RELATIVITY AND RELIGION: THE ABUSE OF EINSTEIN'S THEORY

by Peter E. Hodgson

Abstract. Einstein's special theory of relativity has had a wide influence on fields far removed from physics. It has given the impression that physics has shown that there are now no absolute truths, that all beliefs are relative to the observer, and that traditional stable landmarks have been washed away. We each have our own frame of reference that is as good as any other frame, so that there are no absolute standards by which our actions may be judged. The predictions of relativity theory, such as the elimination of simultaneity, the variation of mass with velocity, and the equivalence of mass and energy, are all highly counterintuitive and yet are precisely confirmed by detailed measurements. The clear rocklike mechanical physics of Newton seems to have dissolved into a swirling mist of unintelligible concepts, and familiar certainties seem to have disappeared.

A detailed analysis of relativity theory shows, however, a completely different picture. Properly understood, it is a logical extension of Newtonian physics that expresses the relations of space and time in a more exact and elegant way and in the process shows forth more clearly the invariant features of the world. The apparently counterintuitive features appear as natural consequences that extend and refine our classical concepts. The traditional landmarks remain, but God's world is more subtle than we had previously imagined.

Keywords: Albert Einstein; Lorentz transformation; Isaac Newton; relativity; space and time.

It is frequently maintained that the theory of relativity, along with quantum mechanics, demolished the nineteenth-century picture of the universe and created a new world picture that differs radically from that of Isaac Newton.

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A previous article (Hodgson 2000) considered quantum mechanics; the present one is devoted to the implications of Albert Einstein's special theory of relativity.

After this theory was published in 1905, it took physicists some time to absorb its implications, but by 1912 the conservative Max Planck could say, "This new way of thinking . . . well surpasses in daring everything that has been achieved in speculative scientific research, even in the theory of knowledge. . . . This revolution in the physical *Weltanschauung*, brought about by the relativity principle, is to be compared in scope and depth only with that caused by the introduction of the Copernican system of the world" (quoted in Holton 1982, xii). The reception of the general theory of relativity was even more dramatic, and the scene was described by Alfred North Whitehead:

> It was my good fortune to be present at the meeting of the Royal Society in London when the Astronomer Royal for England announced that the photographic plates of the famous eclipse, as measured by his colleagues in Greenwich Observatory, had verified the prediction of Einstein that rays of light are bent as they pass in the neighbourhood of the sun. The whole atmosphere of tense interest was exactly that of a Greek drama: we were the chorus commenting on the decree of destiny as disclosed in the development of a supreme incident. There was dramatic quality in the very staging:—the traditional ceremonial, and in the background the picture of Newton to remind us that the greatest of scientific generalisations was now, after more than two centuries, to receive its first modification. Nor was the personal interest wanting: a great adventure in thought had at length come safe to shore. (1925, 15)

The event was widely publicized, and thereafter Einstein became a public figure, the very personification of scientific genius.

Einstein's theory, according to a perceptive writer,

> . . . overturned the concepts of absolute space and time which formed the framework within which the laws governing the behaviour of matter were described in Newtonian physics. By disproving the existence of temporal simultaneity, demonstrating the variability of the lengths and masses of bodies moving at high velocity, establishing the equivalence of mass and energy, and tying together space and time in a four-dimensional manifold of varying curvature, Einstein created a world picture that differed radically from that of Newton in its theoretical principles. (Graham 1981, 35)

To this list may be added time dilation, namely that moving clocks appear to run slow. Many of these implications of the theory, well-confirmed by experiment, seemed contrary to common sense and engendered the feeling that familiar and traditional landmarks had melted away.

The word *relativity* was taken by many to mean the denial of any absolutes, and the equivalence of mass and energy seemed to mark the end of nineteenth-century materialism. Many physicists, such as Sir Arthur S. Eddington and Vladimir A. Fock, used its ideas to support their religious or political beliefs (Graham 1982, 107). Relativity has also been enthusiastically welcomed by artists and novelists, but in ways that deserve Wolfgang Pauli's devastating remark on a scientific paper: "It is not even wrong" (Cropper 2001, 257).

The purpose of this article is to examine these questions and to see the real connection between relativity and religion. It will be shown that Einstein's theory is principally concerned with establishing the objective and invariant features of the world, that its apparently paradoxical aspects are readily understandable, and that absolute space and time remain at the basis of physics. To do this, we first recall Newton's concept of absolute space and time and then the approach of Einstein, which led him to realize the general applicability of the Lorentz transformation, which gives the relation between the coordinates of two systems moving relative to each other with a constant relativistic velocity. (This was described by Hendrik Antoon Lorentz and named after him.) The consequences of this transformation are then explored, and relativity is found to be a natural extension of classical physics. The interpretation of relativity due to Lorentz based on absolute space and time is shown to be consistent with the formalism of relativity and also to provide the basis of physics. The interpretations of relativity are then compared with those of quantum mechanics, and their similarities and differences discussed. The final section is devoted to the connection between relativity and religion.

Although this article is concerned only with the special theory of relativity, J. L. Synge (1964) has rewritten Einstein's theory of gravitation (often referred to as the general theory of relativity) in a form based on absolute space and time.

As in the case of quantum mechanics, it is important in such discussions to distinguish between the formal mathematical structure of a scientific theory and the various interpretations that have grown up around it. The former constitutes the physics, and its success in no way endorses the validity of the interpretations.

NEWTONIAN SPACE AND TIME

The concepts of absolute space and absolute time, independent of the existence of any physical objects, are basic to Newtonian physics. In formulating his concepts of space and time, Newton was strongly influenced and guided by his theological beliefs and saw them as the sensorium of God:

> Does it not appear from phenomena that there is a Being incorporeal, living, intelligent, omnipresent, who in infinite space, as it were His sensory, sees the things themselves intimately, and thoroughly perceives them, and comprehends them wholly by their immediate presence to Himself: of which things the images only carried through the organs of our sense into our little sensoriums, are there seen and beheld by that which in us perceives and thinks. (Barbour 1989, 628)

God is omnipresent and eternal, and so all space and time is equally present to him:

> He is eternal and infinite . . . ; that is, his duration reaches from eternity to eternity; his presence from infinity to infinity. . . . He is not eternity and infinity, but eternal and infinite; he is not duration or space, but he endures and is present. He endures forever, and is everywhere present; and, by existing always and everywhere, he constitutes duration and space. Since every particle of space is *always*, and every indivisible moment of duration is *everywhere*, certainly the Maker and Lord of all things cannot be *never* and *nowhere*. (Newton, *Principia* 941)

Newton concluded that motion "must be referred to some motionless thing such as extension alone or space" (Barbour 1989, 617). Extension has "its own manner of existence which fits neither substance nor accident" (p. 618). In his *De Gravitatione* Newton describes the properties of space in more detail:

> . . . space extends infinitely in all directions. For we cannot imagine any limit anywhere without at the same time imagining that there is space beyond it. . . . The parts of space are motionless. . . . The parts of duration and space are only understood to be the same as they really are because of their mutual order and position; nor do they have any hint of individuality apart from that order and precision, which consequently cannot be altered. . . . Space is the disposition of being *qua* being. No being exists or can exist which is not related to space in some way. God is everywhere, created minds are somewhere, and body is in the space that it occupies; and whatever is neither everywhere nor anywhere does not exist. . . . The positions, distance and local motions of bodies are to be referred to the parts of space. . . . Lastly, space is eternal in duration and immutable in nature, and this is because it is the emanent effect of an eternal and immutable being. (Barbour 1989, 619)

Within this rationalist perspective, Newton formulated in his *Principia* the following definitions of space and time:

> Absolute space in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some moveable dimension or measure of the absolute space; which our senses determine by its position to bodies; and which is commonly taken for immoveable space; such is the dimension of a subterraneous, and aerial or celestial space, determined by its position in respect of the earth. Absolute and relative space are the same in figure and magnitude; but they do not remain always numerically the same. For if the earth, for instance, moves, a space of our air, which relatively and in respect of the earth remains always the same, will at one time become part of the absolute space into which the air passes; at another time it will be another part of the same, and so, absolutely understood, it will be continually changed.
>
> Absolute, true and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration; relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year. (Newton, *Principia* 408–9) (Barbour 1989, 623–24)

Thus,

> . . . the flowing of time is not liable to any change. . . . As the order of the parts of time is immutable, so also is the order of the parts of space. . . . All things are placed in time as to order of succession; and in space as to order of situation. It is

> from their essence or nature that they are places. . . . These are therefore that absolute places; and translations out of these places are the only absolute motions. (Barbour 1989, 624–25)

These definitions are metaphysical, so that it makes sense to speak of doubling the speed of clocks or enlarging space. Without the concept of metaphysical time as an ultimate reference this would have no meaning, and similarly for space. Such definitions need to be supplemented by more physical definitions if they are to be of practical use. Absolute space can be defined physically as the unique reference frame that, if it exists, can be recognized as such by all observers irrespective of their velocities with respect to that frame. Absolute time can be defined in a similar way.

We can think of absolute space as constituting a three-dimensional coordinate right-angled grid extending uniformly in all directions to infinity. Each event is situated within that frame, and its position is specified by the values of the three coordinates. Space and time exist independently of any material objects. In his *De Gravitatione* Newton considers the nature of space and by implication time: "It is not substance; on the one hand, because it is not absolute in itself, but is as it were an emanent effect of God, or a disposition of all being; on the other hand, because it is not among the proper dispositions that denote substance, namely actions, such as thoughts in the mind or notions in the body" (Hall and Hall 1978, 132). In this passage Newton makes it clear that space is not absolute in itself but only as an emanative effect of God. Space and time are in no way part of God, but God's being implies infinite space and time. They "are uncreated and co-existent with God and yet ontologically dependent on him for their being" (Craig 2000).

However, for practical purposes,

> . . . because the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from the positions and distances of things from any body considered as immoveable we define all places, and then with respect to such places we define all motions, considering bodies as transferred from some of these places into others. And so, instead of absolute places and motions we use relative ones; and that without any inconvenience in common affairs; but in philosophical disquisitions, we ought to abstract from our senses and consider things themselves, distinct from what are the only sensible measures of them. For it may be that there is no body really at rest, to which these places and motions may be referred. (Barbour 1989, 625)

Newton also remarked that "it is necessary that the definition of place and hence of local motion, be referred to some motionless thing such as extension alone or space so far as it is seen to be truly distinct from bodies" (Barbour 1989, 617).

Newton thus clearly distinguished these absolute notions of space and time from the results of our attempts to measure space and time, which he called relative. When we make our measurements we do not know whether we are moving relative to absolute space and also whether this has any effect on the results of our measurements. As we improve the accuracy of our measuring apparatus, we may hope to obtain results that approach the values corresponding to absolute space and time, but we cannot be certain of this. Newton's attempt to measure absolute space by using the curvature of the fluid surface in a rotating bucket is able to determine absolute rotation but not absolute motion. This absolute rotation is relative to the whole universe. This may be identified as the ultimate reference frame as there is no sense in saying that the whole universe is rotating, since there is no external reference point. His first Law of Motion does however require absolute space for it to be meaningful (Jammer 1954, 99–103).

It may be remarked, in parenthesis, that even Newton, who so clearly recognized the impossibility of determining absolute position, nevertheless found it very difficult to absorb all its implications, for in his treatment of the solar system he makes the hypothesis that "the centre of the system of the world is at rest" (Newton, *Principia* 231). Furthermore, due to the invariance of Newtonian mechanics under the Galilean transformation (the laws of motion are the same in all systems moving relative to each other with constant velocities), it is not possible to give an invariant meaning to the statement that two events occurring at different times took place in the same positions in space.

In establishing his concepts of space and time, Newton took a God's-eye view of the world. He considered space to be God's sensorium, and since God is omnipresent this establishes absolute simultaneity. Even on the physical level, there is nothing contradictory in conceiving signals being propagated with an arbitrarily large velocity.

Newton's theology thus had a fundamental role in establishing his concepts of space and time. God is explicitly mentioned in the first edition of the *Principia*, and on 10 December 1692 Newton wrote to Richard Bentley, "When I wrote my Treatise about our System, I had an Eye upon such principles as might work with considering Men, for the Belief of a Deity, and nothing can rejoice me more than to find it useful for that purpose" (Cohen 1978, 280).

In the subsequent years there were many discussions of space and time. The nineteenth-century French physicist Henri Poincaré was undecided between relativism and absolutism (Holton 1973, 188). He considered defining time with reference to the sensorium of Newton's "*intelligence infinie*"; "*une sort de grand conscience qui verrait tout, et qui classerait tout dans son temps* [a supermind that sees everything, and orders everything in his own time-frame]," but could not accept this because the infinite intelligence, "*si meme elle existerait, serait impénétrable pour nous* [even if it exists, will be impenetrable to us]." Poincaré was a physicist who used his great abilities to develop and improve existing theories but failed to make the creative leap that enabled the whole problem to be seen in a new light. That was finally achieved by Einstein (Stachel 1990).

EINSTEIN'S CONCEPT OF SPACE AND TIME

In contrast to Newton, Einstein developed his concepts of space and time from the point of view of a human observer, considering how space and time are actually measured, and postulating the constancy of the velocity of light in all inertial systems. This implies the Lorentz transformation, which in turn shows that relative motion affects the measured time, so that moving clocks appear to run slow. This constitutes the essential difference between Einstein and Newton. Einstein's approach is more attuned to the necessity of defining concepts in such a way that they can be measured, but this does not affect the validity of Newton's absolute space and time.

Einstein always looked for the most general principle underlying phenomena. In his early years he was strongly influenced by the philosopher Ernst Mach, and so he developed his concept of space and time from the point of view of an observer, considering how space and time are actually measured. At that time, he was a pure empiricist (Reiser 1930, 51–52) and identified reality with what is given by sensations. He learned about the current theories of electromagnetic phenomena by studying the works of Hermann Helmholtz, James Clerk Maxwell, Gustav Kirchoff, Heinrich Hertz, and Ludwig Boltzmann, and especially the textbook of August Foppl. It is notable that the latter work retains the ether and absolute motion and draws attention to precisely the same problem, namely, that of the relative motion of a magnet and an electrical circuit, that Einstein considers at the beginning of his pioneering paper of 1905. In his major work *The Science of Mechanics*, Mach criticized "the conceptual monstrosity of absolute space" because it is "purely a thought-thing which cannot be pointed to in experience" (Holton 1973, 221). It is thus notable that this paper of Einstein's contained two very general hypotheses that are certainly not empirical, namely, the constancy of the velocity of light and the extension of the principle of relativity to all branches of physics (Holton 1973, 232). This principle maintains that the behavior of phenomena and the laws governing them are independent of the reference frame used to describe them. Contrary to the usual accounts of the genesis of the special theory of relativity, Einstein was not greatly influenced by the result of the Michelson-Morley experiment, showing that it is not possible to detect the motion of the earth through a postulated aether (Holton 1973, 261–352). The essential difference between him and Newton is that Einstein's approach is more attuned to the necessity of defining concepts in such a way that they can be measured, and contained features of rationalism and extreme empiricism that were both essential to Einstein's achievement (Einstein 1949, 679; Holton 1973, 246, 259). This does not affect the validity of Newton's absolute space and time.

The reactions to Einstein's paper ranged from the enthusiastic welcome of the positivists to the guarded skepticism of Max Planck. Thus, the positivist Josef Petzoldt hailed the theory as “the victory over the metaphysics of absolutes in the conception of space and time” (Holton 1973, 275). Although Planck (1960) defended Einstein’s work, he opposed Mach’s view that “nothing is real except the perceptions” and maintained that “the basic aim of science” is “the finding of a *fixed* world picture independent of the variation of time and people” (Holton 1973, 227). In the years following 1905, more physicists came to accept relativity, partly because it explained the result of the Michelson-Morley experiment in a convincing way (unlike the ad hoc Fitzgerald contraction—the apparent contraction of a moving body in its direction of motion) and partly because of its inner consistency (Wien 1909, 32).

The theory of relativity is essentially concerned with the mathematical transformation of quantities measured in one reference frame to those measured in another frame moving with a constant linear velocity relative to the first. Until Einstein, this transformation was believed to be the Galilean transformation. It is a basic requirement of physics that the behavior of phenomena, and hence the laws governing them, is the same whatever frame is used to describe them. Einstein noticed that Maxwell’s equations, which describe all electromagnetic phenomena, are not invariant under the Galilean transformation. They are, however, invariant under a transformation already described by Lorentz. The Lorentz transformation becomes the same as the Galilean transformation for velocities small compared with the velocity of light, and so the difference is normally imperceptible. Einstein explored the consequences of assuming that the Lorentz transformation is applicable generally and not just to electromagnetic phenomena, and he deduced many surprising consequences that were abundantly confirmed by experiment.

Since the Lorentz transformation is equivalent to a rotation in spacetime, the length of the vector representing the spacetime interval between any two events is invariant. Thus, relativity theory reveals the quantities that remain invariant during the transformation from one reference frame to another.

It is possible to derive the Lorentz transformation in many different ways (Lucas and Hodgson 1990, 152), showing that it is fundamental in the sense that to deny it entails the denial of many well-accepted beliefs. One of the simplest, though not the most elegant, of the ways to obtain it uses the constancy of the velocity of light in all reference frames, together with some necessary symmetry principles. In many respects the Lorentz transformation is simpler and more elegant than the Galilean transformation, as it can be expressed as a rotation in spacetime. As Frederick Lindemann has remarked, “if only scientists had had their wits about them, they ought to have been able to reach the Relativity Theory by pure logic soon after Isaac Newton, and not to have to wait for the stimulus given to them by certain empirical observations that were inconsistent with the classical theory" (Harrod 1959, 57). It is therefore more properly seen as an extension of classical physics rather than a component of the new physics. Einstein himself made a similar remark, stressing the continuity of physics: "With respect to the theory of relativity it is not at all a question of a revolutionary act, but of a natural development of a line which can be pursued through centuries" (Seelig 1956, quoted by Holton 1973, 176). Writing to Conrad Habicht in 1905, Einstein described his forthcoming paper as making use of a "*modification* of the theory of space and time" (Holton 1974, 362).

In the years following the publication of the theory, Einstein's empiricism waned, and he increasingly came to believe in the capacity of reason to grasp reality and in the importance of wide-ranging theories. No longer are facts alone the final court of appeal. Thus he was unmoved when the results of the experiments of Walter Kaufmann (1906) disagreed with the prediction of his theory. He was confident that the experiment was faulty, as indeed proved to be the case. It was the same for his theory of gravitation. In a letter to Mach (25 June 1913) he remarks that the next solar eclipse will show whether it is correct or not (Holton 1973, 228). However, as recorded by Ilse Rosenthal-Schneider (1980), when he received a telegram giving the results of Eddington's 1919 expedition and she congratulated him warmly, he was quite unmoved and simply said, "I knew that the theory is correct." When she asked him what he would have done if the result had been otherwise, he replied, "Then I should have been sorry for the dear Lord—the theory is correct" (Holton 1973, 287). This story is somewhat puzzling, because Einstein knew very well that theories that do not agree with experiment just have to be abandoned, yet it serves to emphasize his strong belief in the order of nature and its openness to the human mind. Max Jammer has suggested a possible explanation of Einstein's remark. Since he knew that the theory is correct, "the only way in which the expedition could have noticed a different result was if nature had arranged circumstances in a very unusual and painful way for this particular experimental test not to work. Sooner or later it would have worked out, and Einstein would have been sorry for the dear Lord to have gone to so much trouble in order to produce a different result in this case" (Elkana 1974, 389).

Relativity has several apparently paradoxical features, but their subsequent experimental verification provides retrospective confirmation of their correctness. An example of this is provided by the nonadditivity of velocities. It seems perfectly obvious that velocities add, as indeed they do in Newtonian dynamics. Newton himself says so explicitly in Scholium IV of the *Principia* (Barbour 1989, 624). Thus, if I throw a ball from a moving train in the direction of motion of the train, the velocity of the ball as viewed by a stationary observer is simply the sum of the velocity of the train and that of the ball relative to the train. This expectation is, however, based on the simple fallacy that if a number can be attached to a physical entity, then if there are two such entities the number corresponding to both of them together is the sum of those of the entities individually. This is true for apples: a bag with two apples together with a bag with three apples gives a total of five apples. However, this is not generally true. It is false for gradients, for example, because tangents are not additive. It is also false for velocities, as can be shown from the experimental fact that the maximum velocity is that of light (Whittaker 1948, 50). Instead of simple additivity, the formula for the addition of two velocities contains an extra term that ensures that whatever velocity is added to that of light, the sum remains that of light.[1] Of course the difference from simple additivity is vanishing small for velocities that are small compared with that of light.

It also seems strange that bodies in motion should contract and that they should live longer.[2] These effects also follow from the Lorentz transformation, but it should be noted that these statements apply to what is measured by a stationary observer and not to anything experienced by the body itself. Such effects are not small for velocities near to that of light. Thus, when relativistic neutral pions decay into two photons, these photons would have nearly twice the velocity of light if velocities were additive, whereas their measured velocity is just that of light. Muons, with a half-life of about two microseconds, are produced by the decay of pions high in the earth's atmosphere and penetrate far below ground. In the absence of time dilation, they would be expected to have a range of only about $(3x10^{10})$ x $(2x10^{-6})$ cm, or 600 meters. This provides striking evidence for the theory of relativity.

Similarly, the variability of mass with velocity seems very strange. The word *mass* indicates the amount of stuff, so how can this change? This raises the question of the relativistic definitions of velocity and momentum, energy and force. It is possible to define them in several ways, subject always to the condition that they reduce to the nonrelativistic forms in the limit of velocities small compared with that of light. It is also desirable that the definitions lead to transformation equations that are as simple as possible. If the Newtonian definition of velocity as the derivative of the position with respect to Newtonian time is retained, it is not covariant under the Lorentz transformation. However, this condition is satisfied if we define velocity as the derivative of the position with respect to the proper time.[3]

If we define acceleration as the second derivative of the position with respect to Newtonian time we obtain rather complicated transformations (Leighton 1959, 35) and also introduce the additional concepts of longitudinal and transverse mass, which have no practical use (Born 1962, 276). Once again, double differentiation with respect to the proper time gives accelerations that transform by the Lorentz transformation. Multiplying the Lorentz transformation for velocity by the rest mass m_0 gives the transformations for momentum and energy. We find that the relativistic momentum is given by the product of the mass and the velocity as in Newtonian physics. If we keep the Newtonian definition of velocity, indeed we find that the mass varies with velocity. But if we use the relativistic definition of velocity, we retain an invariant mass.[4] It is only when we insist on retaining Newtonian definitions that we obtain a variable mass; if we accept the relativistic definitions, which is obviously more sensible, we have an invariant mass. Thus, it is not an experimental fact that the mass depends on the velocity, despite many published statements to the contrary.

The momentum-energy transformation also implies that the total energy of a particle is the sum of its kinetic energy and its rest mass, implying that mass is a form of energy.[5] This implication of relativity has been abundantly verified, particularly by several well-known nuclear reactions.

The replacement of the Galilean transformation by the Lorentz transformation can be described as "tying together" space and time, because time now depends on the spatial coordinates and on the relative velocity of the two coordinate frames. This was lyrically described by Hermann Minkowski when he declared, "henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" ([1923] 1952, 75). Contrary to this rhetoric, however, it remains true that space and time are different, if only because it is possible to move at will in all directions in space but only and inexorably forward in time. Causality is now limited to the light cone, so that an event can only be influenced by events in its past light cone and can only influence events in its forward light cone.

The dependence of time on the spatial coordinates and on the relative velocity of the two frames implies that the absolute simultaneity of events cannot be established. This does not imply, however, that temporal simultaneity has been disproved, since it does not exclude the possibility that absolute space and time can be established in some other way, as may be possible in the context of the Big Bang theory.

Thus, because a theory does not presuppose the existence of absolute space and time, it does not follow that these concepts are meaningless or that they have been disproved.

LORENTZ'S CONCEPT OF SPACE AND TIME

Following Newton, Lorentz retained the concepts of absolute space and time, while admitting that there seems to be no way that they can be established or detected. This does not, however, imply there are no practical differences between his interpretation of the relativistic formalism and that of Einstein. Newton and Lorentz both accepted the possibility of instantaneous action at a distance, without having any physical explanation of how this can occur. It is, however, incompatible with Einstein's interpretation because it implies the affirmation of the absolute simultaneity of two distant events (Popper 1956, 20). Thus, experiments like that of Alain Aspect (Aspect, Dalibard, and Roger 1983) designed to test the Bell inequalities could provide a proof of the correctness of the Lorentz interpretation.

The acceptance of absolute space means a return to the concept of the ether, and indeed this has already been reappearing in elementary particle theory, where what is called the vacuum is teeming with virtual particles. Lorentz's interpretation also allows time dilation to be derived in a physical way by considering a light clock (Craig 2001).

Once we accept absolute space, absolute time is implied by the success of our continuing efforts to construct more and more accurate clocks. These ever-closer approximations give the time in our reference frame, and this can be related to the absolute time in the absolute spatial system.

Thus, there is nothing in the formalism of special relativity to exclude the concepts of absolute space and time (Earman 1970). Although it was not possible to measure or detect them in Newton's or Einstein's days, this can now be done in principle by reference to the unique singularity of the Big Bang. Absolute time can be measured from that event, and an absolute spatial system is provided by the cosmic microwave background radiation. The expanding universe provides an inertial system, and anisotropy measurements can detect motion with respect to that frame (Rosen 1968). The times taken for the return of two light rays traveling equal distances parallel and perpendicular to the earth's motion will differ by a very small amount that depends on the rate of expansion of the universe. This is far below the level of detectability in a Michelson-Morley experiment but would be easily measurable if the experiment could be done over cosmic distances. For a distance like that to "the nearest quasar (about three billion parsecs) it amounts to some two hours" (Ne'eman 1974, 6). Such an experiment is impracticable, but E. K. Conklin (1972) has determined the absolute velocity of the earth by measuring the anisotropy of the cosmic microwave background and finds it to be 140 kilometers per second in a known specified direction. Such measurements can be made by any observer, and so this satisfies the conditions for absolute space. Such a preferred reference frame is required by realist interpretations of quantum mechanics (Hardy 1992). If the universe is finite, its center of gravity also provides an absolute point in space, but this cannot be determined. Of course, such considerations do not provide measures of space and time with anything like the accuracy required for practical purposes, but this does not affect their value in defining absolute space and time.

INTERPRETATIONS OF RELATIVITY AND QUANTUM MECHANICS

It is notable that there is a remarkable similarity between the interpretations of relativity and of quantum mechanics. In both cases there is a formal mathematical structure that has proved able to give extremely accurate accounts of experimental data, together with widely different interpretations of the formalism. There is more debate about the interpretations in the case of quantum mechanics than there is for relativity, but in both of them two principal interpretations can be identified. Relativity can be interpreted by the positivism of Einstein or by the realism of Lorentz, while quantum mechanics can be interpreted by the positivism of Bohr or by the realism of Einstein. In both cases the positivistic theory is generally preferred by the majority of physicists. This may be due partly to the physicist's dislike of being drawn into metaphysical discussions and partly to the prestige of Einstein as the sole originator of theory in the case of relativity and the prestige of Bohr, in his position as the leader of the main school of theoretical physics at the time, in the case of quantum mechanics.

It is also remarkable that in both cases one of the interpretations was due to Einstein, but in the case of relativity as a positivist and in the case of quantum mechanics as a realist. This is a reflection of the maturing of his philosophical beliefs as a result of his scientific creativity (Holton 1973, 197–217; Jaki 1978, 183–93). In his early years, when he formulated his theory of relativity, Einstein was profoundly influenced by the sensationalism of Ernst Mach, but subsequently, driven by his scientific creativity, he repudiated this view. He knew from his own experience that it is not possible to construct science just by the ordering of sensations. In his autobiographical notes, Einstein remarked that "in my younger years, Mach's epistemological position influenced me very greatly, a position which today appears to me essentially untenable" (Schilpp 1949, 21). He realized that it is not possible to construct science by ordering sensations: "The mind can proceed so far upon what it knows and can prove. There comes a point where the mind takes a higher plane of knowledge, but it can never prove how it got there. All great discoveries have involved such a leap" (Clark 1973, 552). Einstein found it more fruitful to take a God's-eye view of the world: "I want to know how God created the world. I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts; the rest are details" (Jammer 2000, 124, 234). According to Max Born, Einstein "believed in the power of reason to guess the laws according to which God has built the world" (Born 1956, 205). In his later years, especially during his arguments with Bohr on the interpretation of quantum mechanics, Einstein adopted a realist stance and did not hesitate to speak of unobservables. When he was challenged about this, and asked why he did not still adhere to the positivist approach underlying the theory of relativity, he replied, "Maybe I did believe that, but it is nonsense all the same" (Heisenberg 1971, 63). In answer to a similar question by Philip Frank, he replied, "A good joke should not be repeated too often," and to a similar question by Leopold Infeld, he remarked, "Yes, I may have started it, but I regarded these ideas as temporary. I never thought that others would take them so much more seriously than I did" (Clark 1973, 327).

RELATIVITY AND RELIGION

Modern science is rooted in Christian beliefs about the rationality and contingency of the natural world (Jaki 1978), and our concepts of space and time derive from the theological beliefs of Newton and Einstein (Jammer 2000). However, as Einstein remarked, "an important non-reciprocal relationship holds between religion and science: science is greatly dependent upon religion, but not vice-versa" (Ferré 1980, quoted by Jammer 2000, 133).

Many people thought that the advent of the theory of relativity heralded the end of absolute values. The then Archbishop of Canterbury, Randall Davidson, was told by Lord Haldane that "relativity was going to have a great effect on theology, and that it was his duty as head of the English Church to make himself acquainted with it." The archbishop took this advice seriously, obtained several books on the subject, and tried to read them. He did not have much success in his attempts to understand relativity and indeed was driven to a state of intellectual desperation. He therefore asked Einstein what effect relativity would have on religion and was told, "Do not believe a word of it. It makes no difference. It is purely abstract science" (Bell 1935, 1052; Jammer 2000, 125, 155). According to another version of the story, Einstein replied, "None. Relativity is a purely scientific matter and has nothing to do with religion" (Thomson 1936, 431). So that was that.

The archbishop comes out of this story rather well. In the first place, he actually listened to what he was told and went to the trouble of getting some books on relativity and trying to understand what it was all about. He made the usual assumption that any highly educated arts man can in a few hours master any scientific subject but soon realized his mistake. Then, instead of forgetting about the whole matter, he asked a scientist for his advice and chose a scientist who really knew about the subject. If only his example were followed today, we would be spared the acutely embarrassing spectacle of churchmen and churchwomen moralizing on scientific and technical matters without having understood the first thing about them.

"Einstein repeatedly emphasised his belief that physics did not directly relate to his social views, but this reassurance only increased the bewilderment of lay people." He was strongly opposed to any attempts to use physics to support religious, social, or political beliefs and dismissed the mass enthusiasm for relativity as "mostly psychopathological" (Graham 1982, 119). In spite of Einstein's disclaimer, relativity has had a great effect on moral and sociological affairs, but this is due to misunderstandings of the theory and not to the theory itself. It also can happen that ideas developed within science can stimulate or suggest developments in other fields without there being any logical connection, and examples of this can be found in the philosophical works of Percy Bridgman and Karl Popper (Holton 1982, xiii). Wider applications of relativity, such as those to artistic interpretation, sometimes betray a basic misunderstanding of the theory. It is thought that relativity means that objects can be viewed in many different ways and that their sum gives the total view. On the contrary, relativity tells us that our descriptions are independent of the coordinate system in which they are expressed and that each one of them gives a complete description (Holton 1982, xiv).

The theory of relativity has also influenced a wide range of theological discussions such as the relation of God to time. If God is outside time, past, present, and future are to God an ever-present now. More recently, the process theology developed by Whitehead and Charles Hartshorne has provided an alternative view. Such discussions are beyond the scope of this article. (See also Padgett 1993.)

The theory of relativity is concerned with the quantities that remain invariant during transformations between reference frames. Einstein "did not use the expression 'theory of relativity' in his original paper and for two years afterwards he called it 'invarienten theorie' [theory of invariants]" (Holton 1973, 382). The mathematician Felix Klein and the physicist Arnold Sommerfeld also thought "that the name 'theory of relativity' should be replaced by 'theory of invariants' because the theory is merely a theory of the invariants of the Lorentz transformation or, in the case of general relativity, of a more general transformation." "The term 'theory of relativity' is an unfortunate choice," wrote Sommerfeld, "its essence is not the relativity of space and time but rather the independence of the laws of nature from the viewpoint of the observer. The bad name has misled the public to believe that the theory involves a relativity of ethical conceptions, somehow like Nietzsche's *Beyond Good and Evil*" (Jammer 2000, 33–34). If the theory had been called the theory of invariance, we would have been spared all this trouble.

It does make sense to talk of absolute time, and it may be possible to identify an absolute frame of reference. There is a real difference between past and future, so relativity does not prevent us from trying to influence the future.

If relativity sometimes appears strange and unfamiliar, the fault lies in our own inadequate conception of nature. God's world is more subtle than we thought. In Einstein's own words, "*Raffiniert ist Herrgott, aber boschaft er ist nicht* [God is subtle, but not malicious]" (Pais 1982, vi).

NOTES

I am very grateful to Sarah Nelson and John Lucas for illuminating comments and suggestions, and I acknowledge with particular gratitude the book by Gerald Holton (1982), which has provided much valuable information.

1. The formula for the addition of velocities is $V = (v_1 + v_2) / (1 + v_1 v_2 / c^2)$. It may be derived from the Lorentz transformation (Lucas and Hodgson 1990, 57). A simple and direct derivation attributable to Whittaker is given on p. 8.

2. The Lorentz transformation can be derived in several ways (Lucas and Hodgson 1990, 57, 189). A simple form is

$$\begin{pmatrix} \gamma & i\beta\gamma \\ -i\beta\gamma & \gamma \end{pmatrix} \begin{pmatrix} x \\ ict \end{pmatrix} = \begin{pmatrix} x' \\ ict' \end{pmatrix}$$

Since $\gamma = (1 - v^2 / c^2)^{-1/2}$ is always greater than one, this immediately implies that bodies in motion appear to contract, and to live longer. The apparent lifetime is $\tau = \gamma t$, which is called the proper time.

3. To obtain the transformation for velocities, the Lorentz transformation is differentiated with respect to the proper time, giving

$$\begin{pmatrix} \gamma_v & i\beta\gamma_v \\ -i\beta\gamma_v & \gamma_v \end{pmatrix} \begin{pmatrix} \gamma\beta_x \\ it \end{pmatrix} = \begin{pmatrix} \gamma'\beta'_x \\ it' \end{pmatrix}$$

4. Now multiply by the invariant rest mass *m*, giving

$$\begin{pmatrix} \gamma_v & i\beta\gamma_v \\ -i\beta\gamma_v & \gamma_v \end{pmatrix} \begin{pmatrix} m\gamma\beta_x \\ mit \end{pmatrix} = \begin{pmatrix} m\gamma'\beta_x \\ mit' \end{pmatrix}$$

As $v \longrightarrow 0$, $\gamma\beta \longrightarrow v/c$, so $m\gamma\beta$ may be identified as the relativistic momentum.

5. The second component $m\gamma \approx m + (1/2)\, m\beta^2$, or $mc^2\gamma = mc^2 + (1/2)\, mv^2$, and this is the sum of the rest energy $E = mc^2$ and the kinetic energy $(1/2)\, mv^2$.

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