. The idea that the present can *actually* change the past would introduce huge conceptual problems into quantum mechanics, and would require a major re-thinking and re-construction of the entire theory, centering on the problem of how to retain the massive body of valid predictions. It would bring into play Hofstadter's observation that the whole edifice of contemporary theory would be toppled. Changing the past would often cause big changes in the present. How could one salvage the predictions of the tremendously successful orthodox physical theory?

An alternative possibility is that RNG2, which chooses between "erotic" and "neutral", is being influenced by the participant's earlier choice between L and R, so that the screen behind which the participant looks will tend to be erotic. But this should occur only if RNG1 chooses “picture” not “blank wall”. Moreover, the key variable is an emotional response on the part of the subject that has not yet occurred when the supposed action of the subject’s earlier choice between two *neutral images* upon RNG2s choice is supposed to occur. That emotional response is fixed by an arbitrary mechanism, designed by the experimenters, that has not yet been brought into play.

These problems constitute major difficulties. But Bem’s results are explained in natural, rational, essentially forward-causal way, without any apparent difficulties, provided *Nature’s choice of the participant’s final experience*—a choice that is an absolutely essential element of orthodox quantum theory—favors, relative to the statistical predictions of orthodox quantum mechanics, the occurrence of positive (pleasing) experiences and disfavors the occurrence of negative (displeasing) feelings. If such a biasing of Nature’s choices were to occur, then the observed greater likelihood of the participant’s choosing the screen, L or R, behind which an erotic picture *will lie* would arise directly from the enhanced likelihood that nature will actualize an erotic experience rather than an experience of a neutral picture or a blank wall.

In this experimental set up an erotic experience can occur only if P = T and S = E: the participant’s earlier choice of the between L and R must agree with the later choice of RNG1 between L and R, since otherwise the participant will see only a blank wall, and even if P = T, the choice of stimulus S must be E, since otherwise the participant will see a neutral picture.

A compact way of stating this explanation is to say that the quantum histories [defined by the sequences of choices (P, T, S, F) leading to the final experience F = +, or F = −] that lead to F = + are more likely to occur than the rules of orthodox quantum mechanics predict. Only those histories in which the two L/R choices agree (P = T) can lead to an erotic experience, because if these two choices disagree the participant will see a blank wall. But this enhancement will occur only in the subset of histories in which S = E.

In Bem’s Experiment 2, “Precognitive Avoidance of (Subliminal) Negative Stimuli”, a sequence of similar pairs of neutral pictures is shown to the participant, who chooses a ‘preferred’ picture from each neutral pair. After each such recorded choice of preference P, a RNG1 makes a random choice of one picture from the initial pair. The picture chosen by RNG1 is called the ‘target’ T. Then the apparatus flashes a *subliminal* picture, the stimulus S, that is positive, S = +, if T = P, but is highly negative, S = −, if the preferred neutral picture P is *not* the subsequently randomly chosen target picture T.

The normal idea of forward causation does not allow this random choice of target, and the associated application of a stimulus, both of which occur *after* the recorded choice of preference, to affect, in any instance, the participant’s previously recorded choice of preference between two matched neutral pictures. Yet Bem’s predicted and empirically validated result is that the picture P preferred at an earlier time by a participant is more likely to be the subsequently chosen target picture T than the subsequently chosen non-target, even though the choice between target and non-target was 50–50 random, and was made only later. The non-targeted pictures, which are, according to Bem's empirical findings, less likely to be preferred than chance predicts, are the pictures that occur in conjunction with the later subliminal application to the participant of highly unpleasant pictures. Hence they should lead to unpleasant participant feelings and should therefore, according to the present hypothesis, be less likely than chance predicts to be selected by Nature's choice to become an actually experienced outcome:

$$<(\mathrm{P}, \mathrm{T}\,\mathrm{not}\,\mathrm{P}, \mathrm{S}-, \mathrm{F}-)> \; < \; <\mathrm{P}, \mathrm{T} = \mathrm{P}.\,\mathrm{S}+, \mathrm{F}+ > .$$

This experimental protocol is quite different from the protocol of the first experiment. In the first experiment the stimulus that was applied later to the participant was independent of the participant's earlier choice of preference, whereas in experiment 2 the stimulus that is applied later to the participant depends upon the earlier choice of preference. Moreover, the stimulus was supraliminal in the first experiment but subliminal in the second experiment.

Nevertheless, the apparently retrocausal effect in the second experiment follows from the same quantum assumption as before, namely that Nature's choice of which final experience actually occurs has a tendency to increase the likelihood of positive, and diminish the likelihood of negative, final *feelings* of the participant. In experiment 2 the effect of this biasing is to diminish the likelihood of instances in which the *final feeling* of the participant is negative, due to the earlier application to the participant of an (albeit subliminal) highly negative stimulus.

Bem's experiments 3 and 4 are "Retrocausal Primings". Unlike the first two experiments, they do not involve matched neutral pairs between which the participant must choose. Rather, each instance now involves a single picture, which is emotionally either positive or negative. This non-neutral picture is shown to the participant, who responds by pressing a first or second button according to whether s/he feels the picture to be pleasing or not. The *time* that it takes for the participant to react to the picture is recorded. *Then,* a 'word' is selected by a RNG, and is (supraliminally) shown to the participant. The previously recorded reaction time turns out to be shorter or longer according to whether feeling of the word is "congruent" or 'incongruent" to the feeling of the picture experienced earlier. For example, the word "beautiful" is congruent to the picture of Grace Kelly, but incongruent to a picture of Bela Lugosi as Count Dracula.

There is also a 'normal' version of the experiment in which the word chosen by the RNG is displayed *before* the participant chooses his preference. Bem's experimental set-up is one for which, also in the 'normal' version, the recorded reaction time is shorter or longer according to whether feeling of the word is "congruent" or "incongruent" to the feeling of the picture shown earlier.

The question at issue is: How, in the retrocausal version, can the *reaction time*, which was recorded *earlier,* depend on which word was randomly selected *later*?

This empirical finding is explained by an assumed biasing of "Nature's choice" of the participant's final feeling that favors congruency in the flow of experience over incongruency. Such a putative biasing of Nature's choice has the effect of adding to the effective past, after nature's biased choice, some extra histories that lead to the mentioned positive feelings, or to the subtraction of histories that lead to analogous negative feelings. These differences in the set of contributing histories, in accordance with the nature of the feeling induced by the stimulus word, have an effect on the quantum state of the participant's brain *during the process of his or her choosing between positive and negative pictures.* This effect on the brain during that period is similar to the effect of applying a similar stimulus before the participant's choice of response. In both cases the "effective past" state of the brain of the participant during his or her process of choosing a response is changed in essentially the same way: it is not important whether the change in the effective state of the participant's brain, during the process of choosing his or her preference, comes from changes in the earlier or later boundary condition on that "effective past" state of the brain. The key point is that, as discussed in earlier sections, the "effective past" incorporates the conditions imposed by the occurrence of the *final* outcome! A "history" starts from what is now known, and extends backward from the known present, which depends on nature's most recent choice.

The next three experiments relate to the well-known phenomena of "habituation". The participant is again shown an emotionally matched pair of pictures, and is asked which one s/he prefers. The two matched pictures are both strongly negative, both strongly positive (erotic), or both essentially neutral in the first, second, and third experiments, respectively. (I have slightly reorganized Bem's data in this way for logical clarity, and ignored some inconclusive data with small statistics in which certain later stimuli were supraliminal.) After the participant makes a binary recorded choice of preference, an RNG chooses one of the two similar pictures as target, and the targeted picture is subliminally flashed several times. The subliminal re-exposures, made after the participant's choice of preference of the targeted emotion-generating picture, have the effect of reducing, in the case of the positive pairs of pictures, and increasing in the case of negative pairs of pictures, the fraction of instances in which the (previously) preferred picture was the target rather than the non-target: the effective positivity/negativity of the targeted (and hence repeatedly subliminally represented) pictures was reduced. This is explained by a *reduction* in the emotional intensity of the participant's final feeling, caused by the repeated re-exposure to the highly emotional pictures, and the attendant *diminuation* of the biasing of Nature's choices.

In the final two (memory) experiments the participant is exposed to a sequence of 48 common everyday nouns, and is then tested see which words s/he remembers. Afterwards, 24 of the original set of words are randomly chosen to be 'targets, and then, in a sequence of computer-controlled actions, the participant is repeatedly re-exposed to each of the target words, but to none of the non-target words. It is subsequently found that among the recalled words there are more target words than non-target words. This is explained if Nature's choice of the participant's final feelings favors the feel of congruent streams of conscious experiences over the feel of less congruent ones.

Of course, the actual past has not been changed. If the participant had been graded "pass or fail" according to the number of words recalled, then his grade would not depend upon what happened later. In that earlier test each initially presented word would either be recalled or not recalled, and s/he would pass of fail on the basis of the number recalled. Suppose 60% are recalled and 40% are not recalled, which is failing. Given any thus-determined particular individual outcome one could find out, after the experiment, whether it was targeted or not. Suppose, as an extreme case, that targeting is extremely effective and that every targeted word is recalled, and no non-targeted word is recalled. That would give a perfect positive correlation between recall and targeting, but would not change the grade from failing to passing. If Nature's choices can be biased relative to the orthodox predictions in the way indicated by the Bem experiments, then empirically observed correlations between recorded past events can be a consequence of the actualizing capacity of Nature's biased choices, rather than an expression of correlations that existed prior to Nature's choices of which of the quantum-generated potentialities to make actual. This would render the past unchangeable, but the future somewhat dependent upon our desires, and the congruency of thoughts.

All of Bem's reported results are thus explained by a single presumption, namely that Nature's choices, rather than being strictly random, in accordance with the rules of contemporary orthodox quantum mechanics, are sometimes slightly biased, relative to the predictions of orthodox quantum mechanics, in favor of outcomes that feel pleasing, and against outcomes that feel displeasing.

This explanation is "scientific", in the sense that *it can be falsified*. If the output of the RNGs were to be observed by an independent observer, *before* the RNG-chosen action is made on the participant, then the biasings reported by Bem should disappear, because Nature's choice would then be about the possible experiences of the independent observer rather than about those of the participant.

A more elaborate test would be to have two participants doing the experiment on the same sequence of pictures, with reversed polarities. A dependence upon who first experiences the output of the RNG would, if it were to occur, constitute spectacular support for the notion that our experiences really do influence the course of physically described events, rather than being merely causally inert by-products of a process completely determined by purely physical considerations alone.

In the above discussion I have treated all of the RNGs as true quantum-process-based random number generators. In some of the experiments the RNG was actually a pseudo-random number generator, a PRNG. In principle a PRNG is, in these experiments, just as good as a true RNG, unless *at the time of its effective action* some real observer *actually knows* everything needed to specify what the pseudo-random choice must be. Unless the outcome is actually specified by what is actually currently known by observing agents, the outcome is, within this orthodox framework, effectively undetermined.

Conclusion

Bem's seemingly backward-in-time causal effects can be explained within a quasi-orthodox forward-in-time quantum mechanics. In this variation of orthodox theory, Nature's "random" choices of which outcomes of measurements to actualize are slightly biased away from the random choices prescribed by the orthodox theory in favor of outcomes that actualize positive feelings of the participants, and against outcomes that actualize negative feelings of the participants.

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Appendix E
The Quantum Conception of Man[1]

Quantum Mechanics, Consciousness, Spooky Action-at-a-distance, Bell's Theorem, and Free Will

Each of these topics is a deep subject about which much has been written. I intend to describe here tonight my own view of how these various elements fit together to form a rationally coherent understanding of the world that we human beings inhabit, and of our role within it.

I have been thinking about the matters for more than 50 years. Already in 1958 I was working on them in Zurich with Wolfgang Pauli, a principal founder of quantum mechanics.

When he unexpectedly died, I read von Neumann's book on these matters, and then wrote an essay to myself entitled:

> Mind, Matter, and Quantum Mechanics,

which eventually developed into a 1993 book of the same title.

In the seventies I worked on these matters in Munich with Werner Heisenberg and wrote in the American Journal of Physics a seminal article entitled "The Copenhagen Interpretation of Quantum Mechanics". I have continued to think and write about these matters.

The first topic is quantum mechanics. In order to understand Quantum Mechanics, it is important contrast it with what came before it, namely "Classical Mechanics". Classical Mechanics was created by Isaac Newton, who said "It seems to me probable that God in the beginning created matter in solid, massy, hard, impenetrable movable particles." These particles can interact locally by contact, like billiard balls. But they can also act upon each other by gravitational attraction. In Newton's theory gravity acts instantaneously over astronomical distances. Thus already at the beginning of modern science we encounter a "Spooky action-at-distance."

However, about 200 years later, Maxwell created a wave theory of the interactions between charged particles: The information carried by such a wave could be

[1]Talk presented to the Mount Diablo Astronomical Society, January 27, 2015.

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transmitted no faster than a certain maximal speed that could be calculated, and turned out to be the empirically measured speed of light. Maxwell's waves were Light Waves.

A few years later Einstein, in his theory of relativity, re-formulated all of classical physics so that no physical structure could transmit information faster than the speed of light. Thus Einstein banished Spooky action-at-a-distance from classical physics.

A second main property of classical physics is physical determinism, which says that all physically described properties are completely determined by prior physically described properties.

This property is also called the "Causal Closure of the Physical". It means that the behavior of your physical body was completely predetermined already at the birth of the universe:

This property turns you into a mechanical automaton, and converts your intuition that your conscious "free will" can influence your bodily behavior into a pervasive illusion.

However, that conclusion does not carry over to the quantum world.

Quantum Mechanics.

The quantum story begins with Max Planck's discovery at the beginning of the twentieth century that Light Waves have a corpuscular character: The transfer of energy between light waves and physical particles seems to occur in finite "chunks", called "quanta". The sizes of these "chunks" are directly proportional to the frequency of the light.

Atomic physicists then tried to construct a conception of atoms that would account for all the existing empirical facts. They tried at first to use the same kinds of ideas that Newton had used to explain the motions of the planets circling about the sun to explain, now, the motions of the electrons circling about the atomic nucleus. A 25 year struggle showed that that idea would not work. Then Heisenberg, and also Schrödinger, working independently, discovered the equation that made it all work. And that equation, properly generalized, covered not only single atoms, but also collections of arbitrarily large numbers of atoms, and hence large hard objects such as tables and chairs, and also, among other things, the measuring devices that are used to measure atomic properties. The theory gives predictions about, for example, the location on a dial of visible "Pointer". The position of this pointer reports to us human observers the value of some microscopic property of the system being examined.

The problem, however, is that this straight-forward prediction does not agree with human perceptions. The predicted position of the pointer turns out to be a smear over a large range of possible values, whereas the human observers see the position of the pointer confined, within small errors, to some tiny region of the dial.

Thus the basic problem is:

How are we to deal with this sharp disagreement between the quantum laws, which in principle ought to control the evolving state of the (interacting) atomic constituents of the world, with our perceptions of the world composed of those constituents?

The solution offered by quantum theory is expressed in Bohr's oft-repeated dictum:

> In the drama of existence we are ourselves both actor's and spectators,

and in John Wheeler's likening of the quantum process of measurement to the game of twenty questions.

The details of this solution are most clearly spelled out in John von Neumann's rigorous reformulation of Copenhagen Quantum Mechanics. He explicitly introduces into the quantum dynamics, in addition to the normal quantum dynamical process, which he calls Process II, another dynamical process that he calls Process I.

This Process I converts the "Mental Observer" from a causally inert Spectator to a causally efficacious Actor. This Process I action has two phases. In the first phase the observer's mental aspect, his "ego" in von Neuman's terminology, poses a question: "Will my perception be P, where P is a classically described perception." In the second phase "Nature chooses and implements a psycho-physically described response, "Yes" or "No" to the observer's query.

The two main points are, first, that the observer's mental aspects are given a certain physically effective dynamical role in the evolution of the physically described universe—and, second, that a globally effective "Nature" produces an instantaneous global collapses that reinstate "Spooky action-at-a-distance".

This active dynamical role of the "Ego", even though it is only to instigate probing physical actions, is sufficient to allow, by means of rigorously specified basic quantum mechanical properties alone, a person's mental intentions to influence that person's bodily behavior in the mentally intended way. Quantum mechanics thus explains how your free-willed mental choices can be causally effective in the physical world!

It must be mentioned that in the late 1940s physicists (Tomonaga/Schwinger) created "Relativistic Quantum Field Theory", which allows all of the *empirical* consequences of Einstein's theory of relativity to be maintained in spite of the underlying spooky actions-at-a-distance associated with measurements.

Personal and Social Benefits of the Rescue of Free Will.

1. According to classical mechanics, your mental willful efforts can make no difference in the physically described world. If you are a rational person who bases your beliefs about the world upon science, then a belief in classical mechanics is debilitating, for it rationally causes you to believe that any effort you might make to improve your life or the lives of others is completely futile. On the other hand, your updated knowledge of the quantum mechanical character of the world is empowering because it lends scientific support to your essential-to-life, and experience-based, intuition that actions initiated by your value-based efforts can tend to bring pass that which you personally value.
2. Our legal system is based on the idea of personal responsibility for one's physical actions. But, according to classical mechanics, every physical action was predetermined at the birth of the universe. A person cannot rationally be held responsible for physical actions that were physically pre-ordained at the

birth of the universe. Quantum mechanics, on the other hand, does not entail any such physical predetermination, and thereby evades the classical-mechanics-based challenge to the rationality of our justice system!

Bell's Theorems.

Einstein banished Spooky action-at-a-distance from classical mechanics. His reaction to the instantaneous action at a distance that occurs in standard quantum mechanics was to agree with the founders of quantum mechanics that the rules of quantum mechanics should be viewed as mere practical computational procedures that allow scientists to make reliable predictions about future human experiences on the basis of their past experiences/perceptions. But Einstein believed that behind these merely statistical rules should lie a "reality" that likewise involves no Spooky action-at-a-distance.

Already in classical mechanics one can draw a distinction between a statistical state of a system and the underlying "real" possible states of that system: The statistical state is represented as a sum of terms each of which is a product of a positive weight factor times a possible "real" state.

John Stuart Bell formulated Einstein's position as the assertion that each of the statistically interpreted states of quantum mechanics can be expressed as a sum of terms each of which is a product of a positive weight factor times a possible "real" state that, in accordance with Einstein's intuition, allows no faster-than-light-action-at-a-distance. Bell and his associates proved many theorems that showed that no such decomposition is possible.

Those theorem's address one possible formulation of Einstein's position, but not the general question of whether the various empirical predictions of quantum mechanics can be satisfied if all spooky actions-at-distance are banned, in the sense that (in the standard example of a pertinent experiment, proposed by David Bohm) for each of the two alternative possible choices of which property is measured in a region the outcome there is independent of which experiment is freely chosen and performed at essentially the same time very far away. That is a cleaner formulation of Einstein's stated position, and it can be shown that such a banishing of Spooky actions cannot be reconciled with four basic and empirically well-validated predictions of quantum mechanics.

This result shows that Spooky actions cannot be banned, and hence that a materialistic conception of the physically described aspects of the world is incompatible with the empirical facts!

Appendix F
Mind, Brain, and Neuroscience

Introduction

The currently dominant theories of the connection of our conscious thoughts to our physical brains are based on the principles of classical mechanics. But those theories have achieved essentially no success in answering the "hard" question of how things as conceptually disparate as our conscious thoughts and classically conceived matter can combine together to form psychophysical human beings.

Yet classical mechanics is known to be empirically false. It has been replaced at the fundamental level by quantum mechanics. The primary difference between these two theories is that the classical mechanics never mentions our experiences whereas quantum mechanics is fundamentally about them, as Niels Bohr has often emphasized in statements such as:

> 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 the multifold aspects of our experience [I, 18].

Thus our conscious experiences are the fundamental realities in quantum mechanics, whereas classical mechanics leaves them completely out.

It is therefore manifestly obvious that if a rational understanding of the mind-brain connection is being sought then quantum mechanics is the better theory to use. But why, then, are neuroscientist not using it?

The answer, I believe, it is simply that neuroscientists have not been shown how to do so. They have not been shown how to use the quantum mechanical model of the human person to compute, for example, the measured in vivo brain response to an associated mental choice.

My purpose in this talk is to illustrate how this is done, and compare the results to recent pertinent neuroscience data.

This example illustrates the quantitative workings of the quantum mechanical explanation of the influence of conscious intentions on in vivo brain activity.

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Classical Description

An important feature of the seismic shift from classical to quantum mechanics is that the descriptive concepts of the earlier classical mechanics do not drop out, or fade away, but are transferred from the material reality that was supposed to lie *behind* our experiences to our experiences themselves. Thus in the words of Niels Bohr:

> …it is important to recognize that in every account of physical experience one must describe both the experimental conditions and the observations by the same means of communication that is used in classical physics (II, p. 88).

Von Neumann's Solution to the Quantum Measurement Problem

The immediate consequence of this transfer of classical description to the mental realm is that, in practical measurement situations, the scientist is instructed to divide the world by a cut, called the Heisenberg cut, such that big things directly observed by observers are placed above the cut, and are described in terms of the concepts of classical mechanics, while things lying below the cut are described in quantum mechanical terms.

This rule was imprecise and ambiguous, and led to the so-called "measurement problem." John von Neumann, on the basis of a detailed mathematical examination, resolved this problem by moving the Heisenberg cut all the way up, until everything normally considered to be part of the material world built of atoms and molecules, and of the electromagnetic and gravitational fields that they generate, were placed below the cut and were described in quantum mechanical terms, whereas our conscious experiences, including our perceptions, were generally described in psychological terms, *but with our perceptions of the external world expressed in the usual way associated with the concepts of classical physics.*

The theory thus becomes a genuine psychophysical theory with the boundary between our conscious experiences and the underlying atom-based physical world lying at the mind-brain interface. A key aspect of the theory thus becomes a description of what is happening at the mind-brain interface between the experience-based mental aspects and the quantum mechanically described atom-based aspects of the evolving reality.

Classical Description, Oscillations, and the Quantum Mechanical "Coherent States" of the Electromagnetic Field

What we see, do, and intend to do is described at the mental level in classical terms, but at the brain level in quantum mechanical terms. This need to correlate a classical mental description to a naturally corresponding quantum counterpart at the

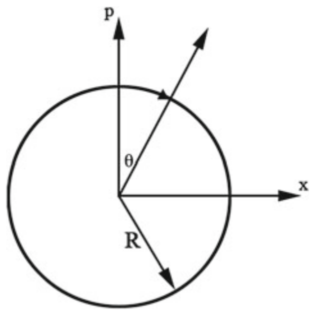

Fig. F1 SHO Kinematics

mind-brain interface is met by taking this connection to be via the well-known "coherent states" of quantum electrodynamics. These are quantum states that exhibit a simple harmonic oscillator (SHO) motion that is essentially identical to a classical SHO motion, except that the classical point particle is replaced by a minimum uncertainty Gaussian quantum wave packet whose center point follows the phase-space trajectory of the classical oscillating point (Fig. F1).

Our interest is in the possible influence upon the radius R of the mental choices made by the owner of the brain, within the framework of von Neumann's dynamical theory of the mind-brain connection.

Von Neumann's Dynamical Theory of the Mind-Brain Connection

The central problem in quantum mechanics is that the basic dynamical equation, the Schroedinger equation, generates not the actual evolving physical reality itself, but only a smear of potentialities for future actualities.

But then how does what actually occurs get picked out from the smear of potentialities?

"What becomes actual" is not picked out by nature acting alone. According to quantum mechanics, some subject/observer/agent must pose a question: "Is my immediately-to-appear experience Experience X?" Yes or No?. Nature immediately answers, and in the "Yes" case delivers Experience X to the observer. In either case, nature changes (instantaneously in a certain way) the entire physical world by eliminating all features that are incompatible with the delivered answer, Yes or No, that it has just chosen. This action takes care of the EPR correlations between outcomes of effectively-simultaneous far-apart experiments.

That choice of probing question on the part of some observer will single out some classically describable possibility. Quantum mathematics does not specify what question will be asked. The choice, according to quantum ideas, is “a free choice on the part of the observer”, where ‘free’ emphasizes that the choice is not determined by the known laws of physics. The fact that what question is asked is classically describable accords with the idea that this choice comes from the mental realm of the observer.

The Pertinent Numbers

The measured general numbers for the Cortex are:

Size of computational unit: $Sz = (1/20 \times 1/20 \times 2.4) \times 10^{-9} m^3$

$$= 6 \times 10^{-12}$$

[Ref. Brain 125(5), 935–951, Buxheoven & Casanova.]

Strength of the magnetic field: H = ½ picotesla

SHO frequency: 20 Hz

R = Radius of SHO orbit in the usual Modified Phase Space in which the coordinate variable is

y = [sq.root $\left(\bar{h}/m\,\omega\right)$] times coordinate variable X, (X meters) (m = 1 kg) (mks units) (angular velocity ω in radians per second) [20 Hz => ω = 20 × 2pi]

[Ref. Wikipedia: Quantum harmonic oscillator]

$$\text{Energy} = 2 \times \left({}^{1}\!/_{2} H^2/\mu_0\right) \times Sz = \omega \times \bar{h} \times R^2$$

$$\mu_0 = 4\pi \times 10^{-7} \bar{h} = 10^{(-34)} \text{ in mks units}$$

$$\begin{aligned} \text{Energy} &= \left({}^{1}\!/_{4} 10^{(-12)}\right)^2 \times (1/4\pi) \times 10^7 \times 6 \times 10^{-12} \\ &= {}^{1}\!/_{4}(6/4\pi) \times 10^{(-29)} \\ &= {}^{1}\!/_{4}(60/4\pi) \times 10^{-(30)} \\ &= 15/4\pi \times 10^{(-30)} \\ \sim &= 10 \times 10(-31) \end{aligned}$$

$$\begin{aligned} \text{Energy} &= \omega \times \bar{h} \times R^2 \\ &= 20 \times 2\pi \times \left(10^{-34}\right) \times R^2 \\ &= (1/8) \times \left(10^{-31}\right) \times R^2 \end{aligned}$$

$$R^2 = 80 \quad R \sim = 9$$

This number indicate that the process is at the quantum scale, and that a small change ΔR in R can give a significant change in the pertinent energy R^2.

The Quantum Zeno Mechanism for Mental Control of Bodily Action, and Recent Empirical Evidence from Neuroscience

Let Ψ(R) be the quantum SHO state whose center is located at radius R on the rotating ray that represents the 20 Hz EM oscillation in the computational unit.

If the current state is Rho(R), and one asks the question "Is the state $\Psi(R + \Delta)$?", then the probability that the answer is "Yes" is $|<P(R)|\Psi(R+\Delta)>|^2$, which for small Δ is $(1-\Delta^2)$.

If Δ is small, then the number N of probing questions that one can ask such that with 90% probability the answers will all be "Yes", so that the intended increase in R will occur with probability at least 90%, is therefore the N such that N $\Delta^2 = 1/10$, or $N = (1/(10\Delta^2))$. Hence the agent can achieve an intended objective $\Delta R = N\Delta$ with 90% certainty if $\Delta R = 1/(10\,\Delta)$ for small Δ.

A pertinent question is: What rates of probing actions are needed in order to account, via this QZE mechanism, for the correlations found recently in neuroscience between intended actions and brain activity? Do we need extremely rapid probing rates?

Reference [1] describes statistically significant correlations between instructed manual motions of monkeys (which I am considering to be governed by QZE) and electromagnetic activity in the motor cortex. Figure 1c at 20 Hz and near 100 ms shows significant structure occurring over a 10 ms interval.

Ref. [1] Nature neuroscience, Propagating waves mediate information transfer in the motor cortex, Doug Rubino, Kay Robbins, & Nicholas Hatsopoulos. (Full text available on Wikipedia.)

If one wishes to achieve a certain increase ΔR over a ten millisecond interval with a uniform set of increases Δ this $\Delta = 1/(10\ \Delta R)$, and the number of steps needed is

$$N = (1/10)\Delta^{(-2)} = (1/10)(10\,\Delta R)^2 = 10 \times (\Delta R)^2$$

To achieve a unit change ΔR in R this number is 10, and the probing actions need occur only once each millisecond. These are normal time scales for neuroscience.

By comparing Fig. 4b, with field potentia 0.5 mV to Fig. 7 with field potentia 20 μV = 0.02 mV I surmise that the R that we are dealing with is probably much less than 9, and that ΔR is therefore not large. So the empirical numbers suggest that the results shown in Ref. [1] are probably concordant with the proposed understanding of von Neumann's theory of the mental causation of bodily action.

Appendix G
Transcending Newton's Legacy[2]

Science can influence our lives in many ways. The influence via technology is evident. But influence through effects on social institutions, such as church and government, can also be important. For example, the well-known influence of Newton's idea of "laws" upon the U.S. constitution could, in view of the immense influence of government upon our rights and freedoms, and upon our economic environment, be exerting tremendous influence upon our lives.

But more important than either of these is probably the influence of science upon our idea of what we are; upon our idea of our place in the universe, and of our connection to the power that forms it. For our aspirations and our values spring, in the end, from our idea of what we are, and nothing is as important in our lives as the nature of the ideas that motivate our actions, and the actions of others.

Science was transformed during the twentieth century by three revolutionary developments: the special theory of relativity, the general theory of relativity, and quantum theory. These developments altered not only scientific practice, but also our ideas about the nature of science and the nature of the world itself. I shall discuss here these three developments with regard to both their essential differences from classical Newtonian science, and their potential impact upon the human condition.

Newtonian Science

Newtonian science must be distinguished from the full thought of Isaac Newton. The former may be characterized by the following three conditions:

1. Absolute Time and Absolute Space. Newton's starting point is the idea of a "true" time and a "true" space. Each is independent of anything external to it,

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and has an inherent quality of uniformity or homogeneity. These two "absolutes" are contrasted by Newton to their "relative", or "apparent" counterparts, which we can grasp through our senses, and can measure by means of clocks and rulers.

2. Local Ontology. Absolute space is conceived by Newton to be populated with small bodies or particles that move with the passage of absolute time.
3. Fixed Laws of Motion. The motions of the particles are governed by "laws". These laws cause the locations and velocities of all particles at all times to be determined by the locations and positions of all particles at any single time. The world is therefore deterministic: its condition at one time determines it condition for all time.

These features of Newtonian science give us a picture of the universe called the Mechanical World-View. According to this view the universe consists of nothing but objectively existing particles moving through absolute space in the course of absolute time in a way completely determined by fixed laws of motion.

This picture of the world is mathematical: the objects are described mathematically, by numbers that give the locations and velocities of all the particles. Moreover, the laws that govern these numbers are mathematical. That Newton aspired to the creation of a mathematical picture of Nature is proclaimed by his title: Mathematical Principles of Natural Philosophy.

Three Problems

Some difficulties with this picture of Nature were evident from the start.

I mention three:

(1) Action-at-a-distance
(2) Creation
(3) Freedom

(1) **The Problem of Action-at-a-Distance.**
The centerpiece of Newton's science is the law of gravity. According to this law, every body in the universe acts instantaneously upon every other one, even though they be separated by astronomical distances. Newton's recognition of a problem with this idea is expressed clearly in his famous assertion: "That one body can act upon another at a distance through the vacuum without the mediation of anything else … is to me so great an absurdity that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it". The ontology set forth in the Principia has, however, nothing to mediate the force of gravity. Newton worked hard to find carrier for gravity compatible with the available empirical evidence, much of which came from his own experiments. Finding in the end nothing

that met his standards he declared: "hypothesis non fingo": I frame no hypothesis.

Two contrasting attitudes toward physical theory can thus be found in Newton's thinking. One attitude reflects his basic overriding commitment to search for truth about Nature. This commitment is massively displayed by his extensive researches into alchemical and theological questions pertaining to the constitution of Nature, by his choice of title mentioned above, and by his careful attention, in the formulation of his principles, to philosophical and ontological details. The second attitude goes with his "hypothesis non fingo". This declaration entails that his theory, as it stood, must, strictly speaking, be construed not as an ontological description of Nature itself, but merely as a codification of connections between measurements. The theory must be viewed as a system of rules that describes how our observations hang together, not as a description of the underlying reality.

These two contrasting attitudes toward physical theories will be the focal point of my discussion of how Newton's ideas fared in the twentieth century. The issue concerns two views of the nature of physical theory. One view holds that basic physical theory ought to provide a description of the real stuff from which the universe is constructed—it should describe the ultimate things-in-themselves.

The second view holds that physical theories should deal fundamentally with quantities that can be measured—they should merely codify the structural features of measurable phenomena.

(2) The Problem of Creation.

The second problem is the problem of creation. Given the Newtonian precepts two questions immediately arise.

1. What fixed the nature of the particles and their laws of interaction?
2. What fixed the initial locations and velocities of the particles in the universe?

Within Newtonian science these two questions are insoluble. Thus from the perspective of the first attitude described above, which holds that basic physical theory should describe the real world, the account provided by Newtonian science is deficient, for it requires something external to the physical world it describes: it needs something to set up the system and fix the undetermined parameters.

From the second point of view, which is that science should merely codify, not explain, this problem of creation might seem to be no problem at all. But the problem is then with the point of view itself, which tends to close off the pursuit of the further knowledge. For, today, within the quantum theoretical framework, physicists are examining theories that purport to answer the first of the questions raised above, just on the basis of self-consistency. Moreover, the second question is moving into science in connection with studies pertaining to the birth of the universe—the big bang. The question is therefore this: "To what can science aspire?" Can it cope with the problem of creation, or must it remain forever mute on this basic question?

(3) The Problem of Freedom.

Beyond these questions is one far more pressing to man. The mechanistic world-view proclaimed by Newtonian science, and "validated" by its technological success, insists that all creative activity ceased with the birth of the universe. It tells us that we are now living in a "dead" universe that grinds inexorably along a path pre-ordained at the birth of the universe, and held in place by immutable laws of nature. Thus any notion that we can, by our efforts, act to bring into being one state of affairs rather than another is sheer illusion and fantasy.

This dreary view is proclaimed in the name of science, and is backed by its authority. Banished, together with freedom, is any rational notion of human responsibility. For responsibility can be placed only where freedom lies, and according to the precepts of Newtonian science all freedom expired when the universe was born.

I shall return to these questions from the perspective of twentieth century science. But first an essential stepping stone from the ideas of Newton to those of the twentieth century must be described.

(4) Galileo and Lorentz.

The laws of Newton have a simple consequence: given one possible universe, evolving in accordance with Newton's laws, it is possible to construct another in a simple way—just add to every particle in the universe any single common velocity. Then all separations between particles are left unchanged, and, according to Newton's laws, this shifted state of affairs will perpetuate itself through all time. This property is called Galilean invariance.

In 1873 James Clark Maxwell proposed a theory of electric and magnetic forces that was wonderfully beautiful and marvelously successful. This theory did for electricity and magnetism what Newton had tried to do for gravity: it explained the forces between charged particles in terms of changes that propagate from point to neighboring point, thus abolishing the need, in electricity and magnetism, for action-at-a-distance. However, the theory of Maxwell was characterized by a certain maximum speed, the velocity of light in vacuum. According to this theory no charged particle could move faster than this maximum speed. Consequently, the property of Galilean invariance was lost. However, Maxwell's theory had a substitute, which involved the characteristic maximum speed, the velocity of light. This new property, called Lorentz invariance, was to play a crucial role in what lay ahead.

(5) Absolute Versus Relative in Twentieth Century Science. The Special Theory of Relativity.

According to Newton's idea of absolute time one can assert that if A and B are two events, each of negligible duration, then either A is earlier than B, or B is earlier than A, or they are simultaneous. The truth of any such assertion, say that "A is earlier than B", is absolute: it does not depend upon anything else.

Consider, however, two such events A and B situated so that nothing can move from either event to the other without traveling faster than light. In this case one cannot determine by direct observation (say the observation of one event from the location of the other) which event occurs earlier than the other. One might expect that such a determination could be achieved by indirect means. However, Einstein showed that if all phenomena in Nature enjoyed the Lorentz invariance property mentioned above then it would be impossible in principle to determine from empirical data which of the two events occurred first.

The Lorentz invariance property seemed to hold universally (phenomena associated with gravity excepted, since Newton's theory of gravity needed to be reformulated along the lines of Maxwell's treatment of the electric force). Consequently, Newton's idea of absolute time seemed to bring into physical theory a property that in principle could have no correlate in observable phenomena. Einstein therefore proposed that physical theory be based not on absolute time and absolute space, as Newton had proposed, but rather upon a space-time structure defined by idealized readings of clocks and rulers.

The resulting theory is the special theory of relativity. Physicists quickly accepted this idea, which produced economy in notation and conception. Thus they replaced the absolutes of Newton by their relative counterparts.

(6) Quantum Theory.

Quantum theory is another twentieth century development that makes measurements primary. It carries the shift from absolute to relative even further than the special theory of relativity. For, according to the orthodox view of quantum theorists, not only must the underlying space-time framework be understood in terms of results of possible measurements, but, in fact, the entire mathematical formalism of quantum theory must be interpreted merely as a tool for making predictions about results of measurements. This view of quantum theory arose from its historical origin and its intrinsic form. But it is sustained by a reason far more compelling than mere "economy": every known ontology that is compatible with the phenomena, as codified by quantum theory, is "grotesque" in some way. Orthodox physicists, reluctant to embrace the grotesque, prefer to adopt a rational stance that separates the predictive mathematical formalism, and the associated scientific practices, from ontological speculations that lack empirical support.

(7) Conversation Between Einstein and Heisenberg.

1. Werner Heisenberg was the principal creator of the formalism of quantum theory. He has given an account of an interesting encounter with Einstein.
2. He prefaces this account with a brief description of the genesis of quantum theory: He, Heisenberg, reflecting upon Einstein's claim that a physical theory should contain only quantities that can be directly measured, and realizing that orbits of electrons inside atoms cannot be

observed, was led to discover rules that directly connect various measurable quantities pertaining to experiments performed on atomic systems, without ever referring to unobservable orbits.

Early in 1926 Heisenberg described this new quantum theory at a symposium in Berlin attended by Einstein. Later, in private, Einstein objected to the feature that the atomic orbits were left out. For, he argued, the trajectories of electrons in cloud chambers can be observed, so it seems absurd to allow them there but not inside atoms. Heisenberg, citing the nonobservability of orbits inside atoms, pointed out that he was merely following the philosophy that Einstein himself had used. To this Einstein replied: "Perhaps I did use such a philosophy earlier, and even wrote it, but it is nonsense all the same." Heisenberg was "astonished": Einstein had reversed himself on the idea with which he had revolutionized physics!

To find the probable cause of this "astonishing" reversal it is necessary only to look at what Einstein had done between the 1905 creation of special relativity and the 1925 creation of quantum theory. The special theory holds, as mentioned earlier, only to the extent that the effects of gravity can be ignored. It was necessary to generalize the special theory to the general case by incorporating a reformulation of Newton's theory of gravity along the lines of Maxwell's theory of the electric force.

Einstein undertook this task and in 1915 announced his general theory of relativity. Though this theory was a generalization of the special theory in many ways, it was fundamentally different. The focus was no longer on observers and results of measurements. The theory was about a space-time structure that exists by itself, governed by its own nature, without relation to anything external. It was about an "absolute" space-time structure. Einstein was driven during his ten-year search for the general theory not by an effort to codify data. He was driven by demands for rational coherence and by a general principle of equivalence. He sent his work to Born saying that no argument in favor of the theory would be given, since once the theory was understood no such argument would be needed.

Einstein had in this work gone beyond the need for "hypothesis non fingo". He had succeeded in doing what Newton had failed to do. He had discovered a mathematical description of something that could be regarded as Nature itself. The difficulty that defeated Newton, namely the action of gravity at a distance without any carrier, he had resolved by first combining: "Newton's absolute time and absolute space into an absolute space-time".

(8) Relaxing Newton's demand for uniformity, and finally imposing his mathematical laws in the form of conditions on deviations from uniformity: the presence of matter was represented by departures from uniformity—by distortions of space-time itself.

An important difference between Einstein's theory and that of Newton is that in Newton's theory time and space are independent of each other, and both are independent of matter. This creates, at least in principle, the possibility of space with nothing in it: an empty arena.

The idea of empty space has puzzled philosophers since antiquity: how can anything be nothing; that is a contradiction in terms. Thus Newton's predecessor Descartes takes extension, hence space, to be something that cannot exist without matter. Newton's contemporary Leibniz takes space to be merely a system of relations. Still, it remains puzzling that so much of the universe can be (almost) empty space if empty space is nothing at all.

Einstein's ontology gives a marvelous solution to this ancient puzzle. Instead of three intrinsically different things—time, space, and matter—whose connection must then, from a logical point of view, be ad hoc, hence puzzling, we have only one thing: inhomogeneous space-time. Considering the direction and achievements of Einstein's general theory of relativity one cannot be surprised that its creator should regard the philosophy of the creator of the special theory of relativity as "nonsense all the same".

The fate in the twentieth century of Newton's two absolutes is then this: the special theory of relativity replaced them by their relative counterparts, but the general theory resurrected them in a combined form that incorporates also the third element of Newton's ontology, matter. However, quantum theory represents a swing from the absolute back to the relative. For, according to the orthodox view, quantum theory must be viewed as codification of connections between measurable, or relative, quantities.

With this background in place, I turn now to the question of the impact of twentieth century science upon our ideas about Nature, and upon our ideas about ourselves.

(9) Impact of Quantum Theory Upon the Mechanistic World-View of Newtonian Science.

Quantum theory gives in general only statistical predictions. The question thus arises: Does Nature itself have genuinely stochastic or random elements? Bohr stated the orthodox position: We find, in practice, that even when we prepare an atomic system to the limits of our capabilities there is still a scatter in the results of certain experiments. Quantum theory gives predictions with a matching irreducible scatter. Thus the statistical character of the theory matches the statistical character of the facts. To say more than this is empirically unsupported speculation: quantum theory says nothing about determinism in Nature.

Quantum theory successfully describes and predicts phenomena on the basis of a mathematical description of atoms. Can we conclude that the world is built of atoms?

If one looks at the mathematical representation of these atoms one finds entities that must, according to the orthodox view, be interpreted only as parts of a computation of expectations pertaining to results of measurements. Thus the ontological foundation is shifted from the level of the atoms to the level of the devices that record these results, or perhaps even to the level of the observers who use these results to make computations. But the devices and observers are assumed to be built from atoms. So the ontological basis swings back to the atoms, etc.

These examples illustrate the difficulty in trying to draw ontological conclusions from a theory that must be interpreted merely as a tool for making predictions about connections between measurements.

(10) Quantum Theory and Reality.

It is clear to everyone that we cannot pass with certainty from knowledge about the structure of phenomena to knowledge about the structure of the underlying reality. Accordingly, the orthodox interpretation of quantum theory tries to isolate, insofar as possible, the mathematical formalism, and the scientific practices associated with it, from more speculative activities: it tries to separate "science" from "natural philosophy". Science is concerned with measurable quantities, and with theoretical structures that codify the observable and testable connections between them. Natural philosophy concerns the conclusions that might reasonably be drawn about the form of the underlying reality on the basis of the evidence provided by science. The fact that Bohr and Heisenberg adhered to the view that the mathematical formalism of quantum theory should be viewed, strictly speaking, merely as a tool for making predictions pertaining to results of measurements in no way implies that they had no interest in the implications that quantum theory has in the realm of natural philosophy. In fact, each in his own way tried to draw from the data provided by quantum theory insights into the nature of the world that lies behind the phenomena.

(11) Heisenberg's Ontology.

Heisenberg in his book "Physics and Philosophy" in the chapter on the Copenhagen interpretation actually sets forth an ontology. He begins with the words "If we want to describe what happens in an atomic event …". He then goes on to describe an ontology in which the actual world is formed by "actual events", which occur only at the level of the macroscopic devices. But the objective world contains also something else. It contains "objective potentia". These "objective potentia" are objective tendencies for the actual events to occur. They are associated with the mathematical probabilities that occur in quantum theory. This ontological substructure gives nothing testable. So it is not "science".

But it gives us an informal way of "understanding" quantum theory. It gives us an idea of what is actually going on.

This ontology described by Heisenberg is not the only ontology compatible with the predictions of quantum theory. But it can be said to be the "most orthodox" ontology. Most quantum physicists probably think about quantum. phenomena informally in these terms: the quantum probability functions corresponds somehow to the **tendency** for the detector to register a particle, or the **tendency** for a grain in a photographic plate to register the absorption of a photon. The actual things occur only at the macroscopic level.

Heisenberg's ontology cannot be deduced from the phenomena, and is therefore speculative, and to be distinguished from science. However, I do not think it unreasonable to consider it seriously. All creation is certainly not simply a collection of measurements floating on nothing else, even though measurements are of particular interest in science, and are the source of our most precise information about the world.

The reason it is interesting to consider the ontologies suggested by the structure of phenomena as codified by quantum theory, and compatible with that structure, is that the conditions thus imposed on ontologies are so restrictive: there is no known ontology that is compatible with the conditions on phenomena imposed by quantum theory that is not "grotesque" in the minds of conservative thinkers. This means that quantum theory has shown us that the world is not at all like what we had previously imagined it to be. It is not at all like the idea of it set forth in the mechanical world-view, formerly (pre 1900) promulgated in the name of science, and still largely dominating the prevailing idea of what science tells us. So any curious person must naturally be led to ask: What idea of the world is compatible with the data provided by science?

(12) World-View Arising From Heisenberg's Ontology

Heisenberg's ontology is the most-orthodox, and, in my opinion, the most reasonable, of the known ontologies that are compatible with the predictions of quantum theory. In the remainder of this article I shall describe the principal features of the picture of Nature that arises from this quantum ontology.

1. The World is Nonlocal.
   Macroscopically separated parts of the universe are linked together in a way that involves strong faster-than-light connections that do not fall off with increasing spatial separation. This nonlocal aspect is the "grotesque" feature of this ontology that makes it unacceptable to conservative thought.
2. Creation is Distributed Over All Time.
   In the quantum ontology the objective potentia are represented by the quantum probability function. At each stage the quantum potentia give tendencies for the next actual event. The occurrence of this next actual event is represented by a "collapse" of the potentia to a new form. The interplay of the Heisenberg uncertainty relations and the Heisenberg equations of motion is such that, even though each successive event effectively closes off certain possibilities, by making fixed and settled things that had formerly been unfixed, still, each event creates new potentialities and possibilities. Consequently, the process of fixing the unspecified degrees of freedom, which in classical physics occurs all at once, at the creation of the universe, is, in the quantum ontology, by

virtue of its mathematical structure, a process that can never close off the possibility of its further action. Thus in the quantum ontology, the creative process, in which things formerly unfixed become fixed and settled, does not expire at the birth of the universe, but extends rather over all time.

3. Two Kinds of Time.

   The quantum ontology has two different times. The first is Einstein Time, which joins with space to form Einstein's space-time. The second is Process Time. I shall now explain the difference. The "numbers" that appeared in Newton's theory, and which described the positions and velocities of the particles, are replaced in quantum theory by

(13) "operators", which evolve in accordance with equations, called Heisenberg's equations of motion.

The evolution of the quantum operators in accordance with Heisenberg's equations of motion is evolution in Einstein time. This evolution generates an association of operators with space-time points: every space-time point, from the infinite past to the infinite future, is associated with a fixed set of operators.

The space-time structure just described is a structure of quantum operators. To obtain the potentia one must take these operators in conjunction with something called the Heisenberg state vector. The Heisenberg state vector does not depend on space-time: it refers to all of space-time. But it combines with the operators associated with any space-time point to produce numerical potentia associated with that space-time point.

Each actual event is associated with a "quantum jump" of the Heisenberg state vector. Thus each actual event induces a sudden jump in the potentia. This jump occurs at every space-time point. The sequence of quantum jumps defines a time that is different from Einstein time. It is called Process Time. Evolution in process time generates change or evolution of the "actual", whereas evolution in Einstein time generates the evolution of the "potentia". Thus the deterministic laws of evolution are not binding on our future, for they determine the evolution of the potentialities, not the actual events themselves.

(14) Meaning in the Quantum Universe.

The creative process is represented in the quantum ontology by the sequence of jumps in the quantum potentia. These potentia are objective tendencies, which tend to make the statistical predictions of quantum theory hold under appropriate conditions. But the question arises: What determines the actual course of events? That is, what determines, in a given actual instance, whether things will be fixed in one way or another? Heisenberg's ontology leaves that crucial question unanswered. Hence the ontology, as presently understood, is incomplete.

At first', it might seem that, in any case, the choice of what actually happens is either deterministically fixed by what has gone before, or has an element of true randomness or wildness. In either case, the ontology would appear to provide no possibility for a meaningful universe: either we would have simply a new determinism, which would render the universe just as "dead", and devoid of possible meaning, as the world of Newtonian mechanics, or there would be an element of randomness, which could hardly add meaning. Thus we are apparently still trapped between the two horns, determinism or randomness, of the usual dilemma of the impossibility of a meaningful universe.

To have meaning a choice must have intentionality: it must exist in conjunction with an image of the future that it acts to block or help bring into being. Any choice that does not refer in this way to the future is a meaningless choice.

In the Newtonian picture the future does not exist in the present, and hence it cannot enter into a present event or choice. Moreover, the future cannot be changed by any event or choice.

But in the quantum ontology the future does exist objectively in the actual present, albeit as potentia. Thus the future can enter into the present event. This event can by altering the potentia for the future events, effectively block or help bring into being a chosen state of affairs. In this sense a quantum event can have effective intentionality and meaning.

(15) Man in the Quantum Universe.

The role of man in the universe is tied to the mind-body problem. From the perspective of the quantum ontology the brain is a macroscopic system similar to a measuring device. The function of the brain is to organize input, and then make a decision that initiates an appropriate action. According to the brain-device analogy this decision is represented as a quantum jump.

Just as in the case of a measuring device, this quantum jump is a macroscopic event: the whole brain, or some macroscopic part of it, is involved.

The problem of understanding, within the framework provided by classical physics, the connection between consciousness and the physics of the brain has been described in some quotations cited by William James: "The passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought and a definite molecular action in the brain occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from one to the other." (Tyndall). Or

> Suppose it to have become quite clear that a shock in consciousness and a molecular action are the subjective and objective faces of the same thing; we continue utterly incapable of uniting the two, so as to conceive that reality of which they are the opposite faces (Spencer).

The quantum ontology does have an analog of the classical motions of molecules moving in accordance with Newton's laws: it is the evolution of the corresponding quantum operators in accordance with Heisenberg's equations. However, the quantum ontology has, also, something else, which has no counterpart or analog in classical physics: the actual event. Within the quantum ontology the conscious event and the physical event can be naturally understood as the psychological and physical faces of the same event, namely the event of selecting and initiating a course of action. On the psychological side there is the felt or conscious event of selecting and initiating this action, and on the physical side there is the physical collapse of the potentia, which selects and initiates this action: the physical brain, as represented in quantum mechanics, collapses to a state in which the instructions that initiate the particular course of action are actualized.

The connection between these two events is not an ad hoc and arbitrary identification of things as totally disparate as, on the one hand, a motion of billions of separate molecules, and, on the other hand, a unified conscious act.

(16) It is, rather, the association and identification of the felt event with the physical event that represents, within the quantum ontology, exactly the change that is felt. In this way conscious events become special instances of the actual events that, according to the quantum ontology, form the fabric of the entire actual universe.

Conclusion

Quantum theory had several founders who had different opinions regarding ontology. Hence it may not entail any specific ontology. However, the most reasonable and well-defined of the prominent quantum ontologies is, in my opinion, the one that combines the claim of Heisenberg that we are dealing with a choice on the part of the observer pertaining to which experiment will be performed, and the claim of Dirac that we are dealing with a choice on the part of "nature" pertaining to which response will be delivered, as formalized by von Neumann's theory of measurement, dubbed "orthodox" by Eugene Wigner. and in which the evolving density matrix represents "potential", expressed as probability for specified experienced response.

The chief features of the world that flow from this ontology are:

1. It is nonlocal: there is some sort of nonseparability of spatially separated parts of the universe.
2. It is creative: the fixing of previously unsettled matters is a continuing process; creativity did not expire with the birth of the universe.
3. It could be complete: no aspect of reality not represented within the quantum ontology seems necessarily required.
4. It allows meaning: choices can have intentionality, hence meaning.

In everyone of these essential aspects the world-view provided by the quantum ontology is the reverse of the one provided by pre-twentieth century science. Consequently, modern science provides man with a vision of himself that is altogether different from, and far more inspirational and philosophically fertile than the one proclaimed in the name of Newtonian science.

No longer is man reduced to a cog in a giant machine, an impotent witness to a pre-ordained fate in some senseless charade. Rather, he appears, most naturally, within the framework of present-day science, as an aspect of a fundamentally nonseparable universe that is creation itself, both as noun and verb, a creative process that unites in an intelligible way the mental and physical aspects of Nature, and is moreover endowed in principle with the capacity to suffuse its evolving form with meaning.

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