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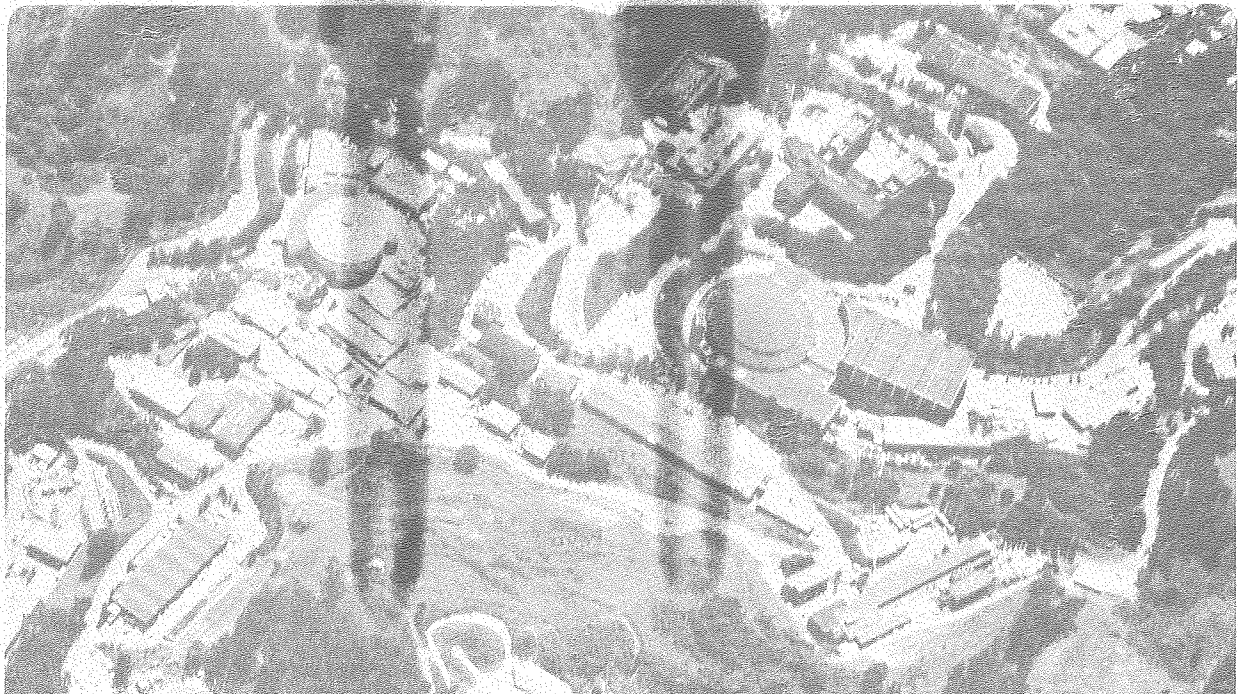
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April 1981

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MIND, MATTER, AND QUANTUM MECHANICS

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ABSTRACT

A theory of psychophysical phenomena is proposed. It resolves simultaneously four basic problems of science, namely the problems of the connections between: (1) mind and matter, (2) quantum theory and reality, (3) relativity theory and "becoming", and (4) relativity theory and Bell's theorem.

1. INTRODUCTION

The purpose of this work is to resolve together four basic questions concerning the nature of Nature. These questions are: (1) How is mind related to matter? (2) How is quantum theory related to reality? (3) How is relativity theory reconciled globally with that which locally we experience directly, namely the coming of reality into being or existence? And (4), how is relativity theory reconciled with the apparent demand of Bell's theorem that what happens in one spacetime region must, in certain situations, depend on decisions made in a spacelike separated region? These four questions will be discussed in detail later on. They are probably the four most fundamental questions in Science.

The resolution of these questions proposed here is based on a modified Whitehead-Heisenberg ontology according to which all that exists is created by a sequence of creative acts or events, each of which brings into being one possibility from the multitude created by prior acts. The focus of the present work is on those special creative acts that correspond to conscious experiences, and a testable model of the relationship between conscious experiences and neural events is proposed. This proposed solution of the mind-body problem requires no ad hoc distortion of the laws of physics. Instead, it arises naturally from the simplest way of conceiving a universe in which the laws of relativistic quantum theory hold. The nature of the proposed mind-body connection is in general accord with some ideas recently advanced by the neurobiologists R.W. Sperry and J.C. Eccles, but is much more specific.

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The organization of the paper is as follows. Section 2 introduces the mind-body problem through the words of William James, Charles Sherrington, and R.W. Sperry. Section 3 gives a brief account of the basic conceptual framework of quantum theory as it relates to the mind-body problem and to the present work. Section 4 gives a sharpened version of the author's earlier formulation of Bell's theorem, with a detailed discussion of the key assumption about the effective freedom of the experimenters. These first four sections provide the necessary background for the main body of the work, which is the theory of psychophysical reality presented in Section 5.

Section 5 is divided into eighteen subsections. The first eleven describe the basic ontology, which is similar to Whitehead's: reality is created by a sequence of self-determining creative acts; the physical world, as represented by the wave-form (i.e., the wave function) of quantum theory, represents tendencies for the creative acts; each creative act is represented in the physical world (as represented in quantum theory) by a collapse of the wave-form. Subsection 12 shows how this ontology accounts quantitatively for the nonlocal transfer of information apparently demanded by Bell's theorem.

Subsection 13 explains how this theory can be reconciled with the theory of relativity. It is noted that relativity theory and quantum theory are both based on Einstein's conceptualization of physical theory as a structure of mathematical relationships between the element of Einstein's static realm of readings of devices. The notion of process, i.e., of the ongoing process of

the unfolding of nature, has no place in this realm, whose elements have, moreover, an ambivalent status as regards their assignment to the worlds of mind and matter. The fact that the statistical regularities described by relativistic quantum theory can be formulated within the limited framework provided by Einstein's realm of readings does not imply that the full understanding of Nature must be formulated in this limited way. Indeed, the unreasonableness of imposing upon Process conditions drawn from Einstein's static realm of readings is noted, and the apparent logical inconsistencies that arose in Whitehead's attempt to do this are analyzed. This analysis provides the rational basis for the fundamental assumption made here that the creative acts are arranged in a well-ordered linear sequence. This ordering of the creative acts does not disrupt the Lorentz invariance of the statistical predictions of quantum theory, which arises naturally from general properties of the creative process.

Subsection 14 applies the general ontological structure developed in the earlier subsections to the problem of the connection between brains and consciousness. On the basis of the results of recent neurobiological research a model of a system of mutually exclusive self-sustaining patterns of neural excitations is proposed. This primary system is linked to a secondary system, the memory system, which records, by enduring structural changes, images of the self-sustaining patterns that occur in the primary system. Neurological mechanisms are postulated that can, by using the templates stored in memory, activate within the primary

system patterns having parts that resemble parts of patterns whose images were previously stored.

The dynamical evolution of the physical brain according to the dynamical laws of quantum theory generates in the conscious brain a superposition of many different mutually exclusive self-sustaining patterns with different statistical weights. The image in physical theory of the conscious act is the act of selecting one of these patterns. The information content of the conscious thought is contained in the self-sustaining pattern of neural excitation that is selected by this conscious act.

Subsections 15 and 16 describe some ideas of the neurobiologists R.W. Sperry and J.C. Eccles. According to these ideas consciousness exercises top-level control over the neural excitations of the brain. This feature is incorporated into the present theory in Subsections 17 and 18, where it is specified that the brain functions as a self-programming computer, that the aforementioned mutually exclusive self-sustaining patterns of neural excitations constitute the top-level code, and that each human experience is a conscious act that is represented in the physical world as described by quantum theory by the selection of a top-level code that is functionally equivalent to the experience. Thus conscious experience, as represented in the physical world described by quantum theory, exercises precisely the top-level control that is consciously experienced. The theory is thus in accord with the main thrust of the ideas of Sperry and Eccles, but is much more detailed and specific,

and overcomes the main objections to their ideas, which is the lack of a clear reconciliation with the laws of physics. In the present theory consciousness enters neither as a mere collective action nor as an ad hoc supernatural agent still to be reconciled with the laws of physics. It enters rather as a process actually demanded by the contemporary laws of physics if the physical world represented by the wave-form of quantum theory is to be kept in line with the world we experience.

Section 6 discusses test, applications, and implications of the theory. Section 7 contrasts the understanding of the mind-matter connection obtained here to the lack of understanding provided by some other ways of interpreting quantum theory.

2. MIND AND MATTER

The idea that Nature has two parts, one containing feelings and thoughts, the other material objects in motion, was created in antiquity. Revived in modern times by Descartes it became the foundation for classical physics. But man, having thus put Nature asunder, was then unable to see her whole. The problem was well described by William James:⁽¹⁾

"Everyone admits the entire incommensurability of feeling as such with material motion as such. 'A motion became a feeling!' — no phrase that our lips can form is so devoid of apprehensible meaning. Accordingly, even the vaguest of evolutionary enthusiasts, when deliberately comparing material with mental facts, have been as forward as anyone else to emphasize the 'chasm' between the inner and outer worlds.

"Can the oscillations of a molecule,' says Mr. Spencer, 'be represented side by side with a nervous shock [he means a mental shock], and the two recognized as one? No effort enables us to assimilate them. That a unit of feeling has nothing in common with a unit of motion becomes more than ever manifest when we bring the two into juxta position.'

"And again

'Suppose it to have become quite clear that a shock in consciousness and a molecular motion are the subjective and objective faces of the

same thing; we continue utterly incapable of uniting the two, so as to conceive that reality of which they are the opposite faces.' "In other words, incapable of perceiving in them any common character. So Tyndall, in that lucky paragraph which has been quoted so often that everyone knows it by heart:

'The passage from the physics of the brain to the corresponding facts of consciousness is unthinkable. Granted that a definite thought and a definite molecular action in the brain occur simultaneously; we do not possess the intellectual organ, nor apparently any rudiment of the organ, which would enable us to pass, by a process of reasoning, from one to the other'

"Or in this other passage:

'We can trace the development of a nervous system and correlate with it parallel phenomena of sensation and thought. But we soar into a vacuum the moment we seek to comprehend the connection between them ... there is no fusion between the two classes of facts — no motor energy in the intellect of man to carry it without logical rupture from one to the other.' "

In a similar vein R.W. Sperry writes in 1952:

"The comment of Charles Sherrington remains as

valid today as when he wrote it more than eighteen years ago:

'We have to regard the relation of mind to brain as still not merely unsolved but still devoid of a basis for its very beginning'.

"It is not a solution which we aspire to but only a basis on which to begin."⁽²⁾

This aspiration motivates the present work.

3. QUANTUM THEORY AND MIND-MATTER

Classical physics works well in many situations, but is inadequate for problems involving the atomic or subatomic structure of objects and materials. For problems of this kind one must use quantum theory, which supercedes classical theory in that it reproduces all the experimentally validated predictions of classical theory, and covers the atomic and subatomic domains as well.

The conceptual framework of quantum theory is profoundly different from that of classical physics, and it allows mind and matter to be seen as the natural parts of a single whole. Indeed, the basic change wrought by quantum theory is precisely a transformation of the physical world from a structure lying outside of mind to one that reaches into mind. This metamorphosis is now explained.

The logical structure of quantum theory is closely tied to the way it is used in practice. To use quantum theory a scientist defines a set of operational specifications A on the devices that are going to prepare some system, and a set of operational specifications B on the responses of devices that are going to detect some properties of this system. The specifications A are transformed into a weight function $\rho_A(x,p)$, and the specifications B are transformed into an efficiency function $\rho_B(x',p')$. Quantum theoretic rules are then used to calculate the propagation function $U_{BA}(x',p';x,p)$, which transforms the function $\rho_A(x,p)$ from the spacetime location of the preparation to the

spacetime location of the detection. Then the probability $P(B,A)$ that the response will satisfy specifications B if the preparations satisfy specifications A is calculated from the formula^(3,4)

$$P(B,A) = \int dx' dp' dx dp \rho_B(x',p') U_{BA}(x',p';x,p) \rho_A(x,p) .$$

This formula is identical to the one used for the same purpose in classical statistical mechanics. There the quantity $\rho_A(x,p)$ is the phase-space probability density associated with the initial specifications A and $\rho_B(x',p')$ is the probability that the response of the detectors will meet specifications B if the detected system is characterized by the phase-space point (x',p') . [For an n-particle system x' is a set of $3n$ variables that specifies the positions of the n particles, and p' is a set of $3n$ variables that specifies the momenta of these particles].

The description given above stresses the close connection between quantum theory and classical statistical mechanics. But important differences also exist. Most important are interference effects, which are exhibited, for example, in the double-slit experiment.

The double-slit experiment is well known: light from a tiny monochromatic source is allowed to pass through a first screen containing two narrow slits and fall on a second screen. The distribution of light on the second screen is grossly different

from the sum of the distributions that would be obtained if each slit were opened separately. This difference is explained quantitatively by assuming that light has a wave structure: the parts of the wave traveling through the two slits can interfere constructively in some areas of the second screen and destructively in other areas to produce the observed interference pattern. But a second aspect of the experiment is the quantization of light: the energy is emitted from the source in discrete units called quanta, which are absorbed as units in tiny regions of the second screen.

The double-slit experiments provide prima facia evidence that light consists of both particles and waves. For the idea that the energy is carried by tiny particles that are guided by waves that pass through both slits can account quantitatively for both the quantization and interference effects. This guider-wave idea was studied by De Broglie⁽⁵⁾ and successfully completed, in the nonrelativistic approximation, by Bohm.⁽⁶⁾

Bohm's model has both waves and particles. The particles are conceptually identical to the point-particles that occur in classical physics. However, the probabilities $P(B,A)$ can be calculated from a knowledge of the waves alone. These probabilities $P(B,A)$ are the only quantities of the theory that can be directly compared to experiment. Thus from a practical point of view the particles are superfluous: they add no content that can be tested or verified, or has any practical use. Indeed, there now exist many variations of Bohm's deterministic model that have superimposed stochastic elements, but that are empirically

indistinguishable from Bohm's.⁽⁷⁾

The orthodox interpretation of quantum theory dispenses altogether with these superfluous classical particles. It represents any physical system by a wave-form alone. Thus an atom is represented by a stable or quasi-stable wave-form. The emission of light from an atom is represented by a change of its wave-form to one that represents a less energetic state, accompanied by the creation of wave-form that corresponds to the quantum of light. This latter wave-form interacts with the wave-form of any atom that lies in the region it transverses to provide a wave-form having a part that corresponds to the absorption of the quantum of light by that atom. In this part the wave-form representing the atom changes to a form representing a more energetic state while the wave-form representing the light quantum disappears.

This orthodox view rests basically on the fact that the information concerning the amount of energy in the quantum of light can be carried just as well by a wave as by a particle. But the particle concept demands information far beyond that of the magnitude of the quantum of energy. It demands also the specification of an exact space-time path from the emitting atom to the absorbing atom, and even of an exact paths of the particles within these atoms. Most physicists believe that this demand for exact space-time paths originates in our experience with macroscopic phenomena and classical physics, and need not be met by nature herself in the microscopic domain of atomic and subatomic physics. For the observed phenomena is represented far more economically and aesthetically without using the notion of classical particles.

The elimination of classical particles means that the functions $\rho_A(x,p)$ and $\rho_B(x',p')$ cannot be interpreted conceptually in the same way as in classical physics. Indeed this possibility was excluded already by the fact that these functions can become negative, which is not compatible with their classical meanings. However, it is only the probabilities $P(B,A)$ that can be directly compared to experience, and these are guaranteed non-negative by the mathematical structure of the theory.

The wave-forms, and the essentially equivalent quantities $\rho_A(x,p)$ and $\rho_B(x',p')$, are not given individual or separate meanings in orthodox quantum theory: their meanings arise solely from their roles as parts of the formula for the probabilities $P(B,A)$. These probabilities are, empirically, the probabilities that the observed responses will conform to operational specifications B under operational conditions A. No further meaning is to be ascribed to the symbols occurring in the theory. Thus the physical laws represented by quantum theory are not a set of laws governing an independent entity that exists apart from observations. Rather they define a mathematical structure of statistical relations among observations. In this sense quantum theory, and the physical world represented by quantum theory, reaches into mind.

Although quantum theory, according to the orthodox view, provides merely a set of mathematical rules for calculating the probabilities $P(B,A)$, rather than a detailed picture of what is actually happening in the external world, it does impose through these rules stringent conditions on the character of the underlying

reality. The most interesting and important of these is discussed in the following section.

4. BELL'S THEOREM

Bell's theorem ⁽⁸⁾ imposes stringent conditions on the nature of reality. It arises from an examination of the statistical predictions of quantum theory in certain particular experimental situations. These situations involve two experimenters who, within the confines of two spacelike-separated spacetime regions, first choose some experimental settings and then observe some experimental results. The theorem shows that it is impossible to reconcile the general validity of the statistical predictions of quantum theory with the idea that the results observed by each experimenter could in principle be independent of the apparently free choice of setting made in the spacelike separated region by the other experimenter: the general validity of the predictions of quantum theory appears to demand strong nonlocal connections that extend over macroscopic distances.

To obtain this conclusion one may consider the following experiment: Suppose a pair of low-energy spin- $\frac{1}{2}$ particles are allowed to scatter off each other in a small spacetime region that is surrounded by an array of fast-electronic detectors. These detectors are arranged to cover almost completely a sphere centered on the scattering region. Only two small holes are left uncovered, and these lie at polar extremities of the sphere. The two particles are detected by the fast electronics upon entering the sphere. Thus if they are not detected shortly afterward by the spherical array then they have escaped through the two holes and, by virtue of the geometric set-up, are traveling on trajectories that will lead one into a Stern-Gerlach device D_1 and the other into a

Stern-Gerlach device D_2 . The arrival times at D_1 and D_2 are such that the devices D_1 and D_2 are confined, during the passage of the particles through them, to the spacetime regions R_1 and R_2 , respectively. The spacetime region R_1 contains also a process that generates from some physical numbers that have been brought into R_1 a "random" number that will be used to select one of several predetermined directions along which the axis of the Stern-Gerlach device will be mechanically aligned. A similar arrangement selects the setting of the axis of the device in R_2 . The entire process consisting of the selection of the direction of the axis of the device D_1 , the deflection of the particle by the device D_1 , the subsequent detection of this particle, and the final recording of the result in some memory bank (or in the brain of a human observer) takes place in the spacetime region R_1 . The similar set of processes associated with the device D_2 is confined to the spacetime region R_2 .

A Stern-Gerlach device has the property of deflecting the particle by a finite amount in one of two directions: the deflection is either in the direction of the (directed) axis of the device or in the opposite direction. The recorded result tells us which of these two possibilities actually occurred.

If the two particles are of the same kind and their energies are sufficiently small then the particles will emerge from the scattering in what is called the singlet state. This state is recognized experimentally by the fact that if the directions of two axes of the two devices D_1 and D_2 are identical (in an appropriate frame) then the directions of the deflections in D_1

and D_2 are opposite: if the common direction of the two axes is called "up" then one of the two deflections is "up" and the other is "down".

We come now to the crucial point. Suppose the axis in D_1 is chosen by our procedure to lie in some particular direction d , and that the subsequent deflection in D_1 is then observed to lie in some particular direction -- which must be either along d or opposed to d . Suppose this particular direction d is also one of the small set of preassigned directions allowed for D_2 . We can arrange that there be a large number of conceivable ways in which the direction d might be chosen for D_2 . To be definite suppose that the physical numbers brought into R_2 include the arrival time of a photon from a distant galaxy, the latest tele-typed Dow-Jones average, and the temperature at the Chicago airport. A computer in R_2 first picks one of these three numbers "at random", and then computes from it a random number that is used to specify the setting of D_2 , which we suppose has a good chance to be d .

There are many conceivable ways that the direction d could be selected for D_2 . But no matter which of these ways is actually used the direction of the deflection at D_2 will be the same: it must be opposite to the observed direction of deflection at D_1 . That is, given the observed direction of deflection at D_1 the deflection at D_2 must be independent of the particular course of events leading to the choice of d .

This independence of the result at D_2 on the manner in which the direction d of D_2 is chosen suggests that in the analysis of the correlations between the directions of the deflections at

D_1 and D_2 it is the directions of D_1 and D_2 that are important, not the manner in which these directions are selected or brought into existence. This suggests that in the analysis of these deflections the directions of D_1 and D_2 can be treated as independent free variables.

These heuristic considerations support the key underlying assumption of Bell's theorem, which is that in the analysis of the correlations between the directions of the deflections in D_1 and D_2 one can consider the choices between the several preassigned directions of the axes of these two devices to be independent free variables. This assumption is not that these choices are literally free, in the sense that they have no causal basis whatever, but merely that they are essentially accidental and can be considered as free in the analysis of the correlations in the directions of deflection in this experiment.

Of course, we ordinarily take for granted that variables determined by the whimsical choices of experimenters via processes that are left completely unspecified in the description of the experiment under consideration should be considered free variables. But in the case of Bell's theorem this assumption must be emphasized for it is the only assumption needed to derive a profound conclusion. The need to regard these choices as effectively free arises from the need to distinguish cause from effect, and allow the consideration of alternative possibilities.

Suppose now that the regions R_1 and R_2 are spacelike separated. This means that no information can travel from R_1

to R_2 (or from R_2 to R_1) without traveling either faster than light or backward in time. According to the theory of relativity no signal can travel either faster than light or backward in time. This suggests that the information about the free choice of setting made in each region will be unable to reach the other region, and hence that the result observed in each region should be independent of the free choice of setting made in the other region. The principles of relativity also entail that the "order" in which the two choices of settings are made should have no physical significance: the scenario in which D_1 is fixed "before" D_2 is required to be physically equivalent to the scenario in which D_1 is fixed "after" D_2 , since "before" and "after" have no invariant meaning for spacelike separated events.

The foregoing discussion concerns a single pair of particles. Consider next a set of n such pairs that can be separately analyzed by fast electronics, but that are bunched together so that all n particles going to D_1 arrive essentially together, on the scale of the region R_1 , and hence that the setting of D_1 is the same for all of them. The analogous conditions are imposed for D_2 and R_2 .

A "set of conceivable results S_i " of the n -particle experiment is represented by a list that specifies for each of the n pairs the directions of the deflections at both D_1 and D_2 . For any given number n , any given settings of D_1 and D_2 and any set of conceivable result S_i of the experiment quantum theory prescribes a probability $P(S_i)$. For any collection C_j of distinct sets of conceivable results S_i the probability that the observed set of results will correspond to some unspecified member of the

collection C_j is, of course, the sum of the probabilities $P(S_i)$ of the individual members S_i of the collection. This probability is called the probability $P(C_j)$ associated with the collection.

To derive the desired result consider two possible settings of D_1 (specified by certain angles $\phi_1 = 0^\circ$ and $\phi_1 = 90^\circ$), and two possible settings of D_2 (specified by the angles $\phi_2 = 0^\circ$ and $\phi_2 = 135^\circ$). Let the four combinations of settings be labelled by the index i ($= 1, 2, 3, \text{ or } 4$). Then the following mathematical result holds:⁽⁹⁾ For any positive number ϵ , there is an integer n and four collections C_i ($i = 1, 2, 3, \text{ or } 4$), one for each of the four combinations of settings of D_1 and D_2 , such that the following two properties hold:

- 1.) For each of the four collections C_i ($i = 1, 2, 3, \text{ or } 4$), the probability $P(C_i)$ associated with C_i is less than ϵ .
- 2.) For any conceivable combination of four sets S_i ($i = 1, 2, 3, \text{ or } 4$), one for each of the four possible combinations of the settings of D_1 and D_2 the requirement that the set of results in each of the two regions R_1 and R_2 be independent of the choice of setting in the other region can be satisfied only if at least one of the four sets of conceivable results S_i belongs to the corresponding collection C_i .

This mathematical fact entails that there is no way to reconcile the validity of the statistical predictions of quantum theory for all four combinations of settings with the requirement that what happens in each region could in principle be independent

of the choice of setting made in the other region. For suppose we start with a conceivable set of results S_i for some one of the four combinations of settings. If the above-stated independence property is satisfied then a change in the setting of D_1 (but not D_2) can give a new set of results in R_1 , but will leave unchanged the original set of results in R_2 .

Alternatively, a change of the setting of D_2 (but not D_1) can give a new set of results in R_2 , but will leave unchanged the original set of results in R_1 . The full set of results S_i for three of the four combinations of settings are thereby fixed. To obtain the results in the fourth case (where both D_1 and D_2 are changed) one can follow-up the original change of D_1 by a change of the setting of D_2 . Alternatively, one can follow-up the original change of D_2 by a change of the setting of D_1 . The principles of the theory of relativity assert, as already mentioned, that the order in which choices of settings are made in the two spacelike separated regions has no physical significance. Thus these two ways of ordering the choices should lead to the same final set of results in the final case, in which D_1 and D_2 are both changed. But this condition fixes uniquely the results in the fourth case to be the combination of the changed set of results in R_1 (obtained from changing D_1 and not D_2) with the changed set of results in R_2 (obtained by changing D_2 and not D_1).

The four sets S_i constructed in this way satisfy the independence property stated in part (2) in the mathematical result stated above. Hence that mathematical result (2) entails

that for at least one of the four combinations of settings i the associated set of results S_i lies in the specified set C_i of conceivable results. The probability for this is less than the arbitrarily small positive number ϵ . Thus there is no way in which what happens in each region could be independent of the free choice of setting made in the spacelike separated region without violating the predictions of quantum theory. Moreover, this violation can be made as large as one likes, by choosing ϵ sufficiently small. And there is no way to re-establish the validity of the quantum predictions by taking a still larger value of n . For by taking n larger one can make ϵ still smaller: the magnitude of the violation of the quantum predictions increases beyond any bound as the number n of instances in the sample tends to infinity.

This argument is more intricate than those of Bell, and Clauser and Horne, but the result is much stronger. For there are no assumptions about determinism, hidden variables, or objective reality. The conclusion is simply that there is no way for nature to select results that are compatible with both the predictions of quantum theory and the condition that the results observed in each region be independent of the choice of experiment made in the other region.

The appearance of words like "particle" and "device" in the above arguments does not entail any essential use of the notion of objective reality. The argument can be reformulated purely in terms of the experiences of human observers, as was discussed in detail in Ref. 10.

Section 5 will explain, among other things, how the strong nonlocal connections apparently demanded by Bell's theorem can be understood in a natural way without violating the essential principles of the theory of relativity.

5. THE PSYCHOPHYSICAL THEORY

The aim of this section is to set forth a theory of psychophysical phenomena that accords with relativity theory and quantum theory, with some recent ideas from the field of neurobiology, and with certain metaphysical principles I find compelling. The central idea is this: the physical world described by the laws of physics is a structure of tendencies in the world of mind. This general idea is latent in Heisenberg's idea of Potentia,⁽¹¹⁾ and in von Neumann's description of quantum processes.⁽¹²⁾ It has been previously advanced by Whitehead,⁽¹³⁾ by myself,⁽¹⁴⁾ and by Wigner.⁽¹⁵⁾ In the following subsections this general idea is developed in detail, with particular attention to relativistic and neurobiological aspects.

5.1 Mind: The Creative Process

Mind is identified with the process of creation. Everything that exists is created by this process, which consists of a well-ordered sequence of creative acts called events. Any event is prior to all those that follow it in this sequence, and is subsequent to all those that come before it in this sequence. Each creative act is a grasping, or prehension, of all that has been created by prior acts in a novel but unified way. Whitehead's book, Process and Reality, is essentially an elaboration of roughly this idea.

5.2 Necessity and Chance

"Naught happens for nothing, but everything from a ground and of necessity".⁽¹⁶⁾ This is the law of necessity. Some writers claim to be comfortable with the idea that there is in Nature, at

its most basic level, an irreducible element of chance. I, however, find unthinkable the idea that between two possibilities there can be a choice having no basis whatsoever. Chance is an idea useful for dealing with a world partly unknown to us. But it has no rational place among the ultimate constituents of Nature.

5.3 Necessity and Free-Will

Man's free-will is no illusion. It constitutes his essence. And it rests upon the law of necessity. Any play of chance would falsify the idea that I, from the ground of my essential nature, make a true choice.

5.4 Necessity and Predetermination

The law of necessity entails that the process of creation is internally determined. But it is not externally predetermined.

A system is externally predetermined if its development can in principle be predetermined by first forming outside of itself a representation of the system and its laws of development, and then, by applying these laws to that representation, determining, before the fact, how the system will develop.

A system is internally determined if its development is determined by its internal constitution.

The creative process is internally determined. But due to its wholeness neither it nor its laws of development can be represented outside of itself. Hence it is not externally predetermined.

Whitehead's similar formula asserts that the world is internally determined and externally free. Both in principle and in practice the only way to determine precisely how Nature will unfold is to

let it unfold.

5.5 Tendency, Propensity, and Probability

An example of tendency is the tendency for "six" to come up on the throw of a loaded die. The number that actually comes up is determined by unknown factors. But the "loading", combined with the conditions of the throw, and some a priori distributions of unspecified variables, create a tendency (or propensity) for "six" to come up. This idea of tendency or propensity can be made quantitative by associating it with the mathematical theory of probability. Popper has developed this "propensity" interpretation of probability and strongly advocated its use in quantum theory.⁽¹⁷⁾

5.6 Emergent Qualities

Each creative act brings into existence something fundamentally new: it creates a novel "emergent" quality.

5.7 Consciousness

At the apex of a hierarchical structure in the decision-making process associated with human brains is a subprocess that enjoys two characteristic properties: a record of its acts is stored in the human memory; and it exercises a partial functional control over both its own development and that of other human biological processes. This subprocess is called human consciousness. It is part of a larger subprocess called consciousness, which includes the conscious processes associated with other creatures. Consciousness is part of the full creature process. The present work is concerned mainly with human consciousness.

5.8 Color

Everything that exists was created by the world process called

mind. For example, "greenness" is a collection of emergent qualities that play a prominent role in human consciousness. These qualities came into being during the phase of the creative process associated with the growth of consciousness. Prior to that they did not exist.

5.9 Spacetime

Spacetime, like color, is an emergent quality that plays a prominent role in human consciousness, and in a certain theoretical activity within consciousness called physics. The success of physics indicates that the concept of spacetime bears an important relationship to the structural properties of the creative process.

5.10 Dynamics

To understand the dynamics of the world process it is helpful to consider first the classical approximation. Suppose the force laws and initial boundary conditions were given. Then Newton's laws would completely determine the development of the system. But what determines the initial conditions? The law of necessity demands that everything be determined by necessity. Hence "free" initial conditions are unacceptable.

Imagine, therefore, that the boundary conditions are set not at some initial time, but gradually by a sequence of acts that imposes a sequence of constraints. After any sequence of acts there remains a collection of possible worlds some of which will be eliminated by the next act. This elimination is achieved by acting on the existing collection with a "projection operator" in phase space that eliminates some members, but leaves the others untouched. The laws of classical physics are not disturbed by fixing the "boundary conditions"

progressively in this way.

An analogous sequence of acts can be defined in quantum physics. Thus the acts that constitute the basic world process are represented in quantum theory by a sequence of projection operators, each of which acts in phase space in such a way as to eliminate certain possibilities, but save others. Each act induces a "collapse" of the wave-form, which is discussed in more detail in the following subsection.

5.11 Collapse of Wave-Forms

The observation of a track in a cloud chamber is the observation of a sequence of tiny water droplets. These droplets are formed by the passage of a charged stable or quasi-stable "particle" through the chamber.

According to quantum theory the wave-form associated with an electron produced by radioactive decay from a heavy nucleus will propagate away from the original nucleus in all directions, and then suddenly collapse to a small region the size of the water droplets when the corresponding track in a cloud chamber is observed. This collapse is completely natural for a probability function, and, correspondingly, there is no tendency or propensity for a quanta to be observed in one place immediately after it is observed in a far-away place.

5.12 Explanation of Bell's Nonlocality

The nonlocal connection apparently demanded by Bell's theorem arises only after two systems originally in close communion move apart. In this motion the diverging parts sweep out a V-shaped region in spacetime: the original region of communion R_0 lies at the base of the V, and the two spacelike separated regions

R_1 and R_2 lie at the two upper endpoints.

This V-shaped region is the spacetime region naturally associated with the nonlocal connection. One can imagine that a huge expanding wall of lead fills up the spacetime region between the two sides of the V, and that two huge sliding walls of lead fill up the spacetime region outside the V. The presence of these lead walls leaves unaffected the quantum correlations and hence presumably also the nonlocal connections demanded by these correlations. On the other hand, the insertion of a weak magnetic field at any place in the V-shaped region generally modifies the quantum correlations, and hence also, presumably, the consequent nonlocal connections.

Bell's nonlocal connection is immediately explained by quantum theory if one accepts that the quantum-theoretic wave-forms represent tendencies for the responses of the measuring devices. According to quantum theory there is a wave-form that occupies the V-shaped region described above. Actually this wave form consists of two superimposed parts, each of which covers the V-shaped region. The way in which the total wave-form decomposes into these two superimposed parts depends on a direction that can be chosen arbitrarily.

Suppose in the basic creative process the events corresponding to the detection of the results of the experiment in R_1 occur before or prior to those in R_2 . We may then chose the arbitrary direction so that one of the two V-shaped wave-forms corresponds to a definite deflection "upward" in R_1 and the other superimposed V-shaped wave-form corresponds to a definite deflection "downward" in R_1 . The superposition of these two parts of the wave-form is

the spin-space analog of the full spherical wave that spreads out from a radioactively decaying nucleus. In that case there was a sudden jump to a new wave-form when a track in a cloud chamber began to form, and the tendencies for future acts were thus suddenly altered. Correspondingly, there is a sudden shift in the composite V-shaped form when the "up" or "down" deflection is detected in R_1 : one of the two superimposed V-shaped parts suddenly disappears, along with tendencies associated with it. Thus when this event in R_1 occurs the tendencies in R_2 are suddenly changed. The way in which these tendencies are changed depends on how the composite wave-form was decomposed into the two parts. But this decomposition depended on the way in which the setting was chosen in R_1 . Hence the information about the choice of setting in R_1 is transmitted immediately to R_2 via the sudden change in the tendencies in R_2 associated with the disappearance of one of the two V-shaped wave-forms. This accounts for the faster-than-light information transfer.

The above description is not just a pictorial description of how one might imagine the information to be transmitted. It is a representation of the quantitative way quantum theory works: the quantum-theoretic calculations can be carried out by associating the collapse of the wave-form with the associated changes in the probabilities $P(B,A)$. Thus quantum theory itself provides an immediate quantitative explanation of the faster-than-light information transfer, once it is admitted that the wave-forms represent real tendencies for responses of devices or observers.

Prior to Bell's theorem there was a general reluctance to ascribe any real tendency interpretation to the wave-forms of quantum theory, precisely because this interpretation immediately entails faster-than-light information transfer. However, this objection to the real tendency interpretation is nullified by Bell's theorem, which apparently shows that faster-than-light (or backward in time) information transfer is in any case demanded by the statistical rules themselves, independently of the question of interpretation.

A real tendency interpretation was suggested by Heisenberg, who asserted that the quantum wave-forms represent "tendencies for events and our knowledge of events".⁽¹¹⁾ To clarify this statement it is necessary to specify the nature of Heisenberg's "events". This is made difficult by the reluctance by members of the Copenhagen school to speak of any reality lying behind quantum theory. (Any such talk undermines the Copenhagen claim of the completeness of the theory). Consequently, the "event" associated with, for example, the detection of a particle by a device can be represented in orthodox quantum theory only by a change in a wave-form or by a change in our knowledge. But a change in a wave-form can represent, again, only a change in "tendencies for events and our knowledge of events". Thus one is trapped in a situation where the "event" dissolves always into further tendencies and there is no final identifiable reality upon which these tendencies can act, other than "our knowledge".

The introduction of real creative acts allows Heisenberg's "events" to be identified with these acts, and the wave-forms to

be identified as representatives of real tendencies for these acts.

This formulation may be merely a detailed statement of what Heisenberg had in mind, but was unable to state without jeopardizing the claim that quantum theory is complete.

5.13 Compatibility with Relativity

Two features of the theory outlined above appear to conflict with the theory of relativity. The first is the absolute ordering of the creative acts: this seems contrary to Einstein's principle that the ordering of two spacelike separated events is defined only relative to some chosen coordinate system. The second is the occurrence of faster-than-light transfer of information: this appears incompatible with Einstein's principle that no signal travels faster than light.

The absolute ordering of the creative acts defines the order in which the parts of reality come into existence. Einstein circumvented this whole question of the order in which things come into existence by creating a new conceptualization of the subject matter of physics.

Einstein approached the problem of space and time by considering observations made by physicists. The observations he considered were primarily of clocks and rulers. His theorizing created a new theoretical realm: Einstein's realm of readings of devices. Each element of this realm is an idealized observation consisting of the readings of a set of idealized devices. These devices include one clock and three rulers. The four corresponding readings provide a spacetime coordination of the observation.

Three features of Einstein's realm of readings are important.

The first is its static nature: the realm is comprised of a fixed collection of entities, called observations, each of which is represented by a fixed set of numbers. The concept of process or change does not enter into this theoretical realm. Time is represented exclusively by the set of fixed clock readings.

The second important feature of Einstein's realm of readings is the ambivalent status of these readings as regards their assignment to the worlds of mind and matter. This ambivalence allows the readings to be regarded both as the subjective data with which experimental and theoretical physicists must eventually deal, and also as objective data located in the external physical world.

The third important feature of Einstein's realm of readings is that its elements can be regarded as the appropriate subject matter of physical theory. The idealized readings can be considered to represent the objective data that scientists can collect. Einstein's theorizing effectively redefined theoretical physics to be the attempt to create a mathematical structure of relationships between the elements of the static realm of readings, rather than as an attempt to understand or describe the process by which Nature unfolds.

Einstein's realm of readings provides the theoretical foundation for quantum theory, and the aforementioned ambivalent status of readings plays an important role in the Copenhagen interpretation. For it allows these readings, considered as observations by idealized human observers, to be projected into the physical world

to form an objective world of readings of devices. These "readings" constitute objective data that quantum theory seeks to correlate. Their ambivalent status creates the blurring of the distinction between the objective and subjective aspects of observations that was so often stressed by Bohr and Heisenberg.

These authors also argue convincingly that, within the theoretical framework provided by Einstein's realm of readings, quantum theory is in principle complete. But then further fundamental progress demands breaking out of Einstein's realm of readings, and coming finally to grips with the question of the relationship of mind to matter. In doing so there is no reason why something so basic to our intuitive grasp of reality as the notion of process, or the unfolding of Nature, should continue to be banned. For this notion was banished in the first place only by Einstein's cleverly contrived realm of readings. Once the notion of process is reinstated the question of the order in which the parts of reality come into existence becomes again meaningful.

If spacetime were some preexisting structure that is filled up by the advancing creative process then it might be reasonable to think that the full process of creation consists of many subprocesses acting independently in different spacelike separated regions. If, on the other hand, spacetime is a structure of relationships that develops during the process of creation itself, then the decomposition of this process into independently acting parts on the basis of spacetime aspects becomes unnatural and subject to possible logical contradictions.

To lay bare the possibility of logical contradiction it is useful to consider the model of process proposed by Whitehead, which incorporates a widespread notion of the demands laid down by the theory of relativity. According to Whitehead the creative process consists of a set of distinct creative acts called actual entities. Relative to any actual entity there is a 'given' world of actual entities that are "settled, actual, and already become." This given actual world provides determinate data for the creative act.

Whitehead cites the theory of relativity to justify the notion of "contemporary" actual entities: two actual entities are contemporary when neither belongs to the 'given' actual world defined by the other. The references to the theory of relativity make clear that Whitehead intends to allow the idea that each actual entity E is associated with a spacetime region R_E , and that its actual world is composed of actual entities whose spacetime regions intersect the union of the backward light cones of the points of R_E . This geometric picture accords with the relativistic concept that influences can propagate only into the forward light cone. Two actual entities are contemporary when the spacetime region of neither lies in the backward light cone of the other. Then two contemporary creative acts, though possibly related through their mutual dependence on actual entities that lie in the intersection of their respective backward light cones, would proceed in "causal independence" in the sense that neither depends directly on the other.

When two contemporary entities have well separated spacetime regions there is little difficulty imagining that each creative act proceeds independently on basis of the settled data in its own actual

world. And if spacetime is a preexisting continuum that is divided into well-defined cells that can be assigned to separate process then again there seems to be no problem with the idea that contemporary processes proceed independently: one can, with a little ingenuity, arrange the cellularization of spacetime so that the process of creation can proceed without being blocked by a situation where neither of two neighboring processes can proceed because the backward light-cone of each intersects the cell associated with its neighbor. However, this notion of a preassigned cellularization is altogether alien to the ideas of relativity theory. On the other hand, if process is prior to spacetime in the sense that the spacetime region corresponding to each entity is selected by the creative act itself then one arrives at a Zeno's paradox type of situation where no creative act can proceed because its data is ill-defined, and in particular is not settled until the data provided by a possible neighboring act is given. That is, if there is no preassigned cellularization of spacetime, but, on the contrary, each creative act selects its own spacetime region, then the property that contemporary acts proceed in causal independence becomes self-contradictory, because the requirement that the regions associated with two contemporary acts be spacelike separated contradicts the requirement that the choices of these two regions proceed in causal independence: the determination of whether two acts are contemporary, hence causally independent, depends on these acts themselves.

Whitehead introduced the notion of causally independent contemporary events with the statement: "Curiously enough, even at this early stage of metaphysical discussion the influence of

'relativity theory' in modern physics is important." This introduction of the causally independent contemporary events is indeed curious from Whitehead's point of view. For his main theme was the organic unity of nature, which is disrupted if the process of creation is allowed to have causally independent parts. Moreover, as just emphasized, the notion of causally independent contemporary events appears to contain a logical contradiction. Thus Whitehead apparently sacrificed the logical and organic coherence of his philosophical system to obtain agreement with what he thought to be the demands of relativity theory.

Relativity theory deals, however, specifically with those parts of our understanding of nature that can be formulated within Einstein's static realm of readings, which is explicitly constructed to have no trace of the idea of process. The empirical fact that some part of our understanding of Nature can be formulated in terms of readings alone, does not imply that a full understanding can be expressed in this limited way. But if, then, process is reintroduced into our description of Nature it is altogether unreasonable to require it to enjoy the relativistic properties characteristic of the completely alien static realm of readings. For it was precisely the elimination of process from this realm that made meaningless the question of the order of spacelike separated events. And it was the meaninglessness of this order that then entailed, if causes precede effects, the causal independence of spacelike separated events.

It is unreasonable to impose upon process relativistic demands drawn from the static realm of readings. However, it is important to reconcile the theory of process with the relativistic features of

relativistic quantum theory. An important point in this connection is that whereas an individual actual process depends on the ordering of the events the predictions of quantum theory are statistical predictions about ensembles defined by operational specifications on the elements of Einstein's static realm of readings. These operational specifications place no conditions on the order in which spacelike separated events occur. Thus the tendencies associated with these specifications cannot depend on these orderings. Nor can they depend on any absolute frame of reference. For in this theory spacetime is a purely relational construct: there is no absolute frame of reference. Thus, by virtue of the basic structure of the fundamental process, and the logical structure of quantum theory, the predictions of quantum theory can depend neither on any absolute frame of reference nor on the order in which spacelike separated events occur.

The second apparent conflict with relativity theory is the faster-than-light transfer of information. But this is no conflict at all. What Einstein forbade was faster-than-light signals, where a signal means a controlled transfer of information. The same quantum theoretical rules that lead to the apparent necessity of faster-than-light information transfer excludes the possibility of faster-than-light signals.¹⁸ This rigorous consequence of the quantum formalism does not necessarily mean that there is no way whatever to transmit a signal faster than light. It does mean that any such signal must involve phenomena not adequately covered by quantum theory.

5.14 Brains and Consciousness

Within the framework of contemporary quantum theory one can imagine the ultimate experiments in mind-brain research to be such

that every neuron in the brain is wired to an apparatus that will record the times at which it fires, and will also, if instructed, induce a firing of this neuron. Additional microdevices will record the microfields at a fine grid of locations in the brain, at a closely spaced sequence of times. The spatial extension of each neuron will be mapped out by techniques that do not perceptibly affect the living brain. Other devices will record the subject's verbal reports regarding his conscious activities.

A possible experimental arrangement will introduce sensory inputs that evoke a conscious choice of motor response. The resulting experimental data will presumably show an initial pattern of neural and field activity that can be associated with the entry of the input information into the brain, followed by a pattern of activity associated with a reorganization of this information, followed, eventually, by a pattern of activity associated with the initiation of the consciously chosen motor response.

I shall assume that the analysis of this data will reveal that the input information is reorganized in a way that allows part of it to be incorporated into a self-sustaining pattern of neural activity that is associated with a conscious thought. The nature of this association will be described in due course.

A simplistic but conceivable way in which certain patterns of neural activity might sustain themselves would work as follows. A set of, for example, one hundred neurons would be connected to the rest of the brain so that each combination of ten of them would be associated with a corresponding key neuron: this key neuron would be activated if and only if the associated combination of ten neurons

fired, and it would then feed back and cause these ten neurons to fire again. There would be roughly 10^{20} different combinations of 10 neurons, and this would entail an equal number of key neurons. But this number 10^{20} is vastly greater than the roughly 10^{10} or 10^{11} neurons in the brain. Thus this model is unsatisfactory.

A more economical arrangement would have the simultaneous firings of any pair of (in the set of one hundred) activate a corresponding key neuron, that would then stimulate this pair to fire again. This would require only $\sim 10^4$ key neurons, but the arrangement would tend to produce a chaotic clamor in which all of the hundred neurons are firing incessantly.

An important feature of the neural structure of brains is the presence of inhibitory neurons.¹⁹ These neurons act to inhibit the firings of the neurons to which they are connected. To get an idea of how a self-sustaining pattern could actually arise in the brain one may consider a set of six neurons arranged in three pairs so that if one member of any one of these three pairs fires then the other member will not fire. This inhibitory structure is superimposed on the previously described structure, which in this case would connect each of the fifteen possible pairs that can be formed from the six basic neurons being considered. Thus the firing of any pair would tend to reexcite itself, subject to the overriding inhibitory factor.

This system has altogether eight alternative possible self-sustaining patterns of three activated neurons: one member or the other of each of the original three pairs can be excited. But these eight patterns are mutually exclusive: no two of them can be activated at the same time, due to the inhibitory arrangement.

If one now considers this system (or actually a vastly more complex system based on the same principle of mutually exclusive self-sustaining patterns) to be imbedded in the much larger structure provided by the whole brain, and recalls that the full representation of the brain provided by contemporary physical theory gives merely a representation of tendencies for responses, then the state of the brain, as represented by contemporary physics, will, prior to the excitation of one of these self-sustaining but mutually exclusive patterns, represent only the tendencies for the excitations of the various alternative patterns. The choice of which of these patterns is activated is, according to the contemporary laws of physics, a matter of pure chance.

The basic idea of the present psychophysical theory is to identify the selection of one of these mutually exclusive self-sustaining patterns of neural excitations as the image in the physical world, as represented by quantum theory, of a creative act from the realm of human consciousness.

Conscious acts are associated with memory. Thus the self-sustaining neural pattern associated with the conscious act will presumably serve as a template for the production in the brain of an enduring image of this pattern. Physical mechanisms for the formation of this enduring image are already beginning to be understood¹⁹, but this detail is not important to the main theme being developed here. What is important is that the enduring image of the neural pattern associated with one conscious act can act as a template in the construction of the neural pattern associated with a later conscious act. Thus the physical representation of a conscious act

is the selection of a self-sustaining pattern of neural excitations that can contain various subpatterns that are images of subpatterns of patterns associated with various earlier conscious acts.

This arrangement may appear complicated. However, the "wiring" of human brains is vastly more complex than that of any man-made computer.¹⁹ Hence its capabilities should far surpass that of any such computer. A more detailed specification of the computer-like features of the brain will be given presently, after a discussion of some ideas of neurobiologists interested in the mind-brain connection.

5.5 Sperry's Model

Before proceeding to a more detailed development of the general idea outlined above, it will be useful to review the ideas of Sperry, who describes his interpretation of consciousness as follows:

"The current interpretation of consciousness takes issue with the prevailing view of 20th century science. In the present scheme the author postulates that the conscious phenomena of subjective experience do interact on the brain process exerting an active causal influence. In this view consciousness is conceived to have a directive role in determining the flow pattern of cerebral excitation. It has long been the custom in brain research to dispense with consciousness as just an 'inner aspect' of the brain process, or as some kind of parallel passive 'epiphenomenon', or 'paraphenomena' or other impotent by-product, or even to regard it as merely an artifact of semantics, a pseudoproblem (Boring, 1942; Eccles, 1966; Hook, 1961).

"The present interpretation by contrast would make

consciousness an integral part of the brain process itself and an essential constituent of the action. Consciousness in the present scheme is put to work. It is given a use and a reason for being, and for having evolved. On these terms subjective mental phenomena can no longer be written off and ignored in objective explanations and models of cerebral function, and mind and consciousness become reinstated into the domain of science...

"Compared to the elemental physiological and molecular properties, the conscious properties of the brain processes are more molar and holistic in nature. They encompass and transcend the details of nerve impulse traffic in the cerebral networks in the same way that the properties of the organism transcend the properties of its cells, or the properties of the molecule transcend the properties of its atomic components, and so on. Just as the holistic properties of the organism have causal effects that determine the course and fate of its constituent cells and molecules, so, in the same way, the conscious properties of cerebral activity are conceived to have analogous causal effects in brain function that control subsets of events in the flow pattern of neural excitation. In this holistic sense the present proposal may be said to place mind over matter, but not as any disembodied or supernatural agent.

"When it is inferred that conscious forces shape the flow pattern of cerebral excitation, it is not meant to imply that the properties of consciousness intervene, interfere, or

in any disrupt the physiology of brain cell activation. The accepted biophysical laws for the generation and transmission of nerve impulses are in no way violated. The electro-physiologist, in other words, does not need to worry about any of this, provided he restricts himself to analytic neuro-physiology. He does need to be concerned, however, if he wishes to follow a sensory input to conscious levels and to explain how a sensation or a percept is produced, or how the subsequent volitional response is generated...

"Although the mental properties in brain activity, as here conceived, do not directly intervene in neuronal physiology, they do supervene. This comes about as a result of a higher level of cerebral interactions that involve integration between large processes and whole patterns of activity. In the dynamics of these higher level interactions the more molar conscious properties are seen to supercede the more elemental physio-chemical forces, just as the properties of the molecule supercede nuclear forces in chemical interactions.

"To put this another way, the individual nerve impulses and associated elemental excitatory events are obliged to operate within larger circuit-system configurations of which they as individuals are only a part. These larger functional entities have their own dynamics in cerebral activity with their own qualities and properties. They interact causally with one another at their own level as entities. It is the emergent dynamic properties of certain of these higher specialized cerebral processes that we interpret as the substance of

consciousness."²⁰

"The foregoing combines important features of both classic dualistic mentalism and monistic materialism. It is mentalistic in that the contents of subjective mental experience are recognized as important aspects of reality in their own right, not to be identified with neural events as these have heretofore been conceived nor reducible to neural events. Further, the subjective mental properties and phenomena are posited to have a top-level control role as causal determinants (Sperry, 1976). On these terms mind moves matter. Not only can subjective mind no longer be ignored in science; it becomes a prime control factor in explanatory models. In former theories of consciousness at all acceptable to science, consciousness has been so defined that the causal march of brain mechanisms would proceed the same, whether it is accompanied by subjective experience or not. This is not the case in the present model."²¹

Sperry draws an analogy between his idea of the connection between consciousness and neural activity and the familiar idea of the connection between an organism and its cellular activity, or the connection between molecule and its atomic or nuclear activity. These latter connections can be viewed classically as the normal connection of an individual to an environment formed of many individuals. In the classical view this connection can, in principle, be reduced to the causal connection between individuals: the collective action of the many individuals of the environment are simply summed up to give a net environmental effect. It may be

possible in some cases to isolate conceptually the causally effective collective qualities, and even to construct theories that deal with these collective qualities as new entities. But according to the classical view these collective features are ultimately reducible simply to the properties of the individuals.

If it is this classical viewpoint that Sperry is adopting then his causal connections between different hierarchical levels become altogether normal and natural. However, consciousness per se becomes irrelevant to the exercise of causal control by the collective environment. The active causal influence exerted by the environment is nothing more than the net effect of the individuals. The superimposed element called consciousness can remain as epiphenomenal as ever.

Sperry's analogies can be interpreted in a classical manner. Indeed, their clarity and reasonableness arise precisely from this fact. However, he is obviously reaching for much more, namely for the idea that certain collective modes are imbued with a holistic unity that goes beyond the simple idea of a collection of individuals acting in unison by virtue of their mutual interactions. For it is only the introduction of this genuinely holistic feature that would justify the introduction of a new entity, consciousness, that is able to exercise control in its own right. But the classical analogies give no idea of how such a genuinely holistic feature could arise or operate, within the bounds of the established laws of physics.

The psychophysical theory developed above shows how quantum theory, interpreted in a most natural way, automatically provides

for the emergence of consciousness as a distinctive new entity associated with certain specific collective processes in brains. Moreover, as will be shown in following sections, this new entity automatically exercises control over neural processes in the brain through the action of the established physical laws of nature--not in spite of them. The theory thus shows how Sperry's general ideas can be rooted in, and in fact emerge naturally from, the quantum theoretic laws of nature.

5.16 Eccles' Model

Taking cognizance of Sperry's ideas Eccles¹⁹ has proposed a different model of brain dynamics in which consciousness again plays a directive role in the flow of neural excitations. In Eccles' model the self-conscious mind "scans" or "probes" the neurons of a certain portion of the brain, called the liaison brain, which consists of certain modules that are "open" to this scanning operation, and then acts back, feebly, on these neurons to exercise directive control over the overall flow of neural activity. The unity of conscious experience comes from a proposed integrating character of the self-conscious mind. But it is left open how the self-conscious mind is able to organize the information extracted from the numerous open modules and form from it a unified conscious thought, and how this conscious thought produces the integrating action on the neural excitations.

The present theory can be considered a more detailed form of Eccles' general idea. However, that general idea, in the form to which it was carried by Eccles, seems to require the self-conscious mind to have an incredible encyclopedic knowledge of the

neural circuitry of the brain, in order to make sense of the firings of the liaison brain and bring about its desired ends by exercising feeble control over selected neurons: the self-conscious mind would have to be a truly god-like entity. Indeed, Eccles speaks of its existence after death of the brain leaves it with nothing to scan.

Eccles likens the self-conscious mind of his model to "a ghost in the machine." Sperry, on the other hand, emphasizes that in his model mind is not a disembodied or supernatural agent.

This description of the ideas of Sperry and Eccles has prepared the way for the presentation of the final and crucial parts of theory being described here.

5.17 Consciousness and Control

The brain is viewed in this theory as a self-programming computer, with the aforementioned mutually exclusive self-sustaining neural patterns acting as the carriers of the top-level codes. Each such code exercises top-level control over lower-level processing centers, which control in turn the bodily functions, and, moreover construct the new top-level code. This new code is constructed by brain processes acting in accordance with the causal quantum-theoretical laws on localized personal data: the new code is formed by integrating, in accordance with directives from the current top-level code, the information coming from external stimuli with blocks of coding taken from codes previously stored in memory. This causal process of construction necessarily produces, by virtue of the character of the quantum-theoretic laws, not just one single new code but a superposition

of many, each with its own quantum mechanical weight. The conscious act has as its image in the physical world, as represented by contemporary physical theory, the selection of one of these superposed codes.

This selection will be determined almost completely by the causal quantum-theoretic laws acting on the localized personal data, provided only one of the superposed codes has nonnegligible weight. But if several of these codes have appreciable weight then the global and seemingly statistical element will become important. Thus the selection process has, from the quantum theoretical viewpoint, both a causal-personal aspect and also a stochastic-nonpersonal aspect.

This model of the connection between mind and matter is in general accord with the ideas of Sperry and Eccles, but is more specific. The conscious act is represented physically by the selection of a new top-level code, which then automatically exercises top-level control over the flow of neural excitations in the brain through the action of the quantum theoretical laws of nature. The unity of conscious thought comes from the unifying integrative character of the conscious creative act, which selects a single code from among the multitude generated by the causal development prescribed by quantum theory.

5.18 Objective Control and Subjective Experience

Every human conscious act is experienced by a human being. Thus it is a human experience. Conversely, each human experience is regarded as a human conscious act.

A familiar example of a (human) conscious act is the act of initiating some motor action, such as raising one's arm. The conscious

act of initiating this action is the same as the experience of initiating this action. This conscious act is represented in the physical world described by contemporary physical theory as the selection of a top-level code that initiates this action.

This example is now generalized. It is postulated that each human experience is the human conscious act of initiating those perceptible actions that are initiated by the top-level code whose selection is the physical representation of that conscious act. This postulate ensures the functional identity of each human experience and its representation in the physical world.

This functional identity of human experiences and their representations in the physical world resolves the objections mentioned by William James (see Section 2) to the classical attempts to understand the connection between mind and matter. Those objections stemmed from the complete dissimilarity of the two ideas: the classical idea of a thought has nothing in common with the classical idea of a collection of particles moving in accordance with Newton's laws. But the conscious act of initiating a perceptible action is closely and naturally related to the selection of the code that initiates this action: the latter is the natural image of the former in the physical world represented by quantum theory.

This way of resolving the mind-body problem is philosophically attractive, and it emerges naturally from quantum theory. It follows from the postulate stated above. But how is this postulate to be reconciled with such familiar experiences as seeing a picture or feeling a pain?

Examining a picture elicits experiences of colors, forms, and

textures, and of various related associations. According to the present theory this examination is a process in which, at the physical level, the top-level codes are issuing directives to the lower-level processing centers. These top-level codes are instructing the lower-level centers to form from the incoming stimuli and previously stored code-images new top-level codes that resemble themselves as closely as possible, and that also initiate the storage into memory of themselves, and hence the information of interest that is being recognized. Thus an experience of, for example, noticing that a certain patch in the painting is green is, according to the present theory, a conscious act whose physical representation is the selection of a top-level code that initiates the process of storing this information in memory. More generally, any act or experience of recognition is the conscious act whose physical representation is the selection of a top-level code that initiates the transfer into memory of the information that is recognized. The felt experience of "noting" or "noticing" something is the felt experience of initiating the process of storing in memory the noted information.

The top-level code is closely tied to its own memory structure. This code provides an overall control that can link actions that range over an entire lifetime. To provide efficient top-level control the lower-level centers organize the available information into a simplified schema. It is only the elements of this simplified schematic representation of the body, the external environment, and internal ideas that can be incorporated into the top-level code and its memory structure.

An experience of pain is an experience whose physical

representation is the selection of a code that initiates the action of registering in this schema damage to some part of the body. In normal circumstances the construction of this code is performed by the lower-level centers, acting under the stimulation of signals from the distressed part. If this stimulation is strong, and the lower-level centers are working normally, then the causal laws of quantum theory will virtually assure the selection of such a code. On the other hand, if these centers are not working normally, or if attention is focused elsewhere, so that the selected top-level code is not the one that would normally be induced by the signals from the distressed parts, then there would be no experience of pain, even if the appropriate stimuli are present.

Conversely, if the normal stimuli for the construction of such "pain" codes by lower-level centers were absent, but the lower-level centers were nevertheless constructing such codes, with weight close to unity, then the "pain" codes would almost surely be selected and the pain experienced. This theoretical picture is in general accord with the clinical evidence on pain.^{24,25}

By analysis of this kind each human experience is to be identified with a conscious act of initiating certain perceptible actions, and the representation of this act in the physical world is then to be identified as the selection of a top-level code that initiates these actions. Human consciousness thus becomes represented in the physical world, as described by quantum-theory, as an agency that exercises precisely the objective control that is subjectively experienced.

6. TESTS, APPLICATIONS, AND IMPLICATIONS

Some tests, applications, and implications of the psychophysical theory described above are discussed in the following subsections.

6.1 Tests and Applications in Mind-Brain Research

The theory gives definite expectations about what brain research should reveal. It should reveal, first of all, the neural connections required to produce and maintain the mutually exclusive self-sustaining patterns of neural excitations that were hypothesized above. The important inhibitory neurons are already known to exist.¹⁹ The "wiring" needed to achieve the self-sustaining excitations must also be present. Moreover, the whole wiring pattern needed for a computer operation of the kind described must exist. The key features are first the "liaison brain" consisting of the collection of neurons in which the top-level program is encoded, second the mechanisms for producing, elsewhere in the brain, enduring images of these codes, and third the mechanism by which parts of these enduring images can be used as templates for the construction of parts of new top-level codes.

The expectations described above refer specifically to the neural structure of the brain, not to consciousness. According to the present theory each human experience must be accompanied by the activation, in a human brain, of an associated top-level code. This assertion has some immediate experimental consequences. For example, it is known that the excitation of a single neuron can produce characteristic conscious sensations (eg. a perceived star¹⁹). According to the present theory the felt or perceived sensation can occur only if the excitation of the neuron results in the activation of an associated pattern in the top-level code. Thus if this activation is blocked in

any way then there should be no associated sensation, perception, or experience.

As the experimental techniques of brain research develop it may become possible to identify the separate blocks of coding integrated into the top-level code. The present theory demands that no nuance of significance or meaning can be present in a conscious thought unless the corresponding blocks of coding are present in the associated top-level code. Thus the picture of the mind-brain interaction presented here is not the one in which our intelligence stands outside or above the brain and scans it to pick up enough information to allow it to form its own idea of what is going on in the physical world, and then exert some appropriate control measures to effect its subjective aims. On the contrary, all of the elements of the momentary subjective human intelligence are required to be present in integrated form in the momentary top-level physical code.

These assertions can in principle be tested by comparing the physical structure of the top-level code to the experienced content of the thought.

6.2 Implications in the Domain of Traditional Physical Phenomena

The psychophysical theory developed in this paper deals specifically with the mind-body problem. To first approximation it has no ramifications outside that domain. Indeed, the approximate separability of the mind-body question from the subject matter of classical physics is the basis of that science. Likewise the justification of the pragmatic Copenhagen interpretation of quantum theory rests precisely the fact that the phenomena traditionally dealt with by quantum theory do not depend on the intricacies of the

mind-body connection.

On the other hand, the general theory set forth here has, in principle, profound implications. For if the modified Whitehead-Heisenberg ontology described here is really correct then the primary task of science is to understand more deeply the general nature of the creative processes: what creative acts other than conscious acts occur, and how are they represented?

The proper course of pursuing these questions is to make specific proposals that have both a rational basis and experimental implications. Work is progressing along these lines and will, I hope, be reported later.

7. COMMENTS ON PARALLELISTIC INTERPRETATIONS

The empirical validity of quantum theory shows that its mathematical structure corresponds in some way to reality. In fact, the wave-forms themselves exhibit an organic unity that gives them an aura of realness not exhibited by their counterparts in classical statistical mechanics. For example, if the detection device is characterized by ψ_B , and ψ_B equals ψ_A , then the probability of detection is unity: the particle is definitely detected. But any change of ψ_A diminishes the probability of detection. And any change in ψ_B diminishes the probability of detection. Thus the wave-form ψ_A acts, in this connection, like an organic whole, which is grasped as a whole by the detection device. Its behavior is qualitatively different from what one would expect from a representation of a collection of different independent elements. For if ψ_A represented a collection of nonidentical elements some change in ψ_B should increase $P(B,A)$.

This characteristic aspect of wholeness in the behavior of the wave-form has led many physicists to the idea that the wave-form should be considered as not merely a calculational tool but rather as a representation of some real aspect of Nature herself. According to this view in its extreme form the entire physical world should be represented by a single wave-form Ψ . Then the Cartesian dualism familiar from classical physics can be carried over virtually unchanged to quantum theory.

This parallelistic viewpoint was apparently adopted by von Neumann, who says¹²: "First, it is inherently entirely correct that the measurement or the related process of subjective perception is a

new entity relative to the physical environment and is not reducible to the latter. Indeed, the subjective perception leads us into the intellectual inner life of the individual, which is extra-observational by its very nature (since it must be taken for granted by any conceivable observation or experiment). Nevertheless, it is a fundamental requirement of the scientific viewpoint--the so-called principle of the psycho-physical parallelism--that it must be possible so to describe the extra-physical process of the subjective perception as if it were in reality in the physical world--i.e., to assign to its parts equivalent physical processes in the objective environment, in ordinary space." He also says that "we must always divide the world into two parts, the one being the observed system, the other the observer. In the former we can follow up all physical processes (in principle at least) arbitrarily precisely. In the latter this is meaningless. The boundary between the two is arbitrary to a very large extent....That this boundary can be pushed arbitrarily deeply into the interior of the body is the content of the principle of psycho-physical parallelism--but this does not change the fact that in each method of description the boundary must be put somewhere, if the method is not to proceed vacuously, i.e., if a comparison with experiment is to be possible. Indeed, experience only makes statements of this type: an observer has made a certain (subjective) observation; and never any like this: a physical quantity has a certain value.

Now quantum mechanics describes the events which occur in the observed portion of the physical world, so long as they do not interact with the observing portion, with the aid of process 2, but as

soon as such an interaction occurs, i.e., a measurement, it requires the application of process 1." (Process 2 is causal development according to the Schroedinger equation, whereas process 1 is an abrupt stochastic change associated with observation or measurement.)

von Neumann's approach is dualistic and parallelistic: he says that the subjective process can be described "as if" it were in reality in the physical world. He also claims that the boundary between the parts of the world treated as the observed system and the observer, respectively, is arbitrary to a large extent. This evidently means that the abrupt change associated with the process of observation or measurement is not a real process, but merely an artifact of man's theorizing about nature, dependent upon where he places an imaginary cut.

If the abrupt changes called process 1 are not real, as von Neumann's words suggest, then the "real" physical world represented by the wave-form Ψ must develop always causally in accordance with process 2. This leads to odd conclusions. For example a person looking at a digital clock that is stopped at some time by a radioactive decay would, in so far as his representation in the physical world is concerned, be split into a sequence of copies of himself, each corresponding to a different perceived reading of the clock. More generally the physical world as represented by Ψ will be continually splitting into parts that represent the different perceptual possibilities of all human observers: the one "absolute" real world represented by Ψ will be splitting into parts representing myriads of personal real worlds.¹⁰

Some physicists unflinchingly accept this "many-worlds" view.²¹ von Neumann himself left this implicit conclusion unstated. Most physicists adopt, when pressed, the agnostic practical position represented by the pragmatic Copenhagen interpretation.

Within the general framework provided by von Neumann's interpretation of quantum theory each creative act of the theory developed here would be represented by a type 1 process.

The present model is similar in a sense to Bohm's point-particle model, except the role played by his point particles is transferred in the present theory to mind. In Bohm's model the wave-form Ψ is real, but the positions of his point-particles would determine which of the mutual exclusive self-sustaining patterns of neural excitations is "selected." Being "selected" means that this pattern will be subjectively experienced or felt, whereas the other patterns will not be felt. But this presents a puzzle: why should the presence of these point-particles endow with feeling the particular part of the wave form Ψ in which they lie. For the other parts of the wave function Ψ are equally real, and particles seem, if anything, even less akin to consciousness than waves, which are more holistic.

In the present model the selection of which code is experienced is controlled not by the presence of classical particles but by a fundamentally holistic creative process. This opens the way for some rational understanding of the connection between mind and matter. The dualistic/parallelistic real-particle interpretation of quantum theory makes that connection even more mysterious than ever.

The dualistic/parallelistic many-worlds interpretation likewise provides no possibility for mind to enter in any significant way into

the unfolding of physical reality. This way of separating physical science from the larger questions of human existence may appear desirable to some. But in the end it is unacceptable.

8. SUMMARY AND CONCLUSIONS

Four fundamental problems were briefly described in the introduction. The first is the problem of mind and matter, which is the problem of conceiving a reality in which the mental events we experience are related naturally to the physical world represented in physical theory. Historically, the difficulty has been that the physical world represented in classical physical theory consists of tiny localized particles in motion (or perhaps localized field amplitudes) that move in accordance with mathematical laws. This picture gives no clue as to what combinations of motions should correspond to a mental event, or why such events should exist at all. For there is absolutely no place in classical physics for mental events--no need for them; no role for them. And these events seem completely incommensurate with the objects that occur in the theory. Moreover, the feeling of power or efficacy associated with subjective conscious acts must, in this picture, be regarded as completely illusory: consciousness can enter the world only as a passive spectator. Yet this feeling of power pervades our conscious experience; it cannot be simply dismissed as sheer illusion without some explanation or evidence.

The decisive break in the problem of mind and matter was the advent of quantum theory, which showed that the laws of classical physics were not valid, and, moreover, that the simple picture of the physical world provided by classical physics was neither accurate nor adequate. However, quantum theory, in its orthodox interpretation, does not resolve the problem of mind and matter. It circumvents the problem by declining to give any picture of all of

the physical world, except the vague one that dimly emerges from the set of statistical rules it provides.

This omission constitutes the second fundamental problem--the problem of quantum theory and reality. The problem here is to formulate a conception of the reality that lies behind the statistical rules of quantum theory.

There are three principal contenders: the many-worlds interpretation, the real-particle interpretation, and the real-tendency interpretation. The first two suffer from a profusion of superfluous entities. Moreover, they provide no basis for the resolution of the problem of mind and matter. In particular, the many-worlds interpretation requires each perceptible world to develop into a multitude of real worlds only one of which we can actually perceive. And consciousness is again, as in classical physics, merely a passive spectator.

The real-particle interpretation, on the other hand, superimposes upon orthodox quantum theory the real particles of classical physics. This wedding is unnatural, and the superimposed real-particles are superfluous in the sense that they add nothing/to ^{that is empirically testable} quantum theory. Their function is merely to single out from the many real worlds of the many-worlds interpretation one single world, which is then identified as the only one that is experienced. This identification does not eliminate or reduce the profusion of worlds generated in the many-worlds interpretation: all of these many worlds are still present in nature, according to this theory. But they are not experienced. Why experience should be associated only with the particular world picked out by the classical particles is

not explained. Hence the mind-matter problem is, if anything, magnified.

The real-tendency interpretation was promulgated by Heisenberg. But it seems to conflict with the dogmas of the relativity theory. However, relativity theory itself is surrounded by long-standing controversies regarding the question of how it should be reconciled globally with that which locally we experience directly, namely the coming of reality into being or existence. This problem of reconciling relativity theory and "process" is the third fundamental problem mentioned in the introduction.

This relativity problem is resolved here by recognizing that Einstein's conception of physical theory identifies it with the construction of mathematical laws that relate various elements from his static realm of readings of devices. This conception eliminates from physical theory, ab initio, the consideration of the process whereby reality comes into being or existence. The ideas and dogmas of the theory of relativity apply naturally only to those aspects of our understanding of nature that can be formulated within Einstein's realm of readings. These aspects are precisely those represented by contemporary physical theory, namely relativistic quantum theory and classical relativity theory. The dogmas of relativity theory cannot be expected to apply to the consideration of the dynamical process by which reality actually unfolds.

This resolution of the relativity problem allows Heisenberg's real-tendency interpretation to be formulated in a clear and concrete form. In line with the ideas of Whitehead, reality is conceived to be created by a sequence of creative acts. The quantum theoretical

statistical rules become a reflection of real tendencies induced by the structure of the creative process.

This way of resolving the final three problems mentioned in the introduction leads naturally to a resolution also of the first problem, which is the problem of mind and matter. Starting from the commonly accepted idea that the brain functions as a computer the present theory identifies each conscious experience with a creative act whose representation in the physical world is the selection of one top-level code from among the multitude automatically generated by the dynamical laws of quantum theory. It is postulated that each conscious experience is the experience of initiating processes that tend to produce certain perceptible changes in the personal reality schema (which consists of the body schema, the external reality schema, and the internal idea schema) and that the representation of this conscious act in the physical world of quantum theory is the selection of the top-level code that initiates the processes that tend to produce these same perceptible changes. Thus the conscious act is functionally equivalent at the level of perceptible changes to its image in the physical world represented by quantum theory. The feeling of power or efficacy that pervades the conscious act is no illusion: it correctly represents the functional efficacy of the conscious creative act both in the world of conscious experience and in physical world represented by quantum theory.

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