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Light as an Expression of Mental Activity

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Fundamental features of special relativity and quantum mechanics, cornerstones of modern physical theory, are explored and found to allow and support the notion that mental activity lies at the core of the physical world. This notion is consonant with the proposition that light, in addition to its explicit formulation in special relativity, may be regarded as an expression of mental activity and as such, capable of instantaneous transmission of information. Precise and reproducible experimental evidence supporting quantum mechanics is shown to constitute evidence for the important involvement of mental activity in the functioning of the physical world.

Special Relativity

The law of inertia states that a physical body distant from other bodies continues in a state of rest or uniform translatory motion (i.e., with constant velocity and direction and without rotation). A central tenet of the postulates of special relativity is that the velocity of light is invariant and is a finite constant in any inertial frame of reference (i.e., a spatial coordinate system, attached to some physical body, in which the law of inertia holds). It is this tenet, along with the postulation of inertial frames of reference that are in uniform translatory motion relative to one another and for which the laws of nature hold, that allows for the results of special relativity. The notion of a physical existent having the same finite velocity in such frames of reference points to a view of light that is unique and seemingly paradoxical.

The importance of light in special relativity is reflected in its central position in the development of the concept of time. In his original paper proposing the theory of special relativity, Einstein (1905/1952) noted that a useful notion of time relies on some means for determining the simultaneity of physical occurrences at spatial locations distant from one another. He defined simultaneity for an inertial frame of reference in terms of the motion of light and went on to develop the relativity of simultaneity and other results of special relativity on

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the foundation of this definition. Specifically, Einstein noted that simultaneity (or the common time of clocks) is delineated for an inertial frame of reference when, by definition, the time required for a ray of light to travel from a spatial point *A* to a spatial point *B* is equal to the time required for a ray of light to travel from point *B* to point *A*.

There is an inconsistency arising from the use of the motion of light, which has an invariant velocity in any inertial frame, to define simultaneity and the stipulation of special relativity that no physical existent may have a velocity greater than that of light. In his popular book on special and general relativity, Einstein (1961) himself emphasized the importance of being able to empirically validate his definition of simultaneity:

> Lightning has struck the rails on our railway embankment at two places *A* and *B* far distant from each other. I make the additional assertion that these two lightning flashes occurred simultaneously. . . . The concept [of simultaneity] does not exist for the physicist until he has the possibility of discovering whether or not it is fulfilled in an actual case. We thus require a definition of simultaneity such that this definition supplies us with the method by means of which, in the present case, he can decide by experiment whether or not both the lightning strokes occurred simultaneously. As long as this requirement is not satisfied, I allow myself to be deceived as a physicist (and of course the same applies if I am not a physicist), when I imagine that I am able to attach a meaning to the statement of simultaneity. (I would ask the reader not to proceed farther until he is fully convinced on this point.) (pp. 21–22)

Given the above noted use of light in defining simultaneity and the limitation on the velocity of physical existents, there is no basis within the theoretical structure of special relativity for *predicting* that the establishment of simultaneity for an inertial frame of reference will be demonstrated in an empirical test. For prediction to have a valid foundation, there must be some basis for the transfer of information that is faster than the velocity of light. The circumstance is somewhat analogous to that found in statistical mechanics where the theoretical derivation from first principles of various distributions (e.g., the Boltzmann distribution) is required for an adequate experimental test of these distributions (Eisberg and Resnick, 1974; Tolman, 1938). Without such a derivation, empirical data provide only a *post hoc* basis for knowledge concerning the physical world and do not support one having a *predictive* component. Given the invariant velocity of light in any inertial frame, a predictive basis essentially requires an existent capable of instantaneous transmission of information. A physical existent of this sort would be the basis for a Newtonian-type mechanics relying on a Galilean-type rather than Lorentz-type transformation for the space and time coordinates of inertial frames that are in uniform motion relative to one another. This Newtonian-type of mechanics is refuted with special relativity.

A physical event has both spatial and temporal coordinates. As the temporal aspect of physical events in special relativity is ultimately founded on Einstein's definition of simultaneity, there is no basis within special relativity for predictions involving the temporal aspect of these events. This conclusion regarding time can be extended readily to the spatial aspect of these events because taking a meaningful measurement of length essentially involves determining simultaneously the spatial coordinates of at least two physical events. Even though predictions regarding physical events are limited within the theoretical structure of special relativity, it is evident that predictions regarding physical events *are* made using special relativity as the informational source and that these predictions have been experimentally confirmed. The nature of this prediction requires clarification to further our understanding of the theoretical activity underlying the special theory of relativity and the empirical data which support it.

Spacelike Separated Events

Spacelike separated events are physical events separated such that the absolute value of the quotient obtained by dividing the spatial distance between the events by the temporal interval between the events is greater than the velocity of light. In a case where x_1 and x_2 represent the spatial coordinates of spacelike separated events A and B respectively in a one dimensional, spatial coordinate frame, t_1 and t_2 represent the temporal coordinates of A and B respectively, and c represents the velocity of light, the mathematical formulation of spacelike separated events can be represented as $|(x_2 - x_1)/(t_2 - t_1)| > c$. Essentially, light originating at one of the events cannot affect the other event. Given Einstein's definition of simultaneity of spatially distant events for an inertial frame of reference, the temporal coordinates of spacelike separated events (in the case of A and B, t_1 and t_2) cannot be meaningfully compared within the theoretical structure of special relativity as elucidated by Einstein. The consideration of spacelike separated events presupposes a common time of the clocks involved in determining the temporal coordinates of these events. A meaningful comparison of these coordinates requires synchronized clocks, and Einstein's definition of this synchronization essentially involves two events in which light originating at one event does affect the other event.

The use of spacelike separated events in special relativity is not based on a clear spatiotemporal foundation rooted in the theoretical structure of special relativity. It is very interesting that when an experiment using matched spacelike separated events was conducted (Aspect, Dalibard, and Roger,1982), the results provided support for the existence of a correlational relationship between these events. Further, the general theoretical structure of quantum mechanics that these results support indicates that these correlations are independent of the spatial distance between the events. As the spacelike separated events and the correlational relationship do not appear to have a basis within special relativity, and as a physical existent capable of the instantaneous transmission of information would reintroduce a Newtonian-type mechanics, it is proposed that these results constitute evidence for the postulated nature of these events and the correlational relationship between them. This proposal is also supported by the absence of a basis for spatiotemporal prediction within the theoretical structure of special relativity and the circumstance that this prediction, which certainly has a mental component, is supported by experimental data.

The Relativity of Simultaneity

Another argument for the involvement of mental activity in the functioning of the physical world is found in Einstein's (1905/1952) discussion concerning the relativity of simultaneity. In this discussion, Einstein proposed that for two inertial frames of reference that are in uniform translatory motion relative to one another, there are different common times of the clocks situated in the respective inertial frames of reference. Einstein, though, depended on the clocks of one inertial frame of reference being synchronized with the clocks of the other inertial frame in order to determine whether simultaneity is absolute or relative. Consider that there exists one inertial frame for which simultaneity is defined in accordance with Einstein's precept and that the question is posed whether simultaneity occurs in exactly the same way in a different inertial frame in uniform translatory motion relative to the former frame? To answer this question, one must first establish how simultaneity could possibly occur in exactly the same way in the latter frame as in the former in order to make a comparison to determine whether it does occur in exactly the same manner. In noting that the time of clocks synchronized in one inertial frame can be used without alteration to set clocks in another inertial frame that is moving uniformly relative to the former, Einstein had his basis of hypothesized absolute simultaneity from which he could then determine whether simultaneity is indeed absolute or relative. An objective physical existent cannot be the basis for establishing this conditional characteristic regarding simultaneity. The velocity limitation of special relativity excludes any objective physical existent with a velocity greater than that of light from being this basis; light itself, as postulated in special relativity, has an invariant velocity in any inertial frame and thus cannot be the basis. The basis for this *conditional* characteristic concerning absolute simultaneity, which Einstein concluded is not actually the case, appears to be theoretical or mental in nature.

Exploring Einstein's 1905 argument on the relativity of simultaneity will point out a problem this hypothesized absolute simultaneity caused. It will also show that the resolution to this problem lies in the imagined nature of certain kinematical quantities that are employed by Einstein in demonstrating the relativity of simultaneity. In his argument, Einstein considered one of the two inertial frames of reference that are in uniform translatory motion relative to one another "stationary" and the other inertial frame "moving." Further, he required that the time of clocks synchronized in the "stationary" frame be used in the "moving" frame in order to determine the flight times of a light ray between the ends of a rod considered at rest in the "moving" frame and aligned along the direction of the relative motion of the inertial frames. (This rod, of course, is considered moving from the standpoint of observers in the "stationary" frame with the same velocity as the "moving" frame.)

In Einstein's argument, simultaneity is defined in the "stationary" frame in terms of the invariant velocity of light, and thus the velocity of light in this frame is constant. When this synchronization is used by observers in the "moving" frame, the light ray, seen by observers in both inertial frames, has a velocity of $c - v$ or $c + v$ relative to the observer in the"moving" frame, as deduced by the "stationary" observer (c is the invariant velocity of light; v is the uniform velocity of one inertial frame relative to the other inertial frame). Whether the light ray has the velocity $c - v$ or $c + v$ depends on whether the ray is moving in the same direction as the "moving" frame or in the opposite direction. When an observer in the "moving" frame applies Einstein's definition of simultaneity from the 1905 paper (which is sensible only with the constant velocity of light in an inertial frame), a contradiction results. The reason is that Einstein has just demonstrated that light has different velocities relative to the "moving" observer (as deduced by the "stationary" observer and known by the moving observer), depending on the direction of travel of the light relative to the direction of travel of the "moving" frame. It is just this juxtaposition of velocities that results in the relativity of simultaneity. When the observer in the "moving" frame applies the criterion for simultaneity, he finds that this criterion is not met because the flight times of the light ray between the ends of the rod are not equal. Thus, Einstein concluded that when clocks at rest in an inertial frame are synchronized in accordance with his definition, clocks at rest in another inertial frame moving in uniform translatory motion relative to the former frame are not so synchronized.

Because of the significance of the theory being considered, I want to review Einstein's argument in more detail. In developing his argument, Einstein (1905/1952) wrote (including the following footnote):

> We imagine further that at the two ends *A* and *B* of the rod [moving with uniform velocity relative to the stationary inertial system], clocks are placed which synchronize with the clocks of the stationary system, that is to say that their indications correspond at any instant to the "time of the stationary system" at the places where they happen to be. These clocks are therefore "synchronous in the stationary system."
>
> We imagine further that with each clock there is a moving observer, and that these observers apply to both clocks the criterion established. . . for the synchronization of two

clocks [that the flight time of a light ray in an inertial frame of reference from spatial point A to spatial point B is equal to the flight time of a light ray from point B to point A]. Let a ray of light depart from A at the time* t_A, let it be reflected at B at the time t_B, and reach A again at the time t'_A. Taking into consideration the principle of the constancy of the velocity of light we find that

$$t_B - t_A = \frac{r_{AB}}{c - v} \quad \text{and} \quad t'_A - t_B = \frac{r_{AB}}{c + v}$$

where r_{AB} denotes the length of the moving rod—measured in the stationary system. Observers moving with the rod would thus find that the two clocks were not synchronous, while observers in the stationary system would declare the clocks to be synchronous.

*"Time" here denotes "time of the stationary system" and also "position of hands of the moving clocks situated at the place under discussion." (p. 42)

Please notice that in Einstein's argument, observers in the "moving" system set their clocks in accordance with the synchronization of clocks in the "stationary" system. He specified that these "moving" observers apply his definition of simultaneity to the flight times of the light ray between the ends A and B of the rod. When this definition of simultaneity is applied by the "moving" observers, they, of course, find that their clocks are not synchronized (i.e., that the flight time from A to B does not equal the flight time from B to A).

In his popular book on special and general relativity, Einstein again developed his argument on the relativity of simultaneity in terms of the knowledge held by a uniformly "moving" observer of the relative velocities $c + v$ and $c - v$. In developing his argument involving a "moving" observer located midpoint on a railway train between positions A and B (on the train for him) and a "stationary" observer on the embankment also located midway between positions A and B (on the embankment for this observer), Einstein (1961) wrote concerning two beams of light emitted from A and B and meeting at the "stationary" observer:

> Now in reality (considered with reference to the railway embankment) he [the observer on the train] is hastening towards the beam of light coming from B, whilst he is riding on ahead of the beam of light coming from A. *Hence the observer will see the beam of light emitted from B earlier than he will see that emitted from A. Observers who take the railway train as their reference-body must therefore come to the conclusion that the lightning flash B took place earlier than the lightning flash A.* (emphasis added) (p. 26)

The way the "moving" observer comes to this conclusion is in juxtaposing the invariant velocity of light in his inertial frame (which is responsible for the synchronization of his clocks) and the relative velocities $c + v$ and $c - v$ which the light beams have relative to him and which are deduced by the "stationary" observer on the embankment. If, for example, the "moving" observer does not care about the relative velocities $c + v$ and $c - v$ but only cares about the invariant velocity of light, he will, of course, not see the light beam emitted from *B* earlier than the light beam emitted from *A*. He will see the beams emitted from *A* and *B* at the same time, as does the "stationary" observer. Remember that the "moving" observer, using only his standpoint, considers himself at rest in his inertial frame as well as the positions *A* and *B* (which for him are on the train). Instead of considering the beams to emanate from places fixed on the embankment, as the "stationary" observer supposes, the "moving" observer, in regarding his frame as the "stationary" frame, considers the light beams to emanate from places fixed relative to the train. (This lack of a preferred inertial frame from which to consider the motion of light is what allows the argument concerning the relativity of simultaneity to be made from either inertial frame.) The relativity of simultaneity would not be demonstrated if the "moving" observer was not aware of the relative velocities $c + v$ and $c - v$ deduced by the "stationary" observer.

An easy way out of the dilemma (perhaps better put—an easy way to postpone the dilemma) is not to concern oneself with light moving between the ends of the "moving" rod, but instead, to use other physical existents. Then there is no contradiction; but circumstances may still exist, and must be accounted for, where light is used (as it is in both Einstein's 1905 paper and his popular account of the relativity of simultaneity). Very importantly, in special relativity, simultaneity (and thus time, and as a consequence of Einstein's arguments, also space) depends on the *motion of light*.

There is a way to resolve the inconsistency. As has been pointed out, the "moving" observer knows $c + v$ and $c - v$ are velocities of the light ray/s relative to him as deduced by the "stationary" observer. These velocities, though, are of course not the velocity of light the "moving" observer measures: This velocity, in accordance with empirical evidence and Einstein's postulate on the invariance of the velocity of light in all inertial frames, has the value *c*. These deduced velocities of light, $c + v$ and $c - v$, are correctly regarded as imagined (or more generally of a cognitive nature) because observers in the "stationary" frame consider them to be velocities of light judged by "moving" observers while actual measurements by these "moving" observers show the velocity of light to be invariant. It is important to note that these imagined velocities are used by a "moving" observer himself in the argument demonstrating the relativity of simultaneity.

Because the velocities deduced by a "stationary" observer as regards the motion of light relative to a "moving" observer may be considered imaginary does not mean these velocities are without physical significance. They are needed in the argument demonstrating the relativity of simultaneity, and thus also in the arguments demonstrating the relativity of length and temporal duration in inertial frames that are in uniform motion relative to one another.

Thus, the inconsistency concerning light having the invariant velocity c in all inertial frames and the velocities $c + v$ and $c - v$ relative to the "moving" observer as deduced by the "stationary" observer (and also known by the "moving" observer) is resolved by considering the velocities $c + v$ and $c - v$ imagined and the invariant value c the actual or real velocity of light (i.e., the velocity that is measured).

I should note that in Newtonian mechanics, the theory superseded by special relativity, there is no difference between what an observer in the "stationary" frame deduces the velocity of some physical existent to be relative to an observer in the "moving" frame and what the observer in this latter frame actually measures the velocity of this physical existent to be. In Newtonian mechanics, this is basically due to the absolute simultaneity in inertial frames of reference that are in uniform translatory motion relative to one another (as reflected in the classical transformation law $t' = t$, where t is the time in one inertial frame and t' is the time in the other inertial frame). Given absolute simultaneity, in Einstein's 1905 argument on the relativity of simultaneity, when the classical addition of velocities is applied by an observer in the "stationary" frame to determine what an observer in the "moving" frame judges the velocity of the ray of light moving between the ends of the rod to be, he (the "stationary" observer), of course, obtains the effective velocities $c - v$ and $c + v$. When the observer in the "moving" frame actually measures the velocity of this light ray, whose clocks are synchronized with the clocks of the "stationary" frame due to absolute simultaneity, he actually would measure $c - v$ and $c + v$. (Of course, empirical evidence does not support this result.)

Quantum Mechanics

Another formulation of the ideas regarding instantaneous transmission of information concerning the physical world may be made by examining the empirically well-supported theory of quantum mechanics. In addition to special relativity, quantum mechanics constitutes part of the bedrock of modern physical theory. Various features of this theory will be reviewed. This review, perhaps seeming at first a bit foreign to psychologists, will set the stage for points that are to be made concerning quantum mechanics and the instantaneous transmission of information concerning the physical world.

The Schroedinger Equation

A central element of quantum mechanics is the time *dependent* Schroedinger equation, initially developed by Erwin Schroedinger in 1925. The Schroedinger time dependent equation is a partial differential equation that describes the motion of a particle considered as a packet of waves (Eisberg and Resnick, 1974; Gasiorwicz, 1974). It sets constraints on the form of the wave function associated with some particle once the force acting on this particle is specified by noting the potential energy corresponding to the force. In physics, various partial differential equations are used to describe different kinds of wave motion (e.g., a wave in a string). A differential equation is a commonly encountered type of equation that has a function as its solution. That the Schroedinger equation is a partial differential equation means that it is a relation between its solution, i.e., $\Psi(x,t)$, and particular derivatives of $\Psi(x,t)$ with respect to the independent space and time variables x and t. Because $\Psi(x,t)$ is dependent on more than one variable, these derivatives must be partial derivatives.

It is understandable that after deBroglie proposed in 1924 that physical existents traditionally considered particles could also have associated wave properties, Schroedinger attempted to develop a wave equation that would describe the motion of these particles. However, as will be discussed later, the Schroedinger wave equation has a very unusual nature that distinguishes it in a fundamental manner from wave equations found in classical mechanics. The equation may be written

$$i\hbar \frac{\partial \Psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + V(x,t)\Psi(x,t)$$

where Ψ(x,t) (the wave function) is a solution for a particle moving in a one dimensional spatial frame, x, through a potential $V(x,t)$ which may have spatial and time dependencies. i is $\sqrt{-1}$; $\hbar$ is the quotient of Planck's constant, a small quantitative value, divided by 2π; and m is the mass of the particle. ∂ is the symbol used for partial differentiation. [Partial differentiation refers to differentiation over one of the independent variables, e.g., x in $\Psi(x,t)$, upon which some function is dependent while the other independent variable/s are held constant, e.g., t in $\Psi(x,t)$.] That $\Psi(x,t)$ is a function means that the value of the variable Ψ depends on both variables x (space) and t (time). (Ψ is said to be a function of x and t.) The value of $\Psi(x,t)$ at a particular spatial and temporal coordinate is designated a probability amplitude, the reason for which will be evident as the discussion progresses.

In quantum mechanics, another key equation is the time *independent* Schroedinger equation

$$E\psi(x) = -\frac{\hbar^2}{2m} \frac{d^2\psi(x)}{dx^2} + V(x)\psi(x).$$

This equation, which soon will be derived from the time dependent Schroedinger equation, is known as an eigenvalue equation, with E the eigenvalue and representing the energy of a physical system (e.g., in a one dimensional spatial coordinate frame, an electron moving in a potential, $V(x)$, having only a spatial dependence). i, $\hbar$, and m are the same as in the time dependent Schroedinger equation. The partial differentiation symbol ∂ has been replaced by d because the time independent Schroedinger equation is an ordinary differential equation; the differentiation is over the only variable upon which the function, which is the solution to the equation, depends. The solution, $\psi(x)$, is the corresponding energy eigenfunction, a function which is distinct from $\Psi(x,t)$ and which varies only in x. In quantum mechanics, much of the description of physical systems is given in terms of eigenfunctions. In fact, solutions to the time dependent Schroedinger equation concerning some physical system can be described in terms of the complete set of energy eigenfunctions concerning the system to which a time component is added.

The time independent Schroedinger equation may be used in the derivation of the various conservation principles found in classical mechanics as well as certain conservation principles pertaining only to quantum mechanics. The manner in which the conservation of energy may be so derived will be indicated and will provide an avenue to discuss some interesting features of quantum mechanics.

The conservation property of the time independent Schroedinger equation derives essentially from the openness to separation of the time dependent Schroedinger equation in which the potential $V(x)$ has only a spatial dependence such that certain solutions $\Psi(x,t)$ may be split into a space component, $\psi(x)$, and a time component, $\phi(t)$ [with $\Psi(x,t)=\psi(x)\phi(t)$]. In separating the variables x and t in the time dependent Schroedinger equation, $\psi(x)\phi(t)$ is substituted for $\Psi(x,t)$ in the equation and both sides of the equation are divided by $\psi(x)\phi(t)$

$$\frac{i\hbar}{\psi(x)\phi(t)}\frac{\partial\psi(x)\phi(t)}{\partial t}=-\frac{\hbar^2}{2m\psi(x)\phi(t)}\frac{\partial^2\psi(x)\phi(t)}{\partial x^2}+V(x)\frac{\psi(x)\phi(t)}{\psi(x)\phi(t)}.$$

As the partial differentiation on the left side of the equation is with respect to t, $\psi(x)$ may be taken out of this differentiation; for a similar reason $\phi(t)$ can be taken out of the partial differentiation on the right side. Thus

$$\frac{i\hbar\psi(x)}{\psi(x)\phi(t)}\frac{d\phi(t)}{dt}=-\frac{\hbar^2\phi(t)}{2m\psi(x)\phi(t)}\frac{d^2\psi(x)}{dx^2}+V(x)\frac{\psi(x)\phi(t)}{\psi(x)\phi(t)}$$

and

$$\frac{i\hbar}{\phi(t)}\frac{d\phi(t)}{dt}=\left[-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2}+V(x)\psi(x)\right]\frac{1}{\psi(x)}.$$

The last equation is the separated time dependent Schroedinger equation. Because each side of the equation is dependent on a different variable, separation of the equation results in each side being equal to a constant value, G

$$\frac{i\hbar}{\phi(t)}\frac{d\phi(t)}{dt}=G,\left[-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2}+V(x)\psi(x)\right]\frac{1}{\psi(x)}=G.$$

The time dependent Schroedinger equation is thus converted into two ordinary differential equations, one concerned only with space and the other only with time.

Since an exponential function ($f(x)=e^x$) is the only function whose derivative is the original function itself (i.e., $df(x)/dx=de^x/dx=e^x$), the time dependent component has a particularly simple solution. The solution is $\phi(t)= e^{-iGt/\hbar}$ as $d\phi(t)/dt = [-iG/\hbar]\phi(t)$. The Planck relation in quantum mechanics is $E=\hbar\omega$ (or $\omega = E/\hbar$), where E is the energy of the physical system, $\hbar$ is the quotient of Planck's constant divided by 2π, and ω is the angular frequency (a quantity related to the wave properties of the system). Now $e^{-i\omega t}= \cos \omega t - i \sin \omega t$. In mathematics, a real number multiplied by i (i.e., $\sqrt{-1}$) is termed imaginary, and as ω (the angular frequency) and the variable t (time) are always real, $-i \sin \omega t$ is a function with only imaginary values. As $\cos \omega t$ represents a mathematically real function and $-i \sin \omega t$ a mathematically imaginary function, $e^{-i\omega t}$ is an oscillatory function of time and may describe the variation over time of a complex wave (i.e., a wave having real and imaginary components) with an angular frequency ω. As $e^{-i\omega t}$ describes the variation over time of a complex wave with angular frequency $\omega = G/\hbar$, and because $\omega = E/\hbar$ from the Planck relation, it is reasonable to equate E (the energy of the system) with G and to conclude that $\phi(t) = e^{-iEt/\hbar}$.

Because G is a constant in the equation $\phi(t) = e^{-iGt/\hbar}$ and because E may be substituted for G, the conservation of energy may easily be derived due to E having the same value at any time [for a potential $V(x)$ with only a spatial dependence and a particle described by a wave function $\Psi(x,t)$ separable into $\psi(x)\phi(t)$]. The conservation of energy may also be extended to wave functions $\Psi(x,t)$ not separable into $\psi(x)\phi(t)$ that may describe the system of interest. As energy is conserved, the energy eigenfunction $\psi(x)$ will remain the same over time unless there is an externally induced change to the system.

The comments of Eisberg and Resnick (1974) are very useful in elucidating the complex nature of $\Psi(x,t)$:

> Since a wave function of quantum mechanics is complex, it specifies simultaneously two real functions, its real part and its imaginary part. . . . This is in contrast to a "wave function" of classical mechanics. For instance, a wave in a string can be specified by one real function which gives the displacement of various elements of the string at various times. This classical wave function is not complex because the classical wave equation does not contain an i since it relates a second time derivative to a second space derivative.
>
> The fact that wave functions are complex functions should not be considered a weak point of the quantum mechanical theory. Actually, it is a desirable feature because it makes it immediately apparent that we should not attempt to give to wave functions a physical existence in the same sense that water waves have a physical existence. The reason is that a complex quantity cannot be measured by an actual physical instrument. The "real" world (using the term in its nonmathematical sense) is the world of "real" quantities (using the term in its mathematical sense).
>
> Therefore, we should not try to answer, or even pose the question: Exactly what is waving, and what is it waving in? The student will remember that consideration of just such

> questions concerning the nature of electromagnetic waves led the nineteenth century physicists to the fallacious concept of the ether. As the wave functions are complex, there is no temptation to make the same mistake again. Instead, it is apparent from the outset that *the wave functions are computational devices* which have a significance only in the context of the Schroedinger theory of which they are a part. (p. 147)

Probability and Stationary States

Born proposed in 1926 that the probability of a particle described by the wave function $\Psi(x,t)$ being located within an infinitesimal spatial interval around x_1, if a measurement of spatial location were to be taken at a particular time t_1, is derived by taking the product of the wave function multiplied by its complex conjugate. The complex conjugate of the wave function is the function resulting from changing the sign (+ or −) of all imaginary terms of the wave function. Thus the probability may be represented as $P(x,t)\,dx = \Psi^*(x,t)\,\Psi(x,t)\,dx$ where $\Psi^*(x,t)$ is the complex conjugate of $\Psi(x,t)$ and dx represents the infinitesimal interval for which the probability is determined. Consider the case of a particle in a spatially dependent potential described by a wave function $\Psi(x,t)$ that can be separated into the space component $\psi(x)$ and the time component $\phi(t)$. Now, using $\Psi(x,t) = \psi(x)\phi(t)$ and $\phi(t) = e^{-i\omega t/\hbar}$ and substituting, one obtains

$$P(x,t)dx=\Psi^*(x,t)\Psi(x,t)dx=[\psi^*(x)\phi^*(t)][\psi(x)\phi(t)]dx=[\psi^*(x)e^{i\omega t}][\psi(x)e^{-i\omega t}]dx.$$

Rearranging terms, one finds

$$[\psi^*(x)e^{i\omega t}][\psi(x)e^{-i\omega t}]\,dx=\psi^*(x)\psi(x)e^{i\omega t}e^{-i\omega t}dx.$$

As $e^{i\omega t}e^{-i\omega t}=e^{i\omega t-i\omega t}$ and as $e^{i\omega t-i\omega t}=e^0=1$, $[\psi^*(x)e^{i\omega t}][\psi(x)e^{-i\omega t}]\,dx=\psi^*(x)\,\psi(x)\,dx$.

The verbal meaning of these equations is that in the absence of an externally induced change in the system, the probabilities corresponding to the possible locations of the particle, if a measurement were taken, have been shown to be constant over time. These probabilities do not appear to have a time dependence, and the state of the system is called a stationary state. It may seem paradoxical that the probabilities of a moving particle in a spatially dependent potential being found at various locations can remain constant over time. It must be remembered, though, that quantum mechanics is a theory that can be applied to classical mechanical problems but is in no way equivalent to classical mechanics.

It is to be pointed out that probability amplitudes, represented by $\Psi(x,t)$, cannot rely on a physical nature for their explanation. This point also applies to the probabilities derived using probability amplitudes which represent information about what *will* happen *if* position measurements are made.

Quantum mechanics provides computational or theoretical devices essentially unrelated to the classically conceived physical world, and quantum mechanics is supported by empirical data *when* measurements are taken. The fact that the probability distributions based on empirical data are in agreement with those predicted by quantum mechanics suggests that some mechanism exists for the instantaneous communication of information concerning these distributions on a computational or theoretical level that is also manifested when actual measurements are taken. In the absence of some classical physical explanation (which Eisberg and Resnick clearly note is not possible in quantum mechanics), how else can potentially widely separated physical events (e.g., the position measurements of some similarly arranged physical systems such as electrons after they pass through a double-slit diaphragm) be assured to assume some particular distribution, a distribution supported by empirical evidence?

Further, spatial location in a one dimensional spatial frame is determined essentially as distance from the origin of the spatial coordinate axis. As previously noted, the measurement of length relies essentially on the simultaneous determination of the spatial coordinates of at least two physical events; the measurement of length depends on the common time of clocks. Thus our energy eigenfunction $\psi(x)$ [and $\psi^*(x)\psi(x)$] actually requires some basis for simultaneity. $\psi(x)$ is independent only of a time that depends on an existent with a finite velocity (such as light as it is generally considered in special relativity) to determine simultaneity and to provide a foundation for both time and space; $\psi(x)$ remains the same over all such time. The time at the core of this function depends on the immediate establishment of simultaneity and thus on an existent that can transfer information instantaneously. As an objective physical existent cannot engage in such a transfer due to the velocity limitation of special relativity, perhaps mental activity is involved in the immediate establishment of simultaneity.

The Particle Interchange Operator

The term operator in quantum mechanics denotes the performance of a mathematical operation on one or more functions with this operation corresponding to a dynamical quantity. Examples of quantum mechanical operators are x_{op} and p_{op} corresponding to spatial location and momentum, respectively. Another example is the Hamiltonian

$$H = -\frac{\hbar^2}{2m}\frac{d^2}{dx^2} + V(x)$$

that when applied to the energy eigenfunction $\psi(x)$ yields the energy of the system, E, multiplied by $\psi(x)$. The form of the resulting equation is the time independent Schroedinger equation

$$E\psi(x) = -\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x).$$

When an operator applied to a function equals a constant multiplied by this function, we have an eigenvalue equation with the constant being the eigenvalue and the function designated the eigenfunction.

The particle interchange operator in quantum mechanics is concerned with a most unusual dynamical quantity (Dicke and Wittke, 1960). Consider a box containing two identical particles, specifically two moving, non-interacting electrons. In quantum mechanics, a theoretical description of the electrons must account for the possibility that either of the two wave functions corresponding to the two electrons may apply to either electron due to the uncertainty principle and their identical natures. The description must account for their indistinguishability. In classical mechanics, each of the electrons may be identified due to distinguishing characteristics such as differing trajectories of the particles. Differing trajectories, for example, cannot be used in quantum mechanics because the uncertainty principle does not allow for the notion of precisely distinguished trajectories. In fact, a precise measurement of the position of either particle is accompanied by uncertainty in momentum and thus in the subsequent position of the electron. Another way of stating the above point is that in quantum mechanics the wave functions corresponding to the two identical particles may overlap to some extent making it difficult to distinguish which wave function corresponds to which particle (Eisberg and Resnick, 1974).

The composite energy eigenfunction of a system composed of two non-identical, non-interacting particles may be expressed as the product of the energy eigenfunctions for each particle, $\psi_T(x_1,\ldots,z_2) = \psi_\epsilon(1)\ \psi_\sigma(2)$, where ψ_ϵ (1) is the eigenfunction for particle 1 evaluated in terms of this particle's coordinates x_1, y_1, z_1 and $\psi_\sigma(2)$ is the eigenfunction for particle 2 evaluated at its coordinates x_2, y_2, z_2. In addition, ψ_ϵ and ψ_σ specify the intrinsic spin angular momentum states for each of the particles (this momentum being a solely quantum mechanical construct). The probability density function (i.e., the function giving the probability per unit volume of locating particle 1 at x_1, y_1, z_1 and particle 2 at x_2, y_2, z_2) for this composite eigenfunction is ψ_ϵ^* (1) $\psi_\sigma^*(2)$ ψ_ϵ (1) ψ_σ (2). In the case of two identical, non-interacting particles, though, this formulation of the composite eigenfunction is in general inadequate. The reason is that the probability density function resulting from the assignment of each component eigenfunction (its particular mathematical form) to the other particle [when $\psi_T(x_1,\ldots,z_2) = \psi_\sigma(1)\psi_\epsilon(2)$] is not necessarily the same. The latter composite eigenfunction describes the circumstances noted for identical particles as well as the former due to the indistinguishability of the particles. Where the probability density functions were not the same, there would exist a means whereby the particles could be distinguished.

The functions that provide a satisfactory basis for describing a system of identical, non-interacting particles are the antisymmetric and the symmetric total eigenfunctions. The antisymmetric total eigenfunction, ψ_A, may be represented as $1/\sqrt{2}\ [\psi_\epsilon(1)\ \psi_\sigma(2) - \psi_\sigma(1)\ \psi_\epsilon(2)]$; the symmetric total eigenfunction, ψ_S, may be represented as $1/\sqrt{2}\ [\psi_\epsilon(1)\ \psi_\sigma(2) + \psi_\sigma(1)\ \psi_\epsilon(2)]$. These eigenfunctions satisfy the time independent Schroedinger equation, and as we shall see, the probability density function resulting from squaring either eigenfunction is unaltered by switching the assignment of the component eigenfunctions to the particles (i.e., by theoretically exchanging the particles). Elementary particles adequately described by ψ_A (e.g., electrons, protons, and neutrons) are called fermions; bosons are elementary particles described by ψ_S (e.g., mesons). Thus ψ_A and ψ_S account for the indistinguishability of non-interacting, identical particles by incorporating the postulate that either of the particles may correspond to either of the component eigenfunctions and taking the sum or difference of the products of the various matchings of these eigenfunctions and particles. $1/\sqrt{2}$ is called a normalization factor and is essentially used for calculational convenience.

The particle interchange operator, P_{12}, is concerned with the theoretical exchange of the identical particles. Applying P_{12} to ψ_A yields

$$\psi_A = 1/\sqrt{2}\,[\psi_\epsilon(1)\psi_\sigma(2) - \psi_\sigma(1)\psi_\epsilon(2)] \overset{\longrightarrow}{\substack{1\text{ to }2\\2\text{ to }1}} 1/\sqrt{2}\,[\psi_\epsilon(2)\psi_\sigma(1) - \psi_\sigma(2)\psi_\epsilon(1)] = -\psi_A.$$

with the exchange indicated by the arrow. Applying P_{12} to ψ_S yields

$$\psi_S = 1/\sqrt{2}\,[\psi_\epsilon(1)\psi_\sigma(2) + \psi_\sigma(1)\psi_\epsilon(2)] \overset{\longrightarrow}{\substack{1\text{ to }2\\2\text{ to }1}} 1/\sqrt{2}\,[\psi_\epsilon(2)\psi_\sigma(1) + \psi_\sigma(2)\psi_\epsilon(1)] = \psi_S.$$

Thus the application of the linear operator P_{12} to ψ_A or ψ_S yields the respective function multiplied by -1 or +1: $P_{12}\psi_A = -\psi_A$ and $P_{12}\psi_S = \psi_S$. These two equations are eigenvalue equations, and +1 and -1 are therefore the eigenvalues of the particle interchange operator. Their squared value is 1, which indicates that the probability density function resulting from the particle interchange operation is unchanged.

Experimental work has confirmed that ψ_A, ψ_S, and P_{12} provide for the correct description of systems of identical particles. Note what is occurring with these constructs. An action that is theoretical in nature (i.e., the theoretical exchange of the particles) is performed requiring the distinguishing of identical particles that in the physical world are indistinguishable. Further, this action is not constrained by spatial or temporal limitations in the physical world; it occurs immediately for particles with any spatial separation and the resulting composite eigenfunction is independent of a time based on an objective physical existent. Specifically, the theoretical action is not constrained by the velocity limitation of special relativity.

The discussion of the particle interchange operator and the total antisymmetric and symmetric eigenfunctions constitutes a case study pointing toward the general conclusion that the mental action found within the structure of quantum mechanics is not constrained by restrictions applicable to the physical world. Rather, this mental action is seen to have its own parameters, for example, that simultaneity (and thus the time and space) underlying the energy eigenfunctions relies on the capability to instantaneously transfer information. It has been shown that the indistinguishability of identical, non-interacting particles in the physical world is based on their distinguishability on an imaginative level and the immediate imaginative interchange of these particles to develop eigenfunctions that correctly describe systems of such particles in the physical world and allow for the correct application of the particle interchange operator.

As demonstrated by their usefulness in the development of predictions that have been experimentally confirmed, these features of quantum mechanics deserve serious consideration by psychologists. The mind that engages in the mental or imaginative activity found within the structure of quantum mechanics is the basis for this activity. Quantum mechanics relies on certain forms of mental action, and physics provides the most precise sort of publicly verifiable data indicating the importance of this mental activity in the physical world.

Conclusion

Various features of special relativity and quantum mechanics have been explored and found to allow and support the notion that mental activity lies at the core of the physical world. This notion is consonant with the proposition that light, in addition to its explicit formulation in special relativity, may be regarded as an expression of mental activity and capable of instantaneous transmission of information. Precise and reproducible experimental evidence supporting quantum mechanics has been shown to constitute evidence for the important involvement of mental activity in the functioning of the physical world.

References

Aspect, A., Dalibard, J., and Roger, G. (1982). Experimental test of Bell's inequalities using time-varying analyzers. *Physical Review Letters, 49*, 1804–1807.

Dicke, R.H., and Wittke, J.P. (1960). *Introduction to quantum mechanics.* Reading, Massachusetts: Addison-Wesley.

Einstein, A. (1952). On the electrodynamics of moving bodies. In H. Lorentz, A. Einstein, H. Minkowski, and H. Weyl (Eds.), *The principle of relativity, a collection of original papers on the special and general theory of relativity* (W. Perrett and G. Jeffrey, Trans.) (pp. 35–65). New York: Dover. (Original work published 1905)

Einstein, A. (1961). *Relativity, the special and the general theory* (R.W. Lawson, Trans.). New York: Bonanza.

Eisberg, R., and Resnick, R. (1974). *Quantum physics of atoms, molecules, solids, nuclei, and particles.* New York: Wiley.

Gasiorwicz, S. (1974). *Quantum physics*. New York: Wiley.

Tolman, R.C. (1938). *Principles of statistical mechanics*. Oxford: Clarendon Press.