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On the Quantum Mechanical Wave Function as a Link Between Cognition and the Physical World: A Role for Psychology

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A straightforward explanation of fundamental tenets concerning the quantum mechanical wave function results in the thesis that the quantum mechanical wave function is a link between human cognition and the physical world. The way in which physicists have not accepted this explanation is discussed, and some of the roots of the problem are explored. The basis for an empirical test as to whether the wave function is a link between human cognition and the physical world is provided through developing an experiment incorporating methodology from psychology and physics. Research in psychology and physics that relied on this methodology indicates that it is likely that Einstein, Podolsky, and Rosen's theoretical result that mutually exclusive wave functions can simultaneously apply to the same concrete physical circumstances can be implemented on an empirical level.

In quantum mechanics, wave functions are associated with physical existents. These wave functions are not waves in what is generally considered to be the real world. As Eisberg and Resnick (1974/1985) noted, "We should not attempt to give to wave functions [in quantum mechanics] a physical existence in the same sense that water waves have a physical existence" (p. 134). Nevertheless, the wave function associated with a physical existent is the basis for whatever can be known concerning that physical existent (Liboff, 1992).

It has been argued that the quantum mechanical wave function is a link between cognition and the physical world (Goswami, 1989, 1990; Snyder, 1983, 1986, 1989, 1990a, 1990b). It is difficult to believe that the quantum mechanical wave function could be such a link. The use of experimental results from psychology, though, provides an avenue to demonstrate that this thesis is correct.

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It is the quantum mechanical wave function that gave rise to Einstein's comment (1949/1969) considering the possibility, which he found untenable, of "telepathically" (p. 85) changing the physical world in a gedankenexperiment that he proposed with Podolsky and Rosen (Einstein, Podolsky, and Rosen, 1935). Physicists have, in general, not accepted that the quantum mechanical wave function serves as a link between cognition and the physical world even though this thesis is the result of a straightforward explanation of the quantum mechanical wave function. Instead, they have opted either for a more complicated explanation that agrees with the predictions of quantum mechanics, involving hidden variables that would restore a classical-like structure to the physical world, or they have opted to accept the validity of quantum mechanical prediction while leaving out any view regarding the ontological implications of quantum mechanics.[1] It should be noted that there has been no such reticence on the part of most physicists to accept the realistic view of the world that a straightforward explanation of Newtonian mechanics entails. As Einstein (1949/1969) wrote in his "Autobiographical Notes":

> Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of "physical reality." In pre-quantum physics there was no doubt as to how this was to be understood. In Newton's theory reality was determined by a material point in space and time [functioning in a deterministic manner independent of cognition]; in Maxwell's theory, by the field in space and time. (pp. 81; 83)

The thesis that the quantum mechanical wave function links cognition and the physical world is based essentially on fundamental tenets of quantum mechanics that are generally accepted by physicists. Two of these tenets are:

> (1) the wave function is the basis for probabilistic predictions concerning the physical existent described by the wave function (originally proposed by Born [1926/1983]), and
>
> (2) the change in the wave function that generally occurs upon the observation of a quantity of the existent described by the wave function is effected immediately throughout space.

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[1] Mermin (1985) put the matter this way:

> Contemporary physicists come in two varieties. Type 1 physicists are bothered by EPR [the Einstein–Podolsky–Rosen gedankenexperiment] and Bell's theorem [an elucidation of this gedankenexperiment]. Type 2 (the majority) are not, but one has to distinguish two subvarieties. Type 2a physicists explain why they are not bothered. Their explanations tend either to miss the point entirely . . . or to contain physical assertions that can be shown to be false [i.e., they incorporate some form of hidden variables]. Type 2b are not bothered and refuse to explain why [even though they accept the validity of quantum mechanical prediction]. (p. 41)

The change in the wave function is not limited by the velocity limitation of the special theory for physical existents, the velocity of light in vacuum. These particular features form the conceptual foundation for the Schrödinger cat gedankenexperiment, a thought experiment that provides an unusual result from a classical standpoint and which provides a basis for the suggested role of the wave function as a link between cognition and the physical world.

The discussion of this gedankenexperiment by a contemporary physicist, Shimony, who is also a philosopher of science, will demonstrate the way in which physicists generally consider the nature of the quantum mechanical wave function. Then Einstein's view on the issue will be presented. The application of experimental methodology and results from psychology in an investigation concerning spin angular momentum, a physical quantity, will provide additional support for the thesis that the quantum mechanical wave function (perhaps more accurately, the wave described by the wave function) is in part cognitive as well as physical. Finally, some of the roots underlying physicists generally not seeing that psychological phenomena are part and parcel of the quantum mechanical wave function are explored.

The Schrödinger Cat Gedankenexperiment

Schrödinger (1935/1983) presented his cat gedankenexperiment in a paper that was written in response to the paper noted above by Einstein, Podolsky, and Rosen (1935). He wrote:

> A cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The Ψ-function of the entire system would express this [experimental circumstance] by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts.
>
> It is typical of these cases [of which the foregoing example is one] that an indeterminancy originally restricted to the atomic domain becomes transformed into macroscopic indeterminancy, which can then be resolved by direct observation. (p. 157)

Shimony (1988) presented his abbreviated version of Schrödinger's gedankenexperiment as follows:

> A photon impinges on a half-silvered mirror. The photon has a probability of one-half of passing through the mirror and a probability of one-half of being reflected. If the photon passes through the mirror, it is detected, and the detection actuates a device that breaks a bottle of cyanide, which in turn kills a cat in a box. It cannot be determined whether the cat is dead or alive until the box is opened. (p. 52)

Then Shimony wrote concerning the gedankenexperiment:

> There would be nothing paradoxical in this state of affairs if the passage of the photon through the mirror were objectively definite but merely unknown prior to observation. The passage of the photon is, however, objectively indefinite, and so is the aliveness of the cat. In other words, the cat is suspended between life and death until it is observed. The conclusion is paradoxical, but at least it concerns only the results of a thought experiment. (p. 52)

The two features of the quantum mechanical wave function noted earlier can be seen readily in the cat gedankenexperiment. Consider Shimony's version. The wave function that describes the photon yields a probabilistic prediction concerning its passage through the mirror. Upon observation of the cat, which serves as the macroscopic measuring instrument, the wave function describing the photon changes immediately to one that allows that the photon went through the mirror or one that allows that the photon did not go through the mirror and was reflected. Note that Shimony does not specify how close the observer needs to be to the cat. The observer can, in principle, be at any distance from the cat, even across the universe, so long as the observer makes an observation regarding whether the cat is alive. (Indeed, the observer does not even have to observe the cat directly but can rely on another observer who has observed the cat and who tells the former observer the result of his observation.)

How does Shimony's version of the Schrödinger gedankenexperiment reflect the view of most physicists that the wave function is not a link between cognition and the physical world, in this case between the observer's perception and the cat? And how does the gedankenexperiment show that the nature of the wave function as suggested here is warranted?

The quantum mechanical wave function is a link because of the two features cited earlier. First, quantum mechanics provides only probabilistic predictions that yield knowledge of the physical world, predictions that have been supported by empirical test. Second, the probabilistic predictions associated with a physical existent in general change immediately throughout space upon observation of a quantity of the physical existent. The velocity limitation of the special theory precludes a physical existent from mediating the change in the wave function from which the probabilities are derived.

In a related vein, Shimony did not explicitly discuss the role and significance of the person as observer in the measurement process in quantum mechanics. Shimony used the term "observation" without referring to who or what was making the observation. Changing the latter quote from Shimony's paper to indicate specifically that a *person* is making the observation does not lessen the statement's validity:

> There would be nothing paradoxical in this state of affairs [concerning whether or not the cat is alive or dead before it is observed] if the passage of the photon through the mirror were objectively definite but merely unknown prior to observation [by a person]. The passage of the photon is, however, objectively indefinite, and so is the aliveness of the cat. In other words, the cat is suspended between life and death until it is observed [by a person]. The conclusion is paradoxical, but at least it concerns only the results of a thought experiment. (Shimony, 1988, p. 52)

Thus, in a circumstance where the observer is specified to be a person, the change in the wave function is tied to the perception of the human observer of the cat. The same point holds, though, for those circumstances where a macroscopic measuring instrument intervenes between a quantum mechanical phenomenon that is in essence probabilistic in nature. It is a human observer who ultimately records the result of any observation. Indeed, the cat gedankenexperiment represents this situation as the cat acts as a macroscopic measuring instrument and is also characterized by the same probabilities as the microscopic physical phenomenon (i.e., the photon) until a human observer makes his or her own observation of the cat. (It has been discussed elsewhere how observation in quantum mechanics necessarily means observation by a person, and in fact implies conscious observation by a person [Snyder, 1989, 1990b].)

After presenting his version of the Schrödinger gedankenexperiment, Shimony discussed recent research that supports the thesis that it is specifically the person as observer that is central to quantum mechanical measurement. Shimony continued:

> It is now more difficult to dismiss the paradoxical nature of the conclusion [that the cat is neither dead nor alive until an observation of it is made], because something similar to Schrödinger's thought experiment has recently been achieved by a number of groups of investigators. (p. 52)

Shimony went on to describe this work that involves the magnetic flux through an almost closed superconducting ring, but in which the ends of the ring are separated by a thin slice of insulating material called a Josephson junction. An electric current can circulate through the ring with electricity passing through the Josephson junction in the quantum mechanical phenomenon called tunneling. The electric current produces a magnetic field. Associated with the component of the magnetic field perpendicular to the ring is the magnetic flux through the ring. For a uniform magnetic field, the value for the magnetic flux is the product of the magnetic field component perpendicular to the plane through the superconducting ring multiplied by the area of the ring. As the electric current produces the magnetic field, and the electric current is comprised of a great many moving electrons (on the order of 10^{23}), the magnetic field can be considered a macroscopic phenomenon, and the flux can be considered a macroscopic quantity characterizing the magnetic field.

Since it is a macroscopic quantity, the magnetic flux, in principle, does not require a macroscopic entity, such as the cat, to register the measurement result concerning a microscopic quantum mechanical existent and to thus make the result available for observation. (In the Schrödinger gedankenexperiment, the microscopic existent is the small amount of radioactive material. In Shimony's version, it is the photon.) The magnetic field acts as both the radioactive material, or the photon, and as the cat in Schrödinger's gedankenexperiment and Shimony's version of it, respectively. As this magnetic flux is a quantity concerning a macroscopic physical existent, it is thus subject, in principle, to direct inspection by a human observer. In the research described by Shimony, the magnetic flux could have one of two values when measured. Though not allowed classically unless there is an external source of energy impacting the system, quantum mechanics allows for the spontaneous change in the values of the flux. This spontaneous change in the value of the flux can involve an indefiniteness in the flux prior to its being measured akin to the indefiniteness regarding whether or not the cat is alive in the Schrödinger gedankenexperiment prior to the cat's being observed.

Even though he cited research indicating that a macroscopic measuring instrument is not necessary in quantum mechanics, Shimony, in line with most physicists, does not acknowledge the central role of the person as observer in the change in the wave function associated with the observed physical system that generally occurs when an observation is made. He concluded his discussion of the magnetic flux through an almost closed superconducting ring by writing:

> Some students of the subject [quantum measurement theory] (including me) [that is, Shimony] believe new physical principles must be discovered before we can understand the peculiar kind of irreversibility that occurs when an indefinite observable becomes definite in the course of a measurement. (p. 53)

By not acknowledging the role of the human observer in the change in the wave function that generally occurs when an observation is made, even in his discussion of research in which the cat in Schrödinger's gedankenexperiment is essentially taken out as an intermediate macroscopic measuring instrument, Shimony does not fully acknowledge the fundamentally probabilistic nature of quantum mechanics. This fundamentally probabilistic nature indicates that quantum mechanics is concerned first with knowledge, which implies the fundamental importance of cognition. In terms of theoretical consistency and simplicity, acknowledging that quantum mechanics is fundamentally probabilistic in nature would only confirm what is accepted on a practical level by most physicists. As Liboff (1992) noted, with the development of quantum mechanics, "At the very core of natural law lay subjective probability — not objective determinism [that characterized Newtonian mechanics]" (p. 28).

Shimony's acceptance on a practical level of the probabilistic nature of the wave function and the thesis that it in general changes upon observation of the existent with which it is associated is representative of the view of many physicists. So is Shimony's reticence to accept on a fundamental level the straightforward explanation of the features noted concerning quantum mechanics. In portraying the cat gedankenexperiment, Shimony acknowledged that quantum mechanics accurately describes what is occurring in this gedankenexperiment. It is through the theory of quantum mechanics, and specifically the quantum mechanical wave function, that the cat has an indefinite status regarding whether it is alive and which can be resolved only by an observation.

Without adopting the structure of the cat gedankenexperiment, Shimony would not be presented with the scenario to which he subsequently expressed reservations. He would not have been able to conclude his discussion of the cat gedankenexperiment by writing that the new principles he believed "must be discovered" (p. 53) would still have to account for "the peculiar kind of irreversibility that occurs when an *indefinite* [emphasis added] observable *becomes definite* [emphasis added] in the course of a measurement" (p. 53). The concept of an indefinite observable occurs in the theory of quantum mechanics, and the observable's taking on a definite value occurs in the course of a measurement in the theory of quantum mechanics. Essentially, Shimony maintained that some type of classical physical process will account for what are uniquely quantum mechanical phenomena.

Einstein's View of the Quantum Mechanical Wave Function

Einstein's view of the quantum mechanical wave function essentially follows the same analysis described by Shimony for the Schrödinger cat gedankenexperiment. After noting that Newtonian mechanics is readily understood in terms of the realistic basis of physics in the quote presented at the beginning of the paper, Einstein (1949/1969) continued:

> In quantum mechanics it is not so easily seen [i.e., the realistic basis of physics]. If one asks: Does a Ψ-function of the quantum theory represent a real factual situation in the same sense in which this is the case of a material system of points or of an electromagnetic field, one hesitates to reply with a simple "yes" or "no"; why? What the Ψ-function (at a definite time) asserts, is this: What is the probability for finding a definite physical magnitude q (or p) [of a physical system] in a definitely given interval, if I measure it at time t? [This is feature 1 of the quantum mechanical wave function noted above.] The probability is here to be viewed as an empirically determinable, and there-

> fore certainly as a "real" quantity which I may determine if I create the same Ψ-function very often and perform a q-measurement each time. But what about the single measured value of q? Did the respective individual system have this q-value even before the measurement? To this question there is no definite answer within the framework of the [existing] theory, since the measurement is a process which implies a finite disturbance of the system from the outside [with the change in wave function, feature 2, the chief consequence of this finite disturbance]; it would therefore be thinkable that the system obtains a definite numerical value for q (or p), i.e., the measured numerical value, only through the measurement itself. (p. 83)[2]

Then Einstein presented the essence of a gedankenexperiment that he had proposed earlier with Podolsky and Rosen (Einstein, Podolsky, and Rosen, 1935).

> We now present . . . the following instance: There is to be a system which at the time t of our observation consists of two partial systems S_1 and S_2, which at this time are spatially separated and (in the sense of the classical physics) are without significant reciprocity. The total system is to be completely described through a known Ψ-function Ψ_{12} in the sense of quantum mechanics. All quantum theoreticians now agree upon the following: If I make a complete measurement of S_1, I get from the results of the measurement and from Ψ_{12} an entirely definite Ψ-function Ψ_2 of the system S_2. The character of Ψ_2 then depends upon *what kind* of measurement I undertake on S_1.
>
> Now it appears to me that one may speak of the real factual situation of the partial system S_2. Of this real factual situation, we know to begin with, before the measurement of S_1, even less than we know of a system described by the Ψ-function. But on one supposition we should, in my opinion, absolutely hold fast: the real factual situation of the system S_2 is independent of what is done with the system S_1, which is spatially separated from the former. According to the type of measurement which I make of S_1, I get, however, a very different Ψ_2 for the second partial system (Ψ_2, Ψ_2^1, . . .). Now, however, the real situation of S_2 must be independent of what happens to S_1. For the same real situation of S_2 it is possible therefore to find, according to one's choice, different types of Ψ-function. (One can escape from this conclusion only by either assuming that the measurement of S_1 ((telepathically)) changes the real situation of S_2 or by denying independent real situations as such to things which are spatially separated from each other. Both alternatives appear to me entirely unacceptable.)
>
> If now . . . physicists . . . accept this consideration as valid, then B [a particular physicist] will have to give up his position that the Ψ-function constitutes a complete description of a real factual situation. For in this case [i.e., the case of a complete description] it would be impossible that two different types of Ψ-functions [representing mutually exclusive situations] could be co-ordinated [simultaneously] with the identical factual situation of S_2 [the same concrete physical circumstances]. (Einstein, 1949/1969, pp. 85; 87)

Bohr's (1935) response to Einstein, Podolsky, and Rosen's gedankenexperiment was that there is an unavoidable interaction between the physical existent measured and the measuring instrument in their gedankenexperiment that cannot be ignored. Essentially, Bohr's response was that the situation that Einstein, Podolsky, and Rosen were referring to is quantum mechanical in its structure. That is, the structure of the gedankenexperiment presented

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[2] The term "existing," along with the brackets that enclose it, that are found in the quote are actually part of the quoted material and not added by myself.

by Einstein, Podolsky, and Rosen was based on: (1) probabilistic prediction rooted in the quantum mechanical wave function that describes the physical system, and (2) the in general immediate change throughout space of the wave function upon measurement of the physical system.

Furthermore, Bohr was saying that because the situation described by Einstein, Podolsky, and Rosen is framed within the theory of quantum mechanics, their result that two very different wave functions (really two mutually exclusive views of the world) can simultaneously characterize the same concrete physical circumstances in quantum mechanics is incorrect.[3] According to Bohr, the particular interaction of the measuring apparatus and S_1 is associated with a specific state of S_2 upon the measurement of S_1. But Einstein, Podolsky, and Rosen's result is basically correct. Two very different wave functions can indeed simultaneously characterize the same concrete physical circumstances, even if the state of S_2 depends on the measurement result at S_1.

Where Bohr was correct was in noting that the conception of physical reality that they indeed adopted in their gedankenexperiment was that "physics is an attempt conceptually to grasp reality as it is thought independently of its being observed" (Einstein, 1949/1969, p. 81), and this conception of physical reality is not part of quantum mechanics. Yet it is quantum mechanics that Einstein, Podolsky, and Rosen used to structure their gedankenexperiment. According to Bohr, in not allowing for the interaction between the physical existent measured and the measuring process, of which the observer is the chief component, in defining an element of physical reality, they were able to frame their argument so as to obtain the result that quantum mechanics is not a complete theory of the physical world. Thus, Bohr was correct in his criticism up to a point, and Einstein, Podolsky, and Rosen were correct without the artificial constraint of their realistic definition of the physical world and its essential independence of the physical theory describing it.

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[3] The wave functions can be considered to simultaneously characterize the same concrete physical circumstances, S_2, because:

(1) in quantum mechanics, there is no physical limitation in principle on the implementation of the particular measurement procedure used on S_2;

(2) the velocity limitation of the special theory precludes a physical existent from mediating the change in wave functions from Ψ_{12} for S_1 and S_2 before the measurement on S_1 to a specific wave function characterizing S_1 and a specific wave function characterizing S_2 after the measurement on S_1.

The instantaneous change in the wave function Ψ_{12} to the wave functions Ψ_1 for S_1 and Ψ_2 for S_2 throughout space when S_1 is measured falls outside the causal structure of spacetime in the special theory. This causal structure involving past and future is limited by the velocity of light in vacuum in an inertial reference frame.

It should be pointed out that, essentially, Einstein maintained that "new physical principles" (Shimony, 1988, p. 53), classical in nature, would provide the foundation for physics in the future. Einstein (1949/1969) wrote concerning the result of the gedankenexperiment he developed with Podolsky and Rosen:

> The statistical character of the present theory [quantum mechanics] would then have to be a necessary consequence of the incompleteness of the description of the systems in quantum mechanics, and there would no longer exist any ground for the supposition that a future basis of physics must be based upon statistics. (p. 87)

A Contribution from Psychology

Physicists implementing the experimental conditions noted by Einstein, Podolsky, and Rosen have moved a long way toward realizing simultaneous mutually exclusive situations characterizing the same concrete physical circumstances. The work of Aspect, Dalibard, and Roger (1982) and Aspect, Grangier, and Roger (1982) is an example. But physicists have not been able to fully develop such situations. This is because physicists have focussed only on manipulating the physical circumstances which are concerned directly with the physical existent measured (e.g., S_2) and the measuring instrument used to measure this existent. While such situations have not been fully implemented, physicists have maintained that a cognitive aspect of this result, a result that is tied to the nature of the quantum mechanical wave function, could not be supported.

Yet it appears to be possible to implement Einstein's result that two very different wave functions can simultaneously characterize the same concrete physical circumstances. And the manner in which it can be done only serves to emphasize that the wave function is a link between cognition and the physical world. It can be done through studying the act of observation in quantum mechanics, something that physicists have not done. Implementing Einstein's result relies on experimental work in psychology. This research involves the effects of altered incoming light on visual experience and visually guided behavior. Helmholtz, the physicist, was especially interested in this research direction during the formative years of psychology that culminated in the establishment of psychology as an independent discipline of study in the latter 1800's.

Helmholtz (1866/1925) reported a study in which a subject wore prisms that displaced objects, including his hand, that were in the field of view laterally from what would have been their normal position had the subject not worn the prisms. In the first trial, the subject's hand was not in view and the subject closed his eyes after having noted a particular object in his field of view. When he reached for the object, he missed it by reaching too far in the direction in which the prisms displaced the object. In reaching for an object, the subject was guided by the position of the object he had seen through the prisms. Repeated trials for the subject using the same method, or sometimes by quickly touching an object with one's hand while viewing this touching process through the prisms, resulted in the subject correctly touching the designated object when the subject's eyes were closed. After showing adaptation in this reaching behavior while wearing the prisms, repeating this method with the prisms removed resulted in the subject erring in reaching for a designated object in the opposite lateral direction to that in which he originally erred when the prisms were worn. Repeated trials corrected these errors for the subject who was no longer wearing the prisms.

Stratton, a psychologist, was also interested in the effects of altered incoming light on visual experience and visually guided behavior. It is the specific line of research that he initiated that concerns us here. This research direction is concerned with the inversion of light on the retina. When light enters the eye, it is reflected across both the horizontal and vertical that divide the top and lower halves, and the right and left halves, respectively, of the visual field. The incoming light is up–down and right–left reversed (Dolezal, 1982; Kandel, Schwartz, and Jessell, 1991). (In the context of this paper, unless more precisely specified, the terms "inversion" and "inverted" will refer to either rotation of the incoming light 180° around the line of sight, or the reflection [or flipping] of incoming light between the top and lower halves of the visual field along the horizontal separating them.)

In the late 1800's, Stratton (1896, 1897a, 1897b) investigated the effects on visual experience of rotating incoming light 180° around the line of sight such that the retinal images were right side up. Stratton's results were remarkable. In commenting on the earlier experiment, he 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. (Stratton, 1896, p. 617)

His comments apply as well to the results of the second, more thorough experiment. In his report on the second experiment, he wrote:

> The inverted position of the retinal image is, therefore, not essential to "upright vision," for it is not essential to a harmony between touch and sight, which, in the final analysis, is the real meaning of upright vision. For some visual objects may be inverted with respect to other visual objects, but the whole system of visual objects can never by itself be either inverted or upright. It could be inverted or upright only with

> respect to certain non-visual experiences with which I might compare my visual system — in other words, with respect to my tactual or motor perceptions. (Stratton, 1897b, pp. 475–476)

Subsequent work by other researchers in which all incoming light was rotated 180° around the line of sight (e.g., Ewert, 1930; Snyder and Pronko, 1952) or only up–down reversed (i.e., the top and bottom halves of the visual field are reversed) [Dolezal, 1982; Kohler, 1962, 1964] has for the most part, if not entirely, provided substantial support for Stratton's finding concerning the relative nature of upright vision. The research indicates that there is a high degree of flexibility of the visual system with regard to inversion of incoming light on the retina, including that an observer subject to such reversal quickly regains very significant competency in interacting with the environment. For example, Snyder and Pronko (1952) found in their study:

> During the 30-day period that the inverting lenses were worn, the visuo–motor coordinations [on the experimental tasks] were refashioned so that the subject performed even better than before the lenses were put on . . . . Introducing the inverted visual field for 30 days and subsequent "normalization" (lenses removed), [sic] modified the learning situation. However, the subject went on learning despite these disrupting factors. (p.116)

In general, visual experience restabilizes quickly considering the relatively very brief period of time that light is inverted compared to the subjects' life experiences prior to their participation in one of the experiments. Visual experience regains a sense of normalcy and is accompanied by the coordination between touch and vision that Stratton (1897b) wrote is "the real meaning of upright vision" (p. 497) [Dolezal, 1982; Erismann and Kohler, 1953, 1958; Kohler, 1962, 1964; Snyder and Pronko, 1952].

As alluded to in the above quote from Snyder and Pronko (1952) and as found by Ewert (1930), in the laboratory, competency on sensorimotor tasks developed with unrotated light has been shown to transfer to circumstances where incoming light is rotated 180° (Ewert, 1930; Snyder and Pronko, 1952). Furthermore, increased competency on the same sensorimotor tasks subsequently developed with rotated light has been shown to transfer to circumstances where the incoming light is no longer rotated 180° (Ewert, 1930; Snyder and Pronko, 1952). The learning curve for these sensorimotor tasks was in general fairly smooth, except for a spike when the incoming light was first rotated 180° around the line of sight. In natural settings, individuals wearing an optical apparatus that inverted incoming light have reported such activities as driving an automobile, riding a motorcycle, or riding a bicycle with a significant degree of skill within a relatively short time of putting on the apparatus for the first time (Dolezal, 1982; Erismann and Kohler, 1953, 1958; Kohler, 1962). Research has indicated that after a relatively brief period of time exposed to inverted light, visual experience in general appears normal. As this visual experience exists in conjunction with the recaptured competency of the individual in the environment, the visual field is upright, just as it was upright before the incoming light was inverted.

In a related study, Brown (1928) wore goggles with prisms that rotated incoming light 75° around the line of sight for one week, and he demonstrated a significant degree of adaptation to this rotation. This occurred even though he described his apparatus as "too unwieldy" (p. 134) to wear every night on a one-half mile trip to his university where various tests were run. Other work investigating adaptation of the visual system to alterations in incoming light has also indicated a very high degree of flexibility in the operation of the visual system (e.g., Gibson, 1933; Held, 1965; Held and Freedman, 1963).

Ewert (1930) and Munn (1955/1965) have disputed the finding that visual experience becomes upright after experience with rotated incoming light. It should be noted, though, that the major concern of Ewert and Munn is not so much the subject's phenomenal experience with rotated light but rather with the interpretation of what this phenomenal experience means. For example, Munn (1955/1965), who was one of Ewert's subjects, wrote:

> Localizing reactions became so automatic at times that a "feeling of normalcy" was present. This is probably the feeling reported by Stratton and interpreted as "seeing right-side up." (p. 293)

Or, Ewert concluded that:

> In all forms of activity where overt localizing responses are present there is rapid adjustment to the distracting visual interference until at the end of 14 days of practice the interference is entirely overcome in some of the activities investigated and almost overcome in the other forms . . . . Constant interference during visual disorientation does not prevent the steady growth of a habit. (Ewert, 1930, pp. 353; 357)

Snyder and Pronko (1952) performed an experiment similar in many respects to Ewert's. Munn (1955/1965) wrote about Snyder and Pronko's work: "The results were essentially like his [Ewert's]" (p. 294). In contrast to Ewert, Snyder and Pronko concluded:

> It appears that perceivings form a behavior sequence going back into the individual's past. If the subject of the present experiment had always worn the inverting lenses, his past perceivings would have been of a piece with those of the moment when the question ["Well, how do things look to you? Are they upside-down?" (p. 113)] was directed at him. Obviously, then, they would not have been in contrast with the latter and would not have called attention to themselves. Stated in another way, if this subject had somehow developed amnesia at the point at which he put on the inverting lenses, then things could not appear upside-down because there would be no basis of comparison or contrast. That they did appear upside-down is clearly a strict function of his previously acquired perceivings. (pp. 113–114)

In *A History of Experimental Psychology*, Boring (1929/1950) wrote about Stratton's work:

> In 1896 Stratton put the matter to test, having his subjects [actually only Stratton himself] wear a system of lenses which reversed the retinal image and made it right side up. The expected happened. The perceived world looked upside down for a time and then became reversed. Taking the glasses off resulted once again in reversal which was soon corrected. Stratton was not, however, confused by the homunculus. He described how up was nothing in the visual sensory pattern other than the opposite of down, and that orientation is achieved by the relation of the visual pattern to somothesis and behavior. When you reach up to get an object imaged at the top of the retina, then you have indeed got the visual field reversed and will not find the object unless you have on Stratton's lenses. Ewert repeated this experiment in 1930, with similar results . . . . Had the view of a freely perceiving agent in the brain not been so strongly entrenched, this problem could not have continued to seem so important in 1604, 1691, 1709, 1838, 1896 and 1930 [1930 being the year that Ewert reported his experimental findings]. (p. 678)

Boring knew of Ewert's work and saw that the empirical results obtained by Ewert supported Stratton's conclusion even if Ewert's own conclusion based on the empirical results he found was not in agreement. Dolezal (1982) wrote concerning the results of his experiment and those found in other experiments:

> In the course of living in a world transformed, the observer's initial fears become calmed, he or she finds the discomforts quite tolerable, the strange sights fade and become common, and ineptness changes to competency. (p. 301)

In sum, research has shown that in inversion of light on the retina, a sense of normalcy returns to a significant degree to visual experience accompanied by a return to high levels of competency in visually guided behavior. Both of these events support Stratton's conclusion that upright vision returns after an individual gains experience in the world with inverted light.

A Biperceptual Capability

Dolezal has proposed that the observer who adapts to inversion of incoming light is biperceptual and biperformatory. Biperceptual refers to the simultaneous existence of the visual perceptual capabilities associated with both pre-inversion and post-inversion conditions. Yet these capabilities are also divided into distinct reference frames for the individual who has undergone inversion of incoming light. Similarly, biperformatory refers to the simultaneous existence of an individual's capabilities to act competently in the environment both before and after inversion of the incoming light. Yet these capabilities are divided into distinct frameworks for the individual who has experienced and adapted to this inversion of incoming light.

Dolezal (1982) wrote:

> The adapted observer appears to differ from the unadapted observer in several main respects. After some 200 hours of living with reversing prisms, an observer once again experiences visual stability of the perturbed environment [i.e., up–down reversal of incoming light]. This is true for a wide range of rates of head movements (HMs). Moreover, the adapted observer has acquired what may be called another "personality" (i.e., he or she has the dual facility to be perceptually and emotionally comfortable and to act competently both with and without transforming prisms). The adapted observer is thus a very different creature from the unadapted observer — somewhat like someone with a second language or a novel set of skills that can only be directly displayed under special circumstances (cf. state-dependent learning and recall). The observer becomes what I call *biperceptual* and *biperformatory* . . . . In general, the adapted observer is capable of living in both worlds, under both sets of information conditions and behavioral requirements with roughly equal comfort and competence. (p. 297)

Dolezal discussed some anecdotal evidence from his own experience to support his thesis of biperceptual and biperformatory capabilities. For example, if there were not some memory specifically associated with learning while wearing up–down reversing prisms that remained accessible after the experiment was completed, then how did Dolezal have an immediate sense of familiarity with a particular scene when he put on the prisms a year after the experiment was completed? Or, if the memory was not tied specifically to his experience while wearing the reversing prisms, why would Dolezal find it difficult to recognize an individual after the experiment that he had only seen prior to that time while wearing the reversing prisms?

Consider the following observation reported by the subject in Snyder and Pronko's study, who happened to be Snyder:

> Toward the end of the experiment [i.e., the period in which the subject wore the inverting glasses], the subject was adequately adjusted [adapted]. The following insightful experience occurred. He was observing the scene from a tall building. Suddenly someone asked, "Well, how do things look to you? Are they upside-down?"
>
> The subject replied, "I wish you hadn't asked me. Things were all right until you popped the question at me. Now, when I recall how they *did* look *before* I put on these lenses, I must answer that they do look upside-down *now*. But until the moment that you asked me I was absolutely unaware of it and hadn't given a thought to the question of whether things were right-side-up or upside-down." (Snyder and Pronko, 1952, p. 113)

In a study of retention of the effects of such inversion, Snyder and Snyder (1957) found that when the inverted conditions are reintroduced for a subject some time after the subject's initial experience with inverted light, the subject's adjustment the second time to the inverted light indicated that learning occurred as a result of the first experience and had been retained over a two-year period between the first and second experiences with inversion of the incoming light. Specifically, Snyder and Snyder found that the time to complete various tasks consistently took less time in the second experience than in the first. The learning curves in the first and second experiences were very similar for each of the tasks, only in the second exposure the times to complete the tasks were consistently lower than the times to complete them in the first exposure.

In his research, Stratton noted how quickly the perceptual framework of the subject exposed to inverted incoming light could switch between the unadapted and the adapted orientation. He also noted the possibility of their coexistence. For example, on the seventh day of wearing his apparatus in the second experiment, Stratton (1897b) wrote:

> When I watched one of my limbs in motion, no involuntary suggestion arose that it was in any other place or moved in any other direction than as sight actually reported it, except that in moving my arm a slightly discordant group of sensations came from my unseen shoulder. If, while looking at the member, I summoned an image of it in its old position, then I could feel the limb there too. But this latter was a relatively weak affair, and cost effort. When I looked away from it, however, I involuntarily felt it in its pre-experimental position, although at the same time conscious of a solicitation to feel it in its new position. This representation of the moving part in terms of the new vision waxed and waned in strength, so that it was sometimes more vivid than the old, and sometimes even completely overshadowed it. (p. 465)

It is remarkable that the visual system has demonstrated a great degree of flexibility in the inversion experiments given the degree of artificiality introduced into the experimental circumstances by the optical apparatuses that have been used. For example, Stratton used a device that allowed for incoming light to only one eye while the other eye was covered. Ewert's device was lightweight but allowed for a limited visual field. In an attempt to widen the visual field over that of most other experiments in which all incoming light is inverted for an extended period of time, Dolezal (1982) built his optical device out of a football helmet and inserted glass prisms in the limited space usually left open for a football player to see. His device weighed 8 pounds, 6 ounces. There is further work to be done in this area of the effect of inverted light on visual experience and visually guided action. But the basic result that there is significant adaptation in visual experience and visually guided action to inversion of incoming light has been established.[4]

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[4] One avenue for further work is suggested by anecdotal evidence developed using the recently developed technique of functional magnetic resonance imaging that changes in visual experience resulting from inversion of incoming light on the retina are reflected in neurophysiological processes. (Anecdotal evidence is all that is available at the present time.) In an experiment that employed this technique, subjects wore glasses that divided their visual fields so an eye would see only half its usual stimuli. The researcher, Schneider, found, "I was getting data on one person and it looked like his brain was upside down. I checked and rechecked the numbers wondering what the heck was going on. Then I found out he had put the glasses on wrong, so that his visual field was flipped upside down. I didn't know it at the time, but just by looking at

Hard-Wiring of the Visual System and the Isotropy of Space

Originally, Stratton was concerned with showing that two theories concerning inversion of incoming light were incorrect. Essentially, these theories maintained some sort of hard-wiring of either the neural component of the visual system (the projection theory) or its supporting musculature (the eye movement theory). In the projection theory, inversion of the retinal image was needed because of the crossing of the lines of direction of light from external objects when light from the external world moves through the eye. Perception was considered to depend on these lines of direction that projected outward to the upright objects in the physical world from which the light rays originated.

The eye movement theory related to the use of the musculature about the eye to provide definitive information about the correct position of objects in the world. Thus, if the eyes move upward in their sockets, they see the upper parts of objects in the physical world, and if the eyes move downward in their sockets, they see the lower part of these objects in the physical world. In this process, though, movement of the eye upward, for example, results in the lower portion of the retina receiving more of the incoming light. Inversion of the incoming light would help to correct this problem and could provide the basis for indicating the upright nature of the physical world.

Basically, physicists have held to the tenet behind the projection theory and the eye movement theory that there is only one way that the visual system can function in order that the physical world is perceived as upright. This is an assumption that Boring (1929/1950) maintained was based on the notion of the homunculus. It can be seen in the descriptions provided of the projection theory and the eye movement theory that both theories carry another even more basic tenet as an assumption regarding the physical world. This assumption is that the physical world itself has an absolute status as regards its being upright. For example, if the physical world were indeed upside down, would scholars seriously entertain a theory of visual perception based on the

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this brain I could tell he was seeing upside down" (Blakeslee, 1993, p. B6). It is important to systematically investigate the initial neurophysiological representation of inverted light as well as the later neurophysiological representation of this inverted light.

In a systematic investigation, it is predicted based on the anecdotal evidence that the inversion of the neurophysiological representation would be confirmed when incoming light is first inverted with an optical apparatus. Some time after wearing an optical apparatus that inverts incoming light, it is predicted that some neurophysiological process in the subject will have reestablished the neurophysiological correlate to upright vision. This could occur either through reestablishing preinversion relationships between the visual and other sensory systems or through at least one element of the neurophysiological representation of the visual field reverting to a state that would characterize that element if incoming light had not been inverted. The latter prediction derives from the evidence indicating reestablishment of upright vision after incoming light to a subject is inverted for some time.

hard-wiring of the visual system? The assumption that the physical world has an absolute status as regards its being upright violates the isotropy of space in that space is not fundamentally the same in different directions.

Altering the Experimental Circumstances Without Changing the Physical System or the Apparatus Used to Measure It

It remains to show how this adaptability of visual experience and visually guided behavior to inversion of incoming light allows Einstein, Podolsky, and Rosen's result to be realized in an experiment. Stratton's results, and those of others following his general line of research, have shown that though sensory data impinging on us may indeed be of fundamentally different forms, the perception associated with these data may be uniform. Now the methodology through which these results were obtained needs to be integrated with an experimental arrangement used in physics.

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 in the following way. Through the use of a Stern–Gerlach apparatus (Eisberg and Resnick, 1974/1985; Liboff, 1992), a nonuniform magnetic field oriented along the z axis is placed in the path of the electron, and the subject watches to see which way the electron moves in the field. The spin component along any one of these axes (in the present case, the z axis) will have one of two values if it is measured along the axis of the nonuniform magnetic field. (As discussed, the introduction of a macroscopic measuring device does not change the experimental circumstances in any critical way.) Assume the z axis is in the vertical direction relative to the subject, appearing to go up and down. The two values of the spin component along the z axis can be designated spin up and spin down according to the motion of the electron passing through the Stern–Gerlach apparatus relative to the vertical axis. Assume that the y axis runs perpendicular to the ideal plane formed by the subject'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 subject, from side to side. The experimental circumstances are depicted in Figure 1, where + and – refer to the positive and negative directions along a spatial axis. 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.

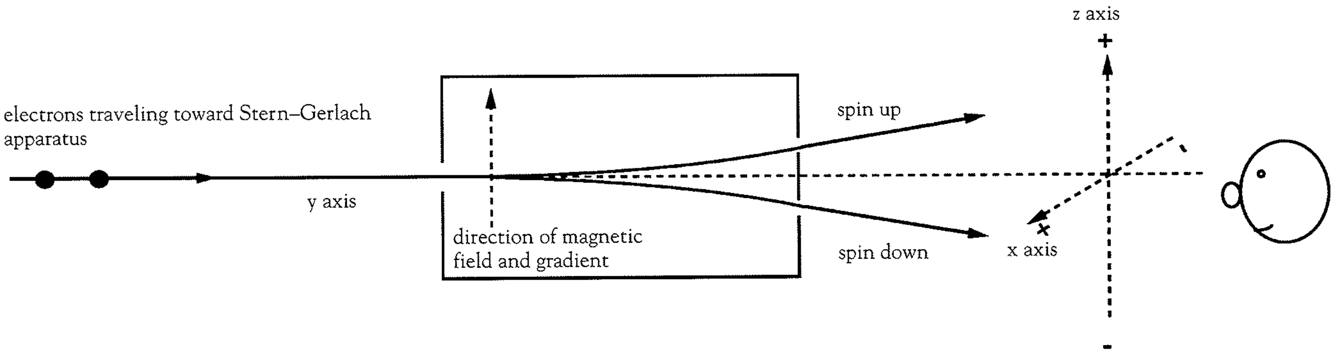

Figure 1. Observer viewing the spin component along z axis of electrons traveling through a Stern–Gerlach apparatus without rotation of incoming light.

This limitation concerning the knowledge of certain paired quantities in quantum mechanics also characterizes the simultaneous precise determination of the position and momentum of an electron (Eisberg and Resnick, 1974/1985; Liboff, 1992). Precise knowledge of the electron's momentum entails complete uncertainty regarding its position, and precise knowledge of its position entails complete uncertainty regarding its momentum. As Einstein, Podolsky, and Rosen (1935) wrote:

> It is shown in quantum mechanics that, if the operators corresponding to two physical quantities, say A and B, do not commute, that is, if $AB \neq BA$, then the precise knowledge of one of them precludes such a knowledge of the other. Furthermore, any attempt to determine the latter experimentally will alter the state of the system in such a way as to destroy the knowledge of the first. (p. 778)

Where A and B are the operators corresponding to the components of the position and momentum of an electron, respectively, along a particular spatial axis, they do not commute. Similarly, where A and B are the operators for any two components along orthogonal spatial axes of the spin angular momentum of an electron, they do not commute.

One can use an apparatus like that developed by Stratton to rotate the incoming light to an experimental subject 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 subject's retina. Given Stratton's results, there is a good possibility that, after a period of orientation with this apparatus, particularly if it is worn for an uninterrupted period and the subject is allowed to move freely in the natural environment, the subject will see the electron moving up or down and not sideways.

Indeed, the natural scenarios tested by Stratton and others are much more complex than the scenario needs to allow for the necessary adaptation for an individual observing the path of an electron along a spatial axis in an inhomogenous magnetic field like that created by a Stern–Gerlach apparatus. It does appear that adaptation to inverted light depends to a significant degree on a subject's experience in moving in his or her natural environment while incoming light is inverted by the optical apparatus. Thus, the observer in the proposed experiment should continually wear the apparatus and move freely in the natural environment. But because of the uncomplicated nature of the adaptation needed in the proposed experiment, the amount of sensorimotor experience in the natural environment required by the subject for the necessary degree of adaptation of the visual perceptual system to occur should not be great.

Once this degree of adaptation occurs in the subject's visual experience, according to the information impinging on the subject's retina, the subject is measuring in a vertical orientation 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 adapted subject up and down along the *x* axis. For this subject, the spin components along the *y* and *z* axes are completely uncertain. Thus, it appears possible to have simultaneous, mutually exclusive situations involving the components of spin angular momentum of the electron along two orthogonal spatial axes. 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.

Evidence supporting a biperceptual character of visual perception after adaptation to inversion of incoming light has been noted. This biperceptual character of visual perception concerns the simultaneous existence of the distinct visual perceptual capabilities associated with both pre-inversion and post-inversion conditions. It may be possible for one subject in the experiment outlined above involving spin angular momentum components along orthogonal spatial axes to be involved in mutually exclusive situations simultaneously concerning the same concrete physical circumstances. That is, the adapted subject may be able to instantly shift from being involved in one of the experimental scenarios to the other.

There is another expression of simultaneous mutually exclusive situations besides that already discussed that is perhaps even more surprising. Consider that an optical apparatus is used that rotates incoming light 180° around the line of sight. For the subject wearing the device but not yet adapted, the negative direction of the *z* axis is associated with spin up and the positive direction of the *z* axis is associated with spin down (Figure 2). Once a significant degree of adaptation in the subject's visual experience occurs, when the subject observes that an electron has spin up in the positive direction of the *z* axis, according to the information impinging on the subject's retina the subject is measuring what in the original situation without rotation of the incoming light is spin up in the negative direction of the *z* axis. Similarly, when the subject observes that an electron has spin down in the negative direction of the *z* axis, according to the information impinging on the subject's retina, the subject is measuring what in the original situation without rotation of the incoming light is spin down in the positive direction of the *z* axis.

If this result is considered in terms of the Schrödinger cat gedankenexperiment, it is as if in one situation, one atom of the radioactive material decayed leading to the cat being dead when observed, while simultaneously in the other situation none of the radioactive material decayed, leading to the cat being alive when observed. One situation involves the observer who has not worn the optical device and who is not wearing the device when he or she observes the electron. The other situation involves the observer who

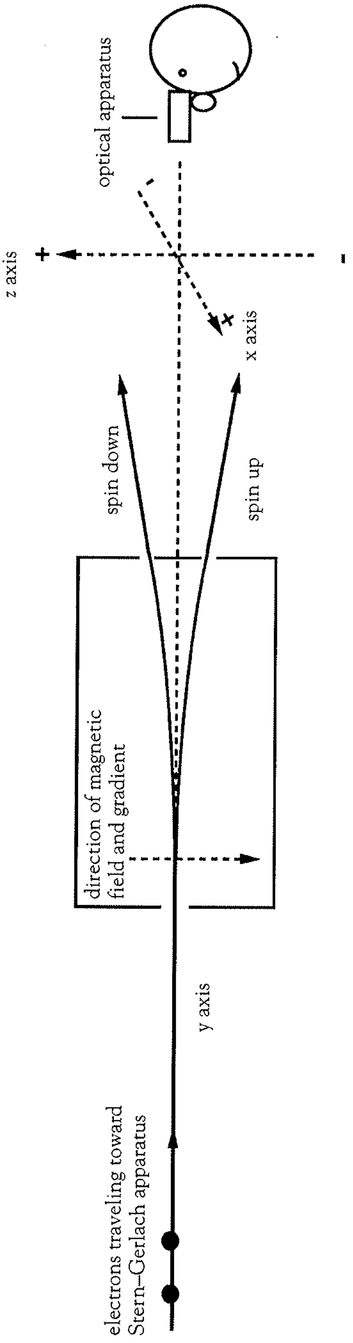

Figure 2. Observer viewing the spin component along *z* axis of electrons traveling through a Stern–Gerlach apparatus with 180° rotation of incoming light around the y axis before adaptation.

is wearing the apparatus when observing the electron and who has adapted to the rotated visual field. In contrast to the Schrödinger cat gedankenexperiment, each observer's perception is similar in structure. But while the effect of the rotation of incoming light for a subject is mitigated upon adaptation, the historical physical event of the rotation of the incoming light due to the optical apparatus remains for the observer wearing the device and acts to distinguish the two situations of the observers.

Practically speaking, the "righting" of the visual field for the adapted subject means that the electron with spin up in the original spatial structure now has spin down in the original spatial structure even though the electron has spin up in the spatial structure of the adapted observer. For the subject wearing the optical apparatus but who has not adapted to the inversion of incoming light, the spatial structure of the world is the same as that for the subject who does not wear the optical apparatus and for whom light is not inverted. The unadapted subject knows that his visual experience is altered by wearing the optical apparatus but that the world itself remains unchanged. The unadapted subject knows that the spin component of the electron is up, that is really in the direction of the positive z axis, though it appears to be down to him, that is in the direction of the negative z axis. But with adaptation to inverted incoming light, including the sense of normalcy in visual experience and competency in visually guided action that supports this sense of normalcy, what appears as a spin up component for the electron to the adapted observer is a spin down component when considered in terms of the original spatial structure, the spatial structure of the subject for whom incoming light is not inverted. Unlike the unadapted observer, the adapted observer does not maintain that the world is unchanged while his visual experience has been altered by inverting incoming light with the use of the optical apparatus. The adapted observer experiences the spin component opposite to that experienced by the unadapted observer. In terms of the impact of incoming light on his retina, the adapted observer who observes a spin up component experiences a spin component in the opposite direction to that which the same pattern of light on the retina supports for the unadapted observer.

In this regard, a portion of Boring's (1929/1950) quote presented above is particularly relevant.

> [Stratton] described how up was nothing in the visual sensory pattern other than the opposite of down, and that orientation is achieved by the relation of the visual pattern to somothesis and behavior. When you reach up to get an object imaged at the top of the retina, then you have indeed got the visual field reversed and will not find the object unless you have on Stratton's lenses. (p. 678)

The world and the subject's experience of the world thus do not appear changed, unless, as the data suggest, the subject thinks about his wearing the optical apparatus and the subsequent experiential and behavioral change that accompanies the initial presentation of light to the retina after it passes through the optical apparatus.

Implications for Einstein's Gedankenexperiment

The experiment discussed above involving the spin angular momentum of an electron traveling through a nonuniform magnetic field in a Stern–Gerlach apparatus in conjunction with rotation of incoming light 90° for an observer can be applied to S_2 in Einstein's gedankenexperiment when the observation at S_1 is made. Let there be two observers of S_2 when an observation at S_1 is made. One observer would not be wearing the optical apparatus and would never have worn it. The other observer would have adapted to the rotation of the visual field that occurs with the device and would be wearing it when observing S_2. One very likely would find that both wave functions in Einstein's gedankenexperiment could describe S_2 for the different observers. Moreover, in view of the results on biperceptual experience resulting from inversion of incoming light, one might find that both wave functions could describe S_2 for the same observer. Einstein's result concerning S_2 is not only the correct result theoretically in quantum mechanics, but it is also subject to empirical test. In sum, because of the results of the experiments in psychology that have been cited and because these results are concerned with adaptation to much more complex perceptual circumstances than would likely occur in the proposed experiment concerning the spin component of electrons along a spatial axis, it is expected that such an experiment would support Einstein's theoretical result that "very different" (Einstein, 1949/1969, p. 85) wave functions can simultaneously describe the same physical circumstances in the manner stated.

How Has the Significance of the Act of Observation Been Missed?

Why have physicists generally missed the significance of the *act* of observation, and specifically human observation, in quantum mechanics? And why have they missed the assumed anisotropy of space that is tied to the assumption of an absolute upright status of the physical world in visual perception? More practically, how, for example, could physicists at the Massachusetts Institute of Technology have missed the significance of Held's work on the plasticity of perception to their own work? Held has been on the faculty at MIT in the Department of Brain and Cognitive Sciences for many years.

In part, physicists have missed the significance of the act of observation because they have looked for consciousness, or cognition in general, to be like a physical *object*, not as an act for which physical objects are the objects of perception. This view of consciousness has allowed Adler (1989) to essentially propose that the discovery of the neutrino depended on a cognitive choice by physicists concerning the content of physical theory in the face of ambiguous empirical results while Adler framed his argument in terms of general philosophical tenets instead of this cognitive choice.

> I believe there is little reason to be convinced by this experiment [the definitive experiment by Cowan, Reines, Harrison, Kruse, and McGuire (1956)] that the neutrino exists apart from the theory and experiments that define it. The theory of beta decay is embedded in the larger theory of conventional physics and the experiment is constructed according to the rules of conventional physics. The neutrino is then a necessary constituent of the theory and the associated experiment. It exists as a building block of physics, but does it necessarily exist apart from the physics that defines it — I think not! (Adler, 1989, p. 880)

Instead of discussing the cognitive framework of physicists who consider the neutrino, Adler attempted to place his view within the philosophical positions of realism, anti-realism, arealism, phenomenalism, and instrumentalism (Snyder, 1990).

As another example, consider a comment by the physical scientist Elitzur (1991) that psychology and physics "do not get along well, especially when the subject of consciousness is brought up" (p. 306). He noted that "physics sees no observable evidence for it [the existence of consciousness]" (p. 306). As represented in the Schrödinger cat gedankenexperiment or the proposed experiment involving an electron traveling through a nonuniform magnetic field, in quantum mechanics, one does not look at consciousness, or perceiving, as one looks at a physical existent. In quantum mechanics, and in experience in general, perceiving fundamentally is that through which the physical world is known. In quantum mechanics, perceiving is not an object in the same sense that a physical existent, such as an electron, is an object for observation. In obtaining empirical evidence that the predictions of quantum mechanics concerning physical existents are correct, one obtains evidence for the means in quantum mechanics through which information is gained in measurement and theoretical formulations, namely human observation and human cognition. This is what a straightforward explanation of the quantum mechanical wave function indicates.

In addition, as has been shown, a distinctly psychological approach can be used to manipulate how these data concerning the physical world are received by the human observer and thereby demonstrate in a more conclusive fashion that there is an irreducible link between cognition and the physical world.

There is a connection between physicists in general not seeing the central role of the act of observation in quantum mechanics and their not seeing that the probabilities in quantum mechanics are fundamentally concerned with an individual's knowledge of the physical world. That physicists do not fully acknowledge that the quantum mechanical wave function provides the basis first for an individual's knowledge of the physical world is tied to their failure to realize the significance of Schrödinger's gedankenexperiment as concerns the link between human observation of a physical entity and the generally accompanying change in this entity upon observation.

When a straightforward explanation of the nature of the quantum mechanical wave function is proposed to physicists, their general response is that there is no new physics in the explanation. Physicists want to see new empirical results that are predicted using a straightforward explanation of the quantum mechanical wave function. Physicists generally maintain that a new result would convince them that the wave function is an indivisible link between cognition and the physical world. In maintaining this position, essentially physicists are looking for an event that does *not* fit in the theory of quantum mechanics and which is also mediated by cognition.

And yet, as discussed, it is the theory of quantum mechanics itself that allows for the fundamental link between cognition and the physical world. An avenue for empirical confirmation is the one discussed above: empirical evidence is found through adjusting the variables affecting the act of perceiving and not those affecting the measured physical system itself. The data obtained in the measurement process concern quantities of the measured physical system. The expected empirical results are those predicted in quantum mechanics.

Physicists cannot expect that a new result that effectively contradicts quantum mechanics can then be used to support the thesis that the wave function is a link between cognition and the physical world. Instead, it can be expected that a cognitive component can affect how the results predicted by quantum mechanics are manifested such that the unusual nature of the results indicates that cognition does indeed play a role in quantum mechanics. It can be shown that cognition provides flexibility such that the empirical results achieved using quantum mechanics are dependent on the cognitive processes in individuals in a way that the physical world cannot mediate.

How could this stance by physicists have come about? In part, it resulted from two factors. One is the great influence wielded by Newtonian mechanics in physics to this day. Most physicists hold that in Newtonian mechanics, the observing individual taking measurements in principle need not disturb the physical entity measured (Einstein, 1949/1969). Even with the advances of modern physical theory, Newtonian mechanics remains of great fundamental importance to physicists. These mechanics are the origin of classical physical theory (that includes the theory of relativity). Subsequent successful classical and non-classical theories maintain their allegiance to Newtonian mechanics in that: (1) in general, they must account for the great successes achieved with these mechanics, and (2) many characteristics of the physical world found in these mechanics, especially the dynamical view of the physical world as well as kinematical features such as position and momentum, are adopted in some form by these subsequent theories.

The second factor concerns the creation of the discipline of psychology in the latter 1800's as a distinct discipline, which was part of a larger differentiation of knowledge into specialty disciplines in the later nineteenth century. The physicists Helmholtz and Fechner were particularly important in the development of psychology (Boring, 1929/1950). In the creation of psychology as a distinct discipline, a sensitivity to psychological phenomena was lost on the part of those who specialize in studying the physical world. This loss occurred just before the development of modern physical theory in the early twentieth century. The experiment reported by Helmholtz above clearly had a significant psychological dimension. If his argument on the relation of vision and touch is followed a bit further, his interest and skill in exploring psychological phenomena is even more apparent:

> Here [in the experiment where an observer wears the glass prisms] it is not the muscular feeling of the hand that is at fault or the judgment of its position, but the judgment of the direction of the gaze, as is shown by the fact that, if after having become used to looking through the prisms and finding the visible objects with the right hand, then we close our eyes and try to touch the same objects with the left hand, which has not been previously used, and which was not in the field of view, we find that there will not be any difficulty about touching them with perfect certainty and precision. Accordingly, in a case of this kind the place is determined perfectly correctly, and thereafter it can be found with certainty by another organ of touch.
>
> We know by experience that children three months old are very slow in learning to point their hands toward objects they see, although they may know very well from the sensations of touch how to direct them to the mouth or to an itching place on the skin. They have to make many trials before they learn to understand the correspondence here between movement of eyes and hands; and so also even in the case of grown people the accuracy of this correspondence has to be continually regulated by constantly repeated experiments and observations. (Helmholtz, 1866/1925, pp. 246–247)

It is very difficult to imagine a contemporary physicist providing such an analysis of the relation of vision to touch in connection with the location of objects in space. If psychology had not become a discipline independent of physics and biology as well as philosophy, those scholars specializing in physical science would not expect data that contradicted quantum mechanics to demonstrate a point rooted in quantum mechanics, namely that the wave function is a connection between cognition and the physical world. For their part, those scholars particularly knowledgeable about psychological phenomena also would have been knowledgeable enough about physics not to have let this position stand. The significance of experiments such as the one reported by Helmholtz would not have been missed by physicists who developed quantum mechanics, and the cognitive feature of the wave function would have been recognized much sooner.

Conclusion

An attempt has been made to demonstrate the way in which physicists have not accepted a straightforward explanation of the quantum mechanical wave function, show some of the roots of the problem, and begin the reintegration of knowledge from psychology and physics. The basis for an empirical test of whether the quantum mechanical wave function is a link between human cognition and the physical world has been presented.

The proposed experiment combines research methodology from both psychology and physics. Results of research that used this methodology indicate that it is likely that Einstein, Podolsky, and Rosen's surprising theoretical result that mutually exclusive quantum mechanical wave functions can simultaneously apply to the same concrete physical circumstances can indeed be implemented on an empirical level. This conclusion lends support to the thesis that the quantum mechanical wave function is a link between human cognition and the physical world.

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