How the *apparent* speed of light invariance follows from Lorentz contraction*

Joseph Lévy

Mail address : 4, square Anatole France
91250 St-Germain-lès-Corbeil
France
E-mail : josephlevy1@compuserve.com

Abstract

The present paper aims at demonstrating that

1/assuming the equality of the two way transit time of light in two perpendicular directions of space (modern versions of Michelson's experiment), and the anisotropy of the one way speed of light in the Earth frame, two facts more and more confirmed today, length contraction appears necessary and can be easily deduced.

2/taking account of the above mentioned assumptions and of clock retardation, the apparent (measured) two way speed of light is demonstrated to be always identical and equal to C.

It is greatly to the credit of Builder and Prokhovnik to have demonstrated that, assuming Lorentz-Fitzgerald contraction, the two way transit time of light is the same in any direction of space.

We agree with the approach of these authors until a certain point, but, contrary to what is often believed, their theory failed to demonstrate that the one way speed of light, although anisotropic, is (paradoxically) always found equal to C.

The reasons of this paradoxical but important result, will be explained here. They represent a decisive argument in favour of Lorentz-Fitzgerald contraction.

I. Introduction.

Since the first steps of relativity, Lorentz-Fitgerald contraction has been the subject of a debate which is not closed today, and divides the physicists in opposite clans.

Some of them consider length contraction (L.C) as a naïve opinion, for example Wesley [1], Phipps [2], Cornille [3], Galeczki [4]. Some others consider it as a fundamental process which explains a lot of experimental facts. Among them Bell [5], Selleri [6], Builder, Prokhovnik [7], Dishington [8], Mansouri and Sexl [9], Wilhelm [10b].

Length contraction has been proposed by Lorentz [11] and Fitzgerald [12] in order to explain the null result of Michelson's experiment.

(In fact the result was not completely null, but much weaker than the one expected).

L. C was never observed. Of course it cannot be observed directly by an observer of the moving frame, since the standard used to measure it, also contracts. But it could be observed indirectly. This was the objective of different renowned physicists who tried to observe the physical modifications entailed by motion: variation of the refractive index of a refringent solid (Rayleigh [13] and Brace [14]), influence of the aether wind on a charged condenser the plates of which make a certain angle with the direction of translation (Trouton and Noble [15]), experiments of Trouton and Rankine [16] and of Chase

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[17] and Tomashek [18] on the electrical resistance of moving objects, and finally of Wood Tomlison and Essex [19] on the frequency of the longitudinal vibration of a rod.

But the experiments proved all negative.

In order to justify the lack of experimental evidence, Lorentz was compelled to postulate the variation of mass with speed (see ref [20], p 99 and 105). But, in ref [21], we demonstrated that the space-time transformations derived from the Lorentz postulates, are reducible to those of Galilei after correction of the systematic errors of measurement due to length contraction, clock retardation and imperfect clock synchronization (i.e Einstein-Poincaré procedure or slow clock transport). So, at first sight, these transformations do not seem really compatible with the law of variation of mass with speed. (In effect in order to demonstrate this law, we generally make use of Einstein's relativity principle which supposes the conservation of the total relativistic momentum in any inertial frame, and does not assume the Galilean transformations).

And then, the other Lorentz assumptions seemed incompatible with one of them. For this reason they appeared questionable to us in some earlier publications (ref [22,23]).

But, since that time, we have become aware that there is no real equivalence of all inertial frames for the description of the physical laws (see end of ref [24] and ref [25]). So, starting from this point, the objections opposed to Lorentz's justification can be overcome. (Note that if Lorentz's theory is reducible to Galilei's, this implies another assumption: the speed of a body with respect to the aether frame must be<C. So if a body A has the speed v_1 with respect to the aether frame and another body B has the speed v_2 with respect to the first, the two bodies and the aether frame being aligned, v_2 must be limited in such a way that $v_2 < (C - v_1)$.

A more recent experiment, by Sherwyn [26], proved also negative: the author considered an elastic rod rotating about one end in the laboratory frame. At low rotation rates, the length of the rod adiabatically follows the length demanded by the equilibrium lengths of the molecular bonds which, obviously, cannot be estimated by laboratory meter sticks, since they experience the same dependence of length on angle. However, according to the author, at high rotation rates, when the time required to rotate 90° becomes comparable to the period of vibration of the structure, the macroscopic length would not be able to exactly follow the "bond equilibrium length".

This statement appears questionable: if the time required to rotate 90° is comparable to the period of vibration, the adiabatic process should still apply. Probably, only for very high rotation rates the length of the rod would have no time enough to exactly follow the "bond equilibrium length".

Note that another argument seemed, at first sight, to go against Lorentz-Fitzgerald contraction: the compressibility of matter is limited, and length contraction seems difficult to justify at very high speeds.

For example at 0,9999C the ratio L/L_0 would be reduced to 1,4%.

But we can answer that the law has been proposed following an experiment performed at low speed (Michelson's experiment). It would not exactly adopt the same form at very high speeds.

Today, the author of this text realizes that there exists some strong arguments lending support to Lorentz-Fitzgerald contraction (L.C.). One of these arguments is that L.C permits one to explain (in all directions of space and not only in two perpendicular directions) the isotropy of the apparent (measured) average two way speed of light.

II. Length contraction is no longer an ad hoc hypothesis today

We know that all the usual measurements of the one way speed of light by means of the Einstein-Poincaré synchronization procedure are in fact equivalent to measurements of the apparent to and fro speed of light [7,27]. This is also true when we use clocks synchronized by slow clock transport [7,27] which is, in fact, approximately equivalent to the Einstein-Poincaré procedure.

According to Anderson, Vetharaniam and Stedman [28], all the recent experiments purporting to illuminate the isotropy of the one way speed of light were based on erroneous ideas (because they considered that the slow clock transport allows exact synchronization).

On the contrary, a number of arguments speak in favour of the anisotropy of the real one way speed of light. Although its direct appraisal is met by some major difficulties, it can be deduced from the measurement of the terrestrial aether velocity, based on the fact that light signals propagate isotropically in the aether frame.

A first estimation of the absolute velocity of the solar system was already made in 1968 by De Vaucouleurs and Peters, by measuring the anisotropy of the red shift relative to many distant galaxies. The experiment was made again by Rubin in 1976.

A more reliable estimate of the solar system velocity was obtained by measuring the anisotropy of the 2.7° K microwave background, uniformly distributed throughout the Universe. "An observer moving with velocity v relative to this microwave background can detect a larger microwave flux in the forward direction (+v) and a smaller microwave flux in the rearward direction (-v). He can observe a violet shift in the forward direction (+v) and a red shift in the rearward direction (-v) (Wilhelm)".

From this data, the absolute velocity of the solar system could be measured (Conklin (1969), Henry (1971), Smoot et al (1977), Gorenstein and Smoot (1981), Partridge (1988)).
Let us also quote the method of measurement based on the determination of the muon flux anisotropy (Monstein and Wesley (1996)).

An assessment of all these experiments is given by Wesley [10a] and Wilhelm [10b].

Marinov [29] also attested having measured the absolute velocity of the solar system by means of different devices (coupled mirror experiment, toothed wheels experiment). The experiments are described in detail in the book of Wesley [1], and are quoted by Wilhelm [10b].

Some physicists were suspicious about Marinov and regret not having the proof that the experiments were actually performed. But Wesley, who knew him very well, attested that he had no reason to doubt his reported results. According to him, "Marinov was extremely reliable and scrupulously honest in all of his personal dealing with people. He had a firm grasp on reality" [30].

The photograph of the toothed wheels apparatus has been published and is available.

The toothed wheels experiment estimated that the absolute velocity of the solar system v is of the order of 360 ± 40 km/sec, and that the speed of light is C-v in the direction of motion of the solar system and C + v in the opposite direction. (Notice that the orbital motion of the Earth around the sun is by far weaker (about 30 km/sec) and that the rotational motion at the latitude of the experiment was of the order of 0,5 km/sec).

This result was in agreement with most of the experiments described above.

Consider now a Michelson interferometer whose longitudinal arm is aligned along the x_0 axis of a system of coordinates S_0 (0, x_0, y_0, z_0) of the Cosmic Substratum. The arm is at rest in the Earth frame which moves along the x_0 axis at speed v.

It is easy to verify that, in return to the unique statement that the speed of light is C-v in the + x_0 direction, and C+v in the opposite direction, the arm will be contracted in the ratio

$$\ell = \ell_0 \sqrt{1 - v^2/C^2} \qquad (1)$$

where ℓ is the length of the arm in motion, and ℓ_0 the length at rest.

With the same standpoint we will demonstrate that the apparent (measured) average two way speed of light along the x_0 axis, is equal to C independently of the speed v.

Let us demonstrate formula (1).

A priori, we do not know if $\ell = \ell_0$ or not. The two way transit time of light along the longitudinal arm will be :

$$t_1 = \frac{\ell}{C - v} + \frac{\ell}{C + v} = \frac{2\ell}{C\left(1 - v^2/C^2\right)} \qquad (2)$$

Now, in the arm perpendicular to the direction of motion, there is no length contraction. The speed of light is C exclusively in the aether frame. The signal starts from a point P of this frame towards a point O at the extremity of the arm and then comes back towards point P'. During that time, the interferometer has covered the path vt_2 (see figure1).

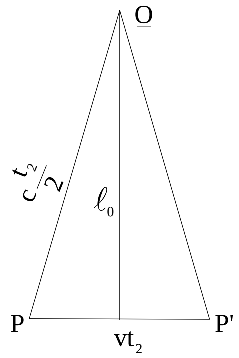

Figure 1

we have

$$\left(C\frac{t_2}{2}\right)^2 - \left(v\frac{t_2}{2}\right)^2 = \ell_0{}^2$$

$$\Rightarrow \qquad \ell_0 = \frac{t_2}{2}\sqrt{C^2 - v^2}$$

so that

$$t_2 = \frac{2\ell_0}{C\sqrt{1-\frac{v^2}{C^2}}} \qquad (3)$$

Neglecting the tiny displacement of the fringes observed when we change the orientation of the apparatus* , which is really too small to explain the existence of an aether wind of the order of 300 km/sec, we can write $t_1 = t_2$, so:

$$\frac{2\ell}{C\left(1-v^2/C^2\right)} = \frac{2\ell_0}{C\sqrt{1-v^2/C^2}}$$

Hence

$$\ell = \ell_0\sqrt{1-v^2/C^2}$$

So, taking account of the anisotropy of the real one way speed of light, length contraction must no longer be considered as an ad hoc hypothesis. On the contrary, it must rather be considered as a necessary cause of the Michelson result.

Now, on account of clock retardation, the apparent (measured) two way transit time of light will be (from (3)):

$$\frac{2\ell_0}{C}$$

Since the length of the longitudinal arm is determined with a contracted standard, it is found equal to ℓ_0 and not to ℓ, so that the apparent (measured) average two way speed of light along the x_0 axis will be found equal to C. (It is in fact different from its real value, which according to formula (2) is $C\left(1-v^2/C^2\right)$.

NB - In the absence of length contraction, the average two way speed of light would not have been found equal to C, in contradiction with the experiment.

III. Length contraction explains the *apparent* speed of light invariance

- But this is not all. We will now demonstrate that L.C leads to the independence of the apparent average two way speed of light with respect to any direction of space and with respect to the speed v.

* Note that, contrary to what is often believed, the modern versions of Michelson's experiment, greatly confirm the isotropy of the two way transit time of light. For example Joos (1930) detected a difference of the apparent two way speed of light in two perpendicular directions of 1.5 km/sec, Jaseja et al (1964) found 1 km/sec, Brillet and Hall (1979) found 16 m/sec, (8 km/sec for Michelson and Morley). For a review of the topic consult H.C Hayden, Phys essays 4,36, (1991).

The demonstration is based on Builder and Prokhovnik's [7] studies whose importance is indisputable but, as we will see, some of the conclusions of Prokhovnik were questionable and could not permit one to demonstrate that the *apparent* average two way speed of light is C in any direction of space.

Consider for that the two aforementioned inertial frames, and suppose that a rod A B making an angle θ with the x_0, x axis, is at rest with respect to frame S (see figure 2).

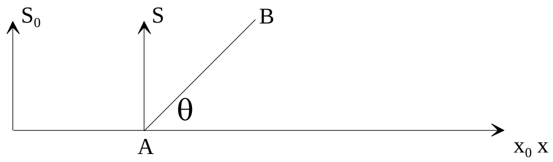

Figure 2

At the two ends of the rod, let us place two mirrors which face one another by their reflecting surface, this one being perpendicular to the axis of the rod $\ell = AB$. At the initial instant, the two frames S_0 and S are coincident. At this very instant a light signal starts from the common origin and runs along the rod towards point B. After reflection the signal comes back to point A.

We do not suppose a priori that $\ell = \ell_0$ (where ℓ_0 is the length of the rod when it is at rest in frame S_0).

We remark that the path of the light signal along the rod is related to the speed C_1 by the relation.

$$C_1 = \frac{AB}{t} \qquad \text{(see figure 3)}$$

where t is the time needed by the signal to cover the distance AB.

In addition, when the signal reaches point B, frame S has moved away from frame S_0 a distance:

$$AA' = vt$$

so $$v = \frac{AA'}{t}$$

Now, from the point of view of an observer of frame S_0, the signal goes from point A to point B' (see figure 3)

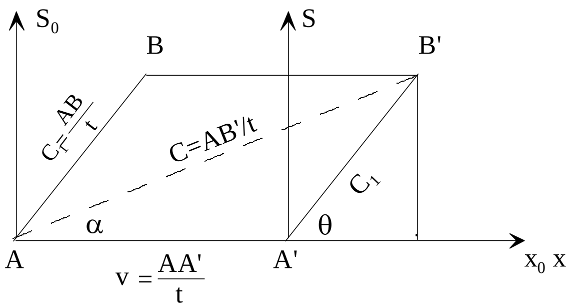

Figure 3

C being the speed of light in frame S_0, we have

$$\frac{AB'}{t} = C$$

and then, the projection of the speed of light with respect to frame S along the x axis will be:

$$C \cos \alpha - v$$

we remark that

$$C \cos \alpha - v = C_1 \cos \theta$$

The three speeds, C, C_1 and v being proportional to the three lengths AB', AB and AA' with the same coefficient of proportionality, we have

$$C^2 = (C_1 \cos \theta + v)^2 + C_1^2 \sin^2 \theta$$

so $$C_1^2 + 2v\, C_1 \cos \theta - (C^2 - v^2) = 0 \qquad (4)$$

(we must emphasize that equation (4) implies that the three speeds C, C_1 and v have been measured with the same clock, which obviously is a clock of frame S_0)

resolving the second degree equation, we obtain:

$$C_1 = -v\cos\theta \pm \sqrt{C^2 - v^2\sin^2\theta}$$

The condition $C_1 = C$ when $v = 0$ compels us to only retain the + sign so:

$$C_1 = -v\cos\theta + \sqrt{C^2 - v^2\sin^2\theta}$$

- Now, the return of light can be illustrated by the figure 4 below:

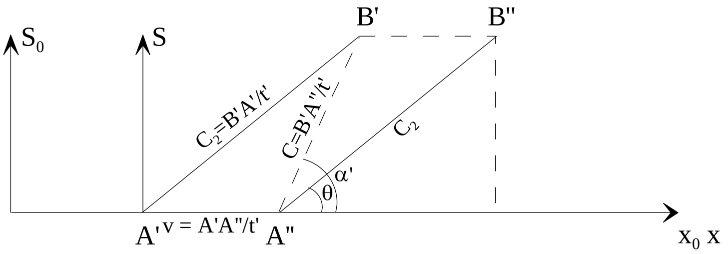

Figure 4

From the point of view of the observer of frame S, the light comes back to its initial position with the speed C_2.

So we can write:

$$C_2 = \frac{B'A'}{t'}$$

For the observer of frame S_0 the light comes from B’ to A’’ with the speed C, so that

$$C = \frac{B'A''}{t'}$$

During the light transfer, frame S has moved from A’ to A’’ with the speed v so:

$$v = \frac{A'A''}{t'}$$

The projection of the speed of light along the x axis will be

$$C_2\cos\theta = C\cos\alpha' + v$$

we easily verify that:

$$(C_2\cos\theta - v)^2 + (C_2\sin\theta)^2 = C^2$$

so

$$C_2 = v\cos\theta + \sqrt{C^2 - v^2\sin^2\theta}$$

The two way transit time of light along the rod AB (measured with clocks of frame S_0) is:

$$2T = \frac{\ell}{C_1} + \frac{\ell}{C_2} \qquad (5)$$

According to the experiment, T must be essentially independent of the angle θ. So 2T must be equal to

$$\frac{2\ell_0}{C\sqrt{1 - v^2/C^2}}$$

which is the two way transit time along the y direction (previously calculated).

We can see that, in order that this condition be satisfied, the projection of the rod along the x axis must shrink in such a way that:

$$\ell\cos\theta = \ell_0\cos\varphi\,\sqrt{1 - v^2/C^2} \qquad \text{(see figure 5)}$$

where φ was the angle separating the rod and the x_0 axis when the rod was at rest in frame S_0.

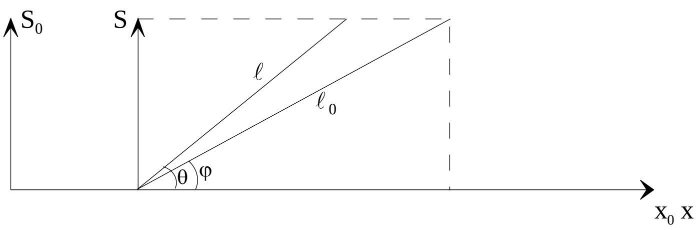

Figure 5

from: $$\ell_0 \cos\varphi = \frac{\ell\cos\theta}{\sqrt{1-v^2/C^2}}$$

and $$\ell_0 \sin\varphi = \ell \sin\theta$$

we easily verify that:

$$\left(\frac{\ell\cos\theta}{\sqrt{1-v^2/C^2}}\right)^2 + (\ell\sin\theta)^2 = \ell_0{}^2$$

finally: $$\ell = \frac{\ell_0\left(1-v^2/C^2\right)^{1/2}}{\left(1-v^2\sin^2\theta/C^2\right)^{1/2}}$$

replacing ℓ by this expression in (5) we obtain, as expected:

$$2T = \frac{2\ell_0}{C\sqrt{1-v^2/C^2}} \qquad (6)$$

Finally, from the above mentioned experiments demonstrating the anisotropy of the real one way speed of light, we deduced that the projections of this speed along the x axis of frame S are $C\cos\alpha - v$ when the light runs in the forward direction and $C\cos\alpha' + v$ when it runs in the rearward direction. These results, combined with the isotropy of the two way transit time of light, suffice to verify that the projection of the rod along the x axis shrinks in such a way that

$$\ell\cos\theta = \ell_0\cos\varphi\sqrt{1-v^2/C^2}$$

- But this is not all. The same conditions combined with clock retardation, allow us to demonstrate that the apparent (measured) two way speed of light is C in any direction of space.

Clock retardation is an experimental fact.

Let us designate as 2ε the two way transit clock display in frame S along the rod. We will have (from (6)):

$$\varepsilon = T\sqrt{1-\frac{v^2}{C^2}}$$
$$= \frac{\ell_0}{C}$$

Now, the length of the rod, measured with the contracted meter stick of frame S, is always found equal to ℓ_0, so that the average two way speed of light is found equal to C in any direction of space and independently of the speed v. (As we have seen this is also the case for the *apparent* one way speed of light measured by means of the Einstein-Poincaré synchronization procedure or by slow clock transport).

This result is highly meaningful and is a direct consequence of the facts observed in the course of the experiments of Michelson and Morley and Marinov (or any other equivalent experiment).

Note

In our demonstration, although we are indebted towards him, we differentiate from Prokhovnik's view [7]; in effect, since $C = AB'/t$ and also $C = B'A''/t'$, it is obvious that t and t' are the real transit times of light along the rod (as measured with clocks of the aether frame).

Now, since $C_1 = \frac{AB}{t}$ and $C_2 = \frac{B'A'}{t'}$ there is no doubt that C_1 and C_2 are also measured with clocks of frame S_0.

This is also the case for $2T = \frac{\ell}{C_1} + \frac{\ell}{C_2}$.

Nevertheless, according to Prokhovnik, in "The logic of special relativity" [7] chapter " The logic of absolute motion", the time $2T = \frac{2\ell_0}{C\sqrt{1-v^2/C^2}}$ is considered as the two way transit time of light along the rod, as measured with clocks of the moving frame, (see formula 5.2.4 of ref 22-1, French edition).

This cannot be true for the above-mentioned reason.

(Note that in our notation the moving frame is designated as S, while in Prokhovnik's notation, S designates the aether frame and A the moving frame. We will continue on the demonstration with our own notation).

In addition, if this were true, the apparent average two way speed of light measured with a meter stick of frame S would not be C. In effect, since this one is also contracted, observer S finds ℓ_0 for the length of the rod.

If Prokhovnik's approach were true, the apparent (measured) average two way speed of light in frame S would have been:

$$\frac{2\ell_0}{2\ell_0 / C\sqrt{1-v^2/C^2}} = C\sqrt{1-v^2/C^2}$$

which is not in agreement with the experimental facts.

The real two way transit time of light along the rod, as measured by an observer of frame S_0, is in fact $2\ell_0 / C\sqrt{1-v^2/C^2}$, and the two way clock display, as measured by an observer of frame S, is $2\ell_0/C$. This corresponds to the experimental facts, since, in return to this, the apparent average two way speed of light in frame S is found equal to

$$2\ell_0 \Big/ \frac{2\ell_0}{C} = C$$

(Note also that the real average two way speed of light along the x_0, x axis is

$$\frac{2\ell_0\sqrt{1-v^2/C^2}}{2\ell_0 / C\sqrt{1-v^2/C^2}} = C(1-v^2/C^2)$$

which, as expected tends towards 0 when $v \Rightarrow C$)

Note

The hypothesis of the aether dragged by the Earth has been generally rejected because it seemed in contradiction with the theory of aberration. But, as demonstrated by Beckmann [31], Mitsopoulos [32] and Makarov [33], this is not the case.

But the theory of the dragged aether is contradicted by the experiment of Lodge [34], who demonstrated that the speed of light is not modified in the neighbourhood of a rotating wheel; and by the experiments of Marinov [29,1] (toothed wheels experiment and coupled mirrors experiment), or all other experiments demonstrating the anisotropy of the one way speed of light.

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