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Quantum Mechanics and the Involvement of Mind in the Physical World: A Response to Garrison

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Garrison's recent article is the background for discussing a number of issues. Among these issues are (1) the nature of probability in quantum mechanics; (2) the relation of observation to the wave packet in quantum mechanics; and (3) the role of immediate change upon measurement in the quantum mechanical wave function throughout space as the basis for the correlations among space-like separated events found in the Einstein–Podolsky–Rosen gedankenexperiment. A proposed empirical test of simultaneous, mutually exclusive situations (indicated by Einstein, Podolsky, and Rosen's work) is discussed in the context of Stratton's work on the orientation of the visual field, and objects within it, upon inversion of the retinal image. The logical nature of simultaneous, mutually exclusive situations is discussed in the context of Gödel's Incompleteness Theorem.

In a letter to his colleague Sandor Ferenczi, Freud reported on a meeting with Einstein. "Yes. I spent [. . .] two hours chatting with Einstein [. . .]. He is cheerful, assured, and likeable, and understands as much about psychology as I do about physics, so we got along very well" (Freud, Freud, and Grubrich–Simitis, 1978, p. 242). One of the interesting things about Freud's comment is that Freud was indeed knowledgeable about physical science and was very much influenced by it in his development of psychoanalysis (Snyder, 1987). Moreover, Einstein was knowledgeable about, and concerned with, psychological issues. Einstein began his first paper on relativity with an essentially psychological notion of the concept of simultaneity and was influenced very much by David Hume concerning the nature of concepts, in particular space and time (Einstein, 1905/1952, 1949/1969).

Why then did Freud imply that neither knew about the other's field of expertise? The lack of knowledge alluded to by Freud results from a funda-

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mental assumption that characterized the disciplines of psychology and physics during Freud's and Einstein's careers and which continues to exert a significant influence until the present day. Even a thorough knowledge of the other's discipline, including knowledge of psychoanalysis or of relativity and quantum mechanics, would not have been sufficient to overcome this assumption, namely that the observer or thinking individual has no effect on the structure and function of the physical world. This fundamental assumption is a basic feature of Newtonian mechanics where the observer or thinking individual in principle need not affect the entity in the physical world that is being measured or otherwise considered. The continued influence of this assumption until the present day testifies to the important influence of concepts from Newtonian mechanics (such as force) as well as to the great success of Newtonian mechanics that all succeeding physical theories have had to account for. This assumption is also found in what Garrison (1990) maintained was Einstein's realistic attitude concerning quantum mechanics.

The Einstein–Podolsky–Rosen Gedankenexperiment

Garrison's comment concerning Einstein's attitude regarding quantum mechanics came in a response to my comments (Snyder, 1990) to Garrison's (1988) article, "Relativity, Complementarity, Indeterminancy, and Psychological Theory." Einstein once asked his colleague Pais during a walk whether Pais really believed that the moon exists only when Pais looked at it (Pais, 1979). As Mermin (1985) noted, what really troubled Einstein about quantum mechanics was not so much its probabilistic basis, but rather the lack of an objective physical world, which for Einstein essentially meant a physical world unaffected by the act of measurement. Garrison (1990) summarized his own response to Einstein's realistic position in writing that an appropriate question for Einstein would be, "Since the moon is not there when I see it, *how can it be there when I do not?*" (p. 231). The basis for a comment like Garrision's, focussing on contrasting verficationist and realist alternatives in studying the physical world, is the experimenter's in principle superluminal (faster-than-light) ability to affect the outcome of certain quantum mechanical experiments, as demonstrated in the Einstein–Podolsky–Rosen gedankenexperiment (i.e., thought experiment) [Einstein, Podolsky, and Rosen, 1935]. This ability is found in the in-principle immediate setting up of experimental circumstances with accompanying predictions of mutually exclusive spacelike separated events which are well verified empirically. (The experimental circumstances with their respective results constitute simultaneous, mutually exclusive situations.) As a result of this ability, one can legitimately ask about the nature of the reality of the physical existents which are measured in these experiments. These existents ought to be subject to the laws of the physical world, one of the most basic ones being the invariance of the velocity of light in any inertial reference frame.

This type of problem puzzled physicists since the development of quantum mechanics in the 1920's and, of course, puzzled Einstein. What Einstein and his colleagues maintained they accomplished in their gedankenexperiment was to demonstrate that quantum mechanics was not a complete physical theory, given their definition of a *complete physical theory* and an *element of physical reality*. In believing that they had demonstrated that quantum mechanics is not a complete physical theory, Einstein and his colleagues maintained that another physical theory, a complete theory, is possible such that this theory would account for every element of physical reality. Essentially, adding various factors to the theory would allow for this complete theory, remove the superluminal ability of the experimenter, and establish the objective character of the physical world.

Contrary to Garrison, my position does not resemble Einstein's regarding quantum mechanics. Rather, it allows that the very puzzling aspect of quantum mechanics noted by Einstein, Podolsky, and Rosen indeed accurately characterizes the physical world, namely that the change in probabilities characterizing the quantities of physical existents as a result of measurement in gedankenexperiments like those of Einstein, Podolsky, and Rosen are in essence not limited by the invariant velocity of light in all inertial reference frames. New variables that will account for this superluminal influence on physical events are not needed. Indeed, it is maintained that the superluminal aspect of the change in probabilities occurring as a result of measurement in quantum mechanics reflects what the probabilities themselves fundamentally stand for, that is knowledge. It is because the probabilities represent knowledge, and not physical existents in a traditional sense, that their change in measurement is not constrained by the invariant velocity of light. Because the nature of these probabilities derived using the wave function in quantum mechanics are important to a proper understanding of the Einstein–Podolsky–Rosen gedankenexperiment, certain fundamental characteristics of quantum mechanics will be briefly discussed.

Fundamental Characteristics of Quantum Mechanics

Quantum mechanics allows for the determination of probabilities concerning the results of measurements of the physical world. In principle, quantum mechanics indicates what will happen in the physical world, not what is happening in the present. As it does not indicate what is happening in the present (as does Newtonian mechanics, for example), but only what may be in the world, quantum mechanics does not describe a physical world functioning in a deterministic manner that can be assumed to function independently of the measurement process. In allowing for the determination of probabilities concerning the results of measurements, quantum mechanics is concerned fundamentally with knowledge of the physical world. Further, because in quantum mechanics there is no independently existing physical world behind the probabilistic knowledge, the probabilities themselves are all that can be assumed to characterize the functioning of the physical world itself.

In addition, the probabilities derived using quantum mechanics are tied to the observational activities of observers. That is, in making a measurement, the probabilities characterizing the physical system of concern are generally altered. In quantum mechanics, a physical system is described by a set of probabilities concerning the results of future measurements, the basis for these probabilities being earlier measurements on the system. As noted, this set of probabilities can be expected to change when measurements of the system are taken in the future.

As indicated by Schrödinger (1935/1983) in a gedankenexperiment, measurement in quantum mechanics necessarily includes observation by a human observer. This feature is due to the probabilistic nature of quantum mechanics. The observer cannot assume that a non-human measuring apparatus can complete a measurement. (This is why Einstein asked his question regarding the existence of the moon referring to Pais himself as the observer and not to some non-human measuring instrument). For the human observer who does not know the results found with this non-human measuring apparatus, the physical system being measured remains characterized by the probabilities prior to the interaction of the non-human measuring instrument and the physical system. For the observer, if he or she is aware that the non-human measuring instrument has interacted with the existent to be measured but remains unaware of the results of the measurement, it is the non-human measuring instrument that comes to be characterized by the probabilities characterizing the physical system being measured. The measurement is completed when a human observer observes the condition of the non-human measuring apparatus and can then infer the condition of the physical system measured. When the human observer observes the non-human measuring apparatus, the human observer obtains a particular value for the quantity in the present, not in the future.

Quantum mechanics thus indicates there is a link between knowing and observing the physical world. Observing sets up the basis for what one knows will happen in the physical world. This knowledge, represented by the probabilities of quantum mechanics, indicates the boundaries concerning what will be observed in the physical world. The past concerns measurements that culminated in human observations and that set the basis for knowledge of subsequent events in the physical world. This knowledge is concerned with the future, and the measurements culminating in observations that in general alter the probabilities concerning future measurements occur in the present.

It is in the quantum mechanical principle that observation of an existent in general changes the probabilities concerning certain physical quantities regarding that existent that Einstein's conundrum is rooted. The change in probabilities resulting from measurement of the physical existents of concern in the Einstein–Podolsky–Rosen gedankenexperiment is not bound by an essential element of physical law, namely the invariant velocity of light in any inertial reference frame. This result is not limited to the spacelike separated events in the Einstein–Podolsky–Rosen gedankenexperiment. It also applies to the change in probabilities resulting from the choice of measurement one makes on a single physical existent. If a single electron is considered, for example, the change in probabilities of locating the electron in various regions that occurs in a measurement of the electron's position is effective throughout space immediately. (Also, the notion of whether a physical existent is indeed unitary or is indeed more than one is problematic when the wave function used to describe an existent or existents is the same in its fundamental nature in either case. This is the case in the Einstein–Podolsky–Rosen circumstance where a single wave function characterizes what are traditionally considered two existents.) As noted, this result concerning quantum mechanical probabilities should not be too surprising because the probabilities concerning measurement events in quantum mechanics are essentially concerned with knowledge of the physical world and not some independently existing physical world itself. That observation can itself affect the resulting probabilities concerning the future measurement of certain quantities for the physical existent of concern indicates that, at least when it is involved in quantum mechanical measurement, observation is not subject to the velocity limitation of special relativity, namely the invariant velocity of light in inertial reference frames.

This link between quantum mechanical probabilities and observation is found in the nature of the wave packet itself that is used to describe the motion of what are generally referred to in quantum mechanics, and always in classical mechanics, as particles. DeBroglie's great contribution to quantum mechanics was in proposing that existents generally considered as particle-like in nature (e.g., an electron) also could have associated waves which would help to describe their motion (Gamow, 1958; Snyder, 1983). This followed Einstein's proposal that light traditionally considered as wave-like in nature was composed of particle-like packets called photons. Schrödinger then proposed that the particle itself could be represented as a packet of waves, with knowledge regarding the particle derived from characteristics of the wave packet.

It is a fundamental of quantum mechanics that everything that can be known regarding some physical existent classically regarded as particle-like can be derived from its associated wave packet. For example, the probability density characterizing a particle's position is derived by taking the absolute square of the particle's wave function at each point throughout space. In quantum mechanics, the wavelength or wavelengths that characterize the wave or waves associated with the particle are related to the momentum or range of possible momenta of the particle. The ability to define the position of the particle depends basically on the extent to, and manner in, which waves of various wavelengths underlie the wave packet describing the particle. If one wave is used, the position of the particle is essentially undefined while the momentum is known exactly. Or a great many waves of varying wavelengths can make up a wave packet such that the wave packet exists essentially as a spike, with the result being that the position of the particle is known with great precision and the momentum is essentially unknown. It is also a fundamental of quantum mechanics that if a measurement is repeated immediately, the same result will be obtained. Thus, when a precise measurement of the position of a particle is made, for the moment the particle's associated wave packet is essentially in the form of spike. This spiked wave packet is composed of a great many waves of varying wavelengths, the result being that the momentum of the particle is completely uncertain.

The wave packet is complex in nature. This means that the wave packet has both real and imaginary mathematical components. The wave packet does not have the physical meaning ascribed for example to water waves. It has been argued that the wave packet in quantum mechanics has a cognitive component (Snyder, 1986, 1989, 1990). Since the wave packet reflects the behavior of the existent when a measurement is taken, and since the wave packet in general is altered upon observation, it is natural to consider that there is a cognitive component to the wave packet and that the wave packet is the link between cognition and the physical world.

Simultaneous, Mutually Exclusive Situations

Results like those obtained by Einstein, Podolsky, and Rosen point toward the existence of simultaneous, mutually exclusive situations in physics (Snyder, 1983, 1990). However, it seems unlikely that a physical existent can have mutually exclusive expressions simultaneously. Various questions arise: First, doesn't the notion of mutual exclusivity preclude these expressions existing simultaneously? And if the expressions are simultaneous, why do we apparently all perceive the same expression?

Concerning the last question, it is generally maintained that any human observer seems to discover in Schrödinger's (1935/1983) gedankenexperiment that the cat is dead whenever any observer looks, if one observer has first looked and seen that the cat is dead. This is the basis for Schrödinger's

(1958/1967) proposition of some universal consciousness in which we all participate. There are two related psychological experiments that bear on this point. But first, it is important to note that fundamental differences do exist with regard to perceptions of the physical world, although these do not manifest themselves in the standardized measurement techniques generally employed in physics. As far as Schrödinger's gedankenexperiment is concerned, as a psychologist, it is safe to say that in a very large sample of people, not everyone would agree that Schrödinger's cat was either alive or dead. Some individuals, differing from the consensus opinion as to the aliveness of the cat, would be considered to have hallucinations (Snyder, 1987).

A Proposed Empirical Test of Simultaneous, Mutually Exclusive Situations

In the late 1800's, a psychologist, Stratton, wore an apparatus on his head that allowed light through a tube into one eye and which excluded all light to his eyes not moving through this tube. In normal circumstances, light on the retina is upside down with regard to the orientation of the objects with which it is associated. Lenses in this tube inverted all of the light from the outside world impinging on the retina so that this light was right side up on the retina rather than upside down (Stratton, 1896, 1897a, 1897b). (Only one eye was used because Stratton did not have automatic convergence of the tubes that were placed in front of each eye.) Specifically, the arrangement of the lenses rotated the light 180 degress around the line of sight. In wearing this apparatus, Stratton's vision progressively became more and more like that in the older, normal circumstances. Beginning a few days after initially putting on this apparatus, Stratton progressively came to see more of the world as right side up even though the light associated with the objects in the world he was seeing was inverted from its normal position on the retina of his eye. Objects in the world appeared right side up even though the light on his retina was inverted from its normal position. In commenting on his earlier experiment, Stratton (1896) wrote:

> In fact, the difficulty of seeing things upright by means of upright retinal images seems to consist solely in the resistance offered by the long-established experience. There is certainly no peculiar inherent difficulty arising from the new conditions themselves. If no previous experience had been stored up to stand in opposition to the new perceptions, it would be absurd to suppose that the visual perceptions in such a case would seem inverted. Any visual field in which the relations of the seen parts to one another would always correspond to the relations found by touch and muscular movement would give us "upright" vision, whether the optic image lay upright, inverted, or at any intermediate angle whatever on the retina. (p. 617)

Stratton was concerned with showing that two theories concerning inversion of the light were incorrect. Essentially, both maintained some sort of hard-wiring of either the neural component of the visual system or its supporting musculature. In the former instance, the light inversion was needed to account for crossing of the lines of direction of light from external objects when the light was moving through the eye. Essentially, it was proposed that the inversion of the incoming light corrected the natural inversion of the light as it travels through the eye. The other possibility related to the use of the musculature about the eye to provide definitive information about the correct position of the objects in the visual field. But this movement of the eye upwards results, for example, in the lower portion of the retina receiving more of the incoming light. Inversion of the incoming light would correct this problem.

Stratton's results provide an example of mutually exclusive circumstances that nonetheless may be perceived in a uniform way. Essentially, though sensory data impinging on us may indeed be of fundamentally different forms, the perception associated with this data may be uniform. Though not concerned with mutually exclusive versions of reality, size constancy and shape constancy also indicate a uniformity of perception even though the associated sensory data impinging on us may vary widely in character.

Stratton's results are relevant to the simultaneous, mutually exclusive situations proposed for quantum mechanics and allow for an empirical test of them. Consider the spin angular momentum of an electron. It is possible to measure the component of this momentum along any one of three orthogonal axes, x, y, and z (three spatial axes all at right angles to one another). Assume in an idealized experiment that this measurement occurs from direct visual inspection of the electron. A nonuniform magnetic field oriented along the z axis is placed in the path of the electron, and the experimenter watches to see which way the electron moves in the field. Assume the z axis is in the vertical direction relative to the experimenter, appearing to go up and down. Assume that the y axis runs perpendicular to the ideal plane formed by the experimenter's face and that prior to entering the nonuniform magnetic field the electron is traveling along this axis. Assume that the x axis runs horizontally relative to the experimenter, from side to side. According to quantum mechanics, precise knowledge resulting from measurement of one of these momentum components means that knowledge of each of the other two momentum components is completely uncertain. Precise knowledge of the component along the z axis, for example, means that knowledge of each of the components along the x and y axes is completely uncertain. This is essentially the situation noted previously for determining simultaneously the position and momentum of an electron (Snyder, 1983). As noted, one can measure either the position or momentum of the electron with arbitrary precision, but this knowledge is associated with uncertainty in knowledge of the quantity not measured. One can use an apparatus like Stratton's to rotate the incoming light to the experimenter such that the light is rotated around the y axis ninety degrees. Then, what was information concerning the z axis is now information concerning the x axis as concerns the light impinging on the experimenter's retina. Given Stratton's results, there is a good possibility that, after a period of orientation with this apparatus, the experimenter will see the electron moving up or down and not sideways. According to the information impinging on the experimenter's retina, the experimenter is measuring what in the original situation without rotation of the incoming light is the x axis. What for observers in the original situation is up and down along the z axis is for the experimenter up and down along the x axis. For this observer, the spin components along the y and z axes are completely uncertain. Thus, it appears possible to have simultaneous, mutually exclusive situations involving the spin angular momentum of the electron. These situations do not exist for the same individual in this particular example, but nonetheless the example shows that, in a general way, simultaneous, mutually exclusive situations can occur.

As for how simultaneous, mutually exclusive expressions are logically possible, it is quizzical. But, as noted, the possibility of such expressions is indicated in the Einstein–Podolsky–Rosen gedankenexperiment and indeed in the nature of quantum mechanics itself. The data indicate that things are this way, though, and there is no reason to back away from the data. Quantum mechanics is well supported empirically. Investigating quantum electrodynamics, quantum chromodynamics, or other such theories that involve relativity as well as basic features of quantum mechanics will not resolve this particular dilemma because the above incorporate the same fundamental principles of quantum mechanics that have been discussed in this paper.

Gödel's Incompleteness Theorem should be noted with regard to the dilemma concerning quantum mechanics. Framed in the terminology of logic, quantum mechanics indicates that a particular proposition and its negation (e.g., P and ~P) may both be true. The proposition is that knowledge of certain paired quantities is mutually exclusive. The negation is that one can have precise knowledge of these paired quantities, at least in certain circumstances, simultaneously. Essentially, this is what Einstein, Podolsky, and Rosen showed in their gedankenexperiment. In a logical system, based on certain assumptions and rules for arguing using these assumptions, this is untenable. Such a system is called inconsistent. It has been demonstrated that if one proposition (e.g., P) in a system can be shown to be inconsistent, then all propositions in the system can be shown to be inconsistent (Smullyan, 1987). Gödel's Incompleteness Theorem is concerned with a self-negating proposition commenting about its status as a theorem in a logical system (specifically, a formal system) of which it is a well-formed statement (i.e., a statement obeying certain guidelines for its formation but which is not necessarily a theorem). Essentially this proposition which is well-formed in a formal system says that it is not a theorem in this formal system. Gödel showed that statements of this kind are indeed true but cannot be proved within the formal system (Hofstader, 1979; Nagel and Newman, 1958; Snyder, 1991). He thus showed the limits of these formal systems which incorporate the kind of logic widely used in scientific theorizing. Quantum mechanics is not the tightly structured logical system discussed by Gödel. But it is possible that quantum mechanics is similar enough in its basic structure to allow for the applicability of Gödel's Incompleteness Theorem.

Conclusion

The superluminal quality found in the Einstein–Podolsky–Rosen gedankenexperiment is founded on the immediate change in quantum mechanical probabilities throughout space upon measurement. The possibility of this change in probabilities, which cannot be based on any known physical existent due to the velocity limitation of special relativity, led to the notion of simultaneous, mutually exclusive situations. Einstein, on the other hand, thought that quantum mechanics was incomplete and implied that other variables were needed to remove the superluminal ability of the experimenter and establish the objective character of the physical world. An empirical test of simultaneous, mutually exclusive situations was proposed which relies on earlier research in psychology on perception. The logical nature of these situations was briefly explored, and it was proposed that Gödel's Incompleteness Theorem might help in understanding the apparently self-contradictory nature of quantum mechanics.

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