Does principle of relativity hold in relativistic physics?

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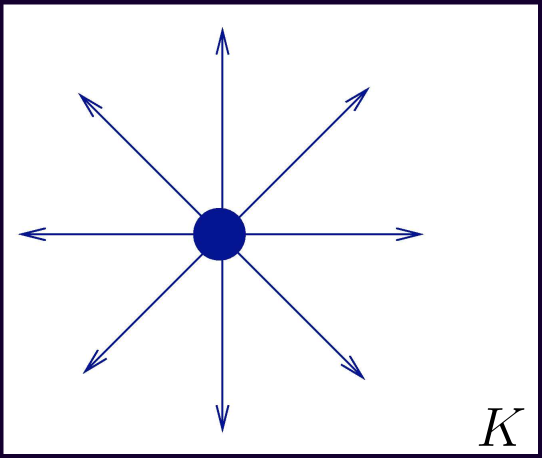
Related paper: L. E. Szabó, "On the meaning of Lorentz covariance", *Foundations of Physics Letters* (forthcoming, October).

Widely accepted view:

Consider a physical object at rest in an arbitrary inertial frame K. Assume we know the relevant physical equations and know the solution of the equations describing the physical properties of the object in question when it is at rest. All these things are expressed in the terms of the space and time coordinates x, y, z, t and some other quantities defined in K on the basis of x, y, z, t.

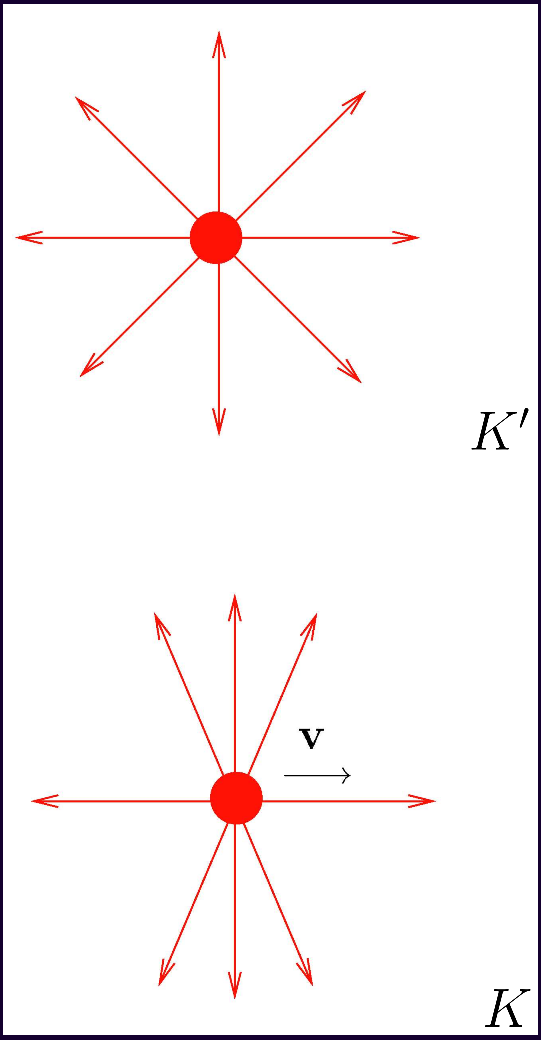


How these physical properties are modified when the object is as a whole, moving at a given constant velocity relative to K?

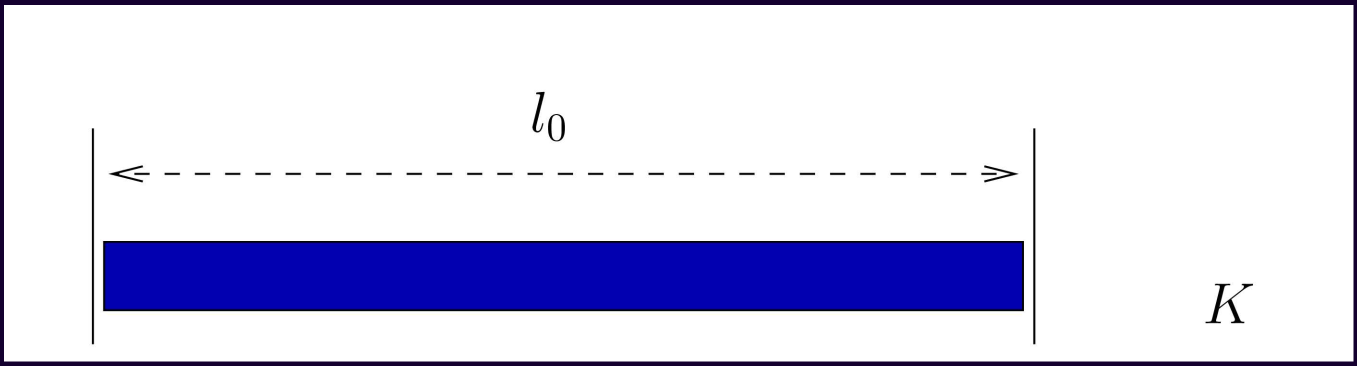
It follows from the Lorentz covariance of the laws of nature that the same equations hold for the primed variables $x', y', z', t', \ldots$ in the co-moving frame K'.

The *moving object is at rest in the co-moving frame* K'. It follows from the relativity principle that the *same rest-solution holds for the primed variables*.

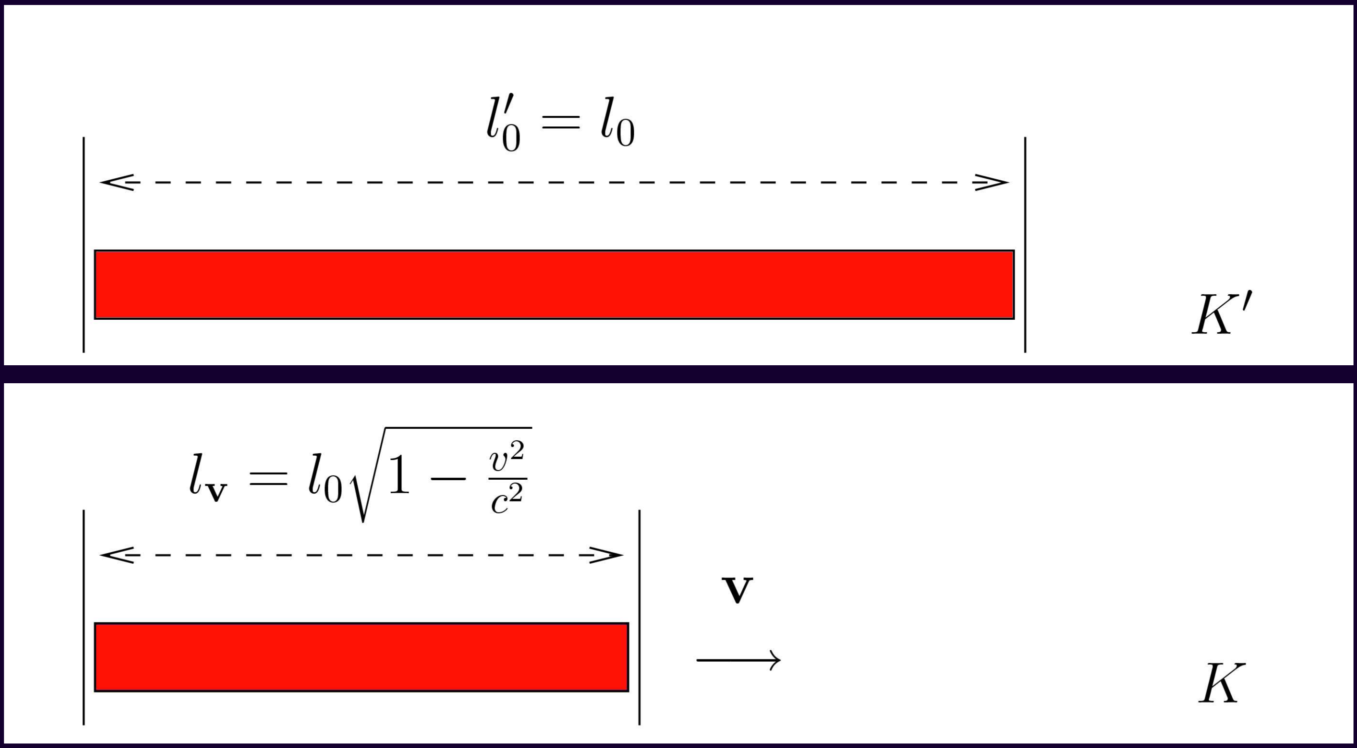
The solution describing t*he system moving as a whole* at constant velocity in the original K is obtained by applying the *Lorentz transformation*.



Similarly:



How the length of the rod is modified when it is, as a whole, moving at a given constant velocity relative to K?



I would like to show that this method, in general, is not correct; the system described by the solution so obtained is not necessarily identical with the original system set in collective motion.

THE RELATIVITY PRINCIPLE

Assume that K' is moving at constant velocity v relative to K along the axis of x. Denote $x(A), y(A), z(A), t(A)$ the space and time tags of an event A, obtainable by means of measuring-rods and clocks at rest relative to K, and denote $x'(A), y'(A), z'(A), t'(A)$ the similar data of the same event, obtainable by means of measuring-rods and clocks co-moving with K'.

In the approximation of classical physics $(v \ll c)$, the relationship between $x'(A), y'(A), z'(A), t'(A)$ and $x(A), y(A), z(A), t(A)$ can be described by the Galilean transformation:

$$t'(A) = t(A), \tag{1}$$
$$x'(A) = x(A) - v\,t(A), \tag{2}$$
$$y'(A) = y(A), \tag{3}$$
$$z'(A) = z(A). \tag{4}$$

The exact relationship is described by the Lorentz transformation:

$$t'(A) = \frac{t(A) - \frac{v\,x(A)}{c^2}}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{5}$$

$$x'(A) = \frac{x(A) - v\,t(A)}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{6}$$

$$y'(A) = y(A), \tag{7}$$

$$z'(A) = z(A). \tag{8}$$

Remark: The transformation rules of the space and time coordinates (usually) predetermine the transformations rules of the other physical variables.

Galilei describes the **RELATIVITY PRINCIPLE** in the following way:

> ... The butterflies and flies will continue their flights indifferently toward every side, nor will it ever happen that they are concentrated toward the stern, as if tired out from keeping up with the course of the ship, from which they will have been separated during long intervals by keeping themselves in the air. And if smoke is made by burning some incense, it will be seen going up in the form of a little cloud, remaining still and moving no more toward one side than the other. *The cause of all these correspondences of effects is the fact that the ship's motion is common to all the things contained in it* [my italics], and to the air also. (*Dialogue*)

In Einstein's formulation:

> If, relative to K, K' is a uniformly moving co-ordinate system devoid of rotation, then natural phenomena run their course with respect to K' according to exactly the same general laws as with respect to K. (*Relativity: The Special and General Theory*)

Relativity Principle *The behavior of the system co-moving as a whole with K', expressed in terms of the results of measurements obtainable by means of measuring-rods, clocks, etc., co-moving with K' is the same as the behavior of the original system, expressed in terms of the measurements with the equipments at rest in K.*

THE GALILEAN/LORENTZ COVARIANCE is a *consequence* of two physical facts:

- the laws of physics satisfy the relativity principle and
- the space and time tags in different inertial frames are connected through the Galilean/Lorentz transformation.

Let us try to unpack these verbal formulations in a more mathematical way!

- Let $\mathcal{E}$ be a set of differential equations describing the behavior of the system in question.

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- Denote $G_v(\mathcal{E}), G_v(\psi)$ and $\Lambda_v(\mathcal{E}), \Lambda_v(\psi)$ the set of equations and conditions expressed in the primed variables applying the Galilean and the Lorentz transformations, respectively (including, of course, the Galilean/Lorentz transformations of all other variables different from the space and time coordinates).

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- Let a solution $[\psi_0]$ is stipulated to describe the behavior of the system when it is, as a whole, at rest relative to K.
- Denote ψ_v the set of conditions and $[\psi_v]$ the corresponding solution of $\mathcal{E}$ that are stipulated to describe the similar behavior of the system as $[\psi_0]$ but, in addition, when the system was previously set, as a whole, into a collective translation at velocity v.

Now, **what relativity principle states** is the following:

$$G_v(\mathcal{E}) = \mathcal{E}', \quad (9)$$
$$G_v(\psi_v) = \psi_0', \quad (10)$$

in the case of classical mechanics, and

$$\Lambda_v(\mathcal{E}) = \mathcal{E}', \quad (11)$$
$$\Lambda_v(\psi_v) = \psi_0', \quad (12)$$

in the case of special relativity.

Relativity principle implies Galilean/Lorentz covariance. But, the relativity principle *is not equivalent* to the Galilean covariance (9) in itself or the Lorentz covariance (11) in itself. It is equivalent to (9) in conjunction with condition (10) in classical physics, or (11) in conjunction with (12) in relativistic physics.

$\mathcal{E}$, ψ_0, and ψ_v as well as the transformations G_v and Λ_v are given by contingent facts of nature. It is therefore a contingent fact of nature whether a certain law of physics is Galilean or Lorentz covariant, and, *independently*, whether it satisfies the principle of relativity.

I will show, however, that the laws of relativistic physics, in general, do not satisfy RELATIVITY PRINCIPLE!

Note: The major source of confusion is the vagueness of the definitions of conditions ψ_0 and ψ_v.

- In principle any $[\psi_0]$ can be considered as a "solution describing the system's behavior when it is, as a whole, at rest relative to K".
- Given any one fixed ψ_0, it is far from obvious, however, what is the corresponding ψ_v. When can we say that $[\psi_v]$ describes the similar behavior of the same system when it was previously set into a collectives motion at velocity v?

As we will see, there is an unambiguous answer to this question in the Galileo covariant classical physics. But ψ_v is vaguely defined in relativity theory. Einstein himself uses this concept in a vague way:

Let there be given a stationary rigid rod; and let its length be l as measured by a measuring-rod which is also stationary. We now imagine the axis of the rod lying along the axis of x of the stationary system of co-ordinates, and that a uniform motion of parallel translation with velocity v along the axis of x in the direction of increasing x is then imparted to the rod. We now inquire as to the length of the moving rod, and imagine its length to be ascertained by the following two operations:

(a) The observer moves together with the given measuring-rod and the rod to be measured, and measures the length of the rod directly by superposing the measuring-rod, in just the same way as if all three were at rest...

In accordance with the principle of relativity the length to be discovered by the operation (a)–we will call it"the length of the rod in the moving system"–must be equal to the length l of the stationary rod. [1905 paper]

But, what exactly does "a uniform motion of parallel translation with velocity v ... imparted to the rod" mean? The following examples will illustrate that the vague nature of this concept complicates matters.

In all examples we will consider a set of interacting particles. We assume that the relevant equations describing the system are Galilean/Lorentz covariant, that is

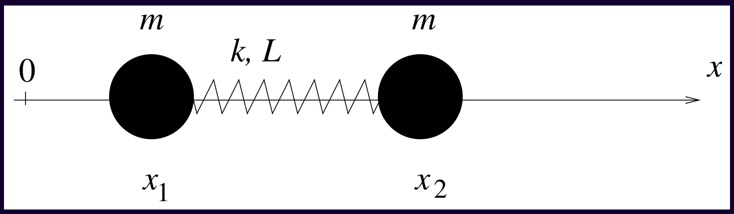
$$G_v\left(\mathcal{E}\right) = \mathcal{E}'$$

and

$$\Lambda_v\left(\mathcal{E}\right) = \mathcal{E}'$$

are satisfied respectively. As it follows from the covariance of the corresponding equations, $G_v^{-1}\left(\psi_0'\right)$ and, respectively, $\Lambda_v^{-1}\left(\psi_0'\right)$ are conditions determining new solutions of $\mathcal{E}$. The question is whether these new solutions are identical with the one determined by ψ_v. If so then the relativity principle is satisfied.

Classical example



$$m\frac{d^2x_1(t)}{dt^2} = k\left(x_2(t) - x_1(t) - L\right), \tag{13}$$
$$m\frac{d^2x_2(t)}{dt^2} = -k\left(x_2(t) - x_1(t) - L\right), \tag{14}$$

The equations are covariant with respect to the Galilean transformation. Expressing (13)–(14) in terms of variables x', t' they have exactly the same form as before:

$$m\frac{d^2x_1'(t')}{dt'^2} = k\left(x_2'(t') - x_1'(t') - L\right), \tag{15}$$
$$m\frac{d^2x_2'(t')}{dt'^2} = -k\left(x_2'(t') - x_1'(t') - L\right). \tag{16}$$

Consider the solution of the (13)–(14) belonging to an arbitrary initial condition ψ_0:

$$\psi_0 \equiv \begin{array}{rcl} x_1(t=0) &=& x_{10}, \\ x_2(t=0) &=& x_{20}, \\ \left.\frac{dx_1}{dt}\right|_{t=0} &=& v_{10}, \\ \left.\frac{dx_2}{dt}\right|_{t=0} &=& v_{20}. \end{array} \qquad (17)$$

The corresponding "primed" initial condition ψ_0' is

$$\psi_0' \equiv \begin{array}{rcl} x_1'(t'=0) &=& x_{10}, \\ x_2'(t'=0) &=& x_{20}, \\ \left.\frac{dx_1'}{dt'}\right|_{t'=0} &=& v_{10}, \\ \left.\frac{dx_2'}{dt'}\right|_{t'=0} &=& v_{20}. \end{array} \tag{18}$$

Applying the inverse Galilean transformation we obtain a set of conditions $G_v^{-1}(\psi_0')$ determining a new solution of the original equations:

$$G_v^{-1}(\psi_0') \equiv \begin{array}{rcl} x_1(t=0) &=& x_{10}, \\ x_2(t=0) &=& x_{20}, \\ \left.\frac{dx_1}{dt}\right|_{t=0} &=& v_{10}+v, \\ \left.\frac{dx_2}{dt}\right|_{t=0} &=& v_{20}+v. \end{array} \tag{19}$$

One can recognize that this is nothing but ψ_v. It is the set of the original initial conditions in superposition with a uniform translation at velocity v. That is to say, the corresponding solution describes the behavior of the same system when it was (at $t=0$) set into a collective translation at velocity v, in superposition with the original initial conditions.

In classical mechanics, as we have seen from this example, the equations of motion not only satisfy the Galilean covariance, but also satisfy the condition $G_v(\psi_v) = \psi_0'$. The principle of relativity holds for *all details of the dynamics* of the system. There is no exception to this rule. In other words, if the world were governed by classical mechanics, relativity principle would be a universally valid principle.

Let us turn now to the relativistic examples.

It is widely held that the new solution $\left[\Lambda_v^{-1}\left(\psi_0'\right)\right]$ (in analogy to $\left[G_v^{-1}\left(\psi_0'\right)\right]$ in classical mechanics) describes a system identical with the original one, but co-moving with the frame K', and that the behavior of the moving system, expressed in terms of the results of measurements obtainable by means of measuring-rods and clocks co-moving with K' is, due to Lorentz covariance, the same as the behavior of the original system, expressed in terms of the measurements with the equipments at rest in K—in accordance with the principle of relativity. **However, the situation is in fact far more complex!**

Imagine a system consisting of interacting particles (for example, relativistic particles coupled to electromagnetic field). Consider the solution of the Lorentz covariant equations in question that belongs to the following general initial conditions:

$$\psi_0 \equiv \qquad \mathbf{r}_i(t=0) \;=\; \mathbf{R}_i, \tag{20}$$

$$\left.\frac{d\mathbf{r}_i(t)}{dt}\right|_{t=0} \;=\; \mathbf{w}_i. \tag{21}$$

(Sometimes the initial conditions for the particles unambiguously determine the initial conditions for the whole interacting system. Anyhow, we are omitting the initial conditions for other variables which are not interesting now.)

It follows from the Lorentz covariance that there exists a solution of the "primed" equations, which satisfies the same conditions:

$$\psi_0' \equiv \qquad \mathbf{r}_i'(t'=0) = \mathbf{R}_i, \tag{22}$$

$$\left.\frac{d\mathbf{r}_i'(t')}{dt'}\right|_{t'=0} = \mathbf{w}_i. \tag{23}$$

Eliminating the primes by means of the Lorentz transformation we obtain

$$t_i^\star = \frac{\frac{v}{c^2}R_{xi}}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{24}$$

$$\Lambda_v^{-1}(\psi_0') \equiv \qquad \mathbf{r}_i(t=t_i^\star) = \begin{pmatrix} \frac{R_{xi}}{\sqrt{1-\frac{v^2}{c^2}}} \\ R_{yi} \\ R_{zi} \end{pmatrix}, \tag{25}$$

$$\left.\frac{d\mathbf{r}_i(t)}{dt}\right|_{t_i^\star} = \begin{pmatrix} \frac{w_{xi}+v}{1+\frac{w_{xi}v}{c^2}} \\ w_{yi} \\ w_{zi} \end{pmatrix}. \tag{26}$$

It is difficult to tell what the new solution deriving from such a nondescript “initial” condition is like, but it is not likely to describe the original system in collective motion at velocity v.

The reason for this is not difficult to understand. Let me explain it by means of a well known old example.

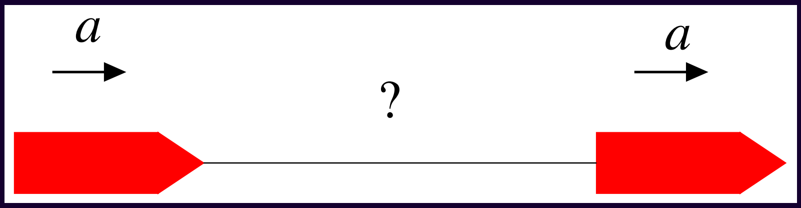
1. E. Dewan and M. Beran, “Note on Stress Effects due to Relativistic Contraction,” *American Journal of Physics* **27**, 517 (1959).

2. A. A. Evett and R. K. Wangsness, “Note on the Separation of Relativistic Moving Rockets,” *American Journal of Physics* **28**, 566 (1960).

3. E. Dewan, “Stress Effects due to Lorentz Contraction,” *American Journal of Physics* **31**, 383 (1963).

4. A. A. Evett, “A Relativistic Rocket Discussion Problem,” *American Journal of Physics* **40**, 1170 (1972).

5. **J. S. Bell, “How to teach special relativity,” in *Speakable and unspeakable in quantum mechanics* (Cambridge University Press, Cambridge, 1987).**



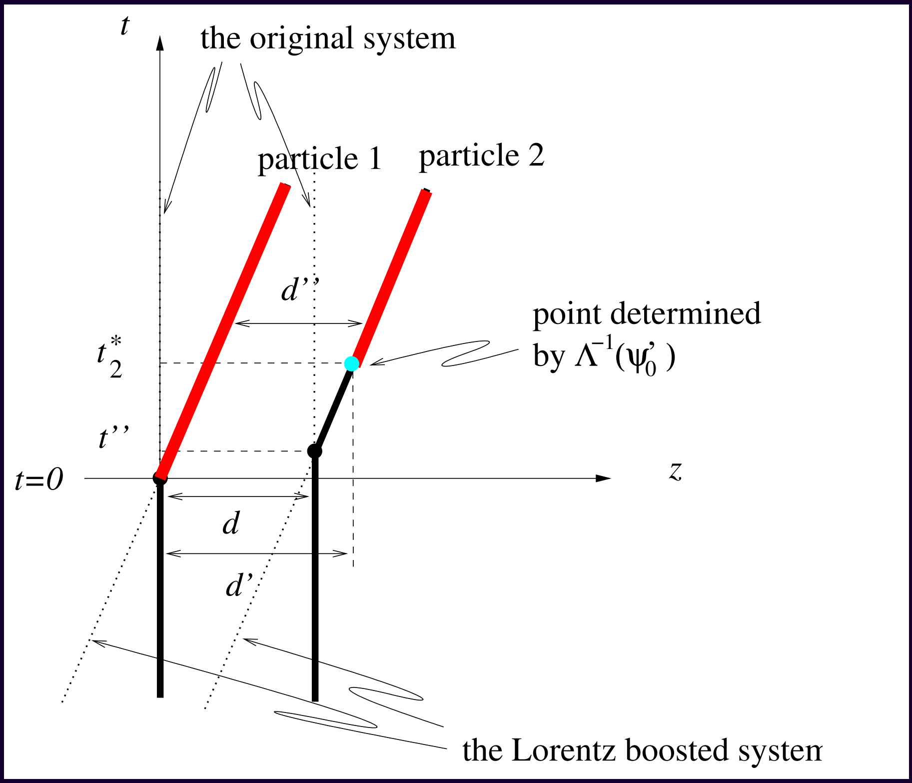
Consider **the system consisting of two particles connected with a spring** (two rockets connected with a thread in the original example). Let us first ignore the spring.

Assume: $\left.\frac{dr_1(t)}{dt}\right|_{t=0} = \left.\frac{dr_2(t)}{dt}\right|_{t=0} = 0$, $r_1(t=0) = 0$ and $r_2(t = 0) = d$, where $d = L$, the equilibrium length of the spring when it is at rest. It follows from (24)–(26) that the Lorentz boosted system corresponds to two particles moving at constant velocity v, such that their motions satisfy the following conditions:

$$\Lambda_v^{-1}\left(\psi_0'\right) \equiv \begin{aligned} t_1^\star &= 0, \\ t_2^\star &= \frac{\frac{v}{c^2}d}{\sqrt{1-\frac{v^2}{c^2}}}, \\ r_1\left(0\right) &= 0, \\ r_2\left(\frac{\frac{v}{c^2}d}{\sqrt{1-\frac{v^2}{c^2}}}\right) &= \frac{d}{\sqrt{1-\frac{v^2}{c^2}}}. \end{aligned} \tag{27}$$

However, this solution does not necessarily desribe the original system in collective motion at velocity v. Consider the following possible scenarios:

Example 1



The two particles are at rest; the distance between them is d. Then, particle 1 starts its motion at constant velocity v at $t = 0$ from the point of coordinate 0 (the last two dimensions are omitted); particle 2 start its motion at velocity v from the point of coordinate d with a delay at time t''.

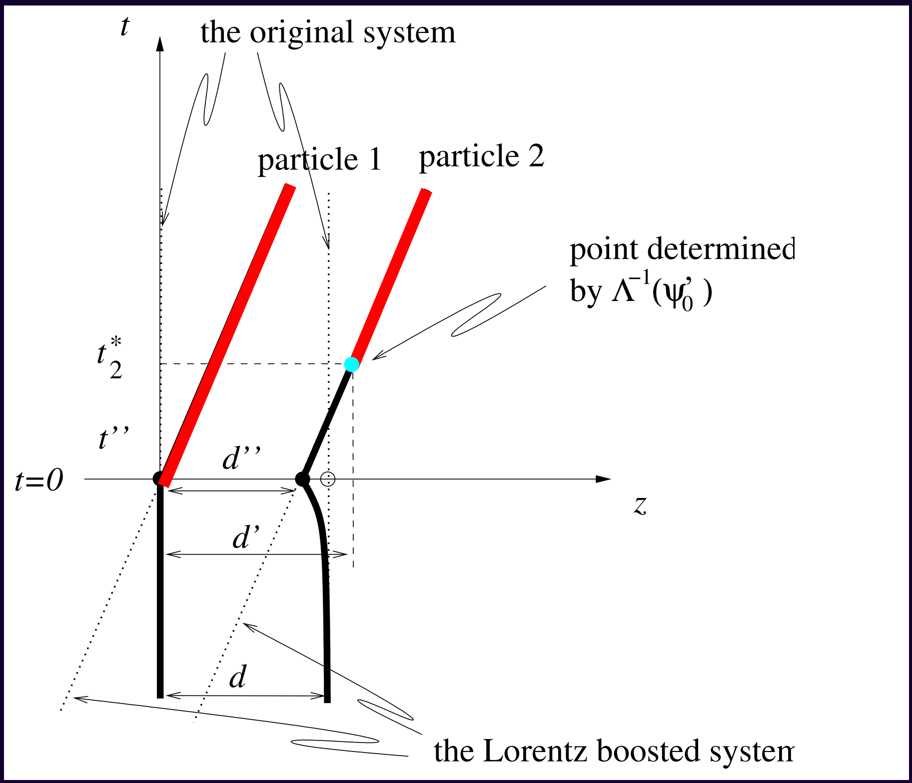
It goes through the point $(t_2^\star, d')$, where $d' = d/\sqrt{1 - v^2/c^2}$, consequently it started from the point of coordinate d at

$$t'' = d\left(v/\left(c^2\sqrt{1 - v^2/c^2}\right) - \left(1 - \sqrt{1 - v^2/c^2}\right)/\left(v\sqrt{1 - v^2/c^2}\right)\right)$$

Meanwhile particle 1 moves closer to particle 2 and the distance between them is $d'' = d\sqrt{1 - v^2/c^2}$, in accordance with the Lorentz contraction.

For large t, the system is identical with the one obtained through the Lorentz boost. But, it would be entirely counter intuitive to say that we simply set the system in collective motion at velocity v, because we **distorted** the system before we set it in motion, one of the particles was relocated relative to the other.

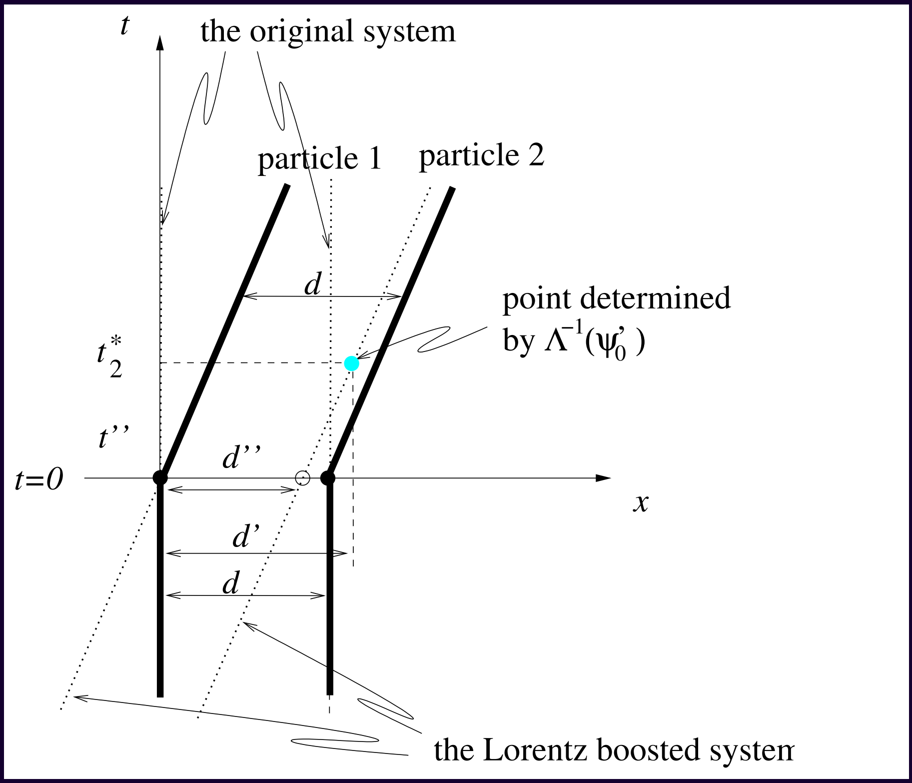
Example 2



Both particles start at $t = 0$. Particle 2 is previously moved to the point of coordinate $d'' = d\sqrt{1 - v^2/c^2}$. For large t, the system is identical with the one obtained through the Lorentz boost.

But, it would be entirely counter intuitive to say that we simply set the system in collective motion at velocity v, because we **distorted** the system before we set it in motion, one of the particles was relocated relative to the other.

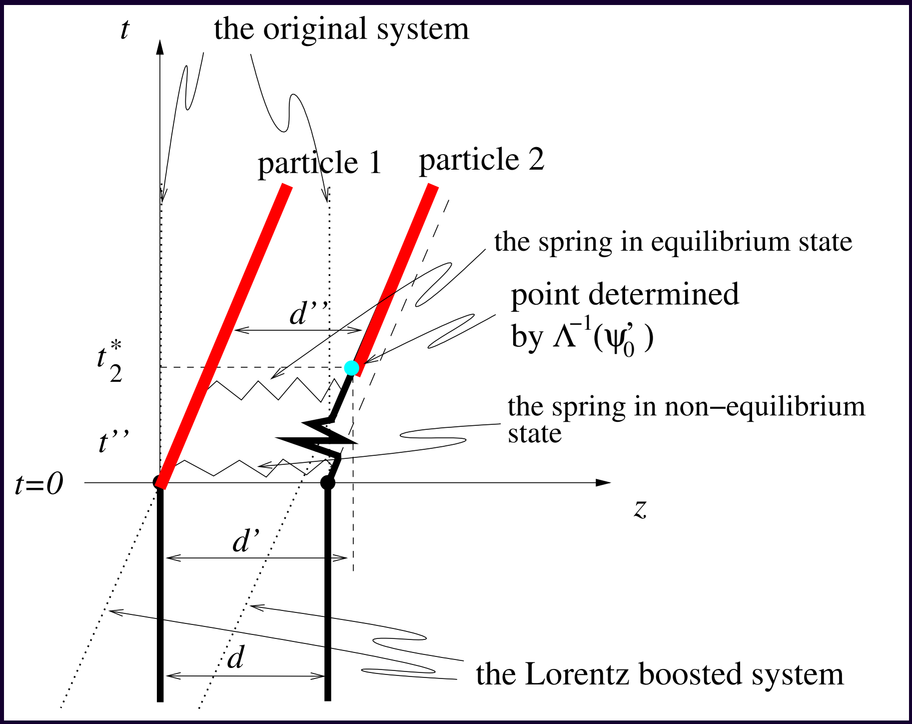
Example 3



Both particles start from their original places. The distance between them remains d. We are entitled to say that the system was set into collective motion at velocity v.

But, the system in collective motion is different from the Lorentz boosted system (for all t).

Example 4

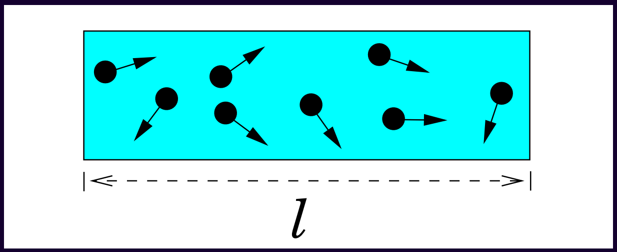


If, however, they are connected with the spring then the spring (when moving at velocity v) first finds itself in a non-equilibrium state of length d, then it relaxes to its equilibrium state (when moving at velocity v). Assume that the equilibrium properties of the spring satisfy the relativity principle (which we will argue for later on). The length of the spring will relax to $d\sqrt{1 - v^2/c^2}$.

The moving system is indeed identical with the Lorentz boosted one, at least for large t, after the relaxation process.

Example 5

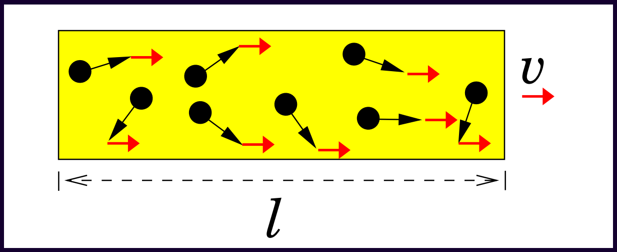
Consider a rod at rest in K. The length of the rod is l. At a given moment of time t_0 we take a record about the positions and velocities of all particles of the rod:



$$
\begin{aligned}
r_i(t = t_0) &= R_i, && (28) \\
\left.\frac{dr_i(t)}{dt}\right|_{t=t_0} &= w_i. && (29)
\end{aligned}
$$

Then, forget this system, and imagine another one which is initiated at moment $t = t_0$ with the initial condition (28)–(29). No doubt, the new system will be identical with a rod of length l, that continues to be at rest in K.

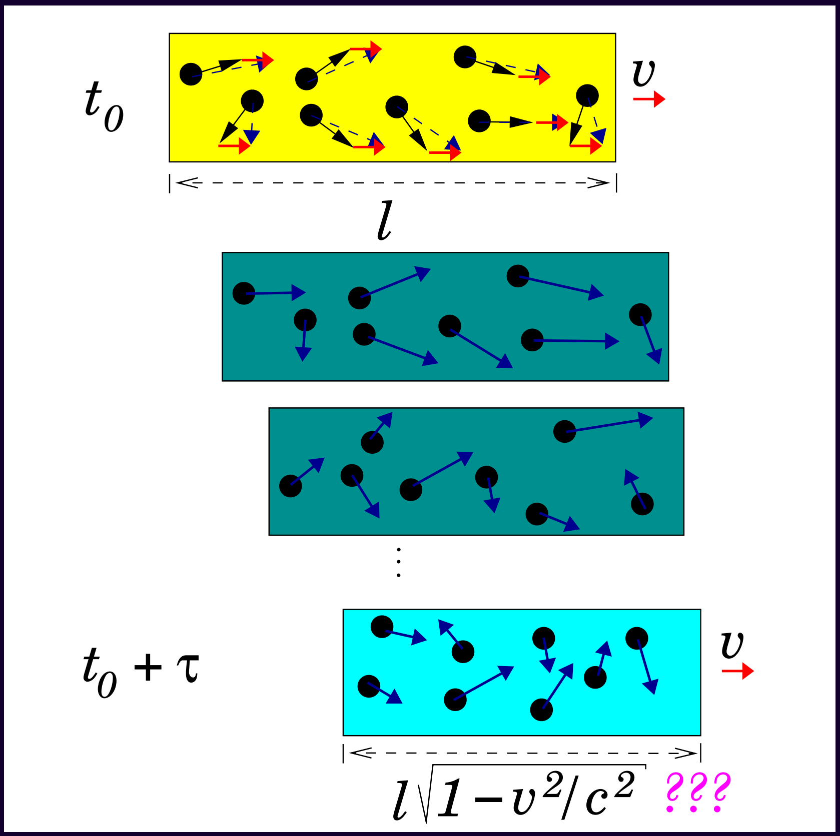
Now, imagine that the new system is initiated at $t = t_0$ with the initial condition



$$r_i(t = t_0) = R_i, \quad (30)$$

$$\left.\frac{dr_i(t)}{dt}\right|_{t=t_0} = w_i + v, \quad (31)$$

instead of (28)–(29). No doubt, in a very short interval of time $(t_0, t_0 + \Delta t)$ this system is a rod of length l, moving at velocity v; the motion of each particle is a superposition of its original motion, according to (28)–(29), and the collective translation at velocity v. In other words, it is a rod co-moving with the reference frame K'. Still, its length is l, contrary to the principle of relativity, according to which the rod should be of length $l\sqrt{1 - v^2/c^2}$.



The resolution of this "contradiction" is that the system initiated in state (30)–(31) at time t_0 finds itself in a non-equilibrium state and then, due to certain dissipations, it *relaxes* to the *new* equilibrium state. What such a new equilibrium state is like, depends on the details of the dissipation/relaxation process. It is, in fact, a *thermodynamical* question.

Thesis:

In spite of the Lorentz covariance of the equations, whether or not the solution determined by the condition $\Lambda_v^{-1}\left(\psi_0'\right)$ is identical with the solution belonging to the condition ψ_v, in other words, whether or not the relativity principle holds, depends on the details of the dissipation/relaxation process in question, *given that*

1. *there is dissipation in the system at all and*
2. *the physical quantities in question, to which the relativity principle applies, are equilibrium quantities characterizing the equilibrium properties of the system.*

For example, in Example 5, the relativity principle does not hold for all dynamical details of all particles of the rod. The reason is that many of these details are sensitive to the initial conditions. The principle holds only for some macroscopic equilibrium properties of the system, like the length of the rod.

It is a typical feature of a dissipative system that it unlearns the initial conditions; some of the properties of the system in equilibrium state, after the relaxation, are independent from the initial conditions. These equilibrium properties are completely determined by the equations themselves *independently of the initial conditions*. If so, the Lorentz covariance of the equations in itself guarantees the satisfaction of the principle of relativity *with respect to these properties*:

Let X be the value of such a physical quantity—characterizing the equilibrium state of the system in question, fully determined by the equations independently of the initial conditions—ascertained by the measuring devices at rest in K. Let X' be the value of the same quantity of the same system when it is in equilibrium and at rest relative to the moving reference frame K', ascertained by the measuring devices co-moving with K'. If the equations are Lorentz covariant, then $X = X'$.

We must recognize that whenever in relativistic physics we derive correct results by applying the principle of relativity, we apply it for such particular equilibrium quantities. *But the relativity principle, in general, does not hold for the whole dynamics of the systems in relativity theory*, **in contrast to classical mechanics**.

When claiming that relativity principle, in general, does not hold for the whole dynamics of the system, a lot depends on what we mean by the system set into uniform motion. One has to admit that this concept is still vague. It was not clearly defined in Einstein's formulation of the principle either. By leaving this concept vague, Einstein tacitly assumes that these details are irrelevant. However, they can be irrelevant only if the system has dissipations and the principle is meant to be valid only for some equilibrium properties with respect to which the system unlearns the initial conditions.

So the best thing we can do is to keep the classical definition of ψ_v: Consider a system of particles the motion of which satisfies the following (initial) conditions:

$$\begin{aligned} \mathbf{r}_i(t=t_0) &= \mathbf{R}_{i0}, \\ \left.\frac{d\mathbf{r}_1}{dt}\right|_{t=t_0} &= \mathbf{V}_{i0}. \end{aligned} \tag{32}$$

The system is set in collective motion at velocity $\mathbf{v}$ at the moment of time t_0 if its motion satisfies

$$\begin{aligned} \mathbf{r}_i(t=t_0) &= \mathbf{R}_{i0}, \\ \left.\frac{d\mathbf{r}_1}{dt}\right|_{t=t_0} &= \mathbf{V}_{i0}+\mathbf{v}. \end{aligned} \tag{33}$$

I have two arguments for such a choice:

1. The usual Einsteinian derivation of Lorentz transformation, simultaneity in K', etc., starts with the declaration of the relativity principle. Therefore, all these things must be logically preceded by the concept of a physical object in a uniform motion relative to K.

2. The second support comes from what Bell calls "Lorentzian pedagogy":

   > Its special merit is to drive home the lesson that the laws of physics in any one reference frame account for all physical phenomena, including the observations of moving observers. And it is often simpler to work in a single frame, rather than to hurry after each moving objects in turn. (*How to teach....*)

Summary:

1. In classical mechanics the principle of relativity is, indeed, a universal principle. It holds, without any restriction, for *all* dynamical details of *all* possible systems described by classical mechanics.

2. In contrast, the principle of relativity is not a universal principle in relativistic physics. It does not hold for the whole range of validity of the Lorentz covariant laws of relativistic physics, but only for the equilibrium quantities characterizing the equilibrium state of dissipative systems.

3. Since dissipation, relaxation and equilibrium are thermodynamical conceptions *par excellence*, the special relativistic principle of relativity is actually a thermodynamical principle, rather than a general principle satisfied by all dynamical laws of physics describing all physical processes in details. One has to recognize that the special relativistic principle of relativity is experimentally confirmed only in such restricted sense.

4. The satisfaction of the principle of relativity in such restricted sense is indeed guaranteed by the Lorentz covariance of those physical equations that determine, independently of the initial conditions, the equilibrium quantities for which the principle of relativity holds. In general, however, Lorentz covariance of the laws of physics does not guarantee the satisfaction of the relativity principle.

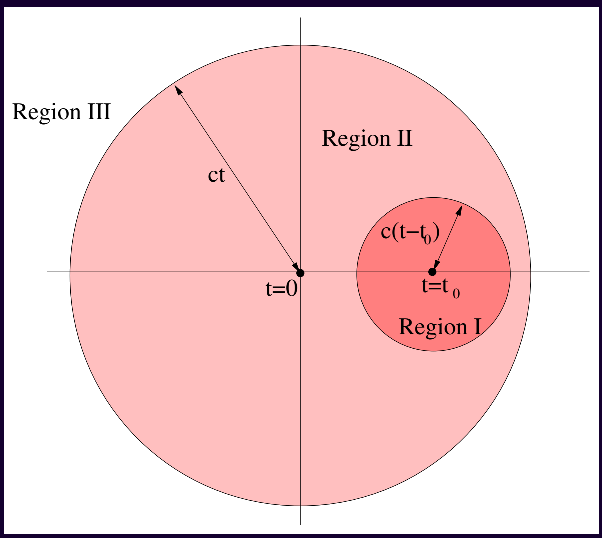
5. It is an experimentally confirmed fact of nature that some laws

of physics are *ab ovo* Lorentz covariant. However, since relativity principle is not a universal principle, it does not entitle us to infer that Lorentz covariance is a fundamental symmetry of physics.

6. The fact that the space and time tags obtained by means of measuring-rods and clocks co-moving with different inertial reference frames can be connected through the Lorentz transformation is compatible with our general observation that the principle of relativity only holds for such equilibrium quantities as the length of a solid rod or the characteristic periods of a clock-like system.

Appendix

It might be interesting how this dissipation/relaxation process goes on in the case of interacting particles. This process can be followed in details by looking at one single point charge accelerated from K to K' (see Jánossy). Suppose the particle is at rest for $t < 0$, the acceleration starts at $t = 0$ and the particle moves with constant velocity v for $t \geq t_0$.



I: "Lorentz-transformed Coulomb field" of the point charge moving at constant velocity

II: Radiation field travelling outwards

III: Coulomb field of the charge at rest

Using the retarded potentials, we can calculate the field of the moving particle at some time $t > t_0$. We find three zones in the field. In Region I, surrounding the particle, we find the "Lorentz-transformed Coulomb field" of the point charge moving at constant velocity. This is the solution we usually find in textbooks. In Region II, surrounding Region I, we find a radiation field travelling outwards which was emitted by the particle in the period $0 < t < t_0$ of acceleration. Finally, outside Region II, the field is produced by the particle at times $t < 0$. The field in Region III is therefore the Coulomb field of the charge at rest. Thus, the principle of relativity *never* holds exactly. Although, the region where "the principle holds" (Region I) is blowing up at the speed of light. In this way the whole configuration relaxes to a solution which is identical with the one derived from the principle of relativity.