# ETHER AND RELATIVITY

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*Summary*

The relative retardation of clocks, predicted by the restricted theory of relativity, demands our recognition of the causal significance of absolute velocities. This demand is also implied by the relativistic equations of electrodynamics and even by the formulation of the restricted theory itself. The observable effects of absolute accelerations and of absolute velocities must be ascribed to interaction of bodies and physical systems with some absolute inertial system. We have no alternative but to identify this absolute system with the universe. Thus, in the context of physics, absolute motion must be understood to mean motion relative to the universe, and any wider or more abstract interpretation of the " absolute " must be denied.

Interaction of bodies and physical systems with the universe cannot be described in terms of Mach's hypothesis, since this is untenable. There is therefore no alternative to the ether hypothesis. It is shown that this is compatible with the restricted theory of relativity and even provides a tenable basis, when taken together with the principle of relativity, for that theory. It is shown that the hypothesis provides a satisfactory and sufficient causal explanation of the predicted relative retardation of clocks, and attention is drawn to its striking pedagogical and heuristic advantages.

## I. Introduction

In a recent letter to *Nature*, Professor Dingle (1957) has pointed out that the relative retardation of clocks, said to be predicted by the restricted theory of relativity (e.g. Einstein 1905; Builder 1957*a*) is an absolute effect which is a function of the velocities of the clocks. He concludes that: "*It should be obvious that if there is an absolute effect which is a function of velocity then the velocity must be absolute. No manipulation of formulae or devising of ingenious experiments can alter that simple fact.*"

Professor Dingle himself holds that this statement demonstrates that the prediction must be wrong. He claims that the restricted theory of relativity is incompatible with the ascription of causal significance to absolute velocities and, in particular, that it is incompatible with the existence of an ether. It will be shown in the following that this claim cannot be sustained.

The importance of the statement is obvious. It means that, if the prediction is correct, the restricted theory thereby demands our recognition of the causal significance of absolute velocities, even although it requires that we should be unable to detect or measure such velocities by observations of dynamical and electrodynamical phenomena.

In other words, if two isolated clocks move, in a region of the universe free of gravitational fields, in such a way that they coincide on two or more occasions,

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the restricted theory predicts that, in general, one will become retarded relative to the other in the interval between their successive coincidences, i.e. it predicts that, in general, something different will happen to the two clocks as a result of their individual motions. This cannot be related causally to their individual accelerations and must be related causally to their individual velocities.

More precisely, according to the restricted theory, the calculation of the relative retardation of the two clocks requires a knowledge of their individual speeds as measured in some inertial reference system. It is not sufficient to know the velocity of the clocks relative to one another ; it would still be necessary to know the velocity of one of the clocks and we would then know the speeds of both. In the much-quoted simple case in which it is postulated that one of the clocks remains at rest in an inertial reference system, so that the velocity of the second clock as measured in this system may be regarded as its velocity relative to the clock at rest, it remains true that the individual speeds of both clocks are thus specified and both are used in the calculation of the relative retardation ; this corresponds to putting $u=0$ in the general case given below.

Suppose that, according to the measures of some one inertial reference system $S$, the speeds of two standard clocks $A$ and $B$ are $u$ and $v$ at any instant $t$ and their coincidences occur at the times $t_1$ and $t_2$. Then, according to measurements made in $S$, the rates of the clocks at the instant $t$ are, respectively,

$$\mathrm{d}t_a/\mathrm{d}t=(1-u^2/c^2)^{\frac{1}{2}}\ ; \qquad \mathrm{d}t_b/\mathrm{d}t=(1-v^2/c^2)^{\frac{1}{2}}, \qquad \text{(1)}$$

so that the proper times of the clocks between their coincidences are given respectively by

$$t_a=\int_{t_1}^{t_2}(1-u^2/c^2)^{\frac{1}{2}}\mathrm{d}t\ ; \qquad t_b=\int_{t_1}^{t_2}(1-v^2/c^2)^{\frac{1}{2}}\mathrm{d}t. \qquad \text{(2)}$$

Thus, in the interval between their coincidences, clock $B$ becomes retarded relative to clock $A$ by the amount

$$t_a-t_b=\int_{t_1}^{t_2}(1-u^2/c^2)^{\frac{1}{2}}\mathrm{d}t-\int_{t_1}^{t_2}(1-v^2/c^2)^{\frac{1}{2}}\mathrm{d}t, \qquad \text{(3)}$$

and it may be shown that the value of this expression is an invariant for *all* systems of reference and for *all* observers.

This expression for the relative retardation is not a function of the accelerations of the clocks ; it therefore fails to suggest, and even precludes, the possibility of a causal relation between the relative retardation and these accelerations. This is consistent with the generally accepted view, which is basic in the general theory of relativity, that the rate of a clock is not a function of its acceleration.

Nor can the expression be written as a function of the velocity of one of the clocks relative to the other. Thus it does not suggest, and indeed precludes, any possibility of a causal relation between the relative retardation and this relative velocity. This is consistent with the fact that the context of the problem precludes any physical interaction between the two clocks, and hence precludes any possibility of ascribing causal significance to the motion of one relative to the other.

The expression of equation (**3**) is an explicit function of the individual speeds $u$ and $v$ of the clocks. It therefore suggests, and indeed implies, a causal relation between the relative retardation and these individual speeds ; this obviously arises out of a causal relation, implied by equations (**1**), between the rates of the individual clocks and their individual speeds. In other words, equations (**1**) themselves require that the two clocks behave differently if their speeds measured in $S$ are different, and require also that each clock will change its behaviour when its speed, measured in $S$, changes.

Any physical explanation of these causal relations must obviously be independent of the inertial reference system chosen for measurement or calculation. This is clearly required by the fact that the equations (**1**)–(**3**) take precisely the same form when expressed in the measures of any inertial reference system whatsoever. It is also required by the context, for this precludes any physical interaction of the clocks with any such reference system. This may be illustrated as follows. We could, if we wished, regard $u$ and $v$ in equation (**3**) as the speeds of the clocks relative to the system $S$, as measured in $S$. Yet we could not ascribe direct causal significance to these speeds relative to $S$, because any corresponding interaction, between the clocks and $S$, is precluded by the context. Indeed, the equations hold even if the system $S$ is purely hypothetical and if the quantities in the equations are merely postulated, or if they are calculated from measurements made in some other system.

It follows from this that any physical explanation of the phenomena described in equations (**1**)–(**3**) must be sought in the form of these equations rather than in their numerical content as determined by the measures of the system $S$. The fact that the form of the equations is independent of the choice of the inertial reference system implies that the existence in nature of the phenomena described by the equations is independent of the existence of any such inertial reference systems, hypothetical or physical.

Yet the fact that the clocks do behave differently when their speeds are different requires that they interact physically with *something*, in a manner which depends on their speeds. For the context requires that the two clocks be ideal standard clocks which behave identically in all respects when subject to the same conditions. Thus any difference in their behaviour must be ascribed to a difference in their physical interaction with their environment.

Since the context requires that the clocks be isolated from interaction with other actual bodies or physical systems in their vicinity, we are forced to conclude that they must interact with something universal or with the universe as a whole. This conclusion is permissible because the existence of the universe is implied by the context. Indeed, as I have pointed out elsewhere (Builder 1957*b*) the problem being considered would fall outside the domain of physical enquiry if this were not the case ; physics can give no guide as to what might be expected to happen to clocks isolated in an abstract empty space not related to this universe.

The only hypothesis that is tenable, and that is compatible with the foregoing considerations, is that there exists a unique absolute inertial system, such as the universe as a whole, which interacts with, and affects the behaviour of, the clocks in a manner dependent on their speeds relative to it, i.e. their absolute speeds.

This hypothesis is clearly sufficient. A reference system $S_0$ at rest relative to this postulated absolute inertial system would be one of the reference systems to which the restricted theory is applicable. We can therefore write for the rates of the clocks $A$ and $B$, as measured in $S_0$,

$$\mathrm{d}t_a/\mathrm{d}t_0=(1-u_0^2/c^2)^{\frac{1}{2}}\,; \quad \mathrm{d}t_b/\mathrm{d}t_0=(1-v_0^2/c^2)^{\frac{1}{2}}, \qquad \dots\dots\dots\dots (4)$$

and for the relative retardation,

$$t_a-t_b=\int_{t_{01}}^{t_{02}}(1-u_0^2/c^2)^{\frac{1}{2}}\mathrm{d}t_0-\int_{t_{01}}^{t_{02}}(1-v_0^2/c^2)^{\frac{1}{2}}\mathrm{d}t_0, \qquad \dots\dots\dots (5)$$

where $u_0$ and $v_0$ are the absolute speeds of the clocks at each absolute time $t_0$.

We thus have in equations (**4**) and (**5**) a causal account of the behaviour of the clocks given explicitly in terms of their absolute speeds $u_0$ and $v_0$. It is true that we cannot measure these speeds, because we cannot identify the system $S_0$; but this is not necessary, because all the *observable* consequences of (**4**) and (**5**) can be verified by measurements made in any inertial system $S$ and by calculations using equations (**1**) and (**3**). In other words, although equations (**1**) and (**3**) do not contain $u_0$ and $v_0$ explicitly, they do express, in terms of the speeds $u$ and $v$, all the *observable* consequences of equations (**4**) and (**5**).

*Thus we conclude that the relative retardation of clocks predicted by the restricted theory does indeed compel us to recognize the causal significance of absolute velocities* and that this recognition is compatible with the fact that these absolute velocities do not appear explicitly in the relativistic expression for the relative retardation, except in the unique and unidentifiable case in which the inertial reference system considered is at absolute rest.

The relative retardation of clocks is an effect which seems to be unique in that its measure is an invariant for all observers, whatever their state of motion. However, it is important to realize that this unique character arises solely from the fact that each of the clocks considered in this context incorporates an integrating device which provides an observable record of the accumulated effects of variations in its rate. Were we considering the periodic processes in a single atom, we would be without such a cumulative record ; but, as has been indicated above, equations (**1**) would still require us to postulate some absolute system which would affect the rate of these periodic processes in accordance with the absolute speed of the atom.

The corresponding relativistic variations of the mass and of the dimensions of a body similarly imply the existence of some absolute system which affects the mass and the dimensions of the body in accordance with its absolute speed. There is not, however, available any known mechanism which, like the integrating mechanism of a clock or the observable senescence of an animal, could provide us with any record of the cumulative effect of such variations. Yet it is clear that, were such mechanisms available, the restricted theory would predict that they would show cumulative effects analogous to the relative clock retardation. *Thus the demand for our recognition of the causal significance of absolute velocities is implied not only in the relativistic variations of the rates of clocks but also in the relativistic variations of the masses and dimensions of bodies.*

It is also implied in the relativistic equations of electrodynamics and even in the context of the restricted theory of relativity itself, as is shown in the next two sections.

## II. Electrodynamical Phenomena

The relativistic equations of electrodynamics are, in form, identical to the Maxwell-Lorentz equations. They differ in that the velocities occurring in them are defined as the velocities measured in the particular reference system being used, whereas the velocities in the Maxwell-Lorentz equations are defined as being relative to the ether, i.e. as absolute velocities. As is well known, the relativistic equations hold in every inertial reference system as relations between quantities measured in that system.

It follows that electrodynamical phenomena, as observed in any inertial reference system $S$, will display characteristics which are precisely the same as those that would, according to the Maxwell-Lorentz theory, be displayed in a reference system $S_0$ at rest in the ether. Thus the asymmetries and the dependence of the phenomena on the individual velocities of particles and bodies, which were such notable features of the Maxwell-Lorentz equations, are retained in the relativistic equations of electrodynamics and must necessarily be displayed in electrodynamical phenomena as observed in any inertial reference system.

It can be demonstrated that the phenomena observed in any inertial reference system $S$ are determined, at least in part, by the individual velocities and accelerations of particles and bodies. The phenomena cannot, in general, be described solely in terms of the velocities and accelerations of the particles and bodies relative to one another, and it will be shown that this is true whether these relative velocities and accelerations are measured in the inertial reference system $S$ (as they should be) or in the rest systems of the particles and bodies considered. It can also be shown that the phenomena observed in $S$ display marked asymmetries which are incompatible with any supposition that the phenomena depend only on the motions of the particles and bodies relative to one another; in particular, Newton's third law does not generally hold.

These points can best be demonstrated by considering the interactions of two point particles. For simplicity, only the interactions which depend on the particle velocities will be considered in detail. This is possible because the main effects of the velocities are independent of the accelerations. In any case, it is already well known and generally appreciated that the phenomena do depend, at least in part, on the individual accelerations of particles as, for example, in the radiation from an isolated point-charge which is subject to acceleration.

Consider first the interaction between a magnetic point-pole $m$ and a point-charge $q$ as observed in any inertial reference system $S$. It will be sufficient to consider two special cases.

(*a*) The pole $m$ at rest at the origin; the charge $q$ moving with uniform velocity $\mathbf{v}$ at the point $\mathbf{r}$.

(*b*) The pole $m$ at the origin moving with the uniform velocity $-\mathbf{v}$; the charge $q$ at rest at the point $\mathbf{r}$.

The instantaneous positions are the same in the two cases, and the velocity of the charge relative to the pole is, in each case, equal to $\mathbf{v}$; this is true whether the relative velocity is measured in $S$ (as it should be) or in the rest system of either of the two particles.

In case (*a*), with the pole at rest, the force $\mathbf{F}$ experienced by the charge, as measured in $S$, is given by

$$\mathbf{F}=(1/c)q\mathbf{v}\times\mathbf{B}_0, \qquad \text{(6a)}$$

where $\mathbf{B}_0$ is the magnetic flux density, due to the pole, at the position $\mathbf{r}$ of the charge.

In case (*b*), with the charge at rest, the force $\mathbf{F}'$ experienced by the charge, as measured in $S$, is given, approximately, by

$$\mathbf{F}'=\frac{1}{c}q\mathbf{v}\times\mathbf{B}_0\left\{1-\frac{3}{2}(\mathbf{v}.\mathbf{r})^2/r^2c^2+\frac{1}{2}\mathbf{v}^2/c^2\right\}, \qquad \text{(6b)}$$

where $\mathbf{B}_0$ has the same value as above. This equation may be derived by appropriate relativistic transformations, or it may be derived directly from the relativistic equations of electrodynamics, taking into account the retardations of the potentials.

Thus the force experienced by the charge, as measured in $S$, is different in the two cases, in spite of the fact that the relative velocity is the same. This difference can be ascribed to the finite time required for the transmission of electromagnetic effects, as expressed by the retardation of the potentials. Furthermore, it is easy to show that, in either case, the force experienced by the pole will usually differ from that experienced by the charge, so that Newton's third law will usually not hold.

This particular example is of special interest because of its relation to the phenomenon of electromagnetic induction displayed by a magnet and a conducting circuit when in motion relative to one another. At least in principle, equations (**6a**) and (**6b**) would permit the observable induction phenomena to be predicted in any specific case once the magnet and circuit configurations and motions had been prescribed. It follows that the observable phenomena in the case of magnet and conductor must depend in part on the individual velocities of the magnet and conductor. This can readily be verified for the simple case of a magnet moving, in the direction of its length, along the axis of a circular conducting circuit, by taking into account the retardation of the potentials.

It is true that, in the limiting case of velocities very small compared with that of light (so that transmission delays, and the consequent retardation of the potentials, can be neglected), the effects can be described in terms of the relative velocity alone. In this case equation (**6b**) is reduced to equation (**6a**). This may be a perfectly satisfactory approximation, from a practical point of view, in dealing with magnets and conductors under laboratory conditions; but the view expressed by Einstein, in the introductory paragraphs of his 1905 paper, that it is a fundamental characteristic of the phenomena, must be rejected. The fact that this view may have somehow suggested the restricted theory to Einstein is not a tenable argument in its favour, since he did not utilize it as a premise of the theory.

Apart from this special interest, it is better to consider the more general case of the interaction of two point charges $q_1$ and $q_2$, moving with velocities $\mathbf{v}_1$ and $\mathbf{v}_2$ at the simultaneous positions $\mathbf{r}_1$ and $\mathbf{r}_2$ in $S$.

It can be shown that the force $\mathbf{F}_1$ experienced by $q_1$, as measured in $S$, is given, approximately, by

$$\mathbf{F}_1=\frac{q_1q_2}{r^2}\left[1-\frac{3}{2}(\mathbf{v}_2.\hat{\mathbf{r}})^2/c^2+\frac{1}{2}\mathbf{v}_2^2/c^2\right]\left[\hat{\mathbf{r}}+\frac{1}{c^2}\mathbf{v}_1\times(\mathbf{v}_2\times\hat{\mathbf{r}})\right], \quad \ldots\ldots (7)$$

where

$$r\mathbf{r}=\mathbf{r}_1-\mathbf{r}_2.$$

This is an asymmetrical function of the individual velocities $\mathbf{v}_1$ and $\mathbf{v}_2$ and cannot be expressed as a function of the relative velocity $\mathbf{v}_1-\mathbf{v}_2$.

If $q_1$ is at rest and $q_2$ is moving with velocity $\mathbf{v}$, the force experienced by $q_1$ is given by

$$\mathbf{F}_1=\frac{q_1q_2}{r^2}\left[1-\frac{3}{2}(\mathbf{v}.\hat{\mathbf{r}})^2/c^2+\frac{1}{2}\mathbf{v}^2/c^2\right]\hat{\mathbf{r}}, \quad \ldots\ldots\ldots\ldots (7a)$$

whereas, when $q_1$ is moving with velocity $-\mathbf{v}$ and $q_2$ is at rest, the force experienced by $q_1$ is

$$\mathbf{F}_1=\frac{q_1q_2}{r^2}\hat{\mathbf{r}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7b)$$

Thus the force experienced by $q_1$ is different in the two cases. Yet the velocity $\mathbf{v}$ of $q_2$ relative to $q_1$ remains the same, and this is so whether it is measured in $S$ (as it should be) or in the rest system of either point charge.

Furthermore the force $\mathbf{F}_1$ experienced by the charge $q_1$ is not equal and opposite to the force $\mathbf{F}_2$ experienced by $q_2$ which, in the general case, is given by

$$\mathbf{F}_2=-\frac{q_1q_2}{r^2}\left[1-\frac{3}{2}(\mathbf{v}_1.\hat{\mathbf{r}})^2/c^2+\frac{1}{2}\mathbf{v}_1^2/c^2\right]\left[\hat{\mathbf{r}}+\frac{1}{c^2}\mathbf{v}_2\times(\mathbf{v}_1\times\hat{\mathbf{r}})\right]. \quad \ldots\ldots (8)$$

This asymmetry, between the forces experienced simultaneously by the two charges, obviously precludes any inference that the forces are determined solely by the relative motions of the charges.

At least in principle, all electromagnetic phenomena can be described in terms of the force formulae of equations (**7**) and (**8**). It is by no means difficult to derive in this way an expression for the force between two elements of currentcarrying conductors, or the force exerted by a current element on a moving charge. By such calculations, it may be shown that the force exerted by one current element on another is a function of the velocities of the charges within each current element and is not, even in part, determined by the velocities of the charges in either element relative to the charges in the other ; and, as is well known, the forces between the elements are asymmetrical and do not satisfy Newton's third law. Similarly it may be shown that, as is well known, the force exerted by a current element on a charge $q$ is a function of the measured velocity $\mathbf{v}$ of the charge and cannot be expressed as a function of its velocity relative to the current element as a whole, or relative to the charges in the current element.

Thus observers in any initial reference system $S$, and therefore also observers in any inertial reference system whatsoever, must agree

(i) that the electrodynamical phenomena are determined, at least in part, by the individual velocities of particles and bodies, and

(ii) that the observed phenomena are characterized by asymmetries which are incompatible with any supposition that they are determined solely by the motions of the particles relative to one another.

Thus the relativistic equations of electrodynamics imply causal relations between the phenomena observable in any inertial reference system, whether actual or hypothetical, and the individual velocities measured in that same system.

As in Section I, the context precludes any possibility of a physical explanation of these causal relations in terms of interaction of the particles and bodies with any one arbitrarily selected inertial reference system. Moreover, since the equations have the same form for every such inertial reference system, actual or hypothetical, the physical explanation of the implied causal relations must be sought in the form of the equations rather than in the numerical content of the equations in any arbitrarily selected inertial reference system. The required physical explanation is immediately available. *It is only necessary to postulate that the phenomena are* caused *by motions of particles and bodies relative to an absolute inertial system in accordance with the Maxwell-Lorentz equations.*

That this postulate is permissible in the context of the restricted theory is obvious. For an inertial reference system $S_0$ at rest relative to such an absolute inertial system is one of the permissible reference systems of the restricted theory. Thus the relativistic equations of electrodynamics must hold in the system $S_0$ ; these are identical in form with the Maxwell-Lorentz equations and become synonymous with them for the system $S_0$ in which the measured velocities are absolute velocities.

That this postulate is sufficient is also obvious. In the Maxwell-Lorentz equations the electrodynamical effects are related explicitly to the absolute velocities which cause them. It is true that we cannot measure these absolute velocities ; but, subject to this limitation, all observable predictions of the Maxwell-Lorentz equations can be verified by observations made in any arbitrarily selected inertial reference system. This may be expressed more specifically by saying that the postulate is sufficient because, if it is correct, it follows that the relativistic equations of electrodynamics must hold in any arbitrarily selected inertial reference system.

Moreover, the postulate is necessary, because there is not available any other tenable physical explanation of the causal relations, between electrodynamical phenomena and the individual velocities of particles and bodies, implied by the relativistic equations of electrodynamics.

*Thus the observable characteristics of electrodynamical phenomena, like the observable behaviour of clocks, demands our recognition of the causal significance of absolute velocities.*

## III. The Restricted Theory of Relativity

The restricted theory of relativity states that the spatial and temporal coordinates of an event, measured in any one inertial reference system, are related by the Lorentz transformations to the spatial and temporal coordinates of the same event, measured in any other inertial reference system.

The theory is thus restricted to measurements made in inertial reference systems. It is, of course, quite inapplicable to measurements made in systems in uniform motion relative to one another unless each of these systems is itself inertial. An inertial system is one in which the Newtonian laws of mechanics hold to a first approximation (Einstein 1905). This means that, if it is in a region of the universe free of gravitational fields, the system must be unaccelerated.

It is generally recognized and accepted that the acceleration of a physical system which is in a region of the universe free of gravitational fields can be detected by observations, within the system, of dynamical phenomena. If this were not so, it would be impossible to identify the class of reference systems, i.e. the inertial ones, to which the restricted theory is applicable.

The absolute character of acceleration forces us, like Newton, to postulate some absolute universal system relative to which bodies and systems are accelerated. Moreover, the possibility of detecting absolute acceleration by its dynamical effects forces us to ascribe these effects to interaction between the bodies affected and this absolute system. In particular, it is necessary to ascribe the inertia of bodies to such interaction. The necessity for this has been argued fully by Mach, Einstein, and others.

This absolute system, implied by the absolute character of accelerations, is of necessity itself an inertial system. It is therefore one of the infinity of inertial systems to which the restricted theory is, in principle, applicable. However, it is distinguished from all the inertial reference systems of the restricted theory by the fact that it alone interacts physically with bodies and systems. *Thus the possibility of defining and identifying the class of inertial reference systems to which the restricted theory is applicable demands the recognition that there must exist a unique absolute system which is itself inertial and which interacts physically with bodies and systems to cause the dynamical effects which enable us to detect accelerations relative to it.*

Acceleration of a body relative to this absolute system must, by the definition of acceleration, result in a change in its absolute velocity. Thus the existence in nature of something corresponding to the concept of absolute acceleration *entails* the existence in nature of something corresponding to the concept of absolute velocity.

It follows that any body or system which is accelerated must thereby suffer a change in its absolute velocity. Similarly, any two bodies which are in motion relative to one another must be moving with different absolute velocities. These statements are necessarily true even though we cannot measure the individual absolute velocities.* We can therefore determine whether the absolute velocity of a body remains constant or changes, and we can determine whether two bodies have the same or different absolute velocities. Moreover, these determinations can be made by purely kinematical observations.

It is true that, in accordance with the *principle of relativity*, we cannot measure or detect the absolute velocities of bodies by observations of dynamical or electrodynamical phenomena. Yet it cannot be validly inferred from this that absolute velocities of bodies could not be measured by other means; this point is discussed further in Section IV below. Nor can the principle of relativity preclude the possibility that there might be observable differences between the behaviour or properties of two bodies whose absolute motions are different and it has been shown, in Sections I and II above, that such differences are in fact observable. Since we have already been forced to postulate an absolute system which interacts with bodies to cause the observable effects of their absolute accelerations, it is reasonable to suppose that the same absolute system may interact with the bodies to cause observable differences, in their behaviour and properties, corresponding to the fact that their absolute velocities are different.

This thesis can be well illustrated by the restricted theory itself. Let there be supposed to exist two inertial reference systems $S$ and $S'$, similarly equipped for the making of physical measurements, which would in all respects be identical if compared together at rest. In other words, the systems are supposed to differ only in that their uniform motions are different. The restricted theory requires that measurements made in $S$ and $S'$ of the behaviour and properties of some other physical system $F$ should give different results. For example, the mass of a particular body in $F$, the length of a particular rod in $F$, or the rate of a particular clock in $F$, will be different according to the measures of $S$ and $S'$.

It is true that we can predict the relation between these measures in $S$ and $S'$ if we know the velocity of $S'$ relative to $S$. Yet we cannot ascribe any causal significance to this relative velocity because, in the context of the restricted theory, interaction between the systems $S$ and $S'$ is precluded by hypothesis. The context of the restricted theory similarly precludes the possibility of physical interaction between the systems $S$ and $F$, or between $S'$ and $F$.

* This argument has been set out in much greater detail by Wiechert (1911), who coined the word " Schreitung " to denote the condition of a body corresponding to what we have here referred to as its absolute velocity. A special term has the advantage that its use precludes any misunderstandings which might arise through attaching to the much-used word " absolute " implications lying outside the scope of the above discussion.

Yet the measures of $S$ and $S'$ are in fact different. There remains no alternative to assuming that this difference is caused by the difference in the absolute velocities of $S$ and $S'$.

The correctness of this assumption is strongly supported by our knowledge that measurements made in any inertial reference system show that the behaviour of clocks and of measuring rods differ if their measured speeds differ, i.e. if their absolute speeds differ. We are thereby compelled to infer that the behaviour of the clocks and measuring rods used in $S$ and $S'$ must be different. Such a difference in behaviour of the devices used for measurement must necessarily lead to, and can be shown to provide a detailed explanation of, the difference in the measures of $S$ and $S'$.

*Thus the restricted theory itself requires our recognition of the existence of an absolute inertial system which interacts with bodies and physical systems in a manner depending on their absolute velocities. In other words, it requires our recognition of the causal significance of absolute velocities.*

## IV. Absolute Space and Motion

It has been shown in the foregoing that the characteristics of physical phenomena, and the accepted formulation of the restricted theory of relativity, are such that we are compelled to admit the existence of an absolute inertial system which interacts physically with bodies and physical systems in a manner which depends on their accelerations and their velocities relative to it.

There is no feasible alternative to supposing that this absolute system is the universe as a whole, or else something universal which is an integral and essential part of the universe. *The term " absolute " must therefore be understood here to characterize anything which is defined, or measured, relative to the universe.* To accept any more abstract interpretation of the absolute would be meaningless in the context of physics, since all our physical measurements and all our physical theories relate to this universe and to it alone. Any question as to whether the universe itself is at rest, or in motion, in some broader or more abstract " absolute " sense lies outside the domain of physical enquiry.*

Thus, in this present context, *absolute motion* is to be understood as motion relative to the universe as a whole and *absolute space* as space defined by the

* This is the basis of the dictum of Poincaré (1908) : " Whoever speaks of absolute space uses a word devoid of meaning." He was, of course, then using the term in an abstract sense not uncommon in philosophy and he was, in fact, distinguishing this abstract absolute space from a universal ether at rest in the universe. This distinction has unfortunately sometimes been overlooked ; for example, Jammer (1954, p. 142) wrongly treats Poincaré's concepts of absolute space and of the ether as being identical and, incorrectly, quotes Poincaré's dictum as applying to both.

It is to be noted that our definition of the " absolute " cuts across the distinction, much discussed by philosophers, between Absolute and Relational Theories of Motion (e.g. see Broad 1923). Yet if we are to continue to use the word " absolute " at all in physics, we cannot ascribe any useful meaning to it other than that adopted here. As a philosopher, Professor Alan Stout's reference to this as the " relatively absolute ", though perhaps not very seriously intended, is not without point.

universe as a whole. Instead of the " universe as a whole " we can simply speak of the " universe " or, since the universe is primarily characterized by the distribution of matter, we could instead speak of the " distributed masses of the universe " as representing the universe approximately. As a still cruder approximation, we may usefully and picturesquely speak of the " fixed " stars as representing the universe, even though these stars are known to be in motion relative to it.

It must be recognized that these definitions of absolute space and of absolute motion are, respectively, purely geometrical and purely kinematical. They imply nothing whatsoever about the dynamical aspects of motion or about the physical characteristics of space. They do, however, make definite the concepts of absolute acceleration and of absolute velocity and enable us to prescribe how these are to be measured, i.e. relative to the universe or, approximately, relative to the fixed stars.

In practice, we can in fact make such purely kinematical measurements of absolute rotation ; we need only observe the rotation, of axes fixed in a body, relative to the fixed stars. On the other hand, purely kinematical measurements of small absolute linear accelerations and of small absolute velocities seem to be quite impracticable. The limitations in the accuracy of our measurements, the lack of any rigid reference framework of sufficient extent, and the time required by light to traverse the vast spaces of the universe, all preclude our mapping the absolute space of the universe with sufficient accuracy to measure small linear accelerations, or small velocities, relative to it. Even if these limitations were reduced, it would still seem to be impossible to deal with the very complex distribution and motion of matter in the universe.

In spite of the nature and extent of these limitations, it seems proper to regard them as being essentially practical rather than fundamental. They are, in fact, strictly applicable only to small accelerations and velocities. For example, it is generally accepted that the absolute velocity of the solar system cannot be very great ; if it were an appreciable fraction of the velocity of light there seems little doubt that this would be revealed by the asymmetry of the Doppler shifts in star light received from different directions.

Thus we are bound to recognize the admissibility of the concept of absolute velocity, and it may even be maintained that such velocities are, in principle, measurable by kinematical methods.

*This is not incompatible with the principle of relativity of the restricted theory.* The principle requires only that the laws which describe physical phenomena should take the same form for every inertial reference system (Poincaré 1904 ; Einstein 1905). Thus it requires only that we should be unable to detect absolute uniform motion by observations of dynamical and electrodynamical phenomena. The principle has no relevance whatsoever to the question of whether or not it is possible, in principle, to detect or measure absolute velocities by the purely kinematical methods referred to above.

Nor does the principle of relativity require that there should be no observable effects of the absolute velocities of bodies and physical systems. It requires only that any observable effects must be such that they fail to provide any measure of absolute velocity. Indeed, it has been shown above that the predictions of the restricted theory compel us to recognize that there are such observable effects.

## V. The Ether Hypothesis

Thus it has been shown that the dynamical and electrodynamical effects, both of absolute accelerations and of absolute velocities, are observable and must be ascribed to interaction of the affected bodies and physical systems with the universe.

To account for the absolute character of acceleration, Newton had postulated an " absolute space ". Mach, like Poincaré, interpreted this concept of Newton in an abstract sense and rejected it as inadmissible in the context of physics.* He postulated (1883) instead that the observed behaviour of bodies is determined by the distributed matter of the universe. This is well known as *Mach's hypothesis*† and it implies that the dynamical behaviour of bodies is determined by their direct and instantaneous interaction with the distributed matter of the universe. Although Mach was dealing only with the observable effects of absolute accelerations, it is obvious that his hypothesis would serve equally to account for any observable effects of absolute velocities.

Mach's *hypothesis* presupposes instantaneous interaction at a distance and cannot now be seriously considered (cf. Einstein 1920, 1924): it cannot be reconciled with the restricted theory of relativity and could in any case be reconciled with the continuous-action field theories of modern physics only by means of a theory including advanced potentials, and no satisfactory theory of this type has yet been, or seems likely to be, worked out.

*Thus Mach's hypothesis must be rejected and there is then no tenable alternative to the ether hypothesis*, i.e. that the space of the universe is endowed with important physical properties and plays a causal role, equal to that played by matter, in physical phenomena. Whether these properties are determined by the distributed matter of the universe, as in Einstein's cosmology, or whether they are *sui generis*, need not concern us here. It does not seem to be generally appreciated that Mach himself (1883, p. 283 of final 1933 edition) discussed the hypothesis of a medium, i.e. what we have called the ether, filling all space and interacting contiguously with bodies to cause the observable effects of acceleration. He held that such an hypothesis is admissible and recognized that it would be sufficient. He deemed his own hypothesis to be more " expedient provisionally "

* Einstein seems never, at least after about 1915, to have seriously considered any such abstract interpretation of Newton's concept, or to have supposed that it could mean anything but the space of the universe endowed with physical properties of causal significance (e.g. Einstein 1920, 1924). Instead, Einstein uses the term absolute, in connexion with space, only to mean that its physical properties are not affected by anything whatsoever, e.g. not even by the presence of matter.

† This is to be distinguished from what Einstein has called *Mach's principle* according to which he utilizes Mach's general idea but supposes that the distributed masses of the universe determine the dynamical behaviour of bodies by determining the properties of space (i.e. of the ether) in the vicinity of the bodies.

only because he claimed that there was then no experimental evidence to determine whether the part played by the distributed masses of the universe, i.e. as an absolute inertial system, is " fundamental or collateral ".

*The tenability and sufficiency of the ether hypothesis are beyond question.* If one is familiar with the historical background of the restricted theory (e.g. Whittaker 1953), with the expositions of the theory presented in the first quarter of the century, and with the whole of Einstein's writings, it is difficult to understand the present widespread view that the ether hypothesis is incompatible with the theory.

There is little doubt that this view originated in Einstein's statement (1905) that: "*The introduction of the 'luminiferous ether' will prove to be superfluous inasmuch as the view to be developed will not require an 'absolute stationary space' provided with special properties, or to assign a velocity vector to a point of the empty space in which electromagnetic processes take place.*" Any doubt that Einstein did, at that time, believe that the ether hypothesis should be discarded is removed by his more definite statement (1907) that: "*. . . the idea of a light ether as a bearer of electric and magnetic fields would not fit into this picture; electromagnetic fields appear here, not as a condition of any medium, but as self-existing things of the same sort as ponderable material and, together with it, have the same characteristic of inertia.*"

Einstein did not present any logical or evidential basis for these opinions. He was dealing with the relations that must subsist between measurements made in different inertial reference systems if the two postulates (that the principle of relativity of uniform motions is valid, and that the velocity of light is independent of the motion of its source) are to be reconciled. There was no *a priori* basis for these postulates; they were generalizations based on experience. Moreover, he adopted a very definite operational approach to the problem of measurement. Thus he could properly claim that he had demonstrated the necessity for adopting the Lorentz transformations without needing to seek any causal explanation of the state of affairs described by the postulates, and so without needing to discuss the ether hypothesis. He could not properly claim any more than this; nor could he, in his chosen context, properly infer anything about the tenability of the ether hypothesis.

It is in any case quite clear that Einstein did not long adhere to the opinions he had expressed in 1905 and 1907. This is clearly demonstrated in his later writings. There is little doubt that this change was forced on him by his formulation of the general theory; he seems first to have stated it in terms of the " ether " when he wrote (1920): "*The next position which it was possible to take up . . . appeared to be the following. The ether does not exist at all. The electromagnetic fields are not states of a medium . . . but are independent realities . . . More careful reflection teaches us, however, that the special theory of relativity does not compel us to deny the existence of an ether . . . On the other hand, there is weighty evidence in favour of the ether hypothesis. To deny the ether is ultimately to assume that empty space has no physical qualities whatever. The fundamental facts of mechanics do not harmonise with this view. According to the general theory of relativity space without ether is unthinkable; for in such space there not only would be no propagation* *of light, but also no possibility of existence for standards of space and time . . . nor therefore any space-time intervals in the physical sense.*"

Fortunately, there is no ambiguity or uncertainty as to the sense in which Einstein used the term " ether " in these passages. In the same context (1920) he relates the ether concept of which he is speaking to the ether of Lorentz, thus: "*What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with the matter and the state of the ether in neighbouring places . . . whereas the state of the Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same. The ether of the general theory of relativity is transmuted conceptually into the ether of Lorentz if we substitute constants for the functions of space which describe the former, disregarding the causes which condition its state.*" His concept of the ether, at this time, is even more specifically set out, in more technical language and in more detail, in his paper " Über den Äther " (1924); unfortunately there does not seem to be any published English translation of this paper. The subsequent developments of his views are not directly relevant to the present discussion: they are beautifully summarized in a document (1952) which is published as Appendix V in the 1955 edition of his " Relativity ".

Quite apart from Einstein's views, we cannot ignore the fact that the restricted theory of relativity had been developed independently by Poincaré and Lorentz before it was presented by Einstein, from a more deductive point of view, in 1905. The historical record, which has been set out in some detail by Whittaker (1953), is quite clear and is readily verified by direct reference to the original literature.

In effect, Poincaré and Lorentz had, in their formulation of the restricted theory, succeeded in reconciling the principle of relativity of uniform motions with the causal significance of velocities relative to the ether, inherent in the Maxwell-Lorentz theory of electrodynamics. In achieving this they did not in any way modify the concept of the ether specified by Lorentz in his extension of the Maxwell theory; but, like Einstein, they were forced to modify the Newtonian mechanics. *Although their derivation does not prove that the ether hypothesis is necessarily correct, it does prove that it is compatible with the restricted theory.*

The compatibility of the ether hypothesis with the restricted theory is also demonstrated in some of the earlier presentations and discussions of the theory. For example, Eddington (1920) presented the theory specifically in terms of the ether hypothesis. His derivation of the Lorentz transformation differs from that of Einstein only in that he starts with a hypothetical system at rest in the ether, whereas Einstein (1905) starts with a system he describes as " stationary ". Formally the derivations are identical and that of Einstein is in no way affected if we suppose his " stationary " frame to be also at rest in the ether. Moreover, Einstein's derivation would be in no way affected if his second postulate were reworded in the form: " That light behaves as if it were propagated in a medium, i.e. its velocity does not depend on that of its source."

*It is therefore to be concluded that we are without any tenable alternative to the ether hypothesis, and that this hypothesis is not only compatible with the restricted theory but is also a sufficient basis for the theory, i.e. when taken together with the principle of relativity.*

It remains only to demonstrate explicitly that the ether hypothesis provides a satisfactory causal explanation of the relative retardation of clocks, and to point out some of its pedagogical and heuristic advantages.

## VI. The Relative Retardation of Clocks

The ether hypothesis provides a satisfactory and sufficient causal explanation of the relative retardation of clocks. This claim has already been justified in the discussion of Section I, since the foregoing shows that we must identify the speeds $u_0$ and $v_0$ of equations (4) and (5) with the speeds of the clocks relative to the ether. Nevertheless, it seems desirable to set out this causal explanation more briefly and directly as in the following.

If the ether does in fact exist, any reference system $S_0$ at rest in it is one of the infinity of possible inertial reference systems of the restricted theory. We can therefore use the restricted theory to predict with certainty that a clock moving with speed $v_0$ relative to $S_0$, and hence relative to the ether, will suffer a reduction of its rate by the factor $(1-v_0^2/c^2)^{\frac{1}{2}}$ compared with the rate of a clock at rest in the ether.

Thus the assumption that motion of a clock through the ether, with speed $v_0$, *causes* a change in its rate by the factor $(1-v_0^2/c^2)^{\frac{1}{2}}$ is compatible with the restricted theory.

On the other hand, this assumption is also consistent with what the Maxwell-Lorentz equations for the ether would lead us to expect. Lorentz (1895) showed that, if the bonds holding the particles of a body together are electromagnetic, or have similar characteristics, then all bodies would be expected to suffer a contraction by a factor $(1-v_0^2/c^2)^{\frac{1}{2}}$, in the direction of their motion, when moving with speed $v_0$ through the ether (Fitzgerald-Lorentz contraction). This in turn requires that a clock in motion through the ether must be slowed down* by the factor $(1-v_0^2/c^2)^{\frac{1}{2}}$, as was first shown by Larmor (1900). If, on the basis of the Maxwell-Lorentz equations, we suppose that the motions of bodies and clocks through the ether do *cause* such reductions in length and in rate, respectively, and if we recognize that true one-way measurements of light velocity are impossible (so that we can measure only the average value of the light velocity over go-and-return paths), it *follows* that measurements made in different inertial

* This immediately follows if one considers a clock consisting of a rigid rod having mirrors at each end to reflect a beam of light backwards and forwards along the length of the rod. If this clock is set in motion with velocity $v_0$, it is easy to show that the frequency with which the light traverses the length of the rod is reduced by the factor $(1-v_0^2/c^2)^{\frac{1}{2}}$. The length contraction thus entails the clock-rate reduction, and the latter is not an independent hypothesis. This point has been overlooked by Broad (1923) and others when they have claimed that the ether theory requires these "two independent hypotheses" to account for the negative result of the Michelson-Morley experiment and for the measured constancy of the velocity of light.

reference systems must be related by the Lorentz transformations. In other words, it follows that the restricted theory of relativity must be valid. This was the course which led to the development of the theory by Poincaré and Lorentz (e.g. Whittaker 1953).

The extensive experimental evidence for the validity of the restricted theory is thus direct evidence for the *tenability* of the assumption that the reductions in length and in clock rates are caused by motion through the ether. This does not *prove* that the assumption is correct or that it is the only possible causal explanation of the fact that measurements made in different inertial reference systems are related by the Lorentz transformations. It does, however, show that the tenability of the assumption can be refuted only by showing its incompatibility with some other part of our physical knowledge of the universe. No grounds for such refutation have yet been demonstrated, and no satisfactory alternative causal explanation has been offered.

We are therefore justified in assuming that a clock in motion through the ether with velocity $v_0$ experiences a reduction in its rate by the factor $(1-v_0^2/c^2)^{\frac{1}{2}}$. Then, if two clocks move differently relative to the ether but coincide on successive occasions, it is apparent that, in general, one will become retarded relative to the other during the interval between such coincidences. If, for example, the first of the clocks remains at rest in the ether, and the second makes a journey away from and back to the first, it is obvious that the second must become retarded relative to the first. It is also easily shown that, if the first clock is in uniform motion relative to the ether and the second moves so that it travels away from the first and back to it, then the second must become retarded relative to the first. In both these simple cases, the second clock is observationally distinguishable from the first by the fact that its journey, away from and back to the first, requires that it should be subject to accelerations, whereas the first clock remains free from acceleration.

Now it is true that we cannot ascertain whether a clock is at rest relative to the ether ; but we can ascertain that it is at rest or in uniform motion relative to the ether ; this requires only that it be at rest or in uniform motion relative to any one inertial reference system. Similarly, we can always ascertain whether a clock is accelerated relative to the ether ; this requires only that its motion be accelerated relative to any one inertial reference system (e.g. Builder 1957*b*).

Thus, if two clocks are observed in an inertial reference system, the first of which is in uniform motion, or at rest, and the second of which is subjected to such accelerations that it moves away from the first and later returns to it, it follows that we must expect the second clock to have become retarded relative to the first in the interval between their coincidences.

Thus the assumption that clocks are slowed down by motion through the ether is a *sufficient* basis for predicting the relative retardation of two clocks which move, in the manner specified, relative to any inertial reference system. This is, of course, identical with the prediction of the restricted theory. We thus provide a tenable causal explanation of the relative retardation of clocks predicted by the restricted theory. In doing so we have ascribed causal significance to the absolute velocities of the clocks, i.e. to their velocities relative to the ether.

## VII. Conclusion

The permissibility of retaining the concepts of absolute space, of absolute motion, and of the ether, and the fact that we can assign to these concepts definite and clear meanings compatible with the restricted theory of relativity, has striking pedagogical and heuristic advantages.

The conceptual difficulties associated with the restricted theory all arise out of the denial that these absolute concepts are permissible, and out of the consequent attempts to avoid them in the presentation of the theory. It is frequently maintained that the theory has forced us to discard entirely the old-fashioned commonsense notions of time and space; but nothing comprehensible or definable has been offered in their place. Moreover, any questions as to what *causes* the relativity of simultaneity, the measured constancy of the velocity of light in all inertial reference systems, or the reciprocity of relativistic variations of length, of mass, and of clock rates, are evaded by vague references to the principle of relativity, to the four-dimensional character of space-time, and so on.

On the other hand, the presentation of the restricted theory in terms of the absolute concepts (following generally the lines of its development by Poincaré and Lorentz) involves no conceptual difficulties. The relativity of simultaneity, the reciprocity of relativistic variations, and the constancy of the measured velocity of light, then all appear simply as comprehensible effects of the motions, relative to the ether, of the bodies observed and of the measuring instruments used. The only other important factor that has to be taken into account is the impossibility of making true measurements of light velocity over a one-way path, so that we are restricted to measurements which give only an average value of the velocity of light transmitted over a go-and-return path. On this basis the presentation involves no more than a few simple calculations, and can be made easily intelligible and comprehensible to junior university students.

The heuristic value of this approach is also noteworthy. It reduces many questions, which would otherwise lead to discursive and inconclusive arguments, to a form in which a simple and conclusive answer can be given. For example, the relative retardation of clocks predicted by the restricted theory becomes a simple and intelligible consequence of the motion of the clocks relative to the ether.

Similarly, we are enabled to answer intelligibly what are otherwise very difficult and contentious questions, namely: Are the observed relativistic variations of length, of mass, and of clock rates, *real*? How can "reality" be reconciled with their reciprocal character? The answer is, of course, simply that these effects are *really-observable*, but that what corresponds to them in nature are real effects caused by the motions, both of the observed bodies and of the observing instruments, relative to the ether.

It is worth remarking that the pedagogical and heuristic advantages of this approach depend only on the *tenability* of the ether hypothesis and on the admissibility of the absolute concepts, i.e. on their compatibility with the restricted theory and with the general body of physical knowledge. These advantages would remain even if there were also available an alternative and equally tenable set of hypotheses and concepts.

It has not been practicable to give detailed references to the work of the many previous authors like Wiechert, Lodge, Ives, who have put forward important arguments in favour of the absolute concepts. Still less would it have been practicable to refer to, or to answer, the innumerable ebullient attacks made on the ether hypothesis in the last 50 years.

I have, in fact, tried to confine myself to material relevant to the discussion of what seems to me to be a new, and perhaps decisive, consideration in favour of the absolute concepts, i.e. the recognition (Dingle 1957) that the relative retardation of clocks, predicted by the restricted theory, is an absolute effect which demands our recognition of the causal significance of absolute velocities.

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