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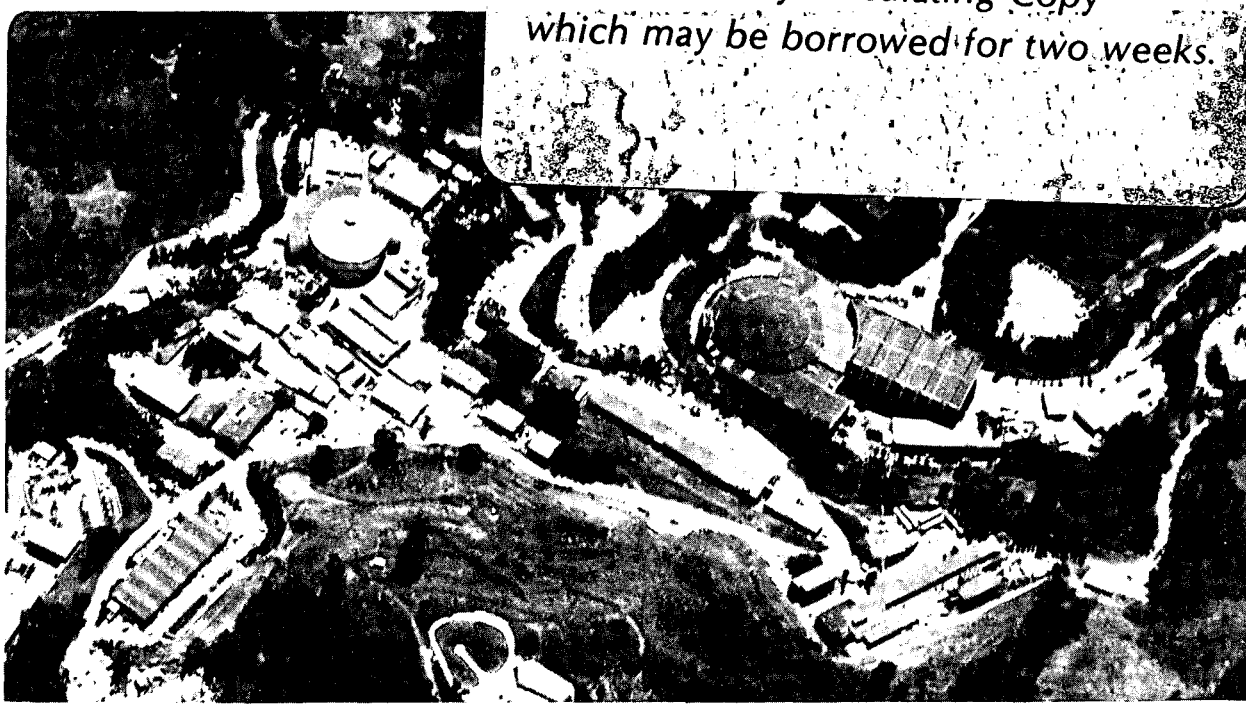

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Quantum Theory and the Physicists' Conception of Nature: Philosophical Implications of Bell's Theorem

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1. Introduction

During the eighteenth and nineteenth centuries classical physics gave a very successful account of physical phenomena, yet was not generally accepted by philosophers as an adequate basis for an understanding of nature. This rejection was due fundamentally to the problem of the non-connection between mind and matter. In a coherent understanding of nature all parts must stand together in a way such that none can stand alone. Yet classical physics is so internally coherent as to preclude any rationally ordained coupling between the physical reality it describes and anything else. Classical physics not only fails to demand the mental; it fails even to provide a rational place for the mental. And if the mental is introduced ad hoc then it must remain totally ineffectual, in absolute contradiction to our deepest experience.

Another reason for the reluctance of philosophers to accept the ideas of classical physics as a basis for a comprehensive metaphysics is that a philosophy based on strict mathematical determinism is cut off at the start from any adequate basis for dealing with the moral and other human issues whose resolution is the ultimate task of a complete philosophy.

The rise of quantum theory in the present century appeared at first to render the physicists' conception of nature even less adequate as a foundation for metaphysics. The reasons are two. First, a principal theme in orthodox quantum thinking is precisely the rejection of metaphysics. The orthodox attitude is to renounce the quest for an understanding of physical phenomena in terms of basic realities, and settle for some computational rules that allow scientists to form expectations pertaining to observations obtained under well-defined conditions specified in terms of classical physical ideas. This revision in the announced aim of physics signifies that the clear idea of physical reality provided by classical physics has been snatched away by quantum theory, which provides in its place nothing but some computational rules of mysterious origin. Such

rules may be sufficient for scientific purposes, but they are not enough for philosophers in search of a unified understanding of all of nature.

A second reason for the apparent inadequacy of the quantum physicists' conception of nature as the foundation for a unified metaphysics is that the quantum rules effectively replace the mind-matter duality of classical physics by a quantum triality: the physical world of classical physics is subdivided into two parts; a macroscopic part described in terms of the reality concepts of classical physics, and a microscopic part described in terms of the formalism of quantum theory. Thus a new schism is added, and there is an apparent shift away from metaphysical unity, rather than toward it.

The general reluctance of quantum physicists to embrace a metaphysics, or comprehensive ontology, stems from two considerations. The first is the possibility that two different ontological systems might lead to the same computational rules. If the predictions generated by the orthodox quantum theoretical rules completely exhaust the set of empirically testable propositions obtainable from physical theory then any metaphysical assertion that is more than the mere assertion that these calculational rules hold is scientifically unwarranted.

The second consideration inhibiting the embrace of a comprehensive ontology is the problem of nonlocality. Apart from the so-called many-worlds interpretation, which is objectionable on other grounds, no ontology not involving faster-than-light propagation of influences has been proposed that can account for all of the predictions of quantum theory. Since quantum physicists are generally reluctant to accept the idea that there are faster-than-light influences, they are left with no ontology to embrace.

2. Three Ontologies Proposed To Account For Quantum Phenomena

For the sake of definiteness let me briefly describe the three principal ontologies that have been proposed by quantum physicists. These are the many-worlds ontology of Everett[1], the pilot-wave ontology of Bohm[2] and the actual-event ontology of Heisenberg[3].

The many-worlds ontology arises directly from the assumption that the probability amplitude of quantum theory is a real physical quantity, rather than merely a conceptual device to be used by scientists to compute the probability that a measuring device will respond in a specified way. This real physical amplitude is assumed to obey an appropriate Schroedinger equation.

This probability amplitude has (when squared, etc.) the mathematical properties appropriate to a probability density. Consequently, in a measurement situation in which there are, due to quantum uncertainties, several distinct alternative possible outcomes of the measurement, each with a nonzero probability, the region where the probability amplitude is nonzero must split into several "branches", with each branch corresponding to one of the alternative possible results of the measurement. For example, if some measurement has two alternative possible outcomes, one corresponding to the pointer on some device moving to the right by a perceptible amount, and the other corresponding to this pointer moving to the left by a perceptible amount, then, in terms of the location of this pointer, the region in which the probability amplitude is nonzero will, after the measurement, consist of two separated regions, one corresponding to the pointer displaced perceptibly to the right, the other corresponding to the pointer displaced perceptibly to the left. Since this probability amplitude is now assumed to represent reality itself, rather than merely a probability for a possible reality, this separation of the probability amplitude into a set of "branches" entails a separation of reality itself into a set of branches, one corresponding to each of the alternative possible results of the measurement. Only one of these possibilities is observed empirically. This disparity

between what is "real", according to this ontology, and what is observed empirically, is accounted for by arguing, quite plausibly, that the separation of reality into parallel non-interacting branches will induce a corresponding separation of the mental worlds of the observers into parallel non-communicating branches.

This many-worlds ontology might appear to make sense when one considers only idealized measurement situations, in which the regions where the probability amplitude is nonzero separate into well-defined distinct branches, corresponding to the various alternative possible distinct observations. But the idea becomes totally obscure when one considers the general situation of continuous evolution in accordance with the Schroedinger equation. In particular, there appears to be no general way within this ontology to account for the distinct character of our experiences. For the ontology has no fundamental element of discreteness, but consists basically of a superposition of a continuum of possibilities.

The second important proposed ontology is the pilot-wave model. One again takes the probability amplitude of quantum theory to be real, and requires it to obey always the Schroedinger equation. The problem of distinctness is resolved by introducing a second component of reality, a "real world" described exactly as in classical physics. However, this real world moves not in accordance with the classical laws of inertia and acceleration, but rather always along the flow lines defined by the quantum probability amplitude. The distinctness problem is then resolved by assuming that experience is coordinated always to this single distinct real world, rather than to the continuum of such worlds represented by the probability amplitude. However, there is then the embarassment of the "empty branches": in an ideal measurement situation with several distinct possible results there will be, as discussed before, one branch of the probability amplitude corresponding to each of the alternative possible results of the measurement. The "real world" of the pilot-wave model will get into one of these branches, and stay there. The equations of motion of quantum theory then entail that the other branches

can have essentially no influence on the subsequent motion of this real world. Yet these other branches continue to exist as parts of "reality." This is a highly non-economical way for nature to operate. For nature must keep on generating in perpetuum the evolution of these "empty branches" that can never influence the experienced real world.

The third important ontology is the one proposed by Heisenberg. According to this proposal the probability amplitude of quantum theory corresponds to an objective tendency or "potentia" for the occurrence of an actual event. This event effectively selects some particular macroscopic response of the measuring device from among the possibilities that were allowed prior to this event.

Heisenberg's ideas are not out of line with, or incompatible with, the orthodox position. In fact, the orthodox position is defined jointly by the ideas of Bohr and Heisenberg. Bohr's "strict" wordings avoid Heisenberg's ontological commitments, but these wordings are certainly compatible with the idea that the responses of the devices are selected in the way suggested by Heisenberg. Thus Heisenberg's ontology can be said to be the orthodox quantum ontology, to the extent that such an ontology exists at all. In the following I call Heisenberg's ontology the quantum ontology.

3. Mind and Matter in the Quantum Ontology

The previously mentioned problem of the connection between mind and matter takes on a completely new complexion when considered on the basis of the quantum ontology, as opposed to the ontology of classical physics. The main problem from the classical point of view is that the category of ideas used to represent physical properties is disjoint from the category of ideas used to represent mental properties. In the words of William James: "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."[4]

In the words of Tyndall:[4]

> We can trace the develoment in a nervous system and correlate it with a 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.

These assessments were based on the ontology of classical physics, in which the physical aspects of nature were completely represented by the motions of billions of particles (and perhaps some fields), evolving in accordance with the classical equations of motion. The quantum ontology has an analog of this classical structure, namely the probability amplitude. This amplitude refers to the same degrees of freedom as the corresponding classical system. And it evolves according to an equation of motion that is analogous to the classical one.

However, the quantum ontology includes also something else, which is completely different in character. This is the actual event, which represents, in effect, a decision between various alternative possible perceptually distinct courses of action. These actual events were discussed by Heisenberg in the context of the behavior of a quantum measuring device. But they must presumably be occurring wherever quantum processes are taking place within the context of macroscopic systems. From the point of view of the quantum ontology the actual perceived world is constructed from myriads of these

actual events, each of which actualizes in a particular way the potentialities created by the prior events, and moreover fixes in turn the potentialities for subsequent events.

If we take over from the case of measuring devices the idea that these events occur generally at a high level of integration, and effectively decide between macroscopically distinguishable behaviors of the macroscoic system, then the quantum ontology provides the element needed to fuse the mental and physical aspects of nature. 'A motion became a feeling'' Now there is no problem with this idea. For physical motion is represented in quantum theory as the evolution of the probability amplitude, which represents, however, only a "potentia" for an integrative act, not the actual event or act itself. This actual event or act is effectively a decision between different alternative possible perceptually distinct modes of behavior of the macroscopic system. Thus a motion "becomes," or at least provides the conditions for, an act, which decides between perceptually different modes of behavior of the macroscopic system. One can contrast here the mathematically preordained, and hence spiritless, motion of the particles, as represented by the mathematical evolution of the probability amplitude, with the nonpreordained, and hence "spirited", act that decides between the alternative possibilities. The idea that this act should be <u>felt</u> as exactly what it is from the physical point of view, namely a spirited act of deciding between the alternative possible integrated behavior patterns of the complete organism, requires no logical rupture. For there is no identification of a mental aspect with something wholly different. Rather a mental act is identified with a physical act, and both of these acts are the very same act, namely the act of deciding between alternative possible modes of behavior that are, prior to this act, allowed for the macroscopic physical system. I invoke here the main conclusion from von Neumann's analysis of the process of measurement, namely that the quantum act (the decision) can be pushed all the way to the physical phenomena associated with the psychical event. Then the physical and psychical acts become the single identical act of deciding between different macroscopic patterns of behavior.

This identification of each human mental event with the effectively identically physical one does not entail that every physical event is a human mental event. Rather, in keeping with Heisenberg's ideas, the actual physical events can be associated generally with decisions between alternative possible modes of behavior involving the collective action of large numbers of quanta acting coherently. In this way the quantum ontology, which was created solely to provide an understanding of a purely physical phenomenon, namely the behavior of quantum measuring devices, provides automatically the basis for a natural and rational comprehension of the connection between mind and matter. The quantum ontology thus dissolves the mind-matter duality, and brings the physical and mental aspects of nature together in the particular mathematical juxtaposition defined by quantum theory.[5]

4. Nonlocal Character of The Quantum Ontology

Within the quantum ontology of Heisenberg the most striking characteristic of the quantum act or event is its nonlocal nature. Heisenberg discusses this feature in connection with a wave packet that strikes a half-silvered mirror. Such a mirror reflects half of the packet and transmits half. The two parts of the wave packet can then travel to distant regions, where they may encounter measuring devices. The probability amplitude is nonzero in both devices, and hence there exists in both devices an objective tendency, or potentia, for the device to respond. Heisenberg notes that

> if an experiment yields the result that the photon is, say, in the reflected part of the packet then the probability of finding the photon in the other part of the packet immediately becomes zero. The experiment at the position of the reflected packet then exerts a kind of action (reduction of the wave packet) at the distant point occupied by the transmitted packet, and one sees that this action is propagated at a velocity greater than light. However, it is obvious that this kind of action can never be used to transmit a signal, so it is not in conflict with the postulates of the theory of relativity.[6]

A principal characteristic that distinguishes a "signal" from a general influence is that a signal can be controlled by a human choice. In the situation just described it is Nature, not a human being, that decides whether the device in one region will respond or not. Consequently, the faster-than-light action associated with the quantum event or act cannot be used to transmit a signal.

This nonlocal feature of the Heisenberg ontology is troublesome to quantum theorists. When confronted by it most orthodox physicists will retreat to the strict interpretation of Bohr, and renounce the ontological ideas. That is, the typical orthodox quantum physicists, although initially willing to accept informally the idea that something definite actually happens at the level of the device, and the idea that the selection of what actually happens is not predetermined, will not be willing to follow through the consequences of this commitment, as Heisenberg did, but will retreat to the position that quantum theory merely provides testable rules, not ontology. From this pragmatic point of view the reduction of the wave packet need not be explicitly

mentioned at all, and if it is mentioned it is regarded as simply the normal change that is naturally associated with the change in the knowledge, hence expectations, of the human observer-scientist when new information is registered in his consciousness. This instantaneous change in the knowledge of the human observer evidently does not correspond to any faster-than-light physical action. Thus the faster-than-light actions occurring within the Heisenberg ontology are dismissed as spurious, or nonphysical.

This conclusion is reinforced by the fact that the one-quantum situation discussed by Heisenberg can be described in a completely local way within the pilot-wave model. (The evolution of the probability amplitude is determined by the local Schroedinger equation, and the motion of the "classical particle" of the pilot-wave model is then locally determined by the flow lines of the probability amplitude.) Consequently, the nonlocal character of the Heisenberg ontology appears to be a nonphysical peculiarity of this ontology, rather than a reflection of any nonlocal aspect of quantum theory itself.

The logical situation changes when two-quantum systems are considered. Then the pilot-wave model also becomes nonlocal. (The model is local in the six-dimensional space of the composite two-quantum system, but is nonlocal in physical three-dimensional space.) This nonlocal character is completely explicit: the behavior of a quantum in one spacetime region is dynamically influenced by <u>what experimenters do</u> to a quantum located in a second region, which is space*like* separated from the first.

This explicitly nonlocal character of the pilot-wave model is often cited as a sufficient reason for its rejection. But if both the Bohm-type and Heisenberg-type ontologies are rejected, on the bases of their nonlocal character, then the quantum physicist is left with no coherent ontology that is compatible with the validity of the quantum theoretical predictions, even for rudimentary two-quantum systems.

5. Failure of EPR Locality

The considerations of the preceding section were based on specific ontologies. Hence the conclusions that can be drawn are correspondingly limited. Einstein, Podolsky, and Rosen[7] initiated a much more general approach, which is based not on particular ontologies but rather on general principles. These authors gave an argument for the incompleteness of the quantum-theoretical description of physical reality. Their argument was based on a locality assumption that expressed the idea that nothing in one spacetime region can be disturbed or influenced by <u>what is done</u> by an experimenter in another region, which is spacelike separated from the first. Einstein expressed a firm conviction that this locality principle must hold.[8] However, it can now be shown, on the bases of a generalization of the work of J.S. Bell,[9] that, within a very general theoretical framework, this locality principle is incompatible with the assumption that some rudimentary two-quantum predictions of quantum theory are valid.

The EPR-Bell analysis[7-13] involves two spacetime regions, R_1 and R_2, that are spacelike separated: no point in either region can be reached from any point in the other without travelling either faster than light or backward in time. In each region an experimenter is to decide between two alternative possible measurements. The chosen measurement is to be performed in that region, and the result recorded there. The measurement involves a sequence of n pairs of quanta that have been prepared earlier in such a way that one quantum from each pair enters each region, where it is subjected to a measurement. The measurement on each quantum is such that it must yield one or the other of two alternative possible results, which we label by +1 and -1, respectively. Thus $r_{1i} = \pm 1$ and $r_{2i} = \pm 1$ specify the alternative possible results in R_1 and R_2, respectively, of the measurement performed on the quantum from pair i.

The <u>correlation</u> between the results in the two regions is defined by

$$c = \frac{1}{n} \sum_{i=1}^{n} r_{1i} \; r_{2i} = c(r_1, r_2).$$

It lies in the closed interval between plus and minus one. In the physical situation considered by Bell the rules of quantum theory give, for each of the four alternative possible combinations of measurements in the two regions, a corresponding value $\bar{c}$, and predict that the measured value of c will tend to $\bar{c}$ as n tends to infinity. More precisely, for any $\varepsilon > 0$ and $\delta > 0$ the probability that c lies in the region $|c - \bar{c}| > \varepsilon$ can be made less than δ by taking n sufficently large.

To discuss the influence of the choice of measurement performed in one region upon the decisions that nature can be forced to make in the other region we introduce a conceptual framework based on two assumptions. The first assumption is that, within the specific context of the analysis of the quantum theoretical predictions for the measurements under consideration here, the choices to be made by the experimenters can be regarded as free and independent variables. This does not mean that these choices are necessarily literally free, but merely that the causal determinants of these human choices are sufficiently divorced from quantum system under consideration as to have no essential bearing on the fact that measurements yield results that accord with the quantum predictions: the causal determinants of the human choices <u>could</u> be decoupled from the quantum system under study without disrupting the validity of predictions of quantum theory.

The second assumption is that, for each region, and for each of the two alternative possible measurements in that region, if that measurement is chosen then nature must make a definite decision between the alternative possible results of this measurement: two possible values for the outcome of a single decision are either equal or contradictory. This assumption excludes the many-worlds ontology, in which all of the alternative possible results are actually realized, and hence nature makes no decision.

A necessary condition for the noninfluence, within a theoretical structure, of the choice of the value of an independent variable x upon a variable y is that, within this structure, it be possible, for every choice of the independent variables other than x, to

find a possible value y' for the variable y such that x can be varied over its domain with y held fixed at the value y'. For, even though there can be many factors that contribute to the determination of y but are not under theoretical control, such as intrinsic random variables and unspecified causal elements, the very idea that x is a free variable and that the choice of the value of x does not influence or disturb the variable y means that variations of x cannot force y to change: the various factors that enter into the determination of y, whatever they may be, must at least be permitted by the theory to remain unchanged as the value of x is varied.

Let $x_1 = \pm 1$ and $x_2 = \pm 1$ represent the alternative possible choices of the measurements in R_1 and R_2, respectively, and let $r_1(x_1)$ and $r_2(x_2)$ represent the variables measured in R_1 and R_2, respectively, if the choices of the measurements in these regions are x_1 and x_2, respectively. Each possible value $r_1'(+1)$ of the variable $r_1(+1)$ is a sequence of n values +1 or -1, etc. Thus a necessary condition for there to be no influence of x_1 upon $r_2(x_2)$, and no influence of x_2 upon $r_1(x_1)$, is that:

a) if $x_2 = +1$ then there is some possible value $r_2'(+1)$ for the variable $r_2(+1)$ such that x_1 can be varied over its domain $\{+1, -1\}$ without $r_2'(+1)$ changing,

b) if $x_2 = -1$ then there is some possible value $r_2'(-1)$ for the variable $r_2(-1)$ such that x_1 can be varied over its domain $\{+1, -1\}$ without $r_2'(-1)$ changing,

c) if $x_1 = +1$ then there is some possible value $r_1'(+1)$ for the variable $r_1(+1)$ such that x_2 can be varied over its domain $\{+1, -1\}$ without $r_1'(+1)$ changing,

and

d) if $x_1 = -1$ then there is some possible value $r_1'(-1)$ for the variable $r_1(-1)$ such that x_2 can be varied over its domain $\{+1, -1\}$ without $r_1'(-1)$ changing.

These four conditions demand the existence of a set of four values

$$\{r_1'(+1), r_1'(-1), r_2'(+1), \text{ and } r_2'(-1)\}$$

and a set of eight values

$$\{\bar{r}_1'(+1), \bar{r}_1'(+1), \bar{r}_1'(-1), \bar{r}_1'(-1), \bar{r}_2'(+1), \bar{r}_2'(+1), \bar{r}_2'(-1), \bar{r}_2'(-1)\}$$

such that the following conditions hold:

$(r_1'(+1), \bar{r}_2'(+1))$ is poss. if $(x_1, x_2) = (+1\ +1)$ (1a)

$(r_1'(+1), \bar{r}_2'(-1))$ is poss. if $(x_1, x_2) = (+1, -1)$ (1b)

$(r_1'(-1), \bar{r}_2'(+1))$ is poss. if $(x_1, x_2) = (-1, +1)$ (1c)

$(r_1'(-1), \bar{r}_2'(-1))$ is poss. if $(x_1, x_2) = (-1, -1)$ (1d)

$(\bar{r}_1'(+1), r_2'(+1))$ is poss. if $(x_1, x_2) = (+1, +1)$ (1e)

$(\bar{r}_1'(-1), r_2'(+1))$ is poss. if $(x_1, x_2) = (-1, +1)$ (1f)

$(\bar{r}_1'(+1), r_2'(-1))$ is poss. if $(x_1, x_2) = (+1, -1)$ (1g)

$(\bar{r}_1'(-1), r_2'(-1))$ is poss. if $(x_1, x_2) = (-1, -1)$ (1h)

where "is poss. if" means that the pair of possible values $(r_1'(+1), \bar{r}_2'(+1))$ etc. must be compatible with the constraints imposed by quantum theory under the condition that (x_1, x_2) has the value indicated. Each possible value $r_1'(+1)$, etc., is some sequence of n values +1 or -1. The two conditions (1a) and (1b) express the condition (c) that if $x_1 = +1$ then there is some possible value, call it $r_1'(+1)$, of the variable $r_1(+1)$ such that x_2 can, within the structure imposed by the theory, be varied over its domain with the variable $r_1(+1)$ held fixed at the possible value $r_1'(+1)$. The remaining three pairs of equations express the remaining three conditions (a), (b), and (d).

An important distinction must be drawn at this point between satisfying the four conditions (a) through (d) disjunctively, and satisfying them conjunctively. In the disjunctive case the possibilities used to satisfy the four conditions are contradictory possibilities, within the structure imposed by our general theoretical framework, whereas in the conjunctive case these possibilities are noncontradictory, i.e., mutually compatible, within this theoretical structure. It will be argued later that the disjunctive solutions are irrelevant, and may be discarded.

Consider then the two equations (1a) and (1e). These two equations represent two conditions that are to be imposed under the same condition, namely $(x_1, x_2) = (+1, +1)$.

The values $(r_1'(+1), \bar{r}_2'(+1))$ and $(\bar{r}_1'(+1), r_2'(+1))$ represent two possible values for the outcome of the decision that nature would be forced to make if $(x_1, x_2) = (+1, +1)$. The requirement that these two possibilities be noncontradictory demands that they be the same:

$$(r_1'(+1), \bar{r}_2'(+1)) = (\bar{r}_1'(+1), r_2'(+1)). \tag{2a}$$

One obtains in a similar way

$$(r_1'(+1), \bar{r}_2'(-1)) = (\bar{r}_1'(+1), r_2'(-1)), \tag{2b}$$

$$(r_1'(-1), \bar{r}_2'(+1)) = (\bar{r}_1'(-1), r_2'(+1)), \tag{2c}$$

and

$$(r_1'(-1), \bar{r}_2'(-1)) = (\bar{r}_1'(-1), r_2'(-1)). \tag{2d}$$

These four equations reduce the eight equations (1) to the set of four equations

$$(r_1'(+1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (+1, +1) \tag{3a}$$

$$(r_1'(+1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (+1, -1) \tag{3b}$$

$$(r_1'(-1), r_2'(+1)) \text{ is poss. if } (x_1, x_2) = (-1, +1) \tag{3c}$$

and

$$(r_1'(-1), r_2'(-1)) \text{ is poss. if } (x_1, x_2) = (-1, -1). \tag{3d}$$

Since quantum theory makes only statistical predictions "everything is possible". However, for any $\delta > 0$, however small, one can make n sufficiently large so that the total probability that $|c - \bar{c}|$ is greater than 10^{-2} is smaller than δ. Thus, by ignoring a set of possibilities whose total probability can be made arbitrarily small by taking n sufficiently large, we can replace the condition "is poss." by "satisfies $|c - \bar{c}| < 10^{-2}$". Then the four conditions (3) on the set $(r_1'(+1), r_1'(-1), r_2'(+1), r_2'(-1))$ become the four conditions that, for each of the four alternative possible values of (x_1, x_2),

$$|c(r_1'(x_1), r_2'(x_2)) - \bar{c}(x_1, x_2)| < 10^{-2}, \tag{4}$$

where $c(r_1, r_2)$ is the correlation function defined earlier, and $\bar{c}(x_1, x_2)$ is the predicted

limiting value of $c(r_1, r_2)$ as n tends to infinity under the experimental condition (x_1, x_2). That is, the requirement that the four conditions (a) through (d) be satisfied conjunctively, within the structure imposed by the general theoretical framework, demands the existence of at least one set of possible values $(r_1'(+1), r_1'(-1), r_2'(+1), r_2'(-1))$ such that the four equations (4) can all be satisfied.

For certain arrangements of the experimental parameters the predictions of quantum theory are [12]

$$\bar{c}(+1, +1) = -1/\sqrt{2}\ , \tag{5a}$$

$$\bar{c}(+1, -1) = -1/\sqrt{2}\ , \tag{5b}$$

$$\bar{c}(-1, +1) = -1\ , \tag{5c}$$

and

$$\bar{c}(-1, -1) = 0\ . \tag{5d}$$

Thus, apart from the one-percent deviations, the four equations (4) give

$$\frac{1}{n}\sum_{i=1}^{n} r_{1i}'(+1)\, r_{2i}'(+1) = -1/\sqrt{2}\ , \tag{6a}$$

$$\frac{1}{n}\sum_{i=1}^{n} r_{1i}'(+1)\, r_{2i}'(-1) = -1/\sqrt{2}\ , \tag{6b}$$

$$\frac{1}{n}\sum_{i=1}^{n} r_{1i}'(-1)\, r_{2i}'(+1) = -1\ , \tag{6c}$$

and

$$\frac{1}{n}\sum_{i=1}^{n} r_{1i}'(-1)\, r_{2i}'(-1) = 0\ . \tag{6d}$$

From (6c) one obtains $r_{1i}'(-1), = -r_{2i}'(+1)$, which allows (6d) to be written as

$$\frac{1}{n}\sum_{i=1}^{n} r_{2i}'(+1)\, r_{2i}'(-1) = 0 \quad , \tag{6e}$$

This result, combined with (6a) and (6b), and the fact that each r_{1i}' and r_{2i}' is either plus one or minus one, allows one to write

$$\frac{1}{n}\sum_{i=1}^{n} (\sqrt{2}\, r_{1i}'(+1) + r_{2i}'(+1) + r_{2i}'(-1))^2 = 2 + 1 + 1 - 2 - 2 + 0 = 0. \tag{7}$$

But the fact that each r_{1i}' and r_{2i}' is either +1 or -1 also entails that

$$\frac{1}{n}\sum_{i=1}^{n} (\sqrt{2}\, r_{1i}'(+1) + r_{2i}'(+1) + r_{2i}'(-1))^2 \geq (\sqrt{2} - 2)^2. \tag{8}$$

Equations (7) and (8) are contradictory. The small one-percent deviations are not large enough to undo this large contradiction. Thus the four conditions (a) through (d) cannot be satisfied conjunctively.

The logical structure of the argument is this. In nature itself only one of the four values of (x_1, x_2) can be selected. However, our interest is in the structure of adequate theories and ideas about nature, not nature itself. Quantum theory provides a conjunction of predictions pertaining to alternative possible experimental situations. From the standpoint of theoretical structures both logic and common language provide a basis for contemplating and describing connections between the situations that might prevail under related alternative possible conditions. Classical physics is essentially a compendium of such connections.

The locality principle of Einstein, Podolsky, and Rosen is a theoretical connection of this kind: it says essentially that nothing in R_i can be disturbed or influenced by what the experimenter decides at the last minute to do in R_j $(j \neq i)$. This is a conjunction of conditions, each of which is required to hold only under some condition on the choices of the experimenters. Our criterion for noninfluence converts this locality condition to the requirement that there must be at least one set of possible values for the outcomes of

the various decisions that nature could be forced to make such that these possible values are both compatible with the predictions of quantum theory and unaffected by variations in the choice of the experimenter in the other region. However, it has just been demonstrated that there is no set of possible values that satisfy these two conditions.

It is worth emphasizing that the argument does not depend, either explicitly or implicitly, upon the idea that the outcome of nature's decision is predetermined. The whole argument is phrased in a way that tacitly accepts the idea that the outcome of this decision is not predetermined. Nor is there any assumption that the result of any unperformed experiment is physically definite or determinate. For, in the formulation of equations (1), the question is only whether there are any possible values for the outcomes that would allow nature's decisions in each region to remain unaltered as the variable x_i representing the experimenter's choice in the other region is varied. And the conditions (2) merely assert that if two of these possible values represent possible values for the outcome of the same decision then they must, if noncontradictory, be the same. What the actual result "would be" if the experiment were actually performed never enters into the argument: it is neither mentioned, nor represented, nor alluded to. Thus the argument given here avoids the assumption of "counterfactual definiteness" upon which my 1968 and 1971 proofs[11] were explicitly based. The present argument avoids also the assumptions of determinism and hidden-variables present in Bell's original work[9], the hidden-variable factorization property of Clauser and Shimony[14], and the assumption of (microscopic) local realism upon which that hidden-variable factorization property is based. Indeed, in the present approach the entire universe is treated as one giant black box with two inputs representing two tiny elements of freedom in the mental processes of the two experimenters, and two outputs, which represent the results appearing to the two observers: there is no separation of the world into devices and "quanta". Quanta are never mentioned: the predictions of quantum theory pertaining to what we will see at the macroscopic level are merely accepted as given numbers. Thus there are no

ontological assumptions beyond the two general assumptions that the choices of the two experiments can be treated as two free and independent variables, and that two conceivable possible values for the outcome of a single decision by nature are contradictory unless they are equal.

This brings us to the question of the disjunctive solutions of the conditions (a) through (d). These are the solutions in which one or more of the four conditions (2) fail. A failure of any one of these conditions means that the solutions to the four conditions (a) through (d) use, in some instances, contradictory possible values. The problem is to show that such solutions to the set of four conditions (a) through (d) can be ignored, and the necessary condition for noninfluence taken to be the conditions that the four conditions (a) through (d) can be satisfied conjunctively.

Let the four conditions (a) through (d) be called the four conditions C_i. Each condition C_i is a necessary condition for a corresponding property of noninfluence P_i. Each property P_i is of the form: "If the variable x_j has the value x_j' then the choice of the value of the variable x_k ($k \neq j$) does not influence the outcome of the decision that fixes the value of $r_j(x'_j)$."

Each condition C_i is a necessary condition for the corresponding property P_i. The simple conjunction of the properties C_i is simply the conjunction of necessary conditions for the individual properties P_i to hold separately. This simple conjunction of the properties C_i allows the disjunctive solutions: there is no requirement that the possible values used to satisfy the four different conditions be noncontradictory. But one must distinguish the conjunction of the conditions C_i that the four properties P_i hold separately from the condition, C, that follows from the condition that they hold together.

This condition C can be expected to be stronger than the simple conjunction of the four properties C_i. For example, if P_1 were the property that a set of points S is confined to the x axis then P_1 would imply the condition C_1 that the set S be confined to

a set of dimension one. And if P_2 were the property that the set S is confined to the y axis, then P_2 would imply the condition C_2 that the set S be confined to a set of dimension one. But the conjunction of P_1 and P_2 implies the condition, C, that the set S be confined to a set of dimension zero. This condition C is stronger than the conjunction of the two conditions C_1 and C_2.

In our case, the requirement that all four conditions P_i hold does not mean that, for each i, condition P_i holds while others fail. It means that within the theoretical structure under consideration all four P_i hold conjunctively, hence without contradiction. Thus the requirement inherent in the demand that all four conditions P_i hold conjunctively is that all four conditions be imposed together within a realm of noncontradictory possibilities. To show that these four conditions P_i cannot be satisfied within such a realm it is sufficient to show that the four corresponding weaker conditions C_i cannot be satisfied within such a realm. But that is exactly what was shown when it was demonstrated that the four conditions C_i cannot be satisfied conjunctively.

This completes the proof that within the general theoretical framework set up here it is not possible to satisfy together the requirements that, (1), there be no faster-than-light influences and, (2), certain rudimentary two-quanta predictions of quantum theory hold. This theoretical framework is based on two assumptions. The first is that the choices of the two experimenters can, within the present very limited context, be treated as free and independent variables. The second is that two possible values for the outcome of any decision that nature can apparently be forced to make are either equal or contradictory.

The logical foundation for this EPR nonlocality property is the simple mathematical fact, which was proved above, that, for the experiments under consideration here, it is impossible even to conceive or imagine any possible results for the outcomes of the four alternative possible measurements that conform to the

predictions of quantum theory, but in which the possible results in each region are unaffected (i.e., unaltered) by variations in <u>what is done</u> in the far-away region.

6. Consequences for Philosophy

The inadequacy of the concepts of classical physics as a foundation for a comprehensive metaphysics has prompted the view that physics has little to contribute to philosophy. Indeed, classical physics reduces each man to a local automaton, essentially cut off from any greater whole. This bleak isolation, compounded with inexorable predetermination, provides a basis for nothing but the most mundane philosophy. There is no possibility for a spiritual essence that man has unceasingly claimed as his birthright; and no possible basis for human values other than self-interest. Moreover, the intractible irrationality of the classical mind-matter dichotomy defeats the whole enterprise of a comprehensive rational philosophy.

Today, however, the basic concepts of classical physics are known to be profoundly incorrect at the fundamental level: nature behaves in ways that are strictly incompatible with the basic idea of classical physics, namely that the world is built up out of elementary localizable real parts. These real parts were believed to be the atoms, or their constituents, and the local fields associated with them. But orthodox quantum theory tells us that these things can be represented only by probability amplitudes. And if one tries to find the meaning to these probability amplitudes, by identifying the realities to which they refer, then these realities turn out to be the perceptible behavior of macroscopic measuring devices.[15] Yet these devices are themselves built from atoms. Thus the search for basic physical realities leads in circles: each atom turns out to be nothing but potentialities in the behavior pattern of others. What we find, therefore, are not any elementary spacetime realities, but rather a web of relationships in which no part can stand alone: every part derives its meaning and existence only from its place within the whole.[11] This wholistic character of the world, as seen in the light of quantum theory, is rendered even more complete, and incompatible with classical ideas, by the interconnectedness mediated by the faster-than-light influences that seem

to be required if one wishes to have any adequate conceptualization of the physical world beyond the computational rules of present-day quantum theory.

The ontology most in harmony with the structure of quantum theory is the ontology described by Heisenberg. It is similar to the ontology of Whitehead,[16] with one very important difference. Whitehead, citing developments in science, mutilated the natural organic unity of his ontology by introducting "contemporary events," which stood in a relationship of causal disjunction: no one of them could influence any other. The cited development in science was the theory of relativity, which, within the deterministic framework of classical physics, entails the nonexistence of faster-than-light influences, and hence the causal disjunction of events in spacelike separated regions. On the other hand, the basic postulates of relativity theory demand only the nonexistence of faster-than-life signals, not the nonexistence of faster-than-light influences.

In a nondeterministic context, such as quantum theory, or Whitehead's ontology, it is possible to have faster-than-light influences that cannot be faster-than-light signals. The EPR nonlocality property of quantum theory appears to entail that any ontology compatible with quantum theory must involve faster-than-light influences. Heisenberg's ontology fulfills this requirement, whereas Whitehead's ontology, if adulterated by "contemporary events," does not, at least if spacelike separated events are contemporary events, as is indicated by Whitehead.

Metaphysics would be of little worth if it were only a game for philosophers, and had no practical consequences. Although the present forum is not the proper place for a discussion of technical applications in the realm of physics, let me just mention that reasons have been given elsewhere[12] for believing that recent technological developments will require an extension of the scope of quantum theory. To move forward from the present-day computational rules, which cover only a special limiting case, to a comprehensive general physical theory will probably be possible only with the aid of a metaphysical perspective. In this connection the metaphysical ideas discussed

above suggest the need for building-up, by the quantum process itself, the spacetime structure that underlies present-day quantum theory. Work is currently in progress on this program, which holds some promise for extracting something useful in physics from the endeavor to obtain a comprehensive understanding of nature.

More appropriate to this forum is a discussion of the impact upon human values of the penetration into general human awareness of the quantum mechanical conception of nature. The importance of developments in this area can hardly be overstated. For human values control human decisions, and human decisions control the future of all life on this planet.

What a man values depends largely on his perceived connection to his perceived environment. This perceived environment can be family, community, nation, and more abstract constructs. The rise of classical physics had a profound impact upon human values, through its impact on perceived connection to perceived environment. Men were educated to see the world as a giant machine, in which each man was nothing but a local mechanical cog, whose whole history and future were preordained at the beginning of time. The gods upon which prior value systems were based were reduced to total impotence, once the initial creative instant had passed. As for man himself this reduction to impotence was complete. Moreover, all but the most mundane of material links between a man and anything else was banished.

This classical view of man and nature is still promulgated in the name of science. Thus science is seen as demanding a perception of man as nothing more than a local cog in a mechanical universe, unconnected to any creative aspect of nature. For, according to the classical picture, every creative aspect of nature exhausted itself during the first instant.

What Science will eventually uncover is not yet known. But atomic physics, in the form of quantum theory, has already established that this mundane classical view is <u>fundamentally</u> incorrect. That in itself is a tremendously important achievement,

recognition of which should be reverberating throughout our schools and faculties. Although no alternative picture of nature has gained general acceptance among quantum scientists, the most orthodox view, and the one closest to the ideas of most practicing quantum physicists, is undoubtedly the ontology of Heisenberg. Its explicitly nonlocal character, and present lack of detailed explication, has been a deterrent to its acceptance by practical-minded scientists. But the first apparent deficiency, its nonlocal character, is almost certainly a necessary feature of any coherent picture of nature that is compatible with rudimentary predictions of quantum theory. The second deficiency, its lack of explication, awaits an empirical and theoretical exploration of the boundaries of the scope of present-day quantum theory.

In the Heisenberg ontology the real world of classical physics is transformed into a world of potentialities, which condition, but do not control, the world of actual events. These events, or acts, create the actual form of the evolving universe by deciding between the possibilities created by the evolving potentialities. These creative acts, stands outside spacetime, and presumably create all spacetime relationships. Human mental acts belong to this world of creative acts, but do not exhaust it.[17]

The scientific task of explicating this general quantum-mechanical ontology is just beginning. But even the general features of the quantum ontology entail a conception of man and nature profoundly different from the picture provided by classical physics. For man appears no longer as an isolated automaton. He appears rather as an integral part of the highly nonlocal creative activity of the universe. This revision of the conception of a man, and of his perceived relation to the rest of nature, cannot help but have an immense impact on what is perceived as valuable. It must inevitably lead away from the egocentric bias that was the rational product of the ontology of classical physics, to the values inherent in the image of self not as local isolated automaton, but rather as nonlocalizable integrated aspect of the creative impulse of the universe. The critical question is whether this offering of science in the realm of human values can come to

fruition soon enough to avert the perils that have arisen from the power of science in other realms.

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