Retrocausal Effects as a Consequence of Quantum Mechanics Refined to Accommodate the Principle of Sufficient Reason

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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. 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 response to the probing action of an observer is determined by pure chance, and hence on the basis of absolutely no reason at all. This appeal to pure chance can be deemed to have no rational fundamental place in reason-based Western science. It is argued here, on the basis of the other basic principles of quantum physics, 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 way when the reason for the choice is empirically identifiable. It is shown here that if the statistical laws of quantum mechanics were to be biased in this way then the basically forward-in-time unfolding of empirical reality described by orthodox quantum mechanics would generate the appearances of backward-time-effects of the kind that have been reported in the scientific literature.

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Introduction.

An article recently published by the Cornell psychologist Daryl J. Bem [1] in a distinguished psychology journal has provoked a heated discussion in the New York Times. 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 small change in the rules, and one that seems reasonable and natural in its own right. 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 [2], more than eighty years ago.

In classical mechanics one deals directly with physically described properties alone: the evolution of the physically described universe is deterministically governed by the physical variable themselves, and the role of our minds is reduced to that of helpless spectators. Our empirical knowledge can be viewed as simply a partial account of the full mechanistic physical reality itself, and hence of no fundamental import.

In quantum mechanics the relationship between the physically described aspects of the universe and our empirical knowledge of it is highly nontrivial, and the role of our empirical knowledge, and the account of how we acquire it, become, therefore, essential parts of the theory.

The founders of quantum mechanics already achieved a profound rethinking about the nature of the universe, when they recognized that the mathematically and physically described universe that appears in quantum physics represents not the world of material reality contemplated in the classical physics of Isaac Newton and his direct successors, but rather a world of *potentialities* or *possibilities* for our future acquisitions of *knowledge*. It is neither irrational nor surprising that a scientific theory based upon empirical (*experienced*) phenomena, and designed to allow us to predict correlations between various empirical phenomena 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 is also the empirical foundation upon which science is based; 2), an account of the process by means of which we acquire our conscious *knowledge* of the 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 apparent acceptance by most western-oriented scientists and philosophers of the notion that the element of chance, which enters quite reasonably into the *pragmatic* formulation of physical theory, in the practical context where many pertinent things are unknown to us, stems from an occurrence of raw pure chance at the underlying *ontological* level. Such a feature would seem to be contrary to the rationalist ideals of western science. From a strictly rational point of view it seems reasonable to examine the mathematical impact of accepting, *at the basic ontological level*, Einstein's dictum that: "God does not play dice with the universe", and to attribute the effective entry of pure chance at the pragmatic level to our lack of knowledge of the *reasons* for the "choices on the part of nature"---which enter prominently into orthodox quantum mechanics---to be what they turn out to be.

It is well known---as will be reviewed presently---that biasing of the normal quantum *statistical* rules leads to an apparent breakdown of the normal *causal* structure of phenomena. This seeming breakdown of the causal structure dovetails neatly with the empirical findings reported by Bem, and the similar retrocausal findings reported earlier by others [3,4]. In particular, the rejection of the "irrational" idea that definite choices can pop out of nowhere, and the acceptance, instead, of the principle of sufficient reason, produces a rational revision of orthodox quantum mechanics that naturally accommodates the reported retrocausal phenomena.

Implementing The Principle Of Sufficient Reason

I make no judgment on the significance of the purported evidence for the existence of various 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---that the actual 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. Only a small, and intrinsically reasonable, modification of the existing orthodox QM is needed in order to accommodate the reported data.

What is required if science is to be able to deal rationally and successfully with these purported phenomena, in case they are valid, is a modification of the existing theory that can naturally accommodate these reported phenomena, while also accounting naturally for the successes of contemporary basic physical theory in the normal cases where it works so well.

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 pq-qp was non-zero. Yet there was also *a rejection of a basic classical presupposition*, namely the idea that a physical theory should properly be about connections between physically described material events. The founders of quantum theory insisted [5] that their physical theory was a pragmatic theory --- i.e., was directed at predicting practically useful connections between empirical (i.e., experienced) events.

This original pragmatic Copenhagen QM was, however, 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 observer's, must be understood to be built out of quantum mechanically described particles. This is what allows us to understand and describe many observed properties of these physically described systems --- such as their rigidity and electrical conductance --- and

permits us to identify a certain aspect of our theoretical conception of nature, namely the quantum state, that is described in physical terms, and that covers 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). We have a deterministic law, the Schroedinger 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 Schroedinger equation, into a *conglomeration of positions corresponding to the different possible times of detection*; not to a single position, which is what we observe.

How do we understand the similar fact that the unrestricted validity of that Schoedinger 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. How do we understand this huge disparity between the representation of the universe evolving in accordance with the Schroedinger 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 discrete conscious thoughts are connected to the evolving physically described state of the universe, and of our evolving physically described brains..

The problem, in brief, is that if we just let the whole quantum state of the universe evolve in accordance with the quantum equation of motion, then the state of the measuring devices, and of our observing brains, will evolve into a smeared out continuum of macroscopic components of the kind that correspond to our experience.

It seems clear that 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. ([5] p.62, p.65)

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 an 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 was treated quantum mechanically, and *our knowledge*, and *the process by means of which we acquired our knowledge about the physically described world,* were elevated to essential features of the theory, not merely postponed, or ignored! Thus certain aspects of reality that had been treated over-simplistically in the earlier theories---namely "our knowledge" and "the process by means of which we acquire our knowledge", were incorporated into the new theory in a detailed way.

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

This response is asserted, by orthodox quantum mechanics, to be controlled by *random chance:* by *a throw of nature's dice*. An element of pure capriciousness is thereby introduced into *nature's creative process*. This process creates a sequence of physically described universes, with the universe created at each stage concordant with the new state of "our knowledge".

Nature's choices have in QM a nonlocal or global character. The rules entail that the information about the choices made and executed by an experimenter/observer in one space-time region must be available in faraway spacetime regions. [I use Dirac's word "nature", not "God", to emphasize that I am referring to a concept originating exclusively and strictly from science (i.e., QM), not from any religion or holy text, or from any mystical insights.]

Given this science-based toehold it seems not unreasonable to ascribe to "nature" the capacity to base its definite choices on some principle that can be construed as supplying "reasons" for nature's choices to be what they are,

rather popping out of nothing at all. But given the nonlocal character of nature's choices, we must allow nature's reason's to be based on faraway realities, most of which are unknown to us.

The question is then: What are nature's sufficient reasons? What is a possible universal principle behind nature's choices that will *normally* produce responses that conform to the normal statistical rules of QM, but that will under appropriate circumstances produce results that violate the causality structure that flows from the normal (chancy) statistical rules of orthodox QM in a way that will naturally account for the occurrence, under appropriate conditions, of the retrocausal phenomena reported by Bem.

The argumentation that follows shows that a rationally coherent answer to these questions follows from the orthodox quantum theory of measurement, modified *only* by changing the normal statistical rule of the orthodox theory, which governs nature's responses to the probing actions initiated by observers. This modification requires each of nature's choices to have a reason, and specifies that one such reason is to produce positive emotional responses and avoid negative emotional responses in the streams of consciousness of observers. In classical materialist physics such a biasing of the statistics would not produce evidence of retrocausation, but in quantum mechanics it does! That is what will now be proved.

Readers who are not quantum physicists should, at least on their first reading, skim lightly over the rest of this section, and the next, which are application of the mathematical machinery of quantum mechanics, and essentially jump ahead to the section pertaining to delayed choice, which gives an intuitive understanding of this retrocausal effect as a corollary of the completely orthodox Wheeler delayed choice effect.

A relatively straightforward and rational resolution of this retrocausation problem lies in a combination of the ideas developed in references [6] and [7]. The second of these two references pertains to classical mechanics, but there is an analogous result in QM, with the canonical transformations in CM replaced by unitary transformations in QM. The pertinent mathematical fact is that

(Sum over all U of $U\,Q\,U^{\dagger}$) = I (Trace Q/Trace I),

where Q is a projection operator, I is the unit matrix/operator, U` is the Hermitian Conjugate of U, and the sum over U is a sum over all unitary matrices U, with weights specified by the normalized invariant Haar measure, which is mapped invariantly unto itself under any unitary transformation from either left or right.

The pertinence of this formula arises from quantum entanglement, and the fact that at each moment of nature's creative process---i.e., at each of nature's choices---there can be a host of different queries being posed by different observers, and the existing quantum state rho might entail the existence of correlations between the answers to these queries.

To construct a theory useful in scientific practice, the founders of quantum mechanics brought the experimenters/observers and their experiences into the dynamics in a very specific way. The founders postulated that in order to tie the evolving quantum system to empirical findings, some particular *probing action* must first be executed by an "observer". The simplest form of such a probing action specifies, jointly, one conceivable possible experience E and an *associated* physical action upon the existing quantum state. This physical action reduces that existing quantum state (i.e., density matrix rho) to a sum of two terms: a 'Yes' term that is the part of the existing state rho that is compatible with the possible experience E, and a 'No' term corresponding to the non-occurrence of that possible experience E. The mathematics automatically assigns to each of these two alternatives, 'Yes' and 'No', a statistical weight such that the sum of these two weights is unity. Multiple-choice probing actions can be encompassed by repeatedly subdividing the 'No' possibility into a new "Yes" and "No". Then, in the words of Dirac,
"nature chooses" either "Yes" or "No", randomly with the specified statistical weights.

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

$$\text{rho}(n+1)_Y = P(n+1)\ \text{rho}(n)\ P(n+1)/\text{Trace}\ (P(n+1)\ \text{rho}(n)\ P(n+1)),$$

$$\langle P(n+1)\rangle_Y = \text{Trace}\ (P(n+1)\ \text{rho}(n)\ P(n+1)) = \text{Trace}\ (P(n+1)\ \text{rho}(n)).$$

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 Schroedinger 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, Trace XY=Trace YX. (The trace operation is defined by: Trace M= Sum of the diagonal elements of the matrix M).

Consider the familiar example of a pair of systems created in some space-time region, and then traveling to two far-apart labs. The experimenter/observer in each lab chooses to measure some spin property of the system entering his lab. Let the probing actions in the first and second labs be associated with the projection operators P and Q, respectively.

Suppose you, in your lab, decide to ask whether or not your experience will correspond to the reduction of the current state of the universe (defined by the density matrix rho) to the part of itself, P rho P, compatible with the experience PYes = (The experience associated with the answer "Yes" to the question "Will my experience be the experience associated with the answer "Yes" to the probing action associated with the projection operator P?).

Suppose the observer in the other lab chooses to measure Q. If you know that the other observer is going to measure Q (i.e., is going to see whether nature responds 'Yes' or 'No' to the question "Will I, the second experimenter/observer, experience the thought, feeling, or idea associated with Q?") then how will your knowledge (merely) of what the second experimenter/observer is going to do---or has already done---(namely to choose to measure Q) going to affect your expectations pertaining to what you will see/experience?

The answer is "No Effect! " --- provided the orthodox (pure chance) rules hold.

The point is that the standard prediction in the case that the measurements corresponding to P *and* Q are performed in spacelike separated regions (so that PQ=QP) is that the probability of getting the pair of answers (PYes, QYes) is:

$<PQ>_{YY}$=Tr (PQ rho) (Tr rho = 1).

The probabilility of (PYes, QNo) is

$<P, I-Q>_{YN}$ = Tr (P(I-Q) rho) .

Hence your expectation $<P>_{QY}$ of getting the answer 'Yes' for P if you know (say by prearrangement) that the other experimenter/observer will choose to pose the question corresponding to Q, but have no knowledge of what the other outcome is (was, or will be), but know or believe that the usual statistical (chancy) rules of QM apply, is

$<P>_{YQ}$ = $<PQ>_{YY}$ + $(P(I-Q)>_{YN}$ = Trace (PQ rho) + Trace (P(I-Q) rho)

= Trace (P rho) = $<P>_{Y}$.

due to the linearity of the Trace operation.

Thus your expectation, and also the actual probability if the chancy rules really hold, is the same as if the other experiment (corresponding to Q) was not performed, or some different experiment (corresponding to Q1) was performed. This is the standard normal consequence of the chance-based theory: What happens "here" is independent of what is DONE faraway! This is an important consequence of orthodox QM. The normal *statistical* rule entails the normal *causality* rule that what a faraway experimenter freely decides to do "now" cannot affect what you will observe "here and now"!

Normal causality ideas hold, provided the normal chancy probability rules hold!

But suppose *nature's choice* of response does not conform to the orthodox statistical rule. Suppose, just to illustrate the main point with an extreme example, that nature's choice is based on reasons, and is such that *if* the query corresponding to Q is posed, then nature's answer will definitely be "Yes". Then if the question corresponding to Q is posed, the probability of receiving the answer "Yes" to your local query corresponding to the local operator P will be

$$\langle P \rangle'_{YQ} = \text{Trace } [P ((Q \text{ rho } Q)/\text{Trace } (Q \text{ rho } Q))] =$$

$$\text{Trace } (PQ \text{ rho})/\text{Trace } (Q \text{ rho}),$$

where I have again used the projection operator condition QQ=Q, the fact that PQ=QP, and the fact that, for any X and Y, Trace XY= Trace YX.

The matrix ((Q rho Q)/Trace (Q rho Q)) occurring in the above formula is the density matrix that represents the facts that: 1) the original state (of the observed system) is rho; 2) the measurement corresponding to Q is performed; and 3) the outcome is definitely QYes.

In this situation, in which Q is performed and nature then definitely picks outcome QYes, the expectation $\langle P \rangle_{YQ}$ is no longer generally the same as $\langle P \rangle_Y$ = (Trace P rho), which is what it would be if no question were posed faraway. For example, if rho specifies the condition of complete positive correlation of P and Q',

$$\text{rho} = (PQ' + P'Q)/\text{Trace}(PQ' + P'Q),$$

then, from the above result,

$$\langle P \rangle'_{YQ} = \text{Trace PQ rho/Trace Q rho} = 0/\text{Trace QP'},$$

which is zero for the general case in which P, P', Q, and Q' are all nonzero, whereas if no question is posed in the second region, or if the standard chancy rules hold, then the expectation for PYes is

$$\langle P \rangle_Y = \text{Trace } (P \text{ rho}) = \text{Trace } P (PQ' + P'Q)/ \text{Trace}(PQ' + P'Q)$$

$$= \text{Trace } PQ'/ \text{Trace } (PQ' + P'Q).$$

which is not equal to 0, for P and Q' different from zero.

Thus biasing the normal *statistical* rule produces violations of the normal *causality* rule, which asserts that what happens here does not depend upon what is (freely chosen and) *done* faraway!

This close interlocking of the normal causality rule with the normal statistical rule is very well known, and was used in my theory of presentiment [6] to predict certain strong presentiment effects, within a quantum framework that allows a biasing of nature's choice of which experience occurs, relative to the normal pure-chance-based rules.

The bottom line is that biasing---relative to the normal orthodox chance-based probabilities---of the frequency of the selected-by-nature outcomes QYes, in the emotional experiences of one observer, changes the frequencies associated with the other operator P that is---due to *past* interactions---correlated *in rho* with Q, even though the frequency associated with P pertains to events in a region lying now far away from the region associated with the application of stress to the first observer. Application of a stress "here" affects the frequencies of faraway events!
This follows from direct application of the rules of quantum mechanics, provided the statistical rules can be biased, relative to the normal rules governed by pure chance.

In the Bem experiment with the erotic pictures let P_{ER}, P_{EL}, P_{NR}, and P_{NL} be the projection operators associated with a system that records which picture was chosen to appear on which screen, with the subscripts E and N denoting erotic and nonerotic, respectively, and the subscripts R and L identifying right and left screens, respectively. Thus P_{ER} is the projection operator associated with the observable record of the fact that the combination ER was chosen, etc.. Let Q_{ER} correspond to the observer-related question "Will I, the subject, see/experience the erotic picture if I open the right-hand screen", etc.. Then the orthodox density matrix for the combined PQ system after the interaction between the P and Q subsystems, but before nature's choice of response to the Q question pertaining to the experience of the subject, takes the form

$$\text{rho} = (Q_{ER}\, P_{ER} + Q_{EL}\, P_{EL} + Q_{NR}\, P_{NR} + Q_{NL}\, P_{NL})/\text{Trace N},$$

with each of these P's such that Trace P = ½ Trace I_P , each of the Q's such that Trace Q = ½ Trace I_Q , and N is the numerator of this particular rho. Hence Trace N= Trace I_P Trace I_Q = Trace I. The term Q_{ER} P_{ER} represents the fact that if nature's response to the question corresponding to Q_{ER} were to be "Yes", then natures's response to the question corresponding to P_{ER} will also be "Yes", and similarly for the three other Q projection operators. Then the orthyodox probability that experience P_{ER}Yes occurs is

$$\langle P_{ER} \rangle_y = \text{Trace } (P_{ER} \text{ rho})$$

$$= \text{Trace } P_{ER} Q_{ER} / \text{Tr N}$$

$$= ¼ .$$

But in the extremely biased case in which nature always chooses Erotic and never chooses Nonerotic, the *effective* rho becomes

$$\text{rho'} = (2Q_{ER} P_{ER} + 2Q_{EL} P_{EL})/\text{Trace N},$$

and

$$\langle P_{ER} \rangle'_y = \text{Trace } (P_{ER} \text{ rho'})$$

$$= \text{Trace } 2Q_{ER} P_{ER} / \text{Trace N}$$

$$= 1/2$$

This means that in the biased case the frequency with which the response YP_{ER} appears will be twice what it is predicted to be in the orthodox theory: the biasing of nature's choice between erotic and nonerotic *experiences of the subject* has affected the *observed records* of which pictures appears behind which screen! This result is just another manifestation of the seeming breakdown of normal *causality* concepts if the normal *statistical* rules are not maintained.

This dependence of normal causation upon the validity of the normal quantum rules of chance is, of course, well known! But the upshot here is the interesting conclusion that making the dynamics *more rational* makes it *less causal.*

e failure of normal ideas about causation was achieved here not by foisting some irrational or unnatural ad hoc condition on the dynamics, but rather by merely insisting that the choices made by nature stem from reasons (which may not be apparent to us), and that one contributing reason for nature to choose one response over another is a tendency of nature to favor positive emotional states of conscious observers over negative ones. The rationale behind this hypothetical biasing is that it is the simplest way, within the quantum framework refined to accommodate the principle of sufficient reason, to accommodate the reported data.

Such a reason goes against what some scientists believe to be the proper duty of science and scientists, namely to rule out all ideas of this kind, in favor of the idea of the entry of purely random choices---Einstein notwithstanding. Certainly science has made great progress in eliminating possible needs for a biasing of nature's input into the dynamics in a way such as this that pays attention the experiences of observers. It is surely worthwhile to pursue efforts to circumscribe in this way nature's input to the dynamics, but not to the extent of banning from publication in scientific journals seemingly high quality reports of empirical results that seem to contradict the object of those endeavors.

Why Do the Normal Statistical Rules Normally Hold?

Suppose that the Principle of Sufficient Reason does hold, so that each of nature's choices has a reason to be what it turns out to be. And suppose that these reasons lead to choices that violate the orthodox statistical rules. Then violations of normal ideas about causation are likely to occur. But then the question arises: Why do the normal orthodox quantum rules work as well as they do?

The answer is that we considered above an extreme case in which there was a connection between P and an *identified suspected cause Q*. Normally there can be many entangled Q's that could enter into nature's sufficient reasons, and the favored-by-nature relevant variable Q (in our special case associated with the human subject's emotional experience) will generally be unknowable to the observers of P. In general the scientist will have no idea of which features of the world are driving nature's choices in a given actual

situation. In these usual cases the scientist must perform an averaging that reflects his ignorance.

The usual *classical* way to represent a complete lack of knowledge about the variables in some domain is to average over the range of variables in that domain, ascribing equal weights to equal volumes of phase space. This is the weighting that is invariant under canonical transformations. The *quantum* analog is to take the Trace, which is invariant under unitary transformations, over the domain of factors about which we have no knowledge.

A complete lack of knowledge about the identity of Q, means that we should average Q over the whole set of Q's unitarily equivalent to it, within the full space in which it lies (which is a component of a tensor product of spaces), and about which we lack knowledge. But this averaging needed to account for the lack of knowledge about what reasons are driving nature's choices will effectively erase all dependence on the variables about which one has no knowledge, and reduce the rule for computing expected probabilities to the usual quantum mechanical rules associated with the notion of pure chance.

In more detail the point is this. If nature's choice has a reason, and this reason impels it to answer "Yes" to the posed question corresponding to Q, then the expectation $\langle P \rangle'_Q$ of P, given that Q is performed and that nature's answer to the Q question is "Yes", is"

$$\langle P \rangle'_Q = \text{Trace } [P ((Q \rho Q)/\text{Trace } (Q \rho Q))]$$
$$= \text{Trace } PQ \rho/\text{Trace } Q \rho$$

as already discussed. But suppose that Q is not known. Suppose, for example, that the various possible Q are identified by points on a circle, labeled by the angle θ, and that every point θ on the circle has equal a priori weight. Then the expectation of P is

$$\langle P \rangle'_Q = \text{Trace } P(1/2\pi)\int d\theta\, Q(\theta)\, \rho \,/\text{Trace } I_P\, (1/2\pi)\int d\theta\, Q(\theta)\, \rho.$$

One must integrate over the unknown variable, assigning equal a priori weights to each possibility.

In our case this example generalizes to

$$\langle P\rangle'_Q = [\text{Trace (P Integral over all U of UQU` rho)}]/[\text{Trace } (I_P \text{ Integral over all U of UQU' rho)}]$$

$$= \text{Trace (P rho)/Trace } (I_P \text{ rho})$$

where U` is the Hermitian conjugate of U, and the integral is over the invariant Haar measure on the (compact) space of unitary matrices.

This result means that if Q is unknown then the probability <P> is just what is given by the usual pragmatic statistical rule, which, however, now arises from choices at *the basic ontological level that accord with the principle of sufficient reason.*

One recovers the usual rule also if rho entails no correlation between P and Q. Thus the usual rule comes out automatically when either P is uncorrelated to the favored (or disfavored) Q, or this Q is unknown.

Connection to Wheeler's Delayed Choice

The applicability of this general idea extends to all of the various kinds of psi effects reported by Bem. All of these psi phenomena can be accounted for by accepting von Neumann's formulation of how empirical findings---*increments of knowledge*---enter into the quantum dynamics, provided one refines the orthodox theory by accepting the principle that every choice has a reason, and that a reason for at least some of nature's choices is to favor positive emotional feelings, and to disfavor negative emotional feelings.

My "Presentiment" Paper [6] has already applied essentially this same mathematics to account for Dean Radin's "presentiment" effect [4]. The biasing of the quantum probabilities associated with the subject's nervous system *at a certain time T* was attributed there to an Eccles-type biasing, rather than to the acceptance of the principle of sufficient reason, but the mathematics is the same. And, indeed, even the basic philosophy is the same, because the Eccles biasing is supposed to stem from some reason. In the presentiment case the operator P is associated with the *record* of what was going on in the nervous system of the subject at a time *T' before* the time *T* when the stimulus was applied. This record was formed by the interaction at the earlier time T' between the recording system and the

nervous system. The correlation represented in the density matrix rho was created by this interaction at that earlier time.

In those presentiment experiments, a biasing (over a sequence repetitions of the experimental protocol) of the *frequencies* of nature's positive responses at time *T* to questions about the subject's experiences---induced by allowing the subject to view emotion-laden pictures at the time *T*--leads to an apparent violation of normal ideas about causality, namely to a corresponding increase in the *recorded frequencies* of certain associated activities of the subject's nervous system at a time *T'* prior to the application of the stress.

This seeming backward-in-time effect can be viewed as a direct consequence of a well-known rigorous seeming backward-in-time property of QM, namely the Wheeler "delayed choice:" effect, combined with a *biasing*---i.e., a violation---of the normal chancy weightings of nature's choices of responses to probing actions pertaining to emotional states.

As regards the standard Wheeler delayed-choice effect itself, the *orthodox* theory entails that when nature makes her choice of response, the past is 'effectively reduced' to the portion of the former past that fits smoothly onto the new, reduced, state of the universe, which nature has just chosen. The *parts of the former past* that conflict with nature's current choice are *effectively* eliminated. Here "effectively" means "for the purpose of making predictions pertaining to the future": As far as the potentialities for the next event are concerned, it is just "as if" the past were now "reduced" to that part of the former past that evolves onto the new contemporary reality, created by nature's current response, with the remainder of the former past suddenly eradicated.

[Wheeler's delayed choice experiment is essentially this: Suppose, during a double-slit experiment, at a time T before a photon reaches your eye, but after the photon has passed through the slits, you focus your vision on the slits through which photons that are coming, one at a time. Then you will "see" that each photon passed at the earlier time *T'*---prior to your choice of how to focus your attention---through one slit or the other, not both. But if at the later time T you choose to focus your attention straight ahead then you will see the particles building up a pattern of stripes that depend upon the distance between the two slits, indicating that the wave packet went, at the earlier time *T'*, through both slits: the later choice at time *T* on the part of the

observer of what to observe influences the content of the *effective* quantum state at the earlier time T'. This redefinition causes no conceptual problem in the orthodox theory because the physically described quantum state is not a material reality: it is merely a representation of *potentialities for future experiences of observers*, and each of these experiences depend upon what the observer eventually chooses to observe.

The *actual* evolution proceeds in a well-ordered sequence, with each event associated with a finite (small) space-time region of zero temporal thickness, no part of which lies in the backward light-cone of any point in any of the regions associated with any earlier (in the ordered sequence of events) event. (See [8], Fig. 13.1) Each event creates a new *effective* past, but does not alter any past actual event.

The notorious "nonlocality" feature of orthodox quantum mechanics can be attributed to this "delayed choice" effect of nature's present choice upon the new effective past. This new effective past, *created by the prolongation of the newly created present physical state into the past via the (inverse of) the Schroedinger equation,* is only a portion of what was formerly present. The effective elimination of parts of the former past *effectively eradicates the records of the parts of the past that have been eliminated.* Thus the reduction of the state rho associated with the measurement made *here* can affect the potentialities associated with faraway observations of records pertaining to what led up to the measurement made here.

If, due to an application of stress to the subject *now, at time T,* the frequency (over a set of replications of the empirical protocol) with which nature chooses now a QYes response is heightened---relative to normal---in a large sample of events, this altered fraction of QYes instances will be connected to an altered number of correlated PYes responses. Thus the results obtained earlier by formal mathematics can be understood intuitively as corollaries to the standard Wheeler delayed choice effect.

In this refinement of orthodox quantum theory there is still a one-way creative advance into the future, controlled by the orthodox rules, merely expanded to accommodate the now reason-based choices on the part of nature.

In the retrocausal priming reported by Bem, the reductions that occur at the later time have the effect of selecting states of the brain that encode the

memories of the priming experiences. If the emotional element is strong enough to bias the normal statistical rules, then there will be a biasing of the frequencies in the records of what occurred earlier that will depend on which experience occurred later. The mathematics is essentially the same as for the erotic pictures experiments.

Conclusion

Numerous reported apparently backward-in-time causal effects are naturally explainable within forward-in-time orthodox quantum mechanics, provided the orthodox dependence on pure chance is replaced by the principle of sufficient reason.

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