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A New Interpretation of the Special Theory of Relativity

V. BUONOMANO

Instituto de Matemática, Universidade Estadual de Campinas, Campinas, S.P., Brasil

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Abstract

Assuming the "Big Bang" theory as well as the usual axioms in the Special Theory of Relativity, the time dilations and length contractions are treated as real physical effects. This becomes possible by relating everything to the hypothetical frame, S_a, at rest relative to the "Big Bang" event. This frame in many senses plays the role of the classical aether frame. A clock's real ryhthm, as opposed to its rhythm observed by restricted methods, is then a function of its velocity relative to S_a (assuming a uniform gravitational field).

It is further assumed that gravitational radiation is composed of "electromagnetic-like" waves. Therefore when a clock changes its velocity in a uniform gravitational field it must receive a different total energy due to the average frequency shift (Doppler effect), the time dilations are then caused by the change in energy due to this frequency shift. That is, no two clocks can be in the "same" gravitational field unless they have no relative velocity, and therefore the Special Theory of Relativity is a special case of the General Theory from this viewpoint. Two feasible experimental tests, using the Mössbauer effect, are described that would decide on these viewpoints.

The principle of equivalence and the "twin paradox" are also discussed.

I

Before we proceed with a more or less formal presentation, we would like to give an intuitive description of our viewpoint. This is only meant to help communicate the viewpoint and by no means justify it.

A

First we accept that there was a "Big Bang," after which all the matter and energy began to distribute itself throughout the universe. All the electromagnetic energy (in which we include the so-called gravitational radiation) is transmitted by means of photons, all of which have the velocity c (in vacuum) relative to the hypothetical reference frame, S_a, in which the "Big Bang" event was at rest. Regardless of what happens to the photons they always have the velocity c relative to S_a (in vacuum). S_a then, in many senses, plays the role of the classical aether frame (see Section V.I).

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S_a,† in observing any other frame, S, that has a fixed relative velocity v, observes that the clocks and rods of S experience a dilation by a factor of $1/\sqrt{(1 - v^2/c^2)}$ for some as yet unknown physical reason. S_a also observes that because of this physical change in S's measuring instruments and movement, S always measures the velocity c for light (S need only use one clock and a mirror, so no method of synchronising clocks is used yet) and finds the same form for the laws of mechanics and electromagnetics.

S_a then concludes that because of this the Lorentz transformations must be valid. Therefore S making local measurements of S_a's instruments would observe the same dilations that S_a observes in S's instruments. So S observes the instruments of S_a to dilate by the same factor of $1/\sqrt{(1 - v^2/c^2)}$. S_a would make a sharp distinction between the real dilations, which cannot be the same, and the observed dilations which are symmetric for both observers.

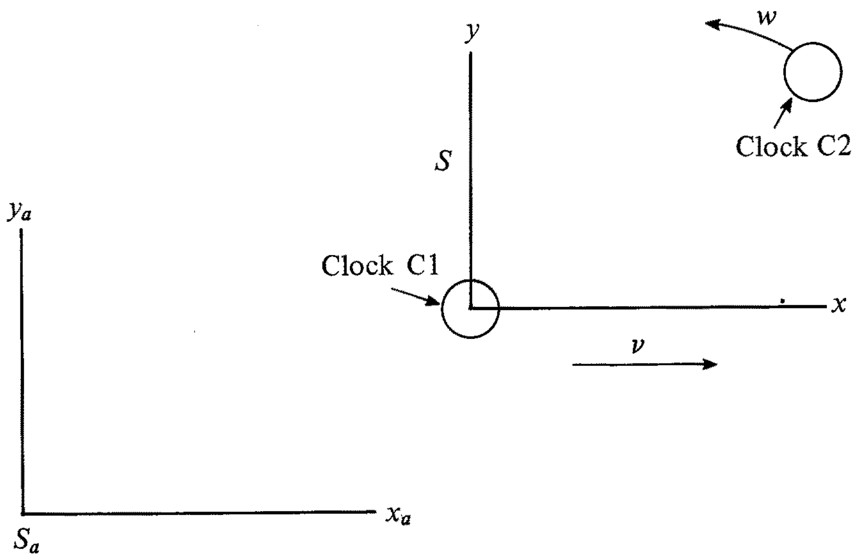

Diagram 1.—S has a velocity v relative to S_a. C2 is a clock rotating in a circle with a tangential velocity of w relative to S around the origin of S where there is fixed an identical clock C1 ($w < v$).

B

Now S_a asks the question, Why do the clocks and rods of S experience this physical change? He then observes that even though he and S are in the same intensity gravitational field they perceive it quite differently because of their

† We use S_a (S, etc.) to denote both the reference frame and an observer in the reference frame.

relative velocity. Due to the Doppler effect there is an average shift in each frequency that S receives because of its change in velocity. This means that S and S_a receive different amounts of gravitational energy (it is assumed that gravitational energy is transmitted via electromagnetic waves), even though they are in the same intensity field, due to these shifts. So S_a concludes that the rhythm of a clock (and the length of a rod) is a function of the total gravitational energy they receive, which is determined by both the intensity and frequency of the gravitational field. Note that from this viewpoint the Special Theory of Relativity is a special case of the General Theory of Relativity in other than a geometric sense.

II

In this section we more or less present the formal viewpoint.

A

We take the following as postulates:

(1) The laws of mechanics and electromagnetics have the same form for all inertial frames.
(2) The velocity of light is constant for all inertial frames.
(3) The "Big Bang" theory of the creation of the universe is correct.

(1) and (2) are just the usual postulates of the Special Theory of Relativity which give, in the usual manner, the Lorentz transformations (we assume clocks are synchronised by Einstein's method, see V.E). Using (3) we can interpret the effects of the Special Theory of Relativity in a fundamentally different way. That is, we say that the time dilations (length contractions) that are consequences of the Lorentz transformations are real physical effects in the same sense that they are in the General Theory. This becomes possible by relating everything to the hypothetical frame, S_a, in which the "Big Bang" event was at rest. It will be seen that in many senses S_a plays the role of the classical aether frame. The rhythm of a clock in a frame S, having a fixed velocity v relative to S_a, is then a function of this velocity. The greater the value of v the slower the rhythm of the clock. If this effect is considered real, it cannot obviously be symmetric for both S_a and S. What is symmetric is that both S_a and S each observe each other's clocks to run slower. That is, it is only the observed dilations that are symmetric, not the real dilation which only S experiences. The reason for this phenomena is because the measuring instruments of S are different from those of S_a and because of the movement of S. This statement is justified in Section III.

This is not to say that it is impossible for S to determine that it is his instruments that have changed, but says only that if S restricts himself to certain methods of measurement he will not be able to discover that his instruments have changed. An experiment, using the Mössbauer effect, is described in Section IV where it is concluded that S must be able to discover his movement relative to S_a if our viewpoint is to be correct. Note that since we have the Lorentz transformations, this viewpoint, to the best of our knowledge, is consistent with all known experiments.

B

Since we treat time dilation as a real effect, we have the question of its cause. If a clock changes its velocity in a uniform gravitational field, and experiences a physical change in its rhythm, there can be only two explanations (as we see it). One, the acceleration of the clock was the causal agent, or two, there is some significance in the velocity itself. We feel the acceleration can be eliminated for the reasons mentioned in Section V.F. This leaves only the velocity. We postulate:

(4) The effect of gravity is transmitted via "electromagnetic-like waves."
(5) The rate of a clock (length of a rod) is a function of the total gravitational energy it receives, which includes both the intensity of the field and the frequencies of the waves.

With these axioms we get what we feel is a pleasing point of view. If two clocks are in the same gravitational field but have a relative velocity, they must perceive this field differently due to the Doppler effect. That is, because there is an average shift in frequency, they receive different energies. This average shift is verified by Ives & Stilwell (1938): From this viewpoint the Special Theory of Relativity is a special case of the General Theory in the following sense. The Special Theory is the special case where the intensity of the gravitational field is constant, and a clock's rhythm changes with velocity because it receives a different total energy due to the frequency shift caused by this change in velocity.

Now it would be desirable at this point to give a single expression for the rhythm of a clock which included both the frequencies and the intensity of the gravitational field. We do not yet know how to do this. Note that if we use the relativistic Doppler formula $\nu' = \nu\sqrt{(1 - v^2/c^2)}/(1 - v/c)$ and assume that S_a receives the same intensity of each frequency from all spatial directions, we can derive that the energy a clock, C1, receives increases with velocity. Let C1 be in a frame S having the velocity v as in Diagram 1. Considering only the x_a direction and one frequency, ν_0, the total energy a clock in S_a receives is $E_a = Ih(\nu_0 + \nu_0) = 2Ih\nu_0$ where I is some constant giving the number of photons and h is Planck's constant. C1 would receive the energy

$$E = Ih(\nu_1 + \nu_2) = Ih\left[\frac{\nu_0\sqrt{(1 - v^2/c^2)}}{1 - v/c} + \frac{\nu_0\sqrt{(1 - v^2/c^2)}}{1 + v/c}\right]$$

$$= \frac{2Ih}{\sqrt{(1 - v^2/c^2)}} > E_a.$$

C

We remark here that even though S_a plays the role of the classical aether frame in many senses, unlike the aether frame there is no absolute significance to it, other than everything having "begun" together there. For example, it is not impossible to imagine another "Big Bang" that took place at a distance of greater than 10^{12} light years. We could then as yet have no knowledge of this "other universe". Letting S_a' play the analogous role to S_a in this "other universe," we are forced to conclude the following. First, within this "other universe" everything would be the same as here, including the same value for the velocity of light. To suppose otherwise would be to attribute properties to space. The relative velocity of S_a and S_a' could be anything, even greater than c. Light from this 'other universe' would not have the velocity c in our system but some other constant. The transformation laws between S_a and S_a' would be the Galilean ones, and therefore between two arbitrary inertial frames in "different universes" the transformation laws would be a composition of the Galilean and the Lorentzian ones.

III

A

In this section we start with the axioms below and derive that the velocity of light is equal to c for all inertial observers. This will justify several statements we made in Section II. It will be clear that there is nothing new about this derivation since it is just replacing the aether frame by S_a.†

(1) The velocity of light in vacuum relative to S_a is always c.
(2) The length of a rod and rate of a clock in a frame S having the velocity v is given by $\Delta l_0\sqrt{(1-v^2/c^2)}$ and $\Delta t_0/\sqrt{(1-v^2/c^2)}$ respectively. Δl_0 and Δt_0 are the rest values in S_a. These are to be taken as real dilations.
(3) The "Big Bang" theory of the creation of the universe is correct.

We first derive the Lorentz transformations between S and S_a, which are as illustrated in Diagram 1. Let $(x_a = 0, t_a = 0)$ be associated with $(x = 0, t = 0)$, and (x, t) and (x_a, t_a) be the coordinates of an event relative to S and S_a respectively. Letting $\gamma_v = 1/\sqrt{(1-v^2/c^2)}$ we have

$$x_a = x/\gamma_v + vt_a$$

since the rods of S are smaller by the factor $1/\gamma_v$. Since all clocks are synchronised by Einstein's method, S_a observes that two clocks of S separated by a distance of x, relative to S, are out of synchronisation by vx/c^2 in the

† For instance, L. Jonossy (1971) presents a particularly clear analysis of many problems from an aether point of view.

time scale of S. This statement is justified in Section V.H. Since the clocks of S run slow by a factor of γ_v we have

$$t_a = (t + vx/c^2)\gamma_v$$

These two equations give, after several algebraic steps, the desired results

$$x_a = (x + vt)\gamma_v \qquad \text{and} \qquad t_a = (t + vx/c^2)\gamma_v$$

We can then either reason similarly or solve these equations for x and t to get the other direction. This only gives us the transformations between S_a and any other inertial frame S. Let S' be another inertial frame having the velocity w relative to S_a along its x_a axis. We then have

$$x_a = (x' + wt')\gamma_w = (x + vt)\gamma_v$$

$$t_a = (t' + wx'/c^2)\gamma_w = (t + vx/c^2)\gamma_v$$

Solving for t and x in terms of x' and t' we get the transformations

$$x = (x' + zt')\gamma_z \qquad \text{and} \qquad t = (t' + zx'/c^2)\gamma_z$$

where $z = (v - w)/(1 - vw/c^2)$. (We used the algebraic identity given in Section V.D.) The origin of S' relative to S satisfies the equations $x = zt'\gamma_z$ and $t = t'\gamma_z$, which gives $x = zt$. So we can interpret z as the velocity of S' relative to S, and therefore have derived the Lorentz transformations. The Lorentz transformations then imply the velocity addition formula $z = (v + w)/(1 + vw/c^2)$, which implies the velocity of light is a constant for all inertial frames, we are now finished.

B

We can derive the constant velocity of light more intuitively as follows. Let S measure the velocity of light using two clocks C1 and C2 separated by a distance d, taking C1 at the origin. Relative to S_a, C2 runs behind C1 by vd/c^2 in the time scale of (V.H) S. Let a light ray leave C1 at $t_a = 0 = t_{c1}$ and arrive at C2 at t_{c2}. S would then conclude the velocity of light c_s is

$$c_s = d/(t_{c2} - t_{c1})$$

Now let us calculate what this number would be from the vantage point of S_a. According to S_a the actual time of the journey is

$$t_a = \frac{d/\gamma_v}{c - v} = \frac{d/c}{(1 - v/c)\gamma_v}$$

in the time units of S_a. This implies the journey takes

$$\frac{d/c}{(1 - v/c)\gamma_v^2}$$

in the time units of S. Subtracting the factor vd/c^2, because the two clocks of S are out of synchronisation by this amount (V.H), we get

$$t_{c2} - t_{c1} = \frac{d/c}{(1 - v/c)\gamma_v^2} - vd/c^2$$

$$= d/c$$

which gives

$$c_s = c.$$

If S had used only one clock and a mirror at C2 the same result is obtained.

We also note that any viewpoint which essentially presupposes the existence of an "aether type frame" must also postulate real dilations, in order for the speed of light to be a universal constant. This is easy to see from the above proof. This means Einstein's definition of synchronised clocks does not, in itself, by definition make the velocity of light a universal constant.

IV

In this section we describe an experiment first proposed in Buonomano & Moore (1973). To the best of our limited experimental knowledge this is a feasible experiment which could dramatically decide between the existing and presented viewpoint. This experiment is described again below (Part D), where also a more complete theoretical discussion is presented than the limited one in that letter. First it is necessary to discuss the so-called rotor type experiment in relationship to the Doppler Effect. It is assumed that the reader is basically familiar with this type of experiment (see Kundig (1963), Champeney *et al.* (1963), or Hay *et al.* (1962)).

A

The rotor type experiment is important because it provides, through the use of the very high sensitivity of the Mossbauer effect, a means of comparing the rhythm of two spacially separated "clocks" at exactly an angle of 90 degrees (this angle is necessary because otherwise the first-order Doppler Effect would dominate the measurements, and in practice the only way to guarantee this angle is by the rotation of one "clock" around the other).

Consider the situation illustrated in Diagram 1. The velocity $\bar{u}$ (a vector) of C2 relative to SP is to a first approximation

$$\bar{u} = (v - w \sin(TH), w \cos(TH))$$

and

$$u = \sqrt{[v^2 + w^2 - 2vw \sin(TH)]}$$

so depending on TH, the velocity of C2 relative to SP, is sometimes greater than C1 and sometimes less, varying between $(v - w)/(1 - vw/c^2)$ and $(v + w)/(1 + v\, w/c^2)$ for $TH = \pi/2$ and $TH = 3\pi/2$ respectively. This then means that C2 sometimes runs faster than C1 and sometimes slower, and has approximately the same rhythm for $\sin(TH) = w/2v$.

B

Because of this several researchers who also advocate a "Lorentzian type" theory (see Buonomano & Moore (1974) for reference) have proposed using a rotor experiment to discover this change of rhythm of C2 as a function of angle. This cannot be done, because when one assumes a "preferred" frame one should also make a distinction between the velocity of the emitter (source) and absorber (observer) relative to that "preferred" frame as in classical physics. When one does this it is found that the Relativistic Doppler Formula is valid. Consequently with this type of experiment this angular dependence of rhythm cannot be detected. More accurately what has been proved (Buonomano & Moore (1974)) is the following. The Relativistic Doppler Formula is completely derivable from any type theory of special relativity which assumes the existence of a preferred reference frame, real time dilations, real length contractions, and uses the classical distinction between the velocity of the source and the observer. This is expressed by the formula

$$\nu_0 = \nu_s[1 - (v_0/c)\cos(\theta_\rho)]\,\gamma_{v_s}/[1 - (v_s/c)\cos(\theta_\rho)]\,\gamma_v$$

$$= \nu_s[1 - (w/c)\cos(\theta_s)]/\gamma_w$$

where v_0 and v_s are the velocities of the source and observer respectively relative to SP. ν_s and ν_0 are the frequencies as measured in reference frames fixed with the source and observer respectively. w is the velocity of the reference frame of the observer relative to the reference frame of the source. θ_ρ and θ_s are the angles as measured in SP and in a reference frame fixed with the source respectively. γ_v is

$$\gamma_v = \sqrt{(1 - v^2/c^2)}$$

In the proof, the first equation is assumed to be the "natural" Doppler Formula in such a theory. It is just the classical Doppler Formula modified in the obvious way relative to the consideration of real time dilations. This proof does not depend on the assumption of the invariance of the phase of a wave.

C

Within the context of the presented theory the above result is only valid in an isotropic gravitation field. The reason for this is that what makes the above formula derivable is that the particular expression

$$T_0 = T/\sqrt{(1 - v^2/c^2)}$$

which in turn is a reflection of the gravitational energy the clock receives as per Assumption (1.5). In the case where there is a large anisotropy it only seems reasonable to assume that the energy a clock receives would be quite direction dependent and therefore expressed by an entirely different function of velocity. (It is not inconceivable that the previous formula could also be derived even in this case, but this would entail making what would seem to be, at this point, unreasonable assumptions. If this could be done, the experiment proposed would not serve as a test.) This fact can be made clearer by considering the extreme case where the gravitational field is entirely from one direction. The gravitational energy a clock would receive in this situation is quite direction dependent (the reader is reminded that the intensity of the field is always considered to be uniform). There is no inertial frame here that has the property of the "preferred" frame in an isotropic uniform gravitational field, in that it represents a frame that receives the minimum gravitational energy of any other frame in the same field.

D

Now consider the experiment proposed by Buonomano & Moore (1973) which is illustrated in Diagram 2. Here the intensity of the Earth's gravitational field is the same at Positions 1 and 2. But at Position 1 the absorber has a velocity w into the Earth's field, while at Position 2 it has the velocity w in the contrary direction. Therefore, according to the hypothesis that the rhythm of a clock is determined by the frequency at which it "perceives" the gravitational waves, the absorber must experience a greater dilation at Position 1 than at Position 2. This experiment is quite different from the one illustrated in Diagram 1 because of the anisotropy of the field due to the Earth. When the rotor is rotating in the plane of the Earth, there is no anisotropy because the Earth's gravitational field can be ignored with regard to the velocities of the "clocks" in that plane (this must really be considered an assumption) since it is perpendicular to the field. This is not the case in the proposed experiment.

E

So the prediction is that at Position 1, C2 will have a different rhythm than at Position 2 relative to C1, and that this will be measurable by the methods used in the above quoted rotor experiments. This is strictly a qualitative prediction since there is no mathematical framework to give a quantitative prediction.

Note, however, that this is in disagreement with both the Special and General Theories of Relativity using the Schwarzschild, Kerr or "rotation" Metrics. That this qualitative prediction does not come from the Special Theory or the "rotation" Metric is easy to see. That it is not derivable using the Schwarzschild Metric is seen to follow from the fact that all the differentials in this metric are quadratic. This implies that the direction in which the absorber is moving is irrelevant, and that the absorber as a clock would have the same rhythm at both Positions 1 and 2. This same thing essentially happens with the Kerr Metric

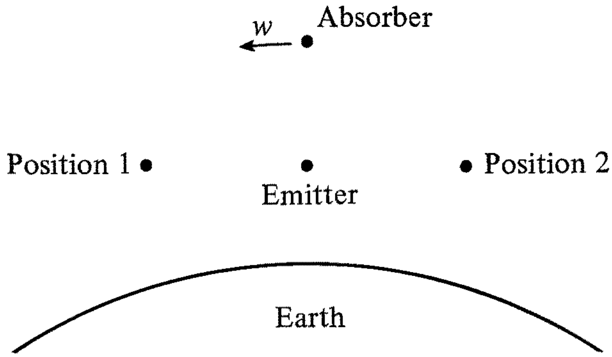

Diagram 2.–The rotor is rotating so that its axis of rotation is parallel to the surface of the earth. The tangential velocity of the absorber is w. Positions 1 and 2 are equidistant from the earth.

since the plane of rotation can be chosen (it need only remain perpendicular to the plane of the surface of the earth) so that the non-quadratic spacial differentials are identical for C2 at both Positions 1 and 2.

V

In this section we briefly present some miscellaneous observations from our viewpoint. We always assume a uniform gravitational intensity unless stated otherwise.

A

From our viewpoint the Principle of Equivalence is substantially weakened. This is because if a clock C1 is accelerating (linearly) it is continually changing its velocity relative to S_a, consequently its rhythm would be continually changing. If it were in an equivalent gravitational field its rhythm would remain constant. So there is a very real and important distinction given to these different states.

B

Consider the Twin Paradox in the following form. Let a clock C1 be "quickly accelerated" to the speed w, relative to S, which it maintains for T seconds relative to S. S has the velocity v relative to S_a, $w < v$. Then let C1 "quickly accelerate" at the point $x = d$ to the speed $-w$ relative to S which it again maintains for T seconds relative to S. Then let C1 "quickly decelerate" to zero velocity, returning to its starting point in S. Then let it be compared with an identical clock S2 which remained stationary there.

Our viewpoint says that C1 will show less time passed than C2. The analysis is as follows from the vantage point of S_a: During the entire trip C2 advances by the amount $2T$ in its own scale by the set-up of the experiment. Because the clocks of S are out of synchronisation by $\gamma_v \, vd/c^2$ relative to S_a (Section

V.H), the time will be $T(1 + vd/c^2)\gamma_v$ and $T(1 - vd/c^2)\gamma_v$ at the velocities $z_2 = (v + w)/(1 + vw/c^2)$ and $z_1 = (v - w)/(1 - vw/c^2)$ for the to and fro parts of the trip respectively. Observing that $d = wT$ we then find the clock C1 shows the time

$$T(1 + vw/c^2)\gamma_v/\gamma_{z_2} + T(1 - vw/c^2)\gamma_v/\gamma_{z_1}$$

having passed in its own scale. After using the algebraic identity given in Section V.D we get

$$T/\gamma_w + T/\gamma_w = 2T/\gamma_w$$

So C1 runs slow by the factor $1/\gamma_w$. This situation is not symmetric because the to and fro time is not equal for an observer fixed with C1. Also if the to and fro time is not symmetric for S then the experiment would be a different one, since C1 would return to a different position in S than its starting point. Observe that the key factor in an "aether analysis" is not which clock accelerated but which clock maintained the greater velocity for the longest time relative to S_a. In the case where the to and fro time is the same for S then on the average (relative to S_a) C1 maintains a greater velocity than C2.

C

Consider S_a and S again, and the Doppler effect strictly from the wave point of view. We can derive the relativistic Doppler effect which is symmetric for S_a and S using the classical distinction between a moving source and observer. Consider an observer with S_a, and the source with S having the velocity $-v$ relative to S_a. Then, classically, we have

$$\nu_a = \nu_s/(1 - v/c)$$

But due to the time dilation S's clocks go slower by γ_v. This gives

$$\nu_a = \nu_s/(1 - v/c)\gamma_v = \nu_s\sqrt{[(1 + v/c)/(1 - v/c)]}$$

Now when the source is with S_a and the observer is with S we have, classically,

$$\nu_s = \nu_a(1 + v/c)$$

But, in this case, since the clocks of S_a go faster than those of S, we get a larger frequency by the same factor.

$$\nu_s = \nu_a(1 + v/c)\nu_v = \nu_a\sqrt{(1 + v/c)/(1 - v/c)}$$

Between two arbitrary inertial frames S and S' we do not get this result, but only an approximation to it.

D

A useful algebraic identity is

$$\frac{1 + vw/c^2}{\sqrt{(1 - v^2/c^2)}\sqrt{(1 - w^2/c^2)}} = \frac{1}{\sqrt{(1 - z_2{}^2/c^2)}}$$

$$\frac{1 - vw/c^2}{\sqrt{(1 - v^2/c^2)}\sqrt{(1 - w^2/c^2)}} = \frac{1}{\sqrt{(1 - z_1{}^2/c^2)}}$$

where $z_1 = (v - w)/(1 - vw/c^2)$ and $z_2 = (v + w)/(1 + vw/c^2)$.

E

With regard to the synchronisation of clocks, we make the following comments. First one does not need a method of synchronising clocks. One could have a clock at the origin of a frame and, at each spacial position, an observer who, simultaneous with an event at his position, sends a light signal to the clock at the origin. This clock can then make a correction for the finite time of transit of the light (using c for the velocity). It is not difficult to see that from S_a's point of view this is exactly equivalent to using clocks which are synchronised by Einstein's method.

Since the synchronisation of clocks is imposed on reality by us, we have the question, Why use this particular method? The answer is that this method is consistent with the Lorentz transformations.

It is clear that the Lorentz transformations implicitly depend on a method of synchronisation. (This is so because the Lorentz transformations imply the velocity of light is constant for all inertial frames, but it is always possible to synchronise two clocks so that the velocity of light between them is any value required.) The reason that this method of synchronisation is consistent with the Lorentz transformations can be understood by analysing the situation from the point of view of S_a in terms of the dilations and movement of S.

F

In Section II we stated that the "cause" of the dilations was the velocity and not the acceleration. We give two reasons why we feel this way (we are assuming dilations to be real).

First let S be an inertial frame with a clock C1 at rest in it. Then let C1 accelerate to some velocity w relative to S, which it retains for a while, then decelerate it back to S. We also require acceleration and deceleration to be symmetric relative to S. Since we consider the time dilations as real, we have to conclude that C1 has a different rhythm at the velocity w than it has when it is at rest in S, where it has the same rhythm before and after its trip. (It is always a tacit assumption in relativity that two clocks in the same inertial frame always have the same rhythm. It is interesting to note that at least for the type clocks used in Hafele & Keating (1972) this assumption can at best be only given a probabilistic interpretation.) Therefore if the acceleration "caused" the dilation then it also "uncaused" it so to speak, since it has the same rhythm after its trip. This means there would have to be a directional distinction for acceleration. We can find no logical explanation for this.

Secondly, if we assume that acceleration "causes" the time dilation, then the only reason we can express the time dilations as a function of velocity is that it took so much acceleration for so much time to produce a given velocity (we are still assuming the "Big Bang" theory). If this was the case, then by the Principle of Equivalence a clock in a gravitational field would continually be changing its rhythm relative to another clock in a different gravitational field. We know this not to be the case from star spectra. Of course, we could deny the Principle of Equivalence in its strongest sense (which we do anyway) and hypothesise two different "causes" for a clock's rhythm to change, one for acceleration and one for a gravitational field. We see no way of doing this.

G

There are several meanings and forms of postulate (1) in Section II. Our viewpoint is clearly inconsistent with the form that means absolutely no distinction can be made between inertial frames. By virtue of the "Big Bang" and the frame S_a we make a very concrete distinction between rates of clocks in different frames. In regard to the form that states that all laws of nature are covariant in relation to the Lorentz transformations, our viewpoint is not clear. This is because one can make a strong conceptual difference between a frame, but not a mathematical one. Also since all of the laws of nature are not known, it is possible that a law of nature exists which has different forms in different inertial frames.

H

At several places we made the statement that S_a would observe two clocks, C1 and C2, in a frame S, having the velocity v, to be out of synchronisation by the amount vx/c^2 in the scale of S. The distance between C1 and C2 relative to S is x, and the clocks are synchronised by Einsteins's method. We justify this here. Let two light rays be emitted from the midpoint between

C1 and C2 in the usual manner. Now according to S_a the difference in the arrival time at C1 and C2 will be

$$t_{a1} - t_{a2} = \frac{x_a/2}{c - v} - \frac{x_a/2}{c + v}$$

$$= \frac{vx_a/c^2}{1 - v^2/c^2}$$

$$= \frac{vx/c^2}{\sqrt{(1 - v^2/c^2)}}$$

since $x_a = x\sqrt{(1 - v^2/c^2)}$. This is in the time scale of S_a. Then in the time scale of S we find the difference to be vx/c^2, since the clocks of S run slower.

I

We have defined the frame S_a as the hypothetical frame in which the "Big Bang" event is at rest. This is, of course, a very unpleasant situation since it is difficult to give meaning to this statement. This presents no difficulty in retrospect since according to our viewpoint it is theoretically possible to experimentally determine the velocity of an inertial frame relative to S_a using the experiment described in Section IV.A. Then any frame with zero velocity is S_a to a translation.

References

Champeney, D. C., Isaak, G. R. and Khan, A. M. (1963). Measurement of relativistic time dilation using the Mössbauer effect, *Nature, London,* **198**, 1186.

Hafele, J. C. and Keating, R. E. (1972). Around the world atomic clocks, *Science, New York,* **177**, 166.

Hay, H. J., Schiffer, J. P. and Egelstaff, P. A. (1962). A measurement of the red shift in an accelerated system, in *Proceedings of the Second Conference of the Mössbauer Effect*, Wiley.

Ives, H. E. and Stilwell, G. H. (1938). An experimental study of the rate of a moving clock, *Journal of the Optical Society of America* **28**, 215.

Janossy, L. (1971). *Theory of Relativity Based on Physical Reality.* Akcadémiai Kiadó, Budapest.

Kündig, W. (1963). Measurement of the transverse Doppler effect in an accelerated system, *Physical Review,* **129**, 2371.

Logan, J. L. (1973). Gravitational waves–A progress report, *Physics Today,* March.

Lorentz, K. (1923). *The Principle of Relativity.* Dover.

Weber, J. Logan, J. L., contains a list of relevant articles.