

Space-time Transformations in Ether Theories

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By assuming the validity of the principle of inertia and the existence of a privileged frame, the transformation laws (TL) between inertial frames are investigated in ether theories. For onedimensional space the TL's are fixed up to two undetermined functions of absolute velocity, $\Delta(v)$ and $E(v)$. If the principle of relativity is finally assumed, these functions acquire their well known Lorentzian expressions Δ_L and E_L . It is concluded that special relativity theory is "unstable", in the sense that any shift, however small, of Δ away from Δ_L and/or of E away from E_L leads to an ether theory. In Earth-based experiments one can expect deviations from c of the two-way and one-way velocity of light of the order of 10^{-12} and 10^{-9} , respectively.

1. Introduction

The interest in the foundations of the Special Relativity Theory (SRT) has been growing for different reasons:

- i) The historical researches carried out by Keswani [1], Zahar [2] and Tyapkin [3], that have led to a better understanding of the roles of Lorentz and Poincaré and of the alternative lines of thought that are logically open;
- ii) The realization [4] that Einstein was opposed to ether only around 1905 but later reverted to this conception in connection both with General and with Special Relativity;
- iii) The lasting influence of older papers such as those by Ives [5], Dirac [6], Builder [7], and Prokhovnik [8] in which the formal apparatus of SRT had been considered from an ether point of view;
- iv) The discovery of Bell's inequality [9], and the consequent development of the Einstein, Podolsky and Rosen paradox [10] that has become an experimentally testable contradiction [11]. In this connection some people believe that the reason for going back to the idea of an ether arises from the fact that in these EPR experiments there is some suggestion that something is going faster than light.

Many interesting papers have recently been devoted to the study of SRT. Among them are those by Honig [12], Mansouri and Sexl [13], Sjödin [14], Winterberg [15], Maciel and Tiomno [16], Cavalleri

and Bernasconi [17] and Spavieri [18]. Two conferences have mostly been devoted to SRT in recent years [19] and the quality of the papers presented is a sure sign that the whole field is growing.

The reasons of the present author for being interested in SRT are explained in the second part of this section. Section 2 deals with the principle of inertia and its consequences and introduces the physical and formal distinction between absolute and moving inertial frames. The units of space and time are chosen in Section 3, where also the transformation laws (TL's) between absolute and moving frames, and between two moving frames are obtained. The relativistic limit is performed in Sect. 4 and the physical conclusions are drawn in the final section.

The assumption that all the conceivable inertial frames are physically equivalent seems very reasonable at first sight, but actually contains a good deal of metaphysics. Consider in fact an inertial system moving with a certain velocity: more concretely, one can imagine a space-ship traveling in the interstellar space and carrying an astronaut-physicist. One knows that if the astronaut travels at normal or high (but not too high) velocity he will experimentally find that the idea of relativity works well. Suppose however that his velocity is such that the light of the stars in front of the space-ship is blue shifted to the point that it actually results of very high energy gamma rays, while the light from the stars in the back is red shifted to become very long radio waves. Obviously the gamma rays would quickly disintegrate the space-ship and the astronaut would die!

In these conditions the idea of relativity cannot be tested and it must obviously be considered metaphysical. One could perhaps agree with this conclusion,

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but object that after all the “interval of metaphysicity” of the relativity idea is very small (extending for β from 0.9999 ... to 1). This is however true in terms of velocity, but not true in terms of $\gamma = (1 - v^2/c^2)^{-1/2}$, for which, instead, the “interval of metaphysicity” extends from a finite value to infinity and is therefore infinitely larger than the interval where relativity can really be put to an empirical test. And it appears more plausible to use γ than β , since the former parameter is proportional to the total energy, which is an exactly conserved physical quantity (unlike velocity) and which can furthermore be totally transformed in real pieces of matter by means of nuclear or particle reactions.

From considerations such as these one might feel an interest in “improving” the theory of relativity and in finding a formulation that avoids the postulate of relativity altogether. A preliminary investigation of this problem is described in the following sections.

2. Transformations between Inertial Frames

The principle of inertia will next be shown to put by itself severe restrictions on the TL's between inertial frames [20] (those reference frames in which the law of inertia is seen to hold). Consider, for simplicity, a one dimensional space and two inertial systems S and S'. Let B be a body upon which no external forces are acting: B must then be observed to move with constant velocity u in S and u' in S'. The equations of motion will be

$$x = u t + x_0 \quad (\text{in S}), \quad (1)$$

$$x' = u' t' + x'_0 \quad (\text{in S'}). \quad (2)$$

Consider now the most general non singular TL's

$$\begin{cases} x' = x'(x, t), \\ t' = t'(x, t), \end{cases} \quad (3)$$

that can be inverted to give

$$\begin{cases} x = x(x', t'), \\ t = t(x', t'). \end{cases} \quad (4)$$

If one substitutes (4) into (1) one gets the equation of motion in S' as

$$x(x', t') = u t(x', t') + x_0. \quad (5)$$

This must however coincide with (2), since there cannot be two different equations for the same motion in a given system. By considering a double power

expansion of the functions (4) around the points $t' = \bar{t}'$ and $x' = \bar{x}'$ one must in particular assume that all second derivatives cancel in (5). For example, one must have

$$\left. \frac{\partial^2 x}{\partial x'^2} \right|_{\bar{x}', \bar{t}'} = u \left. \frac{\partial^2 t}{\partial x'^2} \right|_{\bar{x}', \bar{t}'} \quad (6)$$

whence, given the arbitrariness of \bar{x}' , \bar{t}' and u ,

$$0 = \frac{\partial^2 x}{\partial x'^2} = \frac{\partial^2 t}{\partial x'^2}. \quad (7)$$

It is easy to extend (7) to all types of second derivatives of x and t . By integration one thus gets a linear dependence of x and t on x' and t' :

$$\begin{cases} x = a x' + b t' \\ t = c x' + d t', \end{cases} \quad (8)$$

where we assumed that $x = t = 0$ if $x' = t' = 0$. We have thus proven the following:

Theorem: Given the principle of inertia, the transformation laws between two arbitrary inertial systems must be linear.

Obviously the principle of relativity was not assumed in deducing the previous result. It could perhaps be argued that the two ideas of inertia and of relativity were tightly related at the birth of modern physics in Galilei's writings.

Even if this is true, there can be no doubt that in contemporary physics the principle of relativity covers a much broader set of phenomena (e.g., the electromagnetic ones) than that of inertia. Anyway, in the general part of the present work relativity will not be used, while inertia will be introduced through its consequences (8).

We assume, tentatively, that there is a privileged or absolute inertial frame $S_0(x_0, t_0)$ in which x_0 and t_0 are space and time coordinate, respectively. S_0 could be, for example, the system in which the “ether” is at rest. Other inertial systems will be called “moving” systems and will be denoted by

$$S_1(x_1, t_1); S_2(x_2, t_2); \dots$$

with obvious notation. We can apply (8) and say that

- I) The TL's relating S_0 to $S_i (i = 1, 2, \dots)$ are linear;
- II) The TL's relating S_i to $S_j (i, j = 1, 2, \dots)$ are linear;

It will however be concluded that the TL's I) and II) are of the same type only if the principle of relativity is applied, in which case they both converge either to the Galilei, or to the Lorentz transformations. In all other cases the TL's between two moving systems are different from those between a moving system and the absolute one.

For the moment let us try and be as general as possible and write

$$\begin{cases} x_1 = a_1 x_0 + b_1 t_0 \\ t_1 = c_1 x_0 + d_1 t_0, \end{cases} \quad (9)$$

for the $S_0 \rightarrow S_1$ transformation. We assume that the determinant

$$\Delta_1 = a_1 d_1 - b_1 c_1 \quad (10)$$

is nonzero, so that (9) can be inverted to give

$$\begin{cases} x_0 = (d_1 x_1 - b_1 t_1) / \Delta_1 \\ t_0 = (a_1 t_1 - c_1 x_1) / \Delta_1. \end{cases} \quad (11)$$

Obviously all the coefficients a_1, b_1, c_1, d_1 and the determinant Δ_1 will depend on the absolute velocity v_1 of S_1 with respect to S_0 . Similarly one can write

$$\begin{cases} x_2 = a_{21} x_1 + b_{21} t_1 \\ t_2 = c_{21} x_1 + d_{21} t_1, \end{cases} \quad (12)$$

for the $S_1 \rightarrow S_2$ transformation, with

$$\Delta_{21} = a_{21} d_{21} - b_{21} c_{21} \neq 0, \quad (13)$$

so that

$$\begin{cases} x_1 = (d_{21} x_2 - b_{21} t_2) / \Delta_{21} \\ t_1 = (a_{21} t_2 - c_{21} x_2) / \Delta_{21}. \end{cases} \quad (14)$$

The coefficients $a_{21}, b_{21}, c_{21}, d_{21}$ and the determinant Δ_{21} can be expected *in general* to depend on the absolute velocities v_2 and v_1 , and not simply on the S_1-S_2 relative velocity. That this expectation is correct will be shown in the following.

3. Space-time Transformations

Just as in relativity, the problem arises of defining units of time and of length. One should not try to follow Einstein in his operative definitions of time and space. In fact, according to Popper [21]:

“It is an interesting fact that Einstein himself was for years a dogmatic positivist and operationalist. He later rejected this interpretation: he told me in 1950

that he regretted no mistake he ever made as much as this mistake”.

Some convention about space-time measurements is clearly needed: however we will not reduce the meaning of length and time intervals to their operative definitions.

As for length we assume the following: A measuring rod is produced in S_0 and taken there as unit of length. This allows one to measure x_0 . Many (e.g., identical) measuring rods are produced in S_0 and given to the moving systems S_1, S_2, \dots . This “giving” implies an acceleration of the rod which is brought to rest in the new system. We do not need to worry about the eventual deformations induced by the acceleration and/or by the absolute velocity. Whatever happens, the rod will be used as unit of length in the moving system. In this way x_1 , can be measured in S_1 , x_2 in S_2 , and so on.

Coming to time intervals we can proceed as follows. Many (e.g., identical) clocks are produced in S_0 , such that one can change their rate at will. Some of them are used in S_0 to measure t_0 and the other ones are given to S_1, S_2, \dots . Their rates will be regulated in order to meet the requirement of equal and opposite velocities: S_0 has now space and time units and can thus measure the absolute velocities v_1, v_2, \dots of S_1, S_2, \dots respectively.

The observer in S_0 , will inform those in S_1, S_2, \dots of the exact values of their absolute velocities. At this point the choice of the unit of time and of the rate of the clocks in the moving frames will be made in such a way that S_0 will be seen from S_1, S_2, \dots to move with velocity $-v_1, -v_2, \dots$, respectively.

At this point space and time are completely fixed in all inertial frames.

There is nothing left that can be fixed in order to make sure that if S_j is seen to move with velocity v_{ji} in S_i then S_i is seen to move with velocity $-v_{ji}$ in S_j . It will in fact be shown that in general

$$v_{ij} \neq -v_{ji} \quad (i, j = 1, 2, \dots).$$

We have seen that the transformation laws between the absolute system S_0 and the moving system S_1 are given by (9)–(11). The number of free parameters can be reduced if one imposes the following conditions:

i) The origin of S_1 ($x_1 = 0$) is seen from S_0 to move with equation

$$x_0 = v_1 t_0.$$

From the first of (9) it follows

$$b_1 = -a_1 v_1. \quad (15)$$

ii) The origin of S_0 ($x_0 = 0$) is seen from S_1 to move with equation

$$x_1 = -v_1 t_1.$$

From the first of (11):

$$b_1 = -d_1 v_1. \quad (16)$$

By comparing (15) and (16) one gets

$$d_1 = a_1. \quad (17)$$

Therefore (9) and (11), respectively, become

$$\begin{cases} x_1 = a_1 (x_0 - v_1 t_0) \\ t_1 = a_1 (t_0 - E_1 x_0), \end{cases} \quad (18)$$

and

$$\begin{cases} x_0 = a_1 (x_1 + v_1 t_1) / \Delta_1 \\ t_0 = a_1 (t_1 + E_1 x_1) / \Delta_1, \end{cases} \quad (19)$$

where

$$E_1 \equiv -c_1 / a_1. \quad (20)$$

Furthermore, from (10) one easily obtains

$$\Delta_1 = a_1^2 (1 - v_1 E_1) \quad (21)$$

that can be inverted to give

$$a_1 = \sqrt{\Delta_1} / \sqrt{1 - v_1 E_1}, \quad (22)$$

where the minus sign solution is neglected because space inversion is excluded: the x axes of inertial systems are chosen in such a way that they all point in the same direction.

Notice that (18) and (19) contain only two unknown functions of absolute velocity, as a consequence of (21)–(22). One can choose

$$E_1 = E(v_1), \quad (23)$$

$$\Delta_1 = \Delta(v_1) \quad (24)$$

in order to represent a particular ether theory.

Notice that the first (18) implies that a fixed point $x_1 = \bar{x}_1$ of S_1 is seen from S_0 to obey the equation of motion

$$x_0 = v_1 t_0 + a_1^{-1} \bar{x}_1,$$

that is to move with velocity v_1 . This holds for all points of S_1 (\bar{x}_1 is arbitrary), meaning that S_1 is seen from S_0 to translate rigidly with velocity v_1 . Also S_0 is

seen from S_1 to translate rigidly (with velocity $-v_1$), as it follows immediately from the first (19).

From the first (18) it follows also that a rod at rest in S_1 with length $x'_1 - x_1$ is seen in S_0 at times $t'_0 = t_0$ to lie between the points x'_0 and x_0 such that

$$x'_1 - x_1 = a_1 (x'_0 - x_0);$$

therefore the rod at rest in S_1 is seen from S_0 “contracted” by a factor a_1^{-1} .

From the first (19) it follows also that a rod at rest in S_0 with length $x'_0 - x_0$ is seen in S_1 at times $t'_1 = t_1$ to lie between the points x'_1 and x_1 such that

$$x'_0 - x_0 = \frac{a_1}{\Delta_1} (x'_0 - x_0);$$

this time the “contraction” is by a factor $\Delta_1 a_1^{-1}$.

The contraction factors from S_1 to S_0 and from S_0 to S_1 are thus different if $\Delta_1 \neq 1$. This asymmetry is hardly surprising in an ether theory: it means that observations of contractions can establish whether a frame is at rest or is moving.

A clock at rest in point \bar{x}_1 of S_1 that marks time t_1 is seen from S_0 at time

$$t_0 = a_1 (t_1 + E_1 \bar{x}_1) / \Delta_1$$

as one gets from the second (19).

Apart from a position dependent shift one has a “time dilation” factor a_1 / Δ_1 . A clock at rest in \bar{x}_0 of S_0 marking time t_0 is instead seen from S_1 at time

$$t_1 = a_1 (t_0 - E_1 \bar{x}_0)$$

as it follows from the second (18). Here the “time dilation” factor is a_1 and again there is an asymmetry if $\Delta_1 \neq 1$.

We have seen that the transformation laws between two moving systems S_1 and S_2 are given by (12)–(14). It will next be shown that all the parameters entering in these equations can be expressed in terms of the absolute velocities v_1 and v_2 and of the two unknown functions of absolute velocity $E(v)$ and $\Delta(v)$. But it is useful to start as follows:

i) The origin of S_2 ($x_2 = 0$) is seen from S_1 to move with equation

$$x_1 = v_{21} t_1.$$

Therefore, from the first of (12) it follows

$$b_{21} = -a_{21} v_{21}. \quad (25)$$

ii) The origin of S_1 ($x_1 = 0$) is seen from S_2 to move with equation

$$x_2 = v_{12} t_2.$$

Therefore, from the first of (14) it follows

$$b_{21} = d_{21} v_{12}. \quad (26)$$

By comparison of (26) and (25) one can write

$$d_{21} = \eta_{21} a_{21} \quad (27)$$

if

$$\eta_{21} = -v_{21}/v_{12}. \quad (28)$$

Notice that $\eta_{21} = 1$ if and only if $v_{12} = -v_{21}$. The principle of relativity would require $\eta_{21} = 1$, since the physical relationship between S_1 and S_2 should then be similar to that between S_0 and S_1 . Therefore one can say that $\eta_{21} - 1$ in general measures the breakdown of relativity. From (13) one can now obtain

$$\Delta_{21} = a_{21}^2 (\eta_{21} - v_{21} E_{21}), \quad (29)$$

where η_{21} and E_{21} are respectively given by (28) and by

$$E_{21} \equiv -c_{21}/a_{21}. \quad (30)$$

Notice that (29) can be inverted to give

$$a_{21} = \sqrt{\Delta_{21}} / \sqrt{\eta_{21} - v_{21} E_{21}}. \quad (31)$$

These results allow one to write the transformations (12) and (14) as follows

$$\begin{cases} x_2 = a_{21} (x_1 - v_{21} t_1) \\ t_2 = a_{21} (\eta_{21} t_1 - E_{21} x_1), \end{cases} \quad (32)$$

and

$$\begin{cases} x_1 = a_{21} (\eta_{21} x_2 + v_{21} t_2) / \Delta_{21} \\ t_1 = a_{21} (t_2 + E_{21} x_2) / \Delta_{21}. \end{cases} \quad (33)$$

Given (31), the unknown functions of the absolute velocities are

$$\Delta_{21}, v_{21}, \eta_{21}, E_{21}. \quad (34)$$

Their expressions will be found in the next section.

4. Combination of Transformations

One of the (implicit) conclusions of this work will be that in ether theories the transformation laws of space and time do not form a group. It is nevertheless clear that the combination of the transformation from S_0 to S_1 (18) with the transformation from S_1 to S_2 (32) must

coincide with the direct transformation from S_0 to S_2 , obviously given by

$$\begin{cases} x_2 = a_2 (x_0 - v_2 t_0) \\ t_2 = a_2 (t_0 - E_2 x_0). \end{cases} \quad (35)$$

By inserting (18) in (32) one gets

$$\begin{cases} x_2 = a_{21} a_1 [(x_0 - v_1 t_0) - v_{21} (t_0 - E_1 x_0)] \\ t_2 = a_{21} a_1 [\eta_{21} (t_0 - E_1 x_0) - E_{21} (x_0 - v_1 t_0)]. \end{cases} \quad (36)$$

Comparing with (35) one gets immediately

$$\begin{cases} R_{21} = 1 + v_{21} E_1, \\ R_{21} v_2 = v_1 + v_{21}, \\ R_{21} = \eta_{21} + E_{21} v_1, \\ R_{21} E_2 = \eta_{21} E_2 + E_{21}, \end{cases} \quad (37)$$

where

$$R_{21} \equiv \frac{a_2}{a_{21} a_1}. \quad (38)$$

The system (37) can easily be solved for the unknown quantities (those with index "21") to give

$$v_{21} = \frac{v_2 - v_1}{1 - v_2 E_1}, \quad (39)$$

$$\eta_{21} = \frac{1 - v_1 E_2}{1 - v_2 E_1}, \quad (40)$$

$$E_{21} = \frac{E_2 - E_1}{1 - v_2 E_1}, \quad (41)$$

$$R_{21} = \frac{1 - v_1 E_1}{1 - v_2 E_1}. \quad (42)$$

Notice that the denominator is always the same: $1 - v_2 E(v_1)$.

By using (31) for a_{21} , (22) for a_1 , and the analogous of (22) for a_2 , one can express R_{21} in terms of Δ_{21} , Δ_1 , Δ_2 . By using (42), one finally gets

$$\Delta_{21} = \Delta_2 / \Delta_1. \quad (43)$$

In this way all the unknown quantities (34) have indeed been expressed in terms of v_1 , v_2 , $E(v)$ and $\Delta(v)$.

By using (39)–(43) the transformations (32) and (33) can respectively be written

$$\begin{cases} x_2 = \frac{a_2 a_1}{\Delta_1} [(1 - v_2 E_1) x_1 - (v_2 - v_1) t_1], \\ t_2 = \frac{a_2 a_1}{\Delta_1} [(1 - v_1 E_2) t_1 - (E_2 - E_1) x_1], \end{cases} \quad (44)$$

and

$$\begin{cases} x_1 = \frac{a_1 a_2}{\Delta_2} [(1 - v_1 E_2) x_2 - (v_1 - v_2) t_2], \\ t_1 = \frac{a_1 a_2}{\Delta_2} [(1 - v_2 E_1) t_2 - (E_1 - E_2) x_2]. \end{cases} \quad (45)$$

One can thus see that the form of the “direct” and of the “inverse” transformations is the same, irrespective of which one of the two moving frames S_1, S_2 is endowed with the larger absolute velocity, as one would expect.

The relativistic limit of ether theories can be obtained by imposing two different conditions:

I) Condition $\eta_{21} = 1$: From (40) one gets

$$v_1 E_2 = v_2 E_1,$$

whence one sees immediately that the ratio E/v is a dimensionless universal constant, independent of the considered inertial frame. Since E has dimensions of inverse velocity one can write

$$E(v)/v = c^{-2},$$

where c is a velocity. Therefore, if $E_L(v)$ is the Lorentz expression of $E(v)$ valid in SRT, one gets

$$E(v) = E_L(v) \equiv v c^{-2}. \quad (46)$$

II) Condition $\Delta_1 = 1$: This is a consequence of the fact that a rod at rest in S_1 is seen in S_0 contracted by the factor a_1^{-1} , while a rod at rest in S_0 is seen in S_1 contracted by the factor Δ_1/a_1 . The two contractions can be identical only if $\Delta_1 = 1$. In the same way, obviously, $\Delta_2 = \dots = 1$.

Therefore the function $\Delta(v)$ becomes constant and equal to unity as in the standard Lorentz transformations, that are well known to have a unit determinant:

$$\Delta(v) = \Delta_L(v) \equiv 1. \quad (47)$$

The interesting consequences of the two relativistic conditions are

$$v_{21} = \frac{v_2 - v_1}{1 - v_1 v_2 c^{-2}}, \quad (48)$$

$$E_{21} = \frac{(v_2 - v_1) c^{-2}}{1 - v_1 v_2 c^{-2}} = v_{21} c^{-2}, \quad (49)$$

$$\Delta_{21} = 1. \quad (50)$$

From (22) and (31) it follows

$$a_1 = (1 - v_1^2/c^2)^{-1/2} \quad \text{and} \quad a_{21} = (1 - v_{21}^2/c^2)^{-1/2}, \quad (51)$$

and it is then easy to check that the transformations (18) and (32) both coincide with the Lorentz transformations of special relativity. Quite apart from notation we thus see that every transformation between inertial frames now depends exclusively on the relative velocity.

5. Conclusions

In the previous section we saw that (46), eventually with $c = \infty$, is a necessary consequence of the relativistic postulate. Any other function $E(v)$, even if very close to v/c^2 , but different from it, would single out a privileged frame and would thus effectively constitute an ether theory. The same conclusion holds for the limit $\Delta(v) = 1$ required by the relativistic assumption. We are so led to the conclusion that special relativity as a theory is “unstable”, in the sense that any violation of the conditions

$$E(v) = E_L(v) \equiv v/c^2, \quad \Delta(v) = \Delta_L(v) \equiv 1, \quad (52)$$

however small, leads necessarily to an ether theory. It follows also that there must necessarily exist ether theories compatible with all the experimental evidence that is usually invoked to stress the validity of special relativity.

Depending on the violations of (52) one can consider ether theories of three types

- 1) $E(v) = v/c^2, \quad \Delta(v) \neq 1,$
- 2) $E(v) \neq v/c^2, \quad \Delta(v) = 1,$
- 3) $E(v) \neq v/c^2, \quad \Delta(v) \neq 1.$

In ether theories there are interesting constraints on the function $E(v)$, that follow from (39). First of all one wants that $v_{21} \rightarrow v_2$ if $v_1 \rightarrow 0$ because the latter condition implies that S_1 coincides with S_0 . This means that

$$E(0) = 0. \quad (53)$$

Secondly one wants that v_{21} changes sign if both v_1 and v_2 do (isotropy of space). This implies

$$E(-v) = -E(v). \quad (54)$$

Thirdly, one does not want v_{21} to present any singularity. This implies

$$v_2 E(v_2) \leq 1$$

for all possible values of v_2 . If v_2 can grow without limit one must have $E(v_1)=0$, and this is the Galilean limit, at least for the composition of velocities, see (39). If instead $v_2 \leq c$, then

$$E(v_1) \leq 1/c. \quad (55)$$

Obviously (53) and (55) can be written together

$$0 \leq c E(v) \leq 1. \quad (56)$$

One can calculate the “two-way velocity of light” by composing $\pm c$ (maximum value of absolute velocities) with v_1 . Write

$$c_{21} = \frac{c - v_1}{1 - c E(v_1)},$$

$$\tilde{c}_{21} = \frac{-c - v_1}{1 + c E(v_1)},$$

then one easily gets

$$w_{21} = \frac{1}{2}(|c_{21}| + |\tilde{c}_{21}|) = c \frac{1 - v_1 E_1}{1 - c^2 E_1^2}. \quad (57)$$

The condition $w_{21} = c$ would then lead to

$$v_1 E_1 = c^2 E_1^2,$$

having only two solutions which, given the arbitrariness of v_1 , can be written

$$E(v) = E_G(v) \equiv 0 \quad [\text{Galilean form of } E(v)],$$

$$E(v) = E_L(v) \equiv v/c^2 \quad [\text{Lorentzian form of } E(v)].$$

Therefore, in all ether theories of 2nd and 3rd type $w_{21} \neq c$.

An estimate of the quantitative effects of ether can be obtained in the following way. Since $E(v)$ is an odd

function one can write

$$E(v_1) \simeq \frac{1}{c} (\beta_1 + \alpha \beta_1^3),$$

where $\beta_1 = v_1/c$ and α is an unknown constant expected to be of the order of unity. One then gets

$$c_{21} \simeq c \frac{1 - \beta_1}{1 - \beta_1 - \alpha \beta_1^3} \simeq c \left(1 + \frac{\alpha \beta_1^3}{1 - \beta_1} \right),$$

$$|\tilde{c}_{21}| \simeq c \frac{1 + \beta_1}{1 + \beta_1 + \alpha \beta_1^3} \simeq c \left(1 - \frac{\alpha \beta_1^3}{1 + \beta_1} \right),$$

$$w_{21} = \frac{1}{2} (c_{21} + |\tilde{c}_{21}|) \simeq c \left(1 + \frac{\alpha \beta_1^4}{1 - \beta_1^2} \right).$$

For Earth moving in space one expects $v_1 \simeq 300$ km/sec, $\beta_1 \simeq 10^{-3}$. Therefore the ether corrections to w_{21} are only of order 10^{-12} , while to c_{21} and \tilde{c}_{21} of order 10^{-9} . The latter quantities are, however, more difficult to measure.

What remains to be explained is why an ether theory should choose to approximate special relativity in $E(v)$ to lowest order in β .

Finally, notice that (18) and (19) must reduce to the identities $x_0 = x_1$ and $t_0 = t_1$ if $v_1 \rightarrow 0$. While E_1 is already known to vanish in this limit [see (53)], one must also require that a_1 tends to unity when $v_1 \rightarrow 0$. From (21) it follows

$$\Delta(0) = 1. \quad (58)$$

By requiring that nothing fundamental should change in (18) and (19) if $v_1 \rightarrow -v_1$ (isotropy of space) one can easily show that a_1 and Δ_1 should be even functions of v_1 . Therefore, for low values of v

$$\Delta(v) = 1 + O(v^2). \quad (59)$$

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