THE WORLD ACCORDING TO QUANTUM MECHANICS (OR, THE 18 ERRORS OF HENRY P. STAPP)

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Abstract

Several errors in Stapp's interpretation of quantum mechanics and its application to mental causation (Henry P. Stapp, "Quantum theory and the role of mind in nature," e-Print quant-ph/0103043, to appear in Foundations of Physics) are pointed out. An interpretation of (standard) QM that avoids these errors is presented.

1 INTRODUCTION

According to some theorists [1, 2, 3, 4, 5, 6, 7, 8], consciousness is needed for making sense of quantum mechanics (QM). According to others [9, 10, 11, 12, 13], QM is needed in order to understand consciousness and/or account for its causal efficacy. In a recent contribution to this journal, Henry P. Stapp [14] argues for both: Consciousness is essential for understanding QM, and QM is essential for the causal efficacy of consciousness. In the present article I point out a number of errors that mar Stapp's theory—inconsistencies, fallacies, and conclusions founded on such logical mistakes,—and offer an interpretation of (standard) QM that avoids these errors. In addition I outline an alternative account of mental causation [15, 16].

Section 2 stresses the fact that an algorithm for assigning probabilities to the possible results of possible measurements cannot also represent an evolving state of affairs (Stapp's first error, $\mathcal{E}_1$). The introduction of consciousness into discussions of QM ($\mathcal{E}_2$) serves no other purpose than to provide gratuitous solutions to a pseudoproblem arising from $\mathcal{E}_1$. Stapp's third error ($\mathcal{E}_3$), pointed out in Sec. 3, is a category mistake. It consists in his treating possibilities as if they possessed an actuality of their own. This leads to the erroneous notion that possibilities are things ("propensities") that exist and evolve in time ($\mathcal{E}_4$).

Stapp offers two arguments purporting to support the existence of a dynamically preferred family of constant-time hypersurfaces. The first invokes astronomical data, which support the existence of a historically preferred family of hypersurfaces but not of a dynamically preferred one ($\mathcal{E}_5$). The second is fallacious because it involves inconsistent combinations of (individually valid) counterfactuals ($\mathcal{E}_6$). Equally fallacious, therefore, is Stapp's "proof" of the occurrence of faster-than-light transfers of information ($\mathcal{E}_7$). This is discussed in Sec. 4.

According to Stapp, granting free will to experimenters leads to a physical reality inconsistent with the "block universe" of special relativity (SR), a reality that unfolds in response to choices. This is one ($\mathcal{E}_8$) of a cluster of misconceptions arising from the erroneous notion that the experiential now, and the temporal distinctions that we base on it, have anything to do with the physical world ($\mathcal{E}_9$). Objectively, the past, the present, and the future exist in exactly the same atemporal sense. There is no such thing as "an evolving objective physical world" ($\mathcal{E}_{10}$), and there is no such thing as an objectively open future or an objectively closed past ($\mathcal{E}_{11}$). The results of performed measurements are always "fixed and settled." What is objectively open is the results of unperformed measurements. This is discussed in Sec. 5.

The subject of causation is broached in Sec. 6. Causality, as Hume [17] discovered two and a half centuries ago, lies in the eye of the beholder. While classical physics permits the anthropomorphic projection of causality into the physical world with some measure of consistency, quantum physics does not. Trying to causally explain the quantum-mechanical correlations is putting the cart in front of the horse. It is the correlations that explain why causal explanations work to the extent they do. Stapp's attempt to involve causality at a more fundamental level ($\mathcal{E}_{12}$) depends crucially on his erroneous view that the factual basis on which quantum-mechanical probabilities are to be assigned is determined by Nature rather than by us ($\mathcal{E}_{13}$).

Sections 7 to 9 are of a more constructive nature. In Sec. 7 the significance of the existence of objective probabilities is discussed. They betoken an objective indefiniteness that is crucial for the stability of matter, and they imply the extrinsic nature of the values of quantum-mechanical observables. Extrinsic properties presuppose intrinsic ones, and this implies the co-existence of two logically distinct domains. How these are related to each other is discussed in Sec. 8. Section 9 gets to the heart of QM, which concerns the spatiotemporal differentiation of reality. The fact that this is finite makes QM as inconsistent with a fundamental assumption of field theory as SR is with absolute simultaneity. Stapp shares this erroneous assumption when he considers the physical world differentiated into "neighboring localized microscopic elements" ($\mathcal{E}_{14}$).

Section 10 begins by observing that, contrary to Stapp's contention ($\mathcal{E}_{15}$), the freedom to choose is a classical phenomenon. Subsequently the reader is taken through the steps of Stapp's account of mental causation, and a number of further errors (not all enumerated) are pointed out, such as: The objective brain can (sometimes) be described as a decoherent mixture of "classically described brains" all of which must be regarded as real ($\mathcal{E}_{16}$). Crucial to Stapp's account is the metaphor of the experimenter as interrogator of Nature. Within the Copenhagen framework, which accords a special status to measuring instruments, this is a fitting metaphor for a well-defined scenario. In Stapp's framework, which accords a special status to the neural correlates of mental states, it is not ($\mathcal{E}_{17}$). Its sole purpose is to gloss over the disparity between physical experimentation and psychological attention. Once this purpose is achieved, the metaphor is discarded, for in the end Nature not only provides the answers but also asks the questions. The theory Stapp ends up formulating is completely different from the theory he initially professes to formulate ($\mathcal{E}_{18}$), for in the beginning consciousness is responsible for state vector reductions, while in the end a new physical law is responsible, a law that in no wise depends on the presence of consciousness.

The final section contains concluding remarks.

2 QUANTUM MECHANICS AND CONSCIOUSNESS

Stapp capitalizes on von Neumann's formulation and interpretation of QM as a theory of the objective world interacting with human consciousness [2]. The unobserved world evolves according to a dynamical equation such as the Schrödinger equation, while observations cause "a sudden change that brings the objective physical state of a system in line with a subjectively felt psychical reality" [14]. This makes QM "intrinsically a theory of mind–matter interaction," and more specifically a theory "about the mind–brain connection" [14]. Each of those sudden changes

> injects one "bit" of information into the quantum universe. These bits are stored in the evolving objective quantum state of the universe, which is a compendium of these bits of information.... Thus the quantum state has an ontological character that is in part matter like, since it is expressed in terms of the variables of atomic physics, and it evolves between events under the control of the laws of atomic physics. However, each event injects the information associated with a subjective perception by some observing system into the objective state of the universe [14].

Whatever else a quantum state may represent, there can be no doubt that it is first of all an algorithm for assigning probabilities to the possible results of possible measurements. This is evident from the minimal instrumentalist interpretation of QM, the common denominator of all possible interpretations [18]. It is also evident from J.M. Jauch's definition of the "state" of a quantum-mechanical system as a probability measure resulting from a preparation of the system and his proof [19]—based on Gleason's theorem [20]—that every such probability measure has the well-known density-operator form, which reduces to the familiar Born probability measure if the density operator is idempotent. But if a quantum state is a probability algorithm, then it cannot also represent an actual state of affairs. How could it? A state of affairs is an entirely different kettle of fish; it falls under an entirely different category. This immediately disposes of the "measurement problem" in its crudest form, which arises only if state vectors or density operators are regarded as representing actual states of affairs.

The quantum revolution was guided by the vision of Niels Bohr. In 1913, Bohr rejected classical physics wholesale, initiated the creation of an entirely new physics, and rallied physicists to complete it. The same genius later impressed upon physicists the true import of the new physics: *QM spells the end of mathematical realism.* The symbols and formulae of the new physics can no longer be interpreted as mirroring (representing, describing) the physical world. All that QM places at our disposal is probability measures; it assigns probabilities to the possible outcomes of possible measurements. Any attempt to go beyond the statistical regularities encapsulated by the laws of QM must, at the very least, be consistent with the incontestable probabilistic significance of quantum states. Interpretations that grant quantum states the ontological significance of a state of affairs *do not satisfy this fundamental requirement.*

According to John Bell [21], "measurement" is a bad word. The really bad word, however, is "state," owing to the obvious suggestion that a quantum state represents a state in the usual sense of the word. "Measurement" isn't a good word either, but this is more easily repaired. QM represents the contingent properties of a physical system S—the properties that S can but does not necessarily possess—as subspaces of some vector space. Bohr rightly insisted that a contingent property q can be attributed to S only if the following criterion is satisfied: The possession of q by S must be *indicated*. The properties of quantum systems are *extrinsic* in the specific sense that they cannot be attributed unless they are indicated [22]. *No property is a possessed property unless it is an indicated property.* Since the properties of quantum systems are usually indicated by what we call "measuring devices," this creates the absurd impression that laboratory instruments play a fundamental ontological role. What actually plays a fundamental role in the formulation of QM is *facts*—actual states of affairs—and especially such facts as indicate the possessed properties of quantum-mechanical systems. The word that ought to replace "measurement" in any ontological interpretation of QM is "(property-indicating) fact."

What is a fact? *The Concise Oxford Dictionary* (8th edition, 1990) defines "fact" as a thing that is *known* to have occurred, to exist, or to be true; a datum of *experience*; an item of verified *information*; a piece of *evidence*. Other dictionaries give variations on the same theme. Should we conclude from this that the editors of dictionaries are idealists wanting to convince us that the existence of facts presupposes knowledge or experience? Obviously not. The correct conclusion is that "fact," like "existence," like "reality," is so fundamental a concept that it simply *cannot be defined*. So what is the editor of a dictionary to do? The obvious thing is to fall back on the metalanguage of epistemology. Which is precisely what Bohr did to bring home to lesser spirits the extrinsic nature of the properties of quantum systems.

If "fact" is so fundamental a term that it cannot be defined, the existence of facts—the factuality of events or states of affairs—cannot be accounted for, any more than we can explain why there is anything at all, rather than nothing. (If something can be accounted for, it can be defined in terms of whatever accounts for it.) Before the mystery of existence—the existence of *facts*—we are left with nothing but sheer dumbfoundment. Any attempt to explain the emergence of facts ("the emergence of classicality," as it is sometimes called) must therefore be a wholly gratuitous endeavor.

Classical physics deals with nomologically possible worlds—worlds consistent with physical theory. It does not uniquely determine the actual world. Identifying the actual world among all nomologically possible worlds is strictly a matter of observation. Does this imply that classical physics presupposes conscious observers? Obviously not. In classical physics the actual course of events is in principle fully determined by the actual initial conditions (or the actual initial and final conditions). In quantum physics it also depends on unpredictable actual states of affairs at later (or intermediate) times. Accordingly, picking out the actual world from all nomologically possible worlds requires observation not only of the actual initial conditions (or the actual initial and final conditions) but also of those unpredictable actual states of affairs. Does this imply that quantum physics presupposes conscious observers? If the answer is negative for classical physics, it is equally negative for quantum physics.

QM concerns statistical correlations between (observer-independent) facts, and these correlations warrant interpreting the facts as indicative of properties. That is, they warrant the existence of a physical system to which the indicated properties can be attributed. Suppose that we perform a series of position measurements, and that every position measurement yields exactly one result (that is, each time exactly one detector clicks). Then we are entitled to infer the existence of a persistent entity, to think of the clicks given off by the detectors as matters of fact about the successive positions of this entity, to think of the behavior of the detectors as position measurements, and to think of the detectors as detectors. If instead each time exactly two detectors click, we are entitled to infer the existence of two entities or, rather, of a physical system with the property of having two components. This property is as extrinsic as are the measured positions. There is a determinate number of entities only *because* every time the same number of detectors click. Not only the properties of things but also the number of existing things supervenes on the facts.

The ontological dependence of the properties and the number of existing things on facts warrants a distinction between two domains, a *classical domain* of facts and a *quantum domain* of properties that supervene on the facts. Owing to the ontological dependence of the domain of indicated properties on the domain of property-indicating facts, the quantum domain cannot account for the existence of the classical domain. If one nevertheless assumes that (i) the ultimate physical reality is the quantum domain, and that (ii) the existence of the domain of facts can, and therefore should, be accounted for, then consciousness becomes an obvious candidate: Facts exist because they are perceived.

If in addition one wrongly assumes with von Neumann that the quantum state represents the dynamical evolution of the quantum domain, one is faced with the spurious problem of reconciling two disparate modes of evolution. The obvious "solution" then is to consider one mode of evolution intrinsic to the quantum domain and to blame the other mode on the intervention of conscious observers. This, in brief, is how some of the brightest physicists were led to conclude that QM is an epistemic theory, concerned with our knowledge or experience of the factual situation rather than the factual situation itself. One is reminded of the various God-of-the-gaps proposals of the past. While invoking divine intervention as a filler for explanatory gaps is no longer in fashion, there is a tendency to invoke consciousness instead.

For reasons that are obvious rather than mysterious, probability measures have two modes of "change." Probabilities are assigned on the basis of relevant facts, and they are assigned to sets of possible property-indicating facts, or else to the properties indicated by such facts. They depend (i) on the time t of the possible facts to which they are assigned and (ii) on the facts on which the assignment is based. They therefore "change" not only in a "deterministic" manner, as functions of t, but also unpredictably with every fresh relevant fact. The successful completion of a measurement is the relevant fact *par excellence.* If the outcome is unpredictable, as it generally is, it has to be included among the relevant facts on which further probability assignments ought to be based. The outcome being unpredictable, the basis of relevant facts changes unpredictably as a matter of course, and so do the probabilities assigned on this basis.

The reason for the quotation marks is that a probability is not the kind of thing that *changes.* To see this, consider the Born probability $p\,(R,t)$ of finding a particle in a region R at a time t. While few would think of this probability as something that exists inside R, many appear to think of it as something that exists at the time t. The prevalent idea is that the possibility of finding the particle inside R exists at all times for which $p\,(R,t) > 0$, so the probability associated with this possibility also exists at all those times and changes as a function of time. Yet the possibility that a property-indicating state of affairs obtains at the time t is not something that exists at the time t, anymore than the possibility of finding the particle in R is something that one can find inside R. And the same obviously holds true of the probability associated with this possibility. $p\,(R,t)$ isn't something of which we can say *when* it exists. *A fortiori* it isn't something that can change or evolve. All quantum-mechanical probability assignments are conditional on the existence of a matter of fact about the value of a *given* observable at a *given* time. $p\,(R,t)$ is not associated with the possibility that all of a sudden, at the time t, the particle "materializes" inside R. It is the probability with which the particle is found in R, *given* that at the time t it is found in one of a set of mutually disjoint regions (no matter which one, R being one of them). The parameter t on which this probability depends is the specified time of this actually or counterfactually performed position measurement. It refers to the time of a position-indicating state of affairs, the existence of which is *assumed.*

So much for the "change" of $p\,(R,t)$ associated with the argument t. It is obvious that the sense in which $p\,(R,t)$—for a *fixed* value of t—"changes" when assigned on the basis of a fresh set of facts, is also not the sense in which a state of affairs evolves as time passes.

By misconstruing quantum states as evolving states of affairs with two modes of change, von Neumann [2] created a number of pseudo-problems and spawned an entire industry dedicated to generating gratuitous solutions. Are wave function collapses in the mind but not in the world? Or are they in the mind *because* they are in the world? Or are they in the mind and *therefore* in the world? The first option leads to the many-worlds (or many-minds [8]) extravaganza, the second to nonlinear adulterations of QM [23, 24, 25], the third to epistemic interpretations. If the premise is that system S enters into a "state of entanglement" with apparatus A then apparatus A enters into a "state of entanglement" with Cecily's brain as she takes cognizance of the measurement outcome. The definiteness of observation reports combined with the principle of psycho-physical parallelism [2]—subjective perceptions correspond to objective goings-on in the brain—then spells collapse. Hence Cecily's perceptions exert a causal influence on the "objective physical state" [14] of S via the objective goings-on in her brain and their entanglement with S.

The bottom line: The introduction of consciousness into interpretations of QM affords nothing but gratuitous solutions to pseudo-problems. These pseudo-problems arise whenever quantum states are construed, inconsistently with the statistical significance of quantum states, as evolving states of affairs. There does exist an extra-theoretical element that cannot be accounted for by either classical or quantum physics, but this neither is consciousness nor can be accounted for in epistemic terms. It is the actuality of exactly one of all nomologically possible worlds, or the factuality of property-indicating facts. This (f)actuality owes nothing to the consciousness of an "observing system" [14]; it is what distinguishes the world from any theory about the world.

3 QUANTUM MECHANICS AND PROPENSITIES

The following characterizations of the physical world and of physical states are central to Stapp's "objective interpretation of von Neumann's formulation of quantum theory" [14]:

> The observed physical world is described. . . by a mathematical structure that can best be characterized as representing *information* and *propensities*: the *information* is about certain *events* that have occurred in the past, and the *propensities* are objective tendencies pertaining to future events.
>
> The objective physical state is. . . converted from a material substrate to an informational and dispositional substrate that carries both the information incorporated into it by the psychical realities, and certain dispositions for the occurrence of future psychical realities [14].

The possibility that something happens at the time t, recall, is not something that exists at the time t, anymore than the possibility of finding a particle in a region R is something that one can find inside R. A possibility is not the kind of thing that persists and changes in time.

To think of possibilities as if they possessed an actuality of their own, different from the actuality of facts, and as if they persisted and changed (“evolved”) in time, is an obvious category error. This logical mistake gives rise to the somewhat gentler avatar of the “measurement problem,” which asks: How is it that during a measurement one of the persisting possibilities (or worse, one of the changing probabilities associated with them[1]) becomes a fact, while the others cease to exist? Saying in common language that a possibility becomes a fact is the same as saying that something that is possible—something that *can* be a fact—actually *is* a fact. How can that be a problem? This non-problem becomes a pseudo-problem if one forgets that there is only one kind of actuality and misconstrues the common-language “existence” of a possibility as a second kind of actuality, called “propensity” [27] or “potentiality” [28, 29], that gets converted into the genuine article when a measurement is made.

If one wants to associate a measurement with the “actualization of a possibility” in a logically coherent manner, one must not portray it as a transition from an earlier state of affairs, in which the possibility “exists” as a possibility, to a later state of affairs, in which it is a fact. The possibilities to which QM assigns probabilities can all be formulated in the following manner:

(S) A measurement of the (system-specific) observable Q performed at the time t yields the result q_k.

(Conjunctions can be formulated as well: “Measurements of Q_1 and Q_2 performed at the respective times t_1 and t_2 yield the respective results q^1_i and q^2_k.”) Owing to its explicit reference to the time of measurement, such a sentence cannot *become* true or false. If (S) is true, it always has been and always will be true, and if it is false, it always has been and always will be false. Saying that the possibility expressed by (S) has been actualized is therefore the same as saying that (S) is true. Nothing more must be read into this sentence. The question as to when this actualization took place is utterly meaningless. If the “actualization of a possibility” involves a “transition,” it is the logical transition from a possible world in which Q is not measured at the time t to the actual world in which Q is successfully measured at the time t.

The bottom line: The only problem that is addressed by the introduction of propensities or potentialities into interpretations of QM is another pseudo-problem originating from another logical mistake. It arises if one thinks of the possibilities to which QM refers, and of the probabilities it assigns to them, as if they constituted a self-existent matrix from which facts arise.

4 QUANTUM MECHANICS AND SPECIAL RELATIVITY

It is well known that the statistical regularities with which QM is concerned are consistent with SR, while von Neumann’s interpretation of states as evolving, collapsible states of affairs is not. Stapp tries to reconcile SR with von Neumann’s interpretation by giving “special objective physical status” [14] to a particular family of constant-time hypersurfaces: State reductions occur globally and instantaneously with respect to this family of hypersurfaces. He offers two arguments purporting to support the existence of a “dynamically preferred sequence of instantaneous ‘nows’ ” [14]. The first invokes astronomical data that, incontestably, indicate the existence of a (cosmologically) preferred sequence of “nows.” This argument fails to distinguish sufficiently between (i) a *dynamically* preferred sequence of hypersurfaces—a sequence implied by the dynamical laws and present in every possible world consistent with them—and (ii) a preferred sequence of contingent and historical character that is not implied by the dynamical laws and therefore is not a feature of every nomologically possible world. The astronomical data suggest the existence of a historically preferred sequence but give no evidence of a dynamically preferred one.

The second argument is based on an experiment of the kind first discussed by Lucien Hardy [30]. There are two regions L and R in spacelike separation such that, in a certain coordinate system (x, y, z, t), R is earlier than L. Two two-valued observables L_i and R_i $(i = 1, 2)$ can be measured in each region. The joint probabilities of the various possible results are determined by

$$|\Psi\rangle = |L1+, R1-\rangle - |L2-, R2+\rangle\langle L2-, R2+|L1+, R1-\rangle, \tag{1}$$

and they warrant the following assertions:

$$\begin{align} L_1- &\Rightarrow R_2+, \tag{2}\\ R_2+ &\Rightarrow L_2+, \tag{3}\\ L_2+ &\Rightarrow R_1-, \tag{4}\\ L_1- &\not\Rightarrow R_1-. \tag{5} \end{align}$$

In longhand (2) says that if L_1 is measured and the result is L_1- then if R_2 is measured the result is R_2+. On account of (2), the conditional “If R_2 is measured then R_2+ is obtained” is valid on condition that L_1 is measured and L_1- is obtained. On account of (3), the conditional “If L_2 is measured then L_2+ is obtained” is valid on condition that R_2 is measured and R_2+ is obtained. Combining these two conditional statements, Stapp arrives at the following conclusion:

> (A) If L_1 and R_2 are measured and the outcome of the measurement of L_1 is L_1- then if L_2 had been measured instead of L_1 the outcome L_2+ would have been obtained.

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[1] “Above all, we would like to understand how it is that probabilities become facts.”—S. Treiman [26]. Dozens of similar phrases can be found in the literature.

While it is legitimate to ask for the result that would have been obtained if L_2 had been measured instead of L_1, it is illegitimate to base the answer on the assumption that L_1 was measured. There is no quantum state such that both L_1 and L_2 are dispersion-free. It is therefore logically impossible to counterfactually assign a definite value to L_2 on the basis of a result of a measurement of L_1. Probabilities can be assigned counterfactually (that is, to the possible results of unperformed measurements), but only if the facts on the basis of which they are assigned are consistent with the measurements to the possible results of which they are assigned. The combination of the above two conditional statements is illegitimate because it assigns a probability to a possible outcome of a measurement of L_2 on the basis of an outcome of a measurement of L_1. The existence of an outcome of the former measurement is inconsistent with the existence of an outcome of the latter measurement.

By an equally fallacious route Stapp arrives at the conclusion that the following statement is false:

> (B) If L_1 and R_1 are measured and the outcome of the measurement of L_1 is L_1- then if L_2 had been measured instead of L_1 the outcome L_2+ would have been obtained.

Here, too, two individually correct statements are combined in a logically inconsistent manner: (i) The antecedent (including the assumption that L_1 is measured) and (5) jointly imply that sometimes R_1+ is obtained. (ii) The assumption that R_1+ is obtained and (4) jointly imply that a measurement of L_2 does not yield L_2+. Both statements are correct, but they consider logically incompatible situations, so that no valid conclusions can be drawn from their conjunction.

To buttress his conclusions, Stapp makes the assumption that in the coordinate system (x, y, z, t) no backward-in-time influences occur. He makes this assumption to exclude two possibilities: (i) the possibility that the result R_2+ causally depends on the result L_1- and therefore cannot be invoked to infer that L_2+ would have been obtained had L_2 been measured instead of L_1, and (ii) the possibility that the occasional result R_1+ causally depends on the result L_1- and therefore cannot be invoked to infer that, whenever R_1+ is obtained, L_2+ would not have been obtained had L_2 been measured instead of L_1. Causal considerations, however, are completely irrelevant to the validity or otherwise of Stapp's conclusions. What invalidates his conclusions is the fact that statements concerning the value of one observable cannot be based on assumptions concerning the value of another observable if the two observables are incompatible.

From the truth of (A) (symbolically: $L_1- \wedge R_2\pm \Rightarrow L_2+$) and the falsity of (B) (symbolically: $L_1- \wedge R_1\pm \not\Rightarrow L_2+$) Stapp infers that

> a theoretical constraint upon what nature can choose in region L, under conditions freely chosen by the experimenter in region L, depends nontrivially on which experiment is freely chosen by the experimenter in region R.... But this dependence cannot be upheld without the information about the free choice made in region R getting to region L: *some sort of faster-than-light transfer of information is required.*

The occurrence of L_1 on the left-hand side of the above symbolic formulae representing the truth of (A) and the falsity of (B), respectively, is logically inconsistent with the occurrence of L_2 on the right-hand side. Therefore Stapp's second argument also fails to establish the "special objective physical status" [14] of a particular family of constant-time hypersurfaces, or the existence of a "dynamically preferred sequence of instantaneous 'nows'."

Stapp considers the nonexistence of a such a dynamically preferred sequence in SR an empirically unwarranted "metaphysical idea." What would the *existence* of such a sequence amount to?

The great theoretical breakthrough that gave us SR came with the realization that (i) what propagates with an invariant speed requires no medium, and that (ii) the invariant speed is the finite speed of light c. "Invariant" means "independent of the inertial frame in which it is measured." It is not hard to see that there cannot be more than one invariant speed.

If an event e_1 at (x_1, t_1) is the cause of an event e_2 at (x_2, t_2), the fact that e_2 happens at t_2, rather than at any other time, has two possible explanations. If the causal connection is *mediated*, and if x_1, t_1, and x_2 are fixed, t_2 is determined by the speed of mediation. This could be the speed of a material particle traveling from x_1 to x_2 or the speed of signal propagation in an elastic medium. On the other hand, if the causal connection is *unmediated*, t_2 is determined by the metric structure with respect to which the dynamical laws are formulated, and this metric structure defines an invariant speed. In a nonrelativistic world the metric structure defines an infinite invariant speed—what propagates instantaneously, or with an infinite speed, in one inertial frame, does so in every other inertial frame,—whereas in a relativistic world it defines a finite invariant speed. In a nonrelativistic world, accordingly, the dynamical laws allow for an unmediated causal connection between e_1 and e_2 provided that, invariantly, $t_2 = t_1$, while in a relativistic world they allow for an unmediated causal connection between e_1 and e_2 provided that, invariantly, $(x_2 - x_1)/(t_2 - t_1) = c$.

We live in a world in which the dynamical laws constrain unmediated signal propagation to null geodesics.[2]

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[2] For reasons that are psychological rather than physical, most physicists believe that photons are particles that mediate influences, rather than elementary unmediated influences. (I am not saying that they are either.)

Signal propagation occurring along either timelike or spacelike geodesics cannot be invariant and therefore cannot be unmediated. By claiming the existence of a dynamically preferred family of constant-time hypersurfaces, Stapp therefore effectively postulates the existence of a quantum counterpart to the luminiferous ether. He may be inclined to deny this, but as long as the speed of light is invariant, there can be no other explanation why state reduction occurs with respect to one family of hypersurfaces rather than another (assuming that it does occur). The only way for Stapp to avoid the implication of a "quantum ether" is to revert to the metric of Galilean relativity, which implies the existence of preferred family of constant-time hypersurfaces, at the expense of reintroducing the luminiferous ether. So which is the unwarranted "metaphysical idea"? The existence of a preferred family of hypersurfaces, which, combined with the invariance of the speed of light, implies the existence of one ether or another, or the nonexistence of such a preferred family?

5 QUANTUM MECHANICS AND THE EXPERIENTIAL NOW

We are accustomed to the idea that the redness of a ripe tomato exists in our minds, rather than in the physical world. We find it incomparably more difficult to accept that the same is true of the experiential now: It has no counterpart in the physical world. There simply is no objective way to characterize the present. And since the past and the future are defined relative to the present, they too cannot be defined in objective terms. The temporal modes past, present, and future can be characterized only by how they relate to us as conscious subjects: through memory, through the present-tense immediacy of qualia (introspectible properties like pink or turquoise), or through anticipation. In the world that is accessible to physics we may qualify events or states of affairs as past, present, or future *relative to* other events or states of affairs, but we cannot speak of *the* past, *the* present, or *the* future.

The proper view of physical reality therefore is not only what Nagel [31] has called "the view from nowhere" (the objective world does not contain a preferred position corresponding to the spatial location whence I survey it); it is also what Price has called "the view from nowhen" [32]: The objective world does not contain a preferred time corresponding to the particular moment (the present) at which I experience it. The objective world contains spatial and temporal relations as well as the corresponding relata, but it does not contain any kind of basis for the distinction between a past, a present, and a future. The idea that some things exist not yet and others exist no longer is as true and as false as the idea that a ripe tomato is red.

If we conceive of temporal relations, we conceive of the corresponding relata simultaneously—they exist at the same time *in our minds*—even though they happen or obtain at different times in the objective world. Since we can't help it, that has to be OK. But it is definitely not OK if we sneak into our simultaneous spatial mental picture of a spatiotemporal whole anything that advances across this spatiotemporal whole. We cannot mentally represent a spatiotemporal whole as a simultaneous spatial whole and then imagine this simultaneous spatial whole as persisting in time and the present as advancing through it. There is only one time, the fourth dimension of the spatiotemporal whole. There is not another time in which this spatiotemporal whole persists as a spatial whole and in which the present advances, or in which an objective instantaneous state *evolves*. If the present is anywhere in the spatiotemporal whole, it is trivially and vacuously everywhere—or, rather, everywhen.

In a world that has no room for an advancing now, time does not "flow" or "pass." Objective time is a set of temporal relations between temporal relata that owe their successive character to our minds, rather than to anything in the objective world. To philosophers the perplexities and absurdities entailed by the notion of an objective advancing present or an objectively flowing time are well known [33]. Physicists began to recognize the subjectivity of the present and the nonexistence of an evolving instantaneous state with the discovery of the relativity of simultaneity. In the well-known words of Hermann Weyl [34],

> The objective world simply *is*; it does not *happen*. Only to the gaze of my consciousness, crawling upward along the life line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.

Not only the fleeting and continuously changing image but also the "crawling upward" of our consciousness is a subjective phenomenon. So is change, and so is becoming.

The myth of an evolving instantaneous physical state is supported by a folk tale of considerable appeal. It goes like this: Since the past is no longer real, it can influence the present only through the mediation of something that persists through time. Causal influences reach from the nonexistent past into the nonexistent future by being "carried through time" by something that "stays in the present." There is, accordingly, an evolving instantaneous state, and this includes not only all presently possessed properties but also everything in the past that is causally relevant to the future. This is how we come to conceive of "fields of force" that evolve in time (and therefore, in a relativistic world, according to the principle of local action), and that "mediate" between the past and the future (and therefore, in a relativistic world, between local causes and their distant effects). It is also how we come to believe that the state vector plays a similar causally mediating role. It is high time that we outgrow these incoherent beliefs.

There was a time when characterizing something as subjective was tantamount to denigrating it as an "illusion." This is not my intention. Change and becoming are no less real and no less significant for being subjective. My point is that a theory of mind–matter interaction, which is what Stapp's theory purports to be, must proceed from a clear understanding of which features of the experienced, phenomenal world do, and which do not, have a counterpart in the physical world. Instead of proceeding from such an understanding, Stapp's theory features the chimera of "an evolving objective physical world." It is "a theory of the interaction between the evolving objective state of the physical universe and a sequence of mental events, each of which is associated with a localized individual system."

It might be argued that without an objective becoming there can be no freedom of choice. Such freedom seems to require an open future. In fact, the apparent incompatibility of free volition with the "block universe" of SR is one of the reasons why Stapp rejects the idea that "all of history can be conceived to be laid out in a four-dimensional spacetime." According to him, free will "leads to a picture of a reality that gradually unfolds in response to choices that are not necessarily fixed by the prior physical part of reality alone."

This too is an error. All that the freedom to choose requires is the impossibility of *knowing*, at any one time, what is the case at a later time. Obviously, if I can know at the time t a state of affairs that obtains at the time $t' > t$, I cannot conceive of it as causally dependent on a free choice made by me in the interval between t and t'. If at any time t I can know the future (relative to t), I cannot conceive of myself as a free agent. On the other hand, if the possibility of foreknowledge does not exist, I cannot merely conceive of myself as a free agent. I can actually be a free agent, for the only thing that logically prevents me from being responsible for a later state of affairs is the possibility of knowing the same before the relevant choices are made. The fact that the future in a sense "already" exists is no reason why choices made by me at earlier times cannot be partly responsible for it. (The future relative to a time t exists "already" not in the sense that it exists simultaneously with what exists at the time t, which would be self-contradictory, but in the sense that it exists *objectively* in exactly the same tenseless or atemporal sense in which what exists at the time t exists.)

Since nothing in the physical world corresponds to the distinction between what exists *now* and what does *not yet* exist, the future (relative to a time t) is as closed as the past. If a measurement of the value possessed by Q at the time t is successfully performed at the time $t' \geq t$, and the result is q, then it always has been and always will be true that the value of Q at the time t is q. There is nothing physically open about this. From the point of view of physics, the outcomes of performed measurements are always "fixed and settled" [14]. Nothing objectively changes at the time t (unless $t = t'$). What objectively changes, at the time t', is that subsequently there obtains an actual state of affairs from which the value of Q at the time t can be inferred. The causal interconnectedness of the classical domain ensures that the possibility (in principle) of inferring the value of Q at the time t will persist. (See Sec. 8 below. In measurement theory this is usually referred to as the creation of a record [35].) The misconception that the value of Q at the time t did not exist until it was observed or became inferable has to be seen for what it is: a naive objectification or reification of our ignorance, which ceases to exist, in principle at the time t', and in actual fact when we look at the pointer. What *is* (and always has been, and always will be) objectively open is the results of *unperformed* measurements.

6 QUANTUM MECHANICS AND CAUSALITY

Physics concerns spatiotemporal regularities. Classical physics concerns deterministic regularities that permit us to make (i) definite predictions on the basis of initial positions in phase space, (ii) definite retrodictions on the basis of final positions in phase space, and (iii) definite inferences of intermediate states on the basis of initial and final positions in configuration space. Quantum physics concerns statistical regularities that permit us to assign (i) prior probabilities on the basis of earlier property-indicating facts according to the Born rule, (ii) posterior probabilities on the basis of later property-indicating facts according to the same rule, and (iii) time-symmetric probabilities on the basis of earlier and later property-indicating facts according to the ABL rule [36], so named after Aharonov, Bergmann, and Lebowitz [37].

The deterministic regularities of classical physics lend themselves to a causal interpretation, according to which the observable regularities are due to unobservable causal strings by means of which earlier events necessitate later events. Since the time-symmetric laws of classical physics provide no objective foundation for it, this time-asymmetric interpretation can be nothing but an anthropomorphic projection, into the time-symmetric world of classical physics, of the successive perspective of a conscious agent. Causality lies in the eye of the beholder [17]. It is our way of interpreting events, not a feature of the events in themselves. At best it is a secondary quality like pink or turquoise [38].

The statistical regularities of quantum physics do not admit of this anthropomorphic projection. To begin with, measurement outcomes are *causal primaries*. They are value-indicating states of affairs that are *not* necessitated by antecedent causes. To see this, recall from Sec. 2 that all quantum-mechanical probability assignments involve the assumption that the value of a specific observable at a specific time is indicated by an actual state of affairs. Quantum mechanics never predicts that a measurement will take place, nor when one will take place. And if QM is the fundamental and complete theoretical framework that most of us believe it is, these things cannot be predicted because there is nothing that *necessitates* the existence of a value-indicating state of affairs.

I do not mean to say that in general nothing causes a measurement to yield this particular outcome rather than that. Unless hidden variables are postulated, this is a triviality. What I am saying is that nothing ever *causes* a measurement to take place. A clear distinction between two kinds of probability must be maintained. In the context of a position measurement using an array of detectors, this is the distinction between the probability *that* a detector will respond (no matter which) and the probability that a specific detector will respond *given* that any one detector will respond. The latter probability is the one that quantum mechanics is concerned with. The former probability can be measured (for instance, by using similar detectors in series), but it cannot be calculated from first principles, for essentially the same reason that a fundamental coupling constant cannot be so calculated [22].

If anything is causally determined, it can only be the probabilities associated with measurement outcomes. But the dependence of quantum-mechanical probability assignments on facts also does not admit of a causal interpretation, for at least two reasons. For one, there isn't just one way of assigning probabilities. If probability assignments are to be of any use, they have to be based on facts. But the probability $p\,(Q{=}q,t)$ of the result q of a measurement of Q at the time t can be assigned on the basis of several different (sets of) facts. After all, probabilities are nothing but best guesses *given* the facts that are taken into account. This is true even if Nature herself tells us (via the laws of QM) what probabilities we should assign, for Nature does not tell us which facts should be taken into account. This choice is left to us. Stapp's belief that this choice too is dictated by Nature—that the probability $p\,(Q{=}q,t)$ is uniquely determined by a unique past (relative to t)—is an error.

Another reason why quantum-mechanical probabilities cannot be causally explained is that a best guess is not the kind of thing that admits of a causal explanation. While a best guess obviously depends on a *chosen* set of facts, it cannot be construed as an objective propensity that is causally determined by a *unique* set of facts, without committing some of the fallacies pointed out above.

The ontological dependence of all possessed properties on property-indicating states of affairs, combined with the fact that such states of affairs are causal primaries, implies that at a fundamental level *nothing in the physical world is necessitated by antecedent causes.* The acausal foundation of the physical world ought to be regarded as one of the most important discoveries of modern science, rather than deplored as the "Copenhagen renunciation" of all "attempts to understand physical reality" [14]. As the following sections will show, the impossibility of causally construing the quantum-mechanical correlations has significant ontological implications. It does not entail that we must "renounce for all time the aim of trying to understand the world in which we live" [14].

7 OBJECTIVE PROBABILITIES

N. David Mermin believes that all the mysteries of quantum mechanics can be reduced to the single puzzle posed by the existence of objective probabilities [39]. I concur. The objective probabilities Mermin has in mind, however, are not the objectified evolving probabilities Stapp calls "propensities." Probabilities qualify as objective if and only if they are assigned on the basis of all relevant facts, so that there is nothing to be ignorant of. The probabilities of classical statistical physics are always subjective; they make up for facts that we ignore. The prior Born probabilities that we assign to the possible results of performed measurements are equally subjective, inasmuch as we assign them without taking the actual results into account.

The term "objective probability" has two natural definitions. When there *are* actual states of affairs having a bearing on the probability $p\,(Q{=}q,t)$, this probability is objective only if all of them are taken into account, regardless of whether they obtain before or after the time t. In this case $p\,(Q{=}q,t)$ is given by the ABL rule [22, 36].

The second definition is appropriate when there aren't any relevant facts. This is the case when we are dealing with the stationary probability measures that solve the time-independent Schrödinger equation, rather than with probability measures that depend on initial and/or final conditions imposed on the time-dependent Schrödinger equation. The Born probabilities we obtain from stationary states are objective just in case they are counterfactually assigned.

What is the ontological significance of objective Born probabilities? The pertinent issue is the stability of matter. When Bohr wrote his doctoral thesis on the electron theory of metals, he became fascinated by its instabilities. They suggested to him a new type of stabilizing force, one fundamentally different from those familiar in classical physics. Transferring his postdoctoral attention from metals to Rutherford's atom, Bohr realized that this too ought to be unstable, and by imposing his well-known quantum conditions he took the first step toward an understanding of the force that stabilizes matter. When the mature theory arrived twelve years later, it transpired that this "force" hinges on the fuzziness of internal spatial relations. What "fluffs out" matter is the indefiniteness of the relative positions of its constituents. Though today this fact is known to every physicist, few seem to attach to it the importance that it deserves.

The proper way of dealing with fuzzy values is to make counterfactual probability assignments. If a quantity is said to have an "indefinite value," what is really intended is that it does not actually have a value (inasmuch as the value is not measured) but that it *would* have a value if this *were* indicated, and that at least two possible values are associated with positive probabilities. (The counterfactuality cannot be eliminated, though it may be shifted from measurements to fuzzy values: If measurements of an observable Q *are* successfully performed on an ensemble of identically prepared systems, and if the results have positive dispersion, the value of Q *would be* fuzzy with regard to an individual system S if the measurement *were not* performed on S.)

The objective probabilities associated with the results of unperformed measurements thus are the formal expression of an *objective indefiniteness.* The extrinsic nature of the values of quantum-mechanical observables follows directly from this indefiniteness. It is a straightforward consequence of an objective fuzziness in the world in which we live. Here is how: The proper expression of this fuzziness, as we just saw, involves counterfactual probability assignments. These assignments are based on the observable statistical correlations that QM encapsulates. We are therefore dealing with conditional probability assignments whose antecedents may or may not be true. We therefore need a criterion for when an antecedent is true, and this consists in the existence of a value-indicating fact.

The extrinsic nature of possessed values is not confined to atoms and suchlike. As Peres and Zurek [40] rightly insist, "[t]here is nothing in quantum theory making it applicable to three atoms and inapplicable to 10^{23}." Although the moon isn't only there when somebody looks [41], it is there only because of the myriad of facts that betoken its presence. If there weren't any actual state of affairs from which its position could be inferred, it wouldn't have a position, or else its position wouldn't have a value. (There is no need for anyone to actually carry out the inference.) This seems to entail a vicious regress, which at first blush looks like just another version of von Neumann's catastrophe of infinite regression.

The positions of detectors are extrinsic too. They are what they are only because of the facts that indicate what they are. This seems to require the existence of detector detectors indicating the positions of detectors, which seems to require the existence of detectors indicating the positions of detector detectors, and so on *ad infinitum.* Generally speaking, the contingent properties of things "dangle" ontologically from what is the case in the rest of the world. Yet what is the case there can only be described by describing material objects, and the properties of such objects too "dangle" from the goings-on in the rest of the world. This seems to send us chasing the ultimate property-indicating facts in never-ending circles.

So were does the buck stop? As it stands, the question is ill posed. There are no valueless positions in search of value-indicating facts. There are facts, and there are statistical correlations among value-indicating facts. These correlations warrant inferences to the existence of objects with properties that have indefinite values (in the sense explained above), and they also warrant the interpretation of the statistically correlated facts as indicating possessed values. The genuine core of the "measurement problem" is this: Value-indicating facts are actual states of affairs. Facts are by definition factual *per se.* Yet a state of affairs involves objects and their properties, and the properties of objects are extrinsic; their possession is not factual *per se.* So what justifies our treating the value-indicating properties of value-indicating things as if they were intrinsic (the opposite of extrinsic)? The answer will be given in the following section.

8 THE CLASSICAL DOMAIN

The positional indefiniteness of a material object O evinces itself through the unpredictability of the results of position measurements performed on O. Evidence of the corresponding statistical dispersion requires the existence of detectors with sensitive regions that are small and localized enough to probe the range of values over which O's position is distributed. (A detector is any object capable of indicating the presence of another object in a particular region.) If there are no such detectors, the indefiniteness of O's position cannot evince itself. But detectors with sharper positions and sufficiently small sensitive regions cannot exist for all detectable objects. Since no relative position is absolutely sharp, there is a finite limit to the sharpness of the positions of material objects, and there is a finite limit to the spatial resolution of actually existing detectors. Hence there are objects whose positions are the sharpest in existence. These never evince their indefiniteness through unpredictable position-indicating facts. Such objects deserve to be designated "macroscopic." We cannot be certain that a given object qualifies as macroscopic, inasmuch as not all matters of fact about its whereabouts are accessible to us, but we can be certain that macroscopic objects exist.

If the positional indefiniteness of a macroscopic object never evinces itself through unpredictable position-indicating events—the occasional unpredictability of the position of a macroscopic pointer reveals the indefiniteness of a property of a different object, not the indefiniteness of the position of the pointer—then it is legitimate to ignore the positional indefiniteness of macroscopic objects. We can associate such objects with classical trajectories, provided we understand the claims involved. It is not claimed that macroscopic objects have exact positions. It is only claimed that since their positions are the most definite in existence, the indefiniteness of their positions never shows up in the realm of facts. If we make the assumption that macroscopic objects follow definite trajectories, we will never see this assumption contradicted by facts. But if it is legitimate to ignore the positional indefiniteness of macroscopic objects, it is also legitimate to treat the positions of macroscopic objects as intrinsic.

The step from acknowledging the extrinsic nature of all contingent properties to treating the positions of macroscopic objects as intrinsic is of the same nature as the step from acknowledging the purely correlative character of classical laws of motion to the use of causal language. Macroscopic objects evolve predictably in the sense that every time the position of such an object is indicated, its value is consistent with all predictions made on the basis of (i) all past indicated properties and (ii) the classical laws of motion. (As mentioned above, there is one exception: Whenever the position of such an object serves to indicate an unpredictable property in the quantum domain, it is itself not predictable.) This makes it possible to think of the positions of macroscopic objects as forming a self-contained system of positions that "dangle" causally from each other, and this makes it possible to disregard that in reality they "dangle" ontologically from position-indicating facts. Predictability warrants the applicability of causal concepts, and the applicability of causal concepts to macroscopic objects warrants treating their positions as intrinsic.

Causality and intrinsic properties therefore stand and fall together. Where the extrinsic nature of properties cannot be ignored, causal concepts cannot be applied. While correlations that are not manifestly probabilistic (like those between the successive positions of macroscopic objects) can be embellished with causal stories, in the quantum domain causal concepts are out of place. We can impose them on the classical domain with some measure of consistency, although this entails the use of a wrong criterion: Temporal precedence takes the place of causal independence as the criterion that distinguishes causes from effects. But when we deal with correlations that are manifestly probabilistic, projecting our agent causality into the physical world does not work. Trying to causally explain these correlations is putting the cart in front of the horse. It is the statistical correlations that explain why causal explanations work to the extent they do. They work in the classical domain where statistical variations are not in evidence. If we go beyond this domain, we realize that all correlations are essentially statistical, even where statistical variations are not in evidence, and that causality is a function of psychology rather than a physical concept.

9 THE SPATIOTEMPORAL DIFFERENTIATION OF REALITY

According to Richard Feynman, the mother of all quantum effects is the strange behavior of electrons in two-slit experiments [42]. If nothing indicates the slit taken by an electron then this electron goes through both slits without going through a particular slit and without having parts that go through different slits. The bafflement caused by this behavior is symptomatic of a mismatch between the spatial aspect of the physical world and the way in which we all tend to think about space, for psychological and neurophysiological reasons [43, 44].

We tend to think of space as a set of points cardinally equal to the set $I\!R^3$ of triplets of real numbers, or else we tend to think of space as an extended thing that it is inherently divided into mutually disjoint regions (philosophically speaking, an extended substance with intrinsic parts), and we consider it legitimate to mathematically represent this thing by the set $I\!R^3$. (If it's intrinsically divided, then it's divided into infinitesimal regions, and then it seems OK to represent these regions by the elements of $I\!R^3$.)

QM is trying to tell us otherwise. The only positions in existence are (i) the (not manifestly fuzzy) positions of macroscopic objects and (ii) the positions possessed by objects in the quantum domain. The latter are defined by the sensitive regions of macroscopic detectors, are always finite in extent, and are possessed only when indicated. The proper way of thinking, speaking, or writing about a "region of space," therefore, is to never let the logical or grammatical subject of a sentence refer to it. Regions of space are not things that exist by themselves, nor are they parts of a thing that exists by itself. Since they exist only as properties of material things, only predicates of sentences about material things should refer to them.

If they were things, the regions defined by the two slits—let's call them L and R—would be distinct, self-existent parts of space. An object that is in the union $U = L \cup R$ of two distinct, self-existent parts of space, either is in L, or is in R, or is divided by the distinctness of L and R into two parts, one in L and one in R. Since electrons in two-slit experiments can go through U without going through either L or R and without being divided into parts that go through different slits, the two slits cannot be things. L and R are properties that are possessed if and only if their possession is indicated. If they are not possessed (because they are not indicated) then they do not exist. But if they do not exist, they obviously cannot compel electrons to "choose" between them.

A position measurement performed on O at a time t with N detectors D_i (sensitive regions R_i) answers N yes-no questions. It yields truth values ("true" or "false") for N propositions of the form $\mathbf{p}_i =$"O is inside R_i at the time t." Where O is concerned, the world at the time

t is spatially differentiated into N finite regions. They exist for O because the propositions $\mathbf{p}_i$ are either true or false, and these propositions are either true or false because their truth values are indicated. (If their truth values are not indicated, they are neither true nor false but meaningless.)

That we can treat the positions of macroscopic objects as intrinsic, for reasons and subject to qualifications stated in the previous section, does not change the fact that at bottom they too are extrinsic. While the whereabouts of macroscopic objects are abundantly and redundantly indicated, they are never indicated with absolute precision. Hence even for a macroscopic object O the world at any given time t is only finitely differentiated spacewise (that is, no finite region R is differentiated into infinitely many regions R_i such that truth values exist for all propositions $\mathbf{p}_i$).

The *finite* spatial differentiation of reality is one of the most significant ontological implications of QM [22, 43]. It is as inconsistent with the field-theoretic notion that physical properties are instantiated by the "points of space"[3] as special relativity is with the notion of absolute simultaneity. The world is created top-down, by a finite process of differentiation that stops short of an infinite spatial differentiation, rather than built bottom-up, on an infinitely and intrinsically differentiated space, out of locally instantiated physical properties. There are no points on which to build such a world. An infinitely and intrinsically differentiated space, such as $I\!R^3$ is commonly supposed to represent, exists nowhere but in our thoughts. We may think of the trajectories of macroscopic objects as the paths of average (expected) positions, but the fuzziness implied by this way of thinking exists solely in our imagination. It corresponds to nothing in the physical world because it exists only in relation to an unrealized degree of spatial differentiation—it exists only in relation to an imagined backdrop that is more differentiated spacewise than is the physical world.

What is true of the world's spatial aspect is equally true of its temporal aspect. There is no such thing as an intrinsically and infinitely differentiated time. What is temporally differentiated is physical systems, and every physical system is temporally differentiated only to the extent that it has distinct successive states, in the common-language sense of "state" that connotes possessed properties. The world's limited temporal differentiation is a direct consequence of its limited spatial differentiation. Because the world is only finitely differentiated spacewise, no physical system can have an infinite number of distinct states in a finite time span T. Therefore a macroscopic clock (usually indicating time by some macroscopic pointer) can indicate no more than a finite number of distinct times during T, and this means that there exist no more than a finite number of such times during T.

Consider a system S to which, on the basis of its factually warranted properties at the indicated clock times t_1 and t_2, the respective Born probability measures $|\psi_1(t)\rangle$ and $|\psi_2(t)\rangle$ can be assigned. If there isn't any fact that indicates what S is like in the meantime then there isn't anything that S is like in the meantime. Where S is concerned, there isn't any state (in the common-language sense of the word) that obtains in the meantime, let alone an evolving instantaneous state. "[T]here is no interpolating wave function giving the 'state of the system' between measurements" [46]. Not only is there no state that obtains in the meantime but also there is no meantime. And so there isn't any time at which propensities can be attributed to S. Times, like properties, supervene on the facts. Not only the positions of things but also the times at which they are possessed are extrinsic. The times that exist for S are the factually warranted times at which S possesses factually warranted properties.

If there isn't any matter of fact about what S is like in the meantime, we can say that S has *changed* from an object having properties that warrant assigning $|\psi_1(t)\rangle$ to an object having properties that warrant assigning $|\psi_2(t)\rangle$—but *only* in the sense that at the time t_1 the system has the former properties and at t_2 it has the latter properties. The change of S *consists* in the difference between the properties it possesses at t_1 and the properties it possesses at t_2. Where S is concerned, this is all the change that occurs. Nothing can be said about the meantime, not just because in the meantime S lacks properties, but because there isn't any meantime. (Much the same is true of positions between material objects. If a position somewhere between two material objects is not possessed by another material object, it does not exist.)

Stapp's 1972 interpretation of the Copenhagen interpretation combines one correct idea with two erroneous notions [47]:

> The rejection of classical theory in favor of quantum theory represents, in essence, the rejection of the idea that external reality resides in, or inheres in, a space-time continuum. It signalizes the recognition that 'space,' like color, lies in the mind of the beholder.
>
> The principal difficulty in understanding quantum theory lies in the fact that its completeness is incompatible with [the] external existence of the space-time continuum of classical physics.
>
> The theoretical structure did not extend down and anchor itself on fundamental microscopic space-time realities. Instead it turned back and anchored itself in the concrete sense realities that form the basis of social life.

While it is correct that QM is incompatible with the space-time continuum of classical physics, the conclusion that space "lies in the mind of the beholder" is a *non sequitur*, and so is the notion that the theoretical structure

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[3] "A field theory in physics is a theory which associates certain properties with every point of space and time."—M. Redhead [45].

of QM is anchored in "concrete sense realities." What is inconsistent with QM is the existence of an intrinsically and infinitely differentiated space-time continuum. Neither space nor time is a world constituent that exists independently of matter. Therefore neither can be *intrinsically* differentiated. Space and time are modes of differentiation. The objective world *is* in possession of spatial and temporal aspects, but it is only *finitely* differentiated spacewise and timewise. Again, QM presupposes measurements, but measurements *qua* value-indicating facts, not measurements *qua* "concrete sense realities."

In his present theory, Stapp rejects the one correct ingredient in his 1972 interpretation and postulates, as the arena for a local dynamical process satisfying the principle of local causality, the infinitely and intrinsically differentiated space-time continuum of relativistic quantum field theory:

> The evolution of the physical universe involves three related processes. The first is the deterministic evolution of the state of the physical universe. It is controlled by the Schrödinger equation of relativistic quantum field theory. This process is a local dynamical process, with all the causal connections arising solely from interactions between neighboring localized microscopic elements.

As pointed out earlier in this section, these field theoretic notions are as inconsistent with the finite differentiation of the objective world implied by QM as the notion of absolute simultaneity is with special relativity.

10 QUANTUM MECHANICS AND MIND–BRAIN INTERACTION

On the basis of von Neumann's discordant postulates—a classical space-time continuum, a dynamical process subject to local causality, instantaneous collapse due to the injection of "information associated with a subjective perception by some observing system into the objective state of the universe" [14]—Stapp formulates a theory of mind–brain interaction in which choices are claimed to play a crucial role: "The basic building blocks of the new conception of nature are... choices of questions and answers." We freely choose the questions, and Nature freely chooses the answers, within the constraints imposed by the statistical laws of QM.

Like Bohr, Stapp attributes to experimenters the freedom to choose between complementary experimental arrangements: "the choice of which question will be put to nature... is not governed by the physical laws of contemporary physics." Here I agree. The eventual physical effect of such a choice—the experimental setup that is actually in place—is not determined by any of the presently known physical laws, nor is the initial physical effect, which causes, in accordance with the neuroscience of motor control, the actions that lead to the eventual effect.

Just as a specific event in classical physics always leads, under identical conditions, to the same effect, so a specific, causally efficacious plan of action always leads to a specific, causally determined course of action. It is precisely because there is no indeterminacy in the correlations between causes and effects that we can speak of "causes" and "effects." Since causal concepts are applicable only to dispersion-free correlations, quantum indeterminacy can play no mediating role in mental causation. The freedom to choose is a classical phenomenon. The difference between physical causation and mental causation is that the causes of the former, like their effects, belong to the classical domain, while the causes of the latter are not to be found in either physical domain.

The description of the physical effects of mental causes cannot differ from the description of the physical effects of physical causes. The effects of mental causation must be capable of being represented by the same mathematical constructs as the effects of physical causation—that is, by one of the classical force fields. As has been shown elsewhere [15, 16], the relevant field is the electromagnetic four-vector potential. Where this is only physically determined, it is determined (up to gauge transformations) in conformity with Maxwell's equations. Where it includes the effects of causally efficacious mental events, it is no longer so determined.

Stapp asserts that "[a]ccording to the principles of classical physical theory, consciousness makes no difference in behavior: all behavior is determined by microscopic causation." In point of fact, this is so according to certain metaphysical doctrines, not according to the principles of any physical theory. Consciousness can make a difference, although not without infringing physical laws [15, 16]. Like J.C. Eccles [13], Stapp appears to hope that QM will allow the mind to be causally efficacious without infringing physical laws. While Eccles tried, unsuccessfully [15, 16], to exploit quantum-mechanical indeterminism as a loophole through which mind can act on matter without "violating" the laws of physics, Stapp tries to explain the freedom of the experimenter by the freedom of the experimenter's mind to pay or not to pay attention. His argument involves the following seven steps.

(1) Environment-induced decoherence (EID) [48] "creates a powerful tendency for the brain to transform almost instantly into an ensemble of components, each of which is very similar to an *entire classically-described brain*" [14].

Two comments. First, the transformation to which Stapp refers is not a transformation of the brain but the "transformation" of a probability measure associated with one time into a probability measure associated with another, slightly later time. If the prior probability measure associated with the brain and the time t is a coherent superposition

$$\sum_i \sum_k c_i^* c_k |i\rangle\langle k|$$

or a mixture of such superpositions

$$\sum_j \lambda_j \sum_i \sum_k c_{ji}^* c_{jk} |i\rangle\langle k|,$$

the effect of EID is that the prior probability measure associated with the brain and a slightly later time t' is approximately given by the mixture

$$\sum_k c_k^* c_k |k\rangle\langle k|$$

or the mixture (of mixtures)

$$\sum_j \lambda_j \sum_k c_{jk}^* c_{jk} |k\rangle\langle k|.$$

Second, if there is a way of making sense of the phrase "classically described brain" (CDB), the phrase refers to a brain the positional indefiniteness of whose material constituents is not evidenced by such position-indicating facts as are inconsistent with classical laws of motion (Sec. 8).

(2) Each instance of EID in the brain is preceded and brought into play by exocytosis, the release of the contents of a vesicle of neurotransmitter into the synaptic cleft.

The prior probability measure associated with the brain after exocytosis assigns significant probabilities to significantly different outcomes of position measurements that might be performed on some of the brain's material constituents. "Significantly different" is short for "sufficiently different for the probability measure associated with the brain to be subject to EID." The net result, according to Stapp, is "a quantum splitting of the brain into different classically describable components" or elements, all of which must be regarded as real "because interference between the different elements [is] in principle possible."

In point of fact, the net result of exocytosis and EID is a mixed probability measure. As a macroscopic object, a CDB is associated with a probability measure that does not assign significant probabilities to significantly different outcomes of possible position measurements on its material constituents. For this reason we can switch from conditional assignments of probabilities to unconditional attributions of properties (that is, to attributions of *intrinsic* properties); we can talk facts. That is just why we can speak of a "classically described" brain. A "mixture of CDBs," on the other hand, has no sensible translation into the classical language of objects and facts. It is neither an object nor an actual state of affairs but a probability measure pure and simple.

If there isn't any matter of fact about which component of a mixture exists, no component exists. None of them can be "regarded as real." This is the reason why re-interference remains a theoretical possibility. If nothing in the decoherence-inducing environment indicates a particular component, coherence can in principle be restored. Since correlations between the respective probability measures of the environment and the brain are necessary but not sufficient for the existence of a component-indicating fact, the probability measure associated with the brain at a later time could in principle be the initial pure measure, assuming that the initial measure was pure. Whether this is possible under conditions in which a living brain can exist, is a different matter. It stands to reason that under such conditions the decoherence-inducing environment intersects with the classical domain. If so, the existing component will be indicated, in which case the restoration of coherence is ruled out.

A decoherent mixture can be objective in the sense that it specifies objective probabilities. (I agree with Stapp that decoherence is not sufficient for the transformation of objective probabilities into subjective ones.) As explained in Sec. 7, objective probabilities are associated with the possible results of unperformed measurements. An objective probability measure is the proper, counterfactual expression of an objective indefiniteness. If nothing indicates the slit taken by an electron, an objective probability of 1/2 can be assigned to the possibility that the electron has gone through the left (right) slit. In this case saying that the electron went through the left (right) slit is neither true nor false. It is meaningless, for the distinction we make between these alternatives is a distinction that Nature does not make; it corresponds to nothing in the physical world; it exists solely in our minds.

In view of the unavoidable intersection between the decoherence-inducing environment and the classical domain, a mixture of *living* CDBs can only be a subjective probability measure, arising from an incomplete knowledge of the relevant facts. It cannot represent the objective brain. Let us assume, nevertheless, that a "mixture of CDBs" is an objective probability measure. (Only in this case does it make sense to keep looking for a process that changes "and" into "or," or objective probabilities into subjective ones, and in which consciousness can play a causal role.) Then this objective probability measure is the formal expression of an objective indefiniteness, and the distinctions that we make between its components are distinctions that Nature does not make; they correspond to nothing in the physical world. Hence even if a "mixture of CDBs" were an objective probability measure, its components could not be regarded as being both real and distinct from each other.

(3) "[D]uring an interval of conscious thinking, the brain

changes by an alternation between two processes." Having generated "by a local deterministic mechanical rule" a "profusion" of "separate, but equally real, quasi-classical branches," the "individual physical system associated with a mental event" undergoes a change by which it "is brought into alignment with the content of that mental event." The physical aspect of this second process "chops off all branches that are incompatible with the associated psychical aspect."

"[I]f the psychical event is the experiencing of some feature of the physical world, then the associated physical event" updates "the brain's representation of that aspect of the physical world. This updating of the (quantum) brain is achieved by discarding from the ensemble of quasi-classical brain states all those branches in which the brain's representation of the physical world is incompatible with the information content of the psychical event" [14].

If the psychical event is the intention to execute a particular plan of action, then the associated physical event discards the branches associated with plans of action that are incompatible with the experienced intention. (Stapp assumes that "the purely mechanical evolution of the state of the brain in accordance with the Schrödinger equation will normally cause the brain to evolve into a growing ensemble of alternative branches, each of which is essentially an entire classically described brain that specifies a possible plan of action.")

Holding the definiteness of perceptions responsible for the quantum-mechanical "reduction process" permits Stapp to pass from perceptions to other mental contents, and to similarly empower volitions: The definiteness of intentions, like that of perceptions, entails reductions. As yet, however, there is no room for free choices. Consciousness (a psychical aspect of perceptual and/or volitional character) is associated with all branches, and reduction occurs *automatically* whenever the mixture of branches becomes inconsistent with the definiteness of mental contents. To make room for free choices, Stapp introduces the metaphor of the experimenter as interrogator of Nature. Making experiments is asking *questions*, and getting results is receiving *answers* from Nature. The experimenter has the freedom to choose which experiments to perform when, and Nature has the freedom to chose the results.

(4) "The central roles in quantum theory of these discrete choices—the choices of which questions will be put to nature, and which answer nature delivers—makes quantum theory a theory of discrete events. . . . Each of these quantum events involves" (i) "a choice of a Yes-No question by the mind–brain system" and (ii) "a choice by Nature of an answer, either Yes or No, to that question. . . . the freedom to choose which questions are put to nature, and when they are asked, allows mind to influence the behaviour of the brain" [14].

Within the Copenhagen framework, the interrogation of Nature by human experimenters is a fitting metaphor for a well-defined scenario. To choose a question is to decide on a specific experimental arrangement, and to choose a time is to decide when to perform the experiment. The mind, however, doesn't experiment with the brain. To save his metaphor, Stapp therefore needs to imbue it with a new sense. In what sense does the mind put questions to the brain, without the intervention of an apparatus? How does it choose its questions and the times to ask them? In Stapp's opinion, *attention* holds the key.

(5) "Asking a question about something is closely connected to focussing one's attention on it. Attending to something is the act of directing one's mental power to some task. This task might be to update one's representation of some feature of the surrounding world, or to plan or execute some other sort of mental or physical action."

Neurobiological data suggest that the world's neural representation contains far more information than its conscious mental representation, and this suggests that attention plays a crucial role in the relation between the two representations. Sudden changes in the visual field can not only *draw* attention, and thereby update the mental representation, but also draw it *away*, and thereby obliterate features of this representation [49]. (The updating of the mental representation that would normally follow a change in the neural representation, may be prevented by focusing attention on a different part of the visual field.) When it is not drawn willy-nilly, attention seems to be capable of being directed freely. According to William James, whom Stapp quotes approvingly, the power to direct our attention is limited to choices between keeping it focused on whatever has captured it or allowing it to be captured by something else:

> [T]he whole drama of the voluntary life hinges on the attention, slightly more or slightly less, which rival motor ideas may receive.
>
> The essential achievement of the will, in short, when it is most "voluntary," is to attend to a difficult object and hold it fast before the mind. . . . Effort of attention is thus the essential phenomenon of will [50].

While this appears to be both plausible and consistent with the neurobiological data, it has nothing to do with probabilistic reductions of mixtures. The questions the mind can put to the brain, by choosing where to fix its attention, are always compatible, for the mind does not need to choose between mutually incompatible experimental arrangements. The relations between mental contents and neural states, in which attention appears to play a significant role, are therefore relations between the mind and a CDB, which belongs to the definite domain of intrinsic properties. It has nothing to do with the relations between this domain and the indefinite domain of extrinsic properties, with which QM is concerned. The intersection between QM and volition is empty.

I do not deny that a complete understanding of the brain must take into account the positional indefiniteness (and hence the quantum-mechanical nature) of the brain's constituents. But of this there can be no evidence in the correspondences between facts and their neural and mental representations. If attention is drawn to the highest bidder, the highest bidder is not a component of a mixture of CDBs but one among several neural events or activities competing for attention in one and the same CDB. And if attention roams freely (that is, if the mind can freely choose the questions it puts to the brain) then also there is nothing stochastic in the answers it receives. Each answer is determined by a definite aspect of a single CDB, rather than by the probabilistic reduction of a mixture of CDBs.

(6) The interactions between the physical universe and the minds of observers have two aspects. The first "is the role of the experimenter in choosing what to attend to; which aspect of nature he wants to probe; which question he wants to ask about the physical world.... The second aspect is the recognition, or coming to know, the answer that nature returns" [14].

Here Stapp glosses over the disparity between physical experimentation and psychological attention by applying the same metaphor to both. In point of fact, experimenters do not choose what to attend to; they decide which experiment they will perform. It is one thing to choose between incompatible experimental arrangements with a view to obtaining information about a part of the physical world that cannot be obtained by simply looking at it. It is something else altogether to choose which directly accessible feature of a CDB to attend to. ("Directly accessible" means "without the intervention of any apparatus" and thus "without having to chose between incompatible setups.") The necessity of a choice exists for totally different reasons, namely, in one case, the impossibility of simultaneous answers to logically inconsistent questions[4] and, in the other case, the brain's limited processing capacity.

Stapp's transference, via the interrogator metaphor, of the non-Boolean structure of the lattice of possible experimental answers to the lattice of possible answers returned by the brain seems to entail that different plans of actions necessarily correspond to different components of a mixture of CDBs. If this were the case, we could never consciously weigh the pros and cons of different possible courses of action, for then different plans of action could not coexist in the same mind, given that consciousness of a plan of action is what reduces the mixture to one of its components. To be consistent with the introspectively evident coexistence of alternative plans of action in the same mind, Stapp would have to allow either that different courses of actions can coexist in the same CDB or that we can be conscious of different components of a mixture of CDBs. But in the former case the choice between alternative plans of action cannot be linked to the reduction of a mixture, and in the latter Stapp's consciousness-based account of state reduction fails.

If the brain's limited processing capacity is the reason why attention is choosy then attention has to be regarded as being in part a neural process. This works in Stapp's favor inasmuch as he wants to account for the causal efficacy of the mind in quantum-mechanical terms. Since no single choice of an experiment can influence the result of another experiment, no single question posed by the mind can be causally efficacious. On this theoretical foundation it makes sense to let the physical system decide which questions will be asked when, and to restrict the mind's freedom to an influence on the rate at which questions are re-posed. This kind of influence *can* be causally efficacious, as the quantum Zeno effect [54, 55] demonstrates, and it agrees with the fact that attention is largely a neural (and hence neurally determined) process. But it also gives the quietus to the interrogator metaphor, for now Nature not only provides the answers but also asks the questions.

By gradually shifting both the content and the application of his metaphor, Stapp is able to make plausible a series of specious transitions. Once the metaphor has served its purpose, it is discarded. In the first of the quotations that follow, Stapp attributes to the mind the freedom to choose its questions. In the second, the mind chooses between whether or not to pose a question chosen by Nature, and it controls the rate of questioning. In the third, the mind only controls the rate at which questions chosen by Nature are repeated. And in the fourth, the mind's freedom is reduced to consenting to the rapid re-posing of questions chosen by Nature.

> The only freedom in the theory—insofar as we leave Nature's choices alone—is the choice made by the individual about *which* question it will ask next, and *when* it will ask it. These are the only inputs of mind to the dynamics of the brain.
>
> [T]he brain does most of the work, in a local mechanical way, and the mind, simply by means of choices between 'Yes' or 'No' options, and control over the *rate* at which questions are put to nature, merely gives top-level guidance.
>
> Mental control comes in only through the option to rapidly pose [the] same question repeatedly,

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[4] It is not only practically impossible but *logically* inconsistent to ask both (i) whether an atom went through the left or through the right cavity *and* (ii) whether the same atom went through both cavities in phase or out of phase. See my discussion [22, 51] of the experiment of Englert, Scully, and Walther [52, 53].

> thus activating the Quantum Zeno Effect, which will tend to keep the state of the brain focussed on [a specific] plan of action....
>
> [M]ind, by means of the limited effect of consenting to the rapid re-posing of the question already constructed and briefly presented by brain, can influence brain activity by causing this activity to stay focussed on the presented course of action.

According to Stapp, if we are very intent on a specific course of action, we must be very skeptical about its being the right course of action; we must keep asking ourselves rapidly, "Shall I execute plan X? Shall I execute plan X? Shall I...." This will make our executing plan X highly probable. On the other hand, if we wish to abstain from a certain course of action, we must not keep asking ourselves whether it should be executed.

(7) Stapp presents a simple dynamical model of mind–brain interaction in which "the 'best possible' question that could be asked by the individual at time t," given the state $S(t)$ of the universe at this time, is the question P_{max} that maximizes $\mathrm{Tr}[PS(t)]$. This question is posed when the probability of a positive answer reaches a relative maximum.

Here Stapp introduces a new physical law, specifying which question Nature will ask herself next and when she will do so. Stapp thus effectively proposes a new theory, as different from standard QM as nonlinear adulterations of QM [23, 24]. The theory which he ends up formulating is completely different from the theory he initially professes to formulate, for in the beginning consciousness is responsible for state vector reductions, while in the end a new physical law is responsible—a law that in no wise depends on the presence of consciousness.

Thus in the end Stapp, like Eccles [13], fails to account for mental causation without implying "violations" of the laws of contemporary physics. Eccles did not introduce a new physical law, but he allowed the mind to load the quantum dice in the process of exocytosis, and this is tantamount to postulating mentally generated local modifications of physical laws [15, 16]. Stapp introduces a new physical law specifying which questions Nature asks herself, and when, and he allows the mind to modify the rates at which Nature interrogates herself. This, too, is tantamount to postulating mentally generated local modifications of a physical law—the very law Stapp himself has introduced.

11 EPILOGUE

Stapp asserts that his "conceptualization of natural process arises... directly from an examination of the mathematical structure injected into science by our study of the structure of the relationships between our experiences." It is a truism that science begins with relationships between experiences. But it does not end there. Science is driven by the desire to know how things *really* are. It owes its immense success in large measure to its powerful "sustaining myth" [56]—the belief that this can be discovered. Knowing how things "really" are does not mean knowing how they are *in themselves*, independently of how they appear to us or how we conceive of them. By definition, that kind of knowledge is beyond our ken. What science aims to achieve is a strongly objective conception of reality (that is, a consistent way of thinking of experienced regularities as aspects of a world that does not depend on its being experienced). The very aim of science thus rules out the intersubjective or weakly objective conception of reality advocated by d'Espagnat [57]. It also rules out interpretations of standard QM that take the quantum state for more than a probability measure, inasmuch as such interpretations are inconsistent with strong objectivity [57, 58, 59, 60]. It further rules out epistemic interpretations, including Stapp's.

If the aim of strong objectivity appears unattainable, it ought to be taken as a sign that we are making the wrong assumptions, and it ought to spur us on to ferret them out. The crucial assumption that stands in the way of a strongly objective conception of reality based on von Neumann's formulation of QM is the idea that the "evolution" of the physical state of the universe "between events" is "a local dynamical process, with all the causal connections arising solely from interactions between neighboring localized microscopic elements" [14]. For Stapp, reality is differentiated, both spacewise and timewise, into infinitesimal "neighboring localized microscopic elements." If the objective physical state is "an informational and dispositional substrate that carries both the information incorporated into it by the psychical realities, and certain dispositions for the occurrence of future psychical realities" [14], this locality assumption is completely gratuitous. The temporal resolution of the human visual system is in the millisecond range; its angular resolution is about an arc minute. Though higher resolutions can be achieved with the help of physical instruments, owing to intrinsic limits to the spatial and temporal magnifying power of such instruments, infinitesimal neighboring intervals or regions can never be distinguished. But if "psychical realities" are only finitely differentiated spacewise and timewise, and if the physical state of the universe only "carries information" about past "psychical realities" and propensities for future "psychical realities," then why should the physical universe be infinitely differentiated?

The recognition that the physical world is only finitely differentiated spacewise and timewise (Sec. 9) clears the way for a rigorous objective distinction between the classical domain of intrinsic properties and the quantum domain of extrinsic properties (Sec. 8). It warrants the special status Bohr accorded to measurement outcomes—

property-indicating facts—and makes it possible to establish an objective criterion for distinguishing measuring apparatuses from "lesser things." Essential to attaining this objective was the realization that the attribution of factuality is beyond the scope of any theory. When the theory has done its part, we are left with the problem of assigning factuality. This problem has exactly one solution. The inexplicable factuality of facts belongs to those properties which, for all *quantitative* purposes, can be treated as intrinsic.

Instead of according a special status to measuring instruments, Stapp accords it to the neural correlates of mental states. Mental states evolve classically. The quantum brain does not, but the definiteness of mental states forces their neural correlates, and through them everything that is entangled with them, to behave in a classical manner. In order to turn his idea of a theory into a proper theory, Stapp would have to establish a criterion for distinguishing the neural correlates of mental states from less exalted aspects of the brain. If we are to reject the Copenhagen interpretation because it fails to establish a criterion for distinguishing measuring instruments, we should equally reject Stapp's theory, for it fails to establish a criterion for distinguishing the neural correlates of mental states. He does, however, venture the following conjecture:

> This suggests to me that the physical correlates of the psychical realities will reside in the low frequency components of the coulomb part of the electromagnetic field. These are dominated by the so-called "coherent states," which are known to be essentially classical in nature, and particularly robust.... This would allow psychical realities...to be present in the simplest life forms, and to predate life [14].

The attempt to identify the neural correlates of consciousness in physical terms appears to lead more or less inevitably to some form of panpsychism. This suggests to me that John Searle's comment on David Chalmers' functionalist account of consciousness [61] applies equally to Stapp's account: "Of all the absurd results in Chalmers' book, panpsychism is the most absurd and provides us with a clue that something is radically wrong with the thesis that implies it" [62].

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