On the Naturalness and Generality of the Principle of Relativity

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Abstract

Special Relativity theory postulates that the laws of physics are the same in all inertial frames of reference (the relativity postulate), and that the velocity of light in vacuum has the same value *c* in all inertial frames of reference (constancy of *c* postulate). We hereby show that relativity principle need not be postulated, since it follows from basic principles, without reliance on Lorentz transformations, or equivalently, reliance on the constancy of light postulate. The independency of the principle of relativity on the constancy of light postulate is featured by a different symmetry of Nature from the one constrained by the Lorentz transformations.

We also show that that the same deductions apply to the relativity of simultaneity principle. Furthermore, we show that the symmetry of the laws of Nature, as being embedded in Nature itself, is a general law, which holds true for **ALL** systems of moving bodies, regardless of the velocity of the signal which carries information between one frame of reference to another, provided that the velocity of the information carrier is constant with respect to its source, and exceeds the relative velocities between the system's reference frames.

Keywords: Relativity principle, Special relativity, Lorentz invariance, Lorentz factor, Symmetry.

Introduction

Special Relativity theory (Einstein, 1905) postulates that: 1. the laws of physics are the same in all inertial frames of reference (the principle of relativity), and 2. The velocity of light in vacuum has the same value c (= 299 792 458 m/s) in all inertial frames of reference (constancy of c).

The second axiom guarantees the consistency of the theory with the Lorentz Invariance principle (Lorentz, 1904), stating that the laws of physics are invariant under a Lorentz transformation between the coordinates of two frames of reference, moving at constant velocity with respect to each other.
By postulating the constancy of the velocity of light in vacuum, Albert Einstein sought to reconcile the physics of moving bodies with electrodynamics. Mathematically, reliance on Lorentz transformation is represented in Special Relativity by the famous Lorentz Factor, a fundamental element in the theory's departure from classical physics, and in its construction of a new relativistic physics of space and time.
A physical demonstration of Lorentz Symmetry is quite simple: Consider two reference frames, F *and* F', moving with constant velocity v with respect to each other (See Fig. 1). A "stationary" observer in frame F defines events with coordinates t, x, y, z. Another observer in F' defines events using the coordinates t′, x′, y′, z′. For simplicity, assume that the coordinate axes in each frame are parallel (x is parallel and x′, y to y′, and z to z′), and that the two systems are synchronized, such that at t = t′ = 0, (x, y, z) = (x′, y′, z′) = (0, 0, 0). If an observer in F records an event t, x, y, z, then according to Lorentz's transformation the observer in F' records the same event with coordinates:

$$t' = \gamma\,(\mathrm{t} - \frac{v\,x}{c^2}),$$
$$x' = \gamma\,(x - v\,t),$$
$$y' = y,$$
$$z' = z \tag{1}$$

Where c is the velocity of light in vacuum, and γ is the Lorentz Factor defined as:

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\beta^2}}, \quad (\beta = \frac{v}{c}) \tag{2}$$

By algebraically solving the equations in (1) for $(t,\ x,\ y,\ z)$ in terms of (t', x', y', z'), or by physically writing the event's equations from the point of view of the observer in F, the resulting Inverse Lorentz Transformations are:

$$t = \gamma\ (t' + \frac{v\ x}{c^2}),$$
$$\mathrm{x} = \gamma\ (x' + v\ t),$$
$$y\ = y',$$
$$z = z' \quad (3)$$

Since the positive direction of the x axis is arbitrary, the two sets of equations have an identical form, implying that the Lorentz transformation does the trick of achieving the desired symmetry of the laws of physics.

The literature on the constancy of the speed of light, and its place in a general theory of physics, is too large to be reviewed here. Decent discussions of these issues could be found in several articles (see e.g., Drory, 2015, 2016; Gao, 2017). On the experimental side, tests of the constancy of c are usually interpreted as lending support to the isotropy and constancy of the speed of light (see, e.g., Krisher, et al., 1990; Müller et al., 2003; Antonini, et a., 2005). Notwithstanding, almost everyone agrees that the constancy of c postulate is counterintuitive. When considering the relative motion between two cars traveling on a highway, we subtract or add velocities, depending on whether the two cars are traveling in the same, or in opposite directions. Similarly, sound waves emitted from a moving source with respect to a detector are redshifted or blueshifted, according to Doppler's formula, depending on whether the waves' source is traveling away or towards the detector. So why the photons, be it a particle or wave, is an exception? In this respect David Mermin asked rhetorically: "How can this be? How can there be a speed c with the property that if something moves with speed c then it must have the speed c in any inertial frame of reference? This fact—known as the constancy of the speed of light—is highly counterintuitive. Indeed, ''counterintuitive'' is too weak a word. It seems downright impossible". (Mermin, 2005, p. 25). We also contend that there is no logical explanation for why light, whether it is conceived as corpuscle, wave, or both, behaves differently than other things known to us in the universe.

Notably, there have been several attempts to drop the constancy of light postulate of Special Relativity theory (see, e.g., Ignatowski, 1910; Torretti 1983; Brown 2005; Behera, 2003, 2007; Feigenbaum, 2008 - for a comprehensive references list, see Gao, 2017). However, it has been recently argued that all the derivations of the Lorentz transformations from Special Relativity, without including its second postulate are flowed, and that one must assume in the

derivation the constancy of c postulate, just as was done by Einstein himself (Drory, 2015, 2016, Gao, 2017).
Another inconvenience with regard to the constancy of c postulate comes from the incoherency between the narrowness and specificity of this postulate, and the overarching generality of the relativity postulate. While the first principle is universal in scope, the second is only a particular property of light, which has obvious electrodynamic origins in Maxwell's theory (Gao, 2017). Similarly, Mermin (1984) remarked that "relativity is not a branch of electromagnetism and the subject can be developed without any reference whatever to light (Mermin, 1984, p. 119). In fact, Einstein himself admitted to some extent (Einstein 1935) that juxtaposing the general law of relativity with the specific principle of constancy of c is an incoherent mixture (see Stachel 1995).

In this short article we avoid the question of the constancy of c (c.f., Albrecht & Magueijo, 1999; Magueijo & Smolin, 2002; Magueijo, 2003; Barrow, 1999), and focus on the first axiom of Special relativity, i.e., the relativity postulate. We shall show that the symmetry in the laws of physics is guaranteed by Nature itself. In other words, the relativity principle need not be postulated since it follows quite naturally from basic principles. If our claim holds true, then the first postulate of Special Relativity becomes redundant, and consequently, the second axiom, which was introduced by Einstein to reconcile Special Relativity with the Lorentz Invariance principle, becomes useless.

Furthermore, we shall demonstrate that the relativity of simultaneity principle, is also a genuine property of Nature. More far reaching is our conclusion hereafter that the symmetry of the laws of Nature, being embedded in Nature itself, hold true for *all* systems of initially moving bodies, regardless of the velocity of the signal which carries information from one frame to another, provided that the velocity of the information carrier is constant with respect to its source, and exceeds the relative velocities between the system's reference frames. This implies that the relativity principle is a general inherent property of Nature, and is independent of c or any other specific constant.

On the Naturalness of Relativity

To show that Nature is inherently symmetric, with respect to its laws, consider the following analysis of the situation discussed earlier. Let us assume as before that two systems are synchronized, such that at $t = t' = 0$, $(x, y, z) = (x', y', z') =$

(0, 0, 0). Now consider the case in which an event starts at the point of origin in F' at $t = t' = 0$, and lasted for a period of $\Delta t' = t'_2 - t'_1 = t' - 0 = t'$, as measured at the event's rest frame by an observer in F'. In non-quantum systems, in which a possible entanglement between F and F' could be ignored, the observer at F have no way of knowing when the event at F' ended, unless information is sent to him from the observer at F' indicating the termination of the event. Such information could be sent by any type of information carrier as long as its velocity, V_c, exceeds the relative velocity v at which F' is departing from F, i.e., V_c should satisfy $V_c > v$. After t seconds for an observer in F, the reference frame F' will be at distance x = v t. Thus, the information about the termination of the event will arrive to the observer at F with delay of:

$$t_d = \frac{x}{V_c} = \frac{v\,t}{V_c} \tag{4}$$

Thus, the termination time registered by the observer at F will be:

$$t = t' + \frac{v\,t}{V_c} \tag{5}$$

Which could be written as:

$$t = \frac{1}{1 - \frac{v}{V_c}}\, t' = \frac{1}{1-\beta}\, t' \tag{6}$$

Where $\beta = \frac{v}{V_c}$

Derivation the distance transformation, using the same method is detailed in the appendix. The resulting transformation is:

$$x = \frac{1+\beta}{1-\beta}\, x' \tag{7}$$

To show that equations 6 and 7 are invariant with the frame of reference, consider the situation from the point of view of an observer in F' who observes an event of duration Δt as measured in the event's rest frame F. Due to the impossibility of a preferred reference by Ether-less Nature, it is obvious that the transformations will now look as follows:

$$t' = \frac{1}{1+\beta}\, t \tag{8}$$

And

$$x' = \frac{1-\beta}{1+\beta}\, x \tag{9}$$

As before, since the positive direction of the x axis is arbitrary, equations (8) and (9) are, respectively, identical to equations (6) and (7), implying the Nature is symmetric without the aid of Lorentz transformation, and that the demonstrated symmetry is valid for all information carriers, and not restricted to light, as long as the information carrier is travels faster than v.

Notably, For $\beta \rightarrow 0$ ($v << V_c$) we obtain:

$$t = \lim_{\beta \to 0} \frac{1}{1-\beta}\, t' = t', \tag{10}$$

and,

$$x = \lim_{\beta \to 0} \frac{1}{1-\beta}\, x' = x' \tag{11}$$

Thus restoring the classical Galilean relationships. It is worth noting that as long as time intervals and lengths are concerned, the transformations depicted in equations 6 and 7 could be derived without synchronization between the clocks at the two reference frames.

Relativity of Simultaneity

An important antecedent of the relativity of time in Special Relativity theory, distinguishing it profoundly from Galileo-Newton physics, is the relativity of simultaneity. Because light takes a finite time to traverse a distance in space, it is not possible to define simultaneity with respect to a universal clock shared by all observers. As example, two events which occur simultaneously at

spatially separated points in space at one reference frame, will not observed as simultaneous in another frame, moving with respect to the first.
In the example above, if two event e_1' and e_2' take place simultaneously at distances x_1' and x_2' from the origin in F', then they cannot be recorded as taking place simultaneously by an observer in F, since the information about the occurrence of e_2' will take more (or less) time to reach an observer in F, than the information about the occurrence of e_1'.

Asymmetry in Space
Interestingly, the symmetry of the time and distance transformations with respect to the choice of the system's coordinates, is gained by virtue of an asymmetry of Nature with regard to the directionality of relative motion between the frames. As could be seen from eq. (6), for $\beta > 0$ (i.e, for F and F' departing from each other) we have $t > t'$ (time extension), whereas for $\beta < 0$ (i.e, for F and F' approaching each other) we have $t < t'$ (time contraction). Similarly eq. (7) reveals that for $\beta > 0$ (i.e, for F and F' departing from each other) we have $x > x'$ (length extension), whereas for $\beta < 0$ (i.e., for F and F' approaching each other) we have $x < x'$ (length contraction). Also, it is pretty obvious, without making the calculations, that simultaneity could be preserved *only* if the two events occur at the same point in F' ($x_1' = x_2'$).

Summary and concluding remarks
The main conclusions from the above analysis could be summarized in the following points:

1. Nature is endowed with Symmetry with respect to its laws. In other words, the principle of relativity is a profound property of Nature, and does not require any axiomatization.
2. The relativity of simultaneity is secured by Nature as well.
3. The principle of relativity applies to *all* physical systems, independently of the modality of the information carrier, and is not specific to systems in which information translation between reference frames is conducted by electromagnetic waves. This results holds true provided that the velocity of the information carrier is constant relative to its source, and exceeds the relative velocities between the system's reference frames.

4. From 3 it follows that the principles of relativity and impossibility of simultaneity, being general inherent properties of Nature, are independent of c, or any other constant.
5. As could be seen from comparing equations (6) and (7), with the corresponding Lorentz transformations of time and distance in equations (1), the symmetry imposed by Nature, without putting any restrictions, has different features than the symmetry emerging from the Lorentz transformations.
6. The principle of relativity with respect to the laws of Nature requires a spatial asymmetry. As could be seen from equations (6) and (7) the direction of relative motion matters. For a departing F' relative to F, an observer in F will measure time and distance extension, while for an approachingF', the same observer in F will measure time and distance contraction. Notice that this asymmetry in direction fits well with the Doppler effect. Waves emitted by an approaching body suffer blueshift, while waves emitted by a receding body suffer redshift. Interestingly, the spatial asymmetry argued on basis of our analysis echoes nicely with similar arguments raised by a well-grounded research in chemistry and microbiology, which emphasizes the crucial role of asymmetry, or "chirality", in the creation and development of all living organisms, from amino acids to the human body (e.g., Wagnie're, 2007; Guijarro & Yus, 2008). This body of research further suggests that the source of all asymmetry in life is to be traced back to the physical asymmetry of the universe (see, e.g., Bock & Marsh, 1991; Borchers, Davis, & Gershwin, 2004). Such a view was succinctly expressed by Louis Pasteur, the celebrated chemist and microbiologist, who wrote that: "The universe is an asymmetrical entity. I am inclined to believe that life as it is manifested to us must be a function of the asymmetry of the universe or of the consequence of this fact. The universe is asymmetrical; for if one placed the entire set of bodies that compose the solar system, each moving in its own way, before a mirror, the image shown would not be superimposable on the reality" (quoted in Debré, 2000).

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Appendix A

Derivation of the length transformation

To derive the distance transformation, consider the two reference-frames F and F' in Figure A. Without loss of generality assume that when F and F' start distancing from each other $t_1 = t_1{}' = 0$, and $x_1 = x_1{}' = 0$. Assume further that F' has onboard a rod placed along its x' axis between the points $x' = 0$ and $x' = x_2'$ (see Figure A) and that the observer in F' uses his clock to measure the length of the rod (in its rest frame) and communicates his measurement to the observer in F.

Assume that the information carrier from frame F' to frame F travels with constant velocity V_c (as measured in the source rest frame). To perform the measurement of the rod's length, at $t_1{}' = t_1 = 0$ a signal is sent from the rare end of the rod, i.e., from $x' = x_2'$ to the observer at the point of origin $x' = 0$.

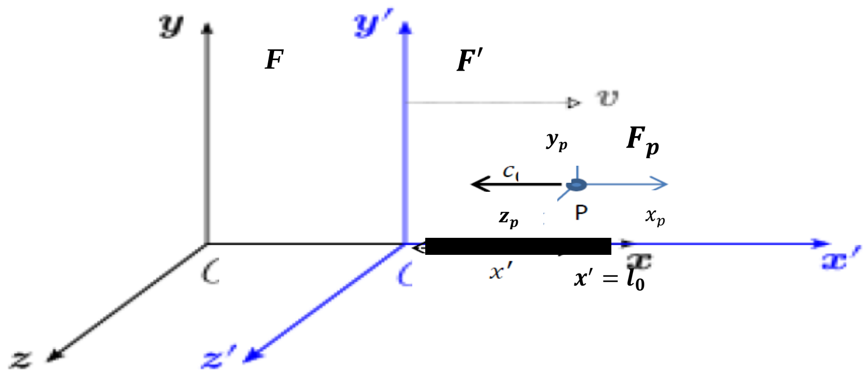

Figure A: Two observers in two reference frames, moving with velocity v with respect to each other.

If the signal arrives to the observer in F' at time $t' = t_2'$, then he or she can calculate the length of the rod as being:

$$l_0 = x_2' = v\, t_2' \tag{1a}$$

Denote by Δt_c is the time duration in the signal's rest-frame for its arrival to the observer in F'. Using eq. 6, t_2' as a function of Δt_c can be expressed as:

$$t_2' = \frac{1}{1 - \frac{-v}{V_c}} \Delta t_p = \frac{1}{1 + \frac{v}{V_c}} \Delta t_c \tag{2a}$$

Which could be rewritten as:

$$\Delta t_c = (1 + \frac{v}{V_c})\, t_2' \tag{3a}$$

Because F' is departing F with velocity v, the signal will reach and observer in F at time t_2 equaling:

$$t_2 = \Delta t_c + \frac{v t_2}{V_c} = \Delta t_c + \frac{v}{V_c}\ t_2 \tag{4a}$$

Substituting the value of Δt_c from eq. 3a in eq. 4a yields:

$$t_2 = (1 + \frac{v}{V_c})\ t_2' + \frac{v}{V_c}\ t_2, \tag{5a}$$

Which could be rewritten as:

$$t_2 = \frac{(1+\frac{v}{V_c})}{(1-\frac{v}{V_c})}\ t_2' \tag{6a}$$

Substituting the value of t_2' from eq. 1a we get:

$$t_2 = \frac{(1+\frac{v}{V_c})}{(1-\frac{v}{V_c})}\frac{l_0}{c} \tag{7a}$$

Thus, the observer in F will conclude that the length of the rod is equal to:

$$l = \text{c}\ t_2 = \frac{(1+\frac{v}{V_c})}{(1-\frac{v}{V_c})}\ l_0 \tag{8a}$$

Or:

$$\frac{l}{l_0} = \frac{1+\beta}{1-\beta} \tag{9a}$$

Where $\beta = \frac{v}{V_c}$.

Regardless of the value of V_c, the above derived relativistic distance equation predicts *distance contraction only when the two reference-frames approach each other* (i.e. for $-1 < \beta \leq 0$). On the other hand, in contradiction of the famous Lorentz contraction, for distancing frames (i.e., $0 < \beta < 1$) eq. 9a predicts *length extension*.