Relativistic physics and the liberation of time

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1. Introduction

In the last ten years I have been working at the description of natural phenomena by observers in motion. It is a problem that many consider solved once and for all by the Lorentz transformations of the Theory of Special Relativity (TSR in the following), but that actually was left open for reasons I will say. The result of this research is twofold: an explanation of the empirical data better than provided by the TSR, and the elimination of those features of the TSR which give rise to paradoxes; all this is obtained thanks to the liberation of time from the enslavement to space forced upon it in Minkowski space. The story is told in detail in a recent book available in portuguese [FS]. In the present paper, similar to a recent publication [LT], I expound the basic ideas of the research leaving aside the mathematical parts.

The theories of special and general relativity had great success in explaining many known phenomena and in predicting new unexpected effects. They constitute important advances of our knowledge of the physical world and belong forever to the history of the natural sciences, similarly to Newton's mechanics and Maxwell's electromagnetism. It is however very difficult to believe that they are forms of final, not modifiable knowledge. On the contrary, if there is an important lesson to learn from epistemology (Popper, Lakatos, Kuhn) it is about the conjectural, provisional, improvable nature of the foundations of the physical theories of the XXth century.

In March 1949, answering his friend M. Solovine who had sent him an affective letter for the seventieth birthday, Einstein wrote: "You imagine that I look backwards on the work of my life with calm satisfaction. But from nearby it looks very different. There is not a single concept of which I am convinced that it will resist firmly." [LS] Einstein did not hide the probable transitoriness of his creations. On April 4, 1955, he wrote the last paper of his life. It was a three pages long preface (in German) to a book celebrating the fiftieth anniversary of the theory of relativity. It ended with the following words: "The last, quick remarks must only demonstrate how far in my opinion we still are from possessing a conceptual basis of physics, on which we can somehow rely." [EF] One has to admire not only the scientific, but also the ethical dimension of the great scientist, who had devoted the superhuman efforts of a lifetime for reaching the deepest truths of nature and now, arrived at the end, declared to posterity: "I did not succeed."

The successes of the relativistic theories are very well known. The reciprocal convertibility of energy and mass, the effects of velocity and gravitation on the pace of clocks, the weight of light and the precession of planetary motions, give only a partial summary of the great conquests of Einsteinian physics. Nevertheless, it would not be correct to conclude that every comparison of the theoretical predictions with experiments invariably led to a perfect agreement. Physics is a human activity and from us inherits the habit to parade successes and to hide difficulties and failures. Thus only silence surrounded the Sagnac effect for which there is a veritable explanatory inability of the two relativistic theories, the attempts by Langevin, Post, Landau and Lifshitz notwithstanding. There are, furthermore, the half explanations of the aberration of starlight and of the clock paradox, phenomena for which the mathematical formalism of the theory can reproduce the observations at the price of twisting the meaning of symbols beyond rightfulness.

One should never forget that behind the equations of a theory there is a huge qualitative structure made of empirical results, generalizations, hypotheses, philosophical choices, historical conditionings, personal tastes, conveniences. When one becomes aware of this reality and compares it with the little portrait of physics handed down by logical empiricism, which is worth less than a caricature, one easily understands that relativity, not only can present weak points side by side with its undeniable successes, but can also survive some failures. The correctness of the mathematical formalism is not enough to validate a scientific structure as coherent and not contradictory. I add that not even hundreds of physicists unconditionally favorable to a theory can warrant the absence of unsolved problems, because much too often their thoughts are oriented since the university studies towards an acritical acceptance of the dominating theory. Rationality and consent are different matters also in the world of research.

In reality the two relativistic theories are crammed with paradoxes. Let us try to make a list, with no claim of completeness, limited to the TSR: the velocity of a light signal, which the theory considers equal for observers at rest and observers pursuing it with velocity 0.99 c; the idea that the simultaneity of spatially separated events does not exist in nature and must therefore be established with a human convention; the relativity of simultaneity, according to which two events simultaneous for an observer in general are no more such for a different observer; the contraction of moving objects and the retardation of moving clocks, phenomena for which the theory does not provide a description in terms of objectivity; the asymmetrical ageing of the twins in relative motion in a theory waving the flag of relativism; the hyperdeterministic universe of relativity, fixing in the least details the future of every observer; the conflict between the reciprocal transformability of mass and energy and the ideology of relativism, which declares all inertial observers perfectly equivalent so depriving energy of its full reality; the existence of a discontinuity between the inertial reference systems and those endowed with a very small acceleration; the propagations from the future towards the past, generated in the theory by the possible existence of superluminal signals.

How is it possible that respected experts of relativistic physics believe that these are not real paradoxes? The answer is not difficult and is based on what in Italian is called "buon senso" (literally: good sense). This expression is easily translated in all neo-Latin languages, but is absent in other languages. English speaking authors use sometimes "common sense", which carries however a very different idea because the common sense is that of the majority and the history of science teaches that in scientific matters the majority is rarely right. On the other hand "buon senso" relates to the "sensate esperienze" of Galilei. Well, if good sense tells us that a certain prediction of a theory is unreasonable, there are two possibilities. Firstly, it is possible that the good sense misleads us, secondly that in the theory there are more or less explicit hypotheses contrary to the natural order of things giving its predictions an incorrect meaning. It is well known that many physicists and philosophers of science of the XXth century followed the fashion of declaring good sense obsolete, but the second road can easily be traveled over and allows one to get rid of all the paradoxes of relativity.

Naturally, it is not a priori obvious that the paradoxes can be eliminated without spoiling the successes of the theory. Nevertheless, it is a fact that the theory reviewed in the present article, based on the replacement of the Lorentz by the "inertial" transformations, not only explains all what the TSR does, but succeeds also where the latter does not. It explains the Sagnac effect, for example.

2. Einstein from positivism to realism

Albert Einstein is the absolutely central personality of XXth century physics. He wrote very much, also about epistemology. Other great physicists published articles and books on the same argument (Planck, Schrödinger, Bohr, Heisenberg), but nobody with the richness, the depth, and the critical and self critical skill of Einstein. Here's an example of what he thought about the relationship between physics and philosophy:

" The reciprocal relationship of epistemology and science is of noteworthy kind. They are dependent upon each other. Epistemology without contact with science becomes an empty scheme. Science without epistemology is – insofar as it is thinkable at all - primitive and muddled. ... He [the scientist] therefore must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as *realist* insofar as he seeks to describe a world independent of the acts of perception; as *idealist* insofar as he looks upon the concepts and theories as the free inventions of the human spirit (not logically derivable from what is empirically given); as *positivist* insofar as he considers his concepts and theories justified *only* to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as *Platonist* or *Pythagorean* insofar as he considers the viewpoint of logical simplicity as an indispensable and effective tool of his research". [AB, pp. 683-684]

Actually, the philosophical attitude of physicists is rarely the eclectic one here described. Different scientists embraced widely different philosophies, but almost always very well defined for every single author. The previous description should rather be understood in the autobiographical sense, as Einstein in different moments of his scientific activity followed very different philosophical ideas. He embraced positivism when the TSR was formulated and defended the interpretation based on relativism during his whole lifetime, but he behaved as a realist in other famous papers of 1905 (on Brownian motion and on the light quanta) and in his long battle against the Copenhagen formulation of quantum mechanics.

Mach's works had a strong impact in the epistemological emptiness that prevailed between the end of the XIXth and the beginning of the XXth century. One can say that the theory of relativity was formulated by trying to satisfy the epistemological demands of the Viennese philosopher. "My friend Besso called my attention to Ernst Mach's DIE MECHANIK IN IHRER ENTWICKLUNG, when I was a student circa 1897. The book's critical attitude towards the fundamental conceptions and fundamental laws generated in me a deep and lasting impression." [Quoted in LK, p. 21].

With the TSR Einstein concluded that every moving clock is bound to slow the pace with which it marks the time. His 1905 point of view was the following: ether does not exist, therefore it does not make any sense to consider motion with respect to nothing. Motion can only be described with respect to concrete systems. The slowdown of clocks is always relative to observers who see them in motion, and a perfect symmetry exists (physical and philosophical) between the conclusions of different inertial observers. Considering a clock in motion relative to the different inertial observers O_1, O_2, ... O_n, who see it moving with respective velocities v_1, v_2, ... v_n, its rate should be slowed by the factors $R(v_1)$, $R(v_2)$, ... $R(v_n)$, given by a unique function of relative velocity, in agreement with the relativity principle. A legitimate question seems to be: "What really happens to the clock, which is it its true rate?" The relativistic answer is that the question itself does not make sense, and that all the points of view of the different observers are equally valid. In this way the philosophy of relativism and subjectivism becomes dominant in physics for the observations of the inertial observers. The argument can be generalized, passing from the time marked by clocks to any other physical quantity: we will see it done by the English physicist J. Jeans in the sixth section.

Einstein's relativism clearly originates in positivism and it is surprising that it was never disavowed by the founder of relativity in spite of his sharp break with Mach. Einstein abandoned Mach's epistemological views in the 1920s, when he created his own theory of physical cognition that anticipated the views of future philosophers of physics, such as Karl Popper: 'There does not appear to be a great relation from the logical point of view between the theory of relativity and Mach's theory. [...] Mach's system studies the existing relations between data of experience;

for Mach science is the totality of these relations. That point of view is wrong, and, in fact, what Mach has done is to make a catalogue, not a system. To the extent that Mach was a good mechanician he was a deplorable philosopher.' " [Quoted in LK, p. 104]

The critical standing was kept till the end, as one can see from the *Scientific Autobiography* (1948) where Einstein expressed a judgment about the Machian philosophy very similar to the previous one. Ten years before, in a letter to M. Solovine Einstein had stated: "In these days the subjective and positivist viewpoint dominates in a most excessive manner. The need for conceiving nature as an objective reality is declared to be an obsolete prejudice, and thus a virtue is made of the necessity of quantum theory. Men are just as subject to suggestion as horses, and each epoch is dominated by a fashion, and the majority do not even see the tyrant who dominates them." [LS] Einstein's criticism of positivism is surely deep and interesting, nevertheless it is difficult to avoid the impression that he systematically underestimated its impact on his scientific creations.

It is worth recalling that important epistemologists shared Einstein's critical evaluation of positivism. E.g., let us read two statements by Karl Popper: "According to positivism, 'our world is only surface - it has no depth'. It consists, in fact, only of our perceptions and of their reflections in our memory. It is a world where nothing is to be searched for, since nothing is hidden. It is a world where nothing can be discovered, nothing can be learnt. It is a world without enigmas." [PP, p. 127] "Positivists, in their anxiety to annihilate metaphysics, annihilate natural science with it. For scientific laws ... cannot be logically reduced to elementary statements of experience. If consistently applied, Wittgenstein's criterion of meaningfulness rejects as meaningless those natural laws the search for which, as Einstein says, is 'the supreme task of the physicist' ... " [SD, p. 36] Popper ascribed the spreading of positivism in physics to the influence of the young Einstein. A statement that seems to me to go to the core of the problem is the following: "The philosophical impact of Mach's positivism was largely transmitted by the young Einstein. But Einstein turned away from Machian positivism, partly because he realized with a shock some of its consequences; consequences which the next generation of brilliant physicists, among them Bohr, Pauli and Heisenberg, not only discovered but enthusiastically embraced: they became subjectivists. But Einstein's withdrawal came too late. Physics had become a stronghold of subjectivist philosophy, and it has remained so ever since." [UQ, pp. 152-153]. In fact Popper could witness Einstein's radical change of opinion about Mach's philosophy: "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." [UQ, pp. 96-97]

The history of quantum theory shows that the most essential conflict that accompanied and followed the birth of the Copenhagen-Göttingen paradigm was a philosophical clash around the idea of physical reality. The realists, headed by Einstein who at this time had turned upside down his philosophical position, included Planck, Ehrenfest, Schrödinger and de Broglie. Winners were however the antirealists (Bohr, Born, Heisenberg, Pauli, Dirac) not because they could prove the realists' ideas false, but because they were united in developing a theory coherent with their philosophical choices and able to explain a remarkable number of phenomena. Anyway, Einstein never accepted the final formulation of quantum mechanics, which he considered at least as incomplete as classical thermodynamics (in so far as not based on atomism). Famous are the letters exchanged with Born from which, beyond an old friendship, surface the differences between the two physicists. Born himself so commented these differences: "... I have the feeling that I have faithfully pursued the path which he showed us in his great days, while he himself stopped at a certain point. This point is the idea that the outer world as it really is, is faithfully and exactly described by science. Seen from this angle, today's theory of matter is indeed a jumble of absurdities, and Einstein from his own point of view was quite right to reject it or, at most, to accept it only as provisional." [MB, p. 164] The initial reference to the path shown by Einstein is clearly directed to the TSR and to the interpretation based on philosophical relativism that accompanied it.

In spite of relativism Einstein made statements of sharply realistic mould in the context of quantum theory. For example: "There is such a thing as the 'real state' of a physical system, which exists objectively, independently of any observation or measurement, and which can be described, in principle, with the means of description afforded by physics." A few lines below he added: "All men, the quantum theoreticians included, actually stick steadfastly to this thesis on reality, as long as they do not discuss the foundations of quantum theory." And right after he stated: "I am not ashamed to make the 'real state of a system' the central concept of my approach." [DB, p. 7]

Einstein insisted on the idea that the physicist should try to form an image of the studied process, almost a hypothetical picture that can acquire validity only after many controls and which must be taken as the basis of the theoretical constructions. In a letter to Born of 1947 he wrote about this: "Therefore I cannot seriously believe in it [in quantum mechanics], because the theory is incompatible with the idea that physics should describe a reality in time and space without spookish actions at a distance." [EB, p. 116]

Another fundamental battle of Einstein was in favor of causality: "Even the great initial success of the quantum theory does not make me believe in the fundamental dice-game, although I am well aware that our younger colleagues interpret this as a consequence of senility. No doubt the day will come when we will see whose instinctive attitude was the correct one." [EB, p. 149] This statement of 1944 joins coherently what Einstein had written twenty years before in a letter to Born: "Bohr's opinion about radiation is of great interest. But I should not want to be forced into abandoning strict causality without defending it more strongly than I have so far. I find the idea quite intolerable that an electron exposed to radiation should choose [of its own free will], not only its moment to jump off, but also its direction. In that case, I would rather be a cobbler, or even an employee in a gaming-house, than a physicist. [EB, p. 82]

Thus Einstein defended realism, causality and description in space and time, against those physicists of Copenhagen and Göttingen who believed to have only continued on the path he had indicated with the TSR. From this comes out all the richness, but also the complexity, of the Einsteinian conceptions. Reckoning with these ideas means entering in the eye of the epistemological-scientific cyclone of the XXth century.

3. Definition of simultaneity

Einstein stated explicitly the conventional nature of the postulate of invariance of the velocity of light. In his fundamental paper of 1905 he wrote: "We have so far defined only an "A time" and a "B time". We have not defined a common "time" for A and B, for the latter cannot be defined at all unless we establish *by definition* that the "time" required by light to travel from A to B equals the "time" it requires to travel from B to A." [EL, p. 40]. This statement is remarkable for two reasons showing the positivistic inclinations of the founder of relativity. Firstly, because it accepts Poincaré's idea that the speed of light is not measurable and can then only be defined; secondly, because the word time, appearing five times, is always between quotation marks, as if it were a dangerous conception. The conventionality of the velocity of light was restated in 1916 when Einstein wrote about the midpoint M of a segment AB whose extreme points are struck "simultaneously" by two strokes of lightning: "that light requires the same time to traverse the path AM ... as the path BM [M being the midpoint of the line AB] is in reality *neither a supposition nor a hypothesis* about the physical nature of light, but a *stipulation* which I can make of my own free will." [SG, p. 18]

In practice, the relativistic synchronization is obtained as follows. Suppose that two identical clocks A and B are at a distance ℓ from one another. A pulse of light starts from A towards B when the clock in A marks time zero; the clock in B is set at time ℓ / c when the pulse arrives there. From synchronization to relativistic simultaneity the step is short. Two instantaneous point like events in A and B at times t_A and t_B (as marked by the respective synchronized clocks) are simultaneous by definition if $t_A = t_B$. Naturally a good positivist does not wonder whether the two events are "really" simultaneous: for him only human manipulations matter and it does not make any sense to think in terms of an objectivity of time.

Thus the notion of relativistic simultaneity depends on human decisions and not on properties of nature. The method coming to everybody's mind does not work: synchronize clocks when they are near and carry them in the points where they are needed. It does not work because it is very clear that transport, that is the fact itself of possessing a velocity, modifies the motion of the clock's hands, as it modifies any periodical motion that one might think to use in order to measure time. The transport of a clock can be executed in a short time at a high velocity, or in a long time at a very low velocity, but there is always an unavoidable finite delay generated by the clock's motion. Given this situation, Poincaré and Einstein decided that the "synchronization" of clocks could be achieved following criteria of any type, provided only they led to a non ambiguous identification of events. The author of relativity made the simplest choice, assuming that the speed of light had the same value in all directions in all inertial frames.

Here it is interesting to stress that the conventional nature of relativistic clock synchronization - and then of the relativistic simultaneity of distant events - opens very interesting perspectives. Let us see why. In general time could be different in two different inertial reference systems $S_0(x_0,y_0,z_0,t_0)$ and $S(x,y,z,t)$, and the "delay" $t-t_0$ (positive, null or negative) of S over S_0 could depend not only on the time t_0, but also on the considered geometrical point. This happens in the TSR, as the Lorentz transformation of time contains also a space coordinate. In other words (and more generally) the time t marked by a clock of S can depend also on the coordinates x, y, z of the point at which the clock is positioned, at least until one finds reasons for the contrary (I found them, see later).

Discussing this problem H. Reichenbach (1925) examined the following situation: in the system S a flash of light leaves point A at time t_1, is reflected backwards by a mirror placed in point B at time t_2 and finally returns in A at time t_3. Naturally t_1 and t_3 are marked by a clock near A, while t_2 is marked by a different clock near B. The problem is how to synchronize the two clocks with one another. In the TSR one assumes that the velocity of light on the one way path A - B is the same as in the two way path B - A - B, so that

$$t_2 - t_1 = \frac{1}{2}\left(t_3 - t_1\right) \tag{1}$$

This formula defines the time t_2 of the B clock in terms of the times t_1 and t_3 of the A clock. It is the choice (1), which determines the presence of x in the (Lorentz) transformation of time. Reichenbach commented that Eq. (1) is essential in the TSR, but it is not epistemologically necessary. A different rule of the form

$$t_2 - t_1 = \varepsilon(t_3 - t_1) \tag{2}$$

with any $0 < \varepsilon < 1$ would likewise be adequate and could not be considered false. He added: "If the special theory of relativity prefers the first definition, i.e., sets ε equal to 1/2, it does so on the ground that this definition leads to simpler relations." [HR, p. 127]

In 1979 Max Jammer discussed Reichenbach's ε coefficient stressing that one of the most fundamental ideas underlying the conceptual edifice of relativity is the conventionality of intrasystemic distant simultaneity. He added: "The "thesis of the conventionality of intrasystemic distant simultaneity" ... consists in the statement that the numerical value of ε need not necessarily be 1/2, but may be any number in the open interval between 0 and 1, *i.e.* $0<\varepsilon<1$, without ever leading to any conflict with experience." [TF, p. 205]

I devoted years of work to the practical confirmation of this intuition. The confirmation came out, ample but with a surprise (see section 5). Anyway, there is an important logical space for different values of ε, that is, in the final analysis, for theories alternative to the TSR! This is the reason why after a century of relativism one can open the doors to a different physics without conflicting with the enormous bulk of experimental results accumulated to date.

An attempt to refute the conventionality of relativistic simultaneity and to defend somehow its objectivity has been made by the philosopher M. Friedman, but his position is weak as based only on the structural simplicity of Minkowski's space, that nobody denies. The real question is to see whether with some slight mathematical complication one can obtain a better description of reality. Recent research has shown that this is indeed the case and that the conventionality of relativistic simultaneity opens a logical space to a different theory that agrees with experiments even better than the TSR.

4. The two most important facts

The Earth moves in space at 2-300 km/sec (about 1‰ of the speed of light) as it takes part, with the Sun, to the rotation of a spiral galaxy, the Milky Way (the revolution round the Sun and the daily rotation have velocities ten and thousand times smaller, respectively). According to the equations of the Galilei-Newton physics the velocity of light relative to a terrestrial laboratory should depend on the propagation direction. In fact, let $\vec{c}$ be the velocity of a punctiform light signal with respect to the privileged system S_0. If $\vec{c}'$ is the velocity of the same signal with respect to a terrestrial laboratory, moving in S_0 with velocity $\vec{v}$, one should have $\vec{c}' = \vec{c} - \vec{v}$. Therefore, if classical physics were correct c' should vary from $c-v$ to $c+v$ when the light propagation direction is changed from parallel to antiparallel to $\vec{v}$.

At first sight it could seem that these effects of the first order in v/c should be easily observable. One should however recall that even before the birth of the TSR Poincaré had argued the impossibility to measure the velocity of an object propagating between two different points. To see the motivations of this unpleasant conclusion let us consider a light signal traveling from A to B. If in B there is a mirror reflecting the signal backwards, it is enough to have a clock near A measuring the times t_1 and t_3 of start and return. The speed of the signal is then given by its definition:

$$c_{\text{ar}} = 2d_{AB} / (t_3 - t_1)$$

where d_{AB} is the A-B distance that can be measured in the standard way using a rigid rod. However, this is a two way velocity and it is possible that the signal velocities from A to B and from B to A be different. For measuring the latter ones two synchronized clocks would be needed, one near A and the other one near B. Unfortunately, during the XXth century nobody knew how to synchronize two distant clocks. All imagined methods gave rise to difficulties. For example, if the clocks are synchronized in A and one is slowly transported from A to B, the very fact of giving it some motion will modify the marked time: the displacement destroys the synchronization!

Well before the formulation of the relativity theory, Poincaré discussed the independence of the velocity of light of its direction of propagation and stated: “That light has a constant velocity and in particular that its velocity is the same in all directions ... is a postulate without which it would be impossible to start any measurement of this velocity. It will always be impossible to verify directly this postulate with experiments.” [HP] The last sentence could perhaps be called “Poincaré's curse”. Agreeing on the impossibility to measure the one way velocities, Einstein decided to solve the problem by decree, assuming the invariance of the velocity of light: the second postulate of the TSR. In fact, as we saw, he described this hypothesis not as a property of nature, but only as a useful stipulation.

This being said, it remains certain that c_{ar} is measurable. Classical physics predicts its variation, due to the Earth motion, much smaller than for the one way velocity (non measurable). More precisely, if the light propagation direction is modified in a terrestrial laboratory, it predicts for c_{ar} variations of the second order, namely of the order of $v^2/c^2 \approx 10^{-6}$.

One of the most precise measurements of c_{ar} was performed in 1978 by a British group and gave the result:

$$c_{ar} = (299\ 792{,}4588 \pm 0{,}0002)\ \mathrm{km/sec}$$

confirmed by subsequent measurements (1987). Thus c_{ar} is known with a precision of 10^{-9}, a thousand times smaller than needed for detecting the second order effects due to the Earth motion. Yet, before and after 1978 one always found the same value within errors, and no dependence on the propagation direction was ever observed, in agreement with the more indirect experiments (such as the Michelson-Morley experiment) that tried to detect the existence of the privileged reference system. Thus we have our first fundamental conclusion:

C1. Within a small error the two way velocity of light is invariant, as it is empirically independent of the propagation direction and the time at which it is measured.

With their famous 1887 experiment Michelson and Morley concluded that no shifts of the interference figures existed due to the Earth motion. To explain this result Fitzgerald and independently Lorentz supposed that the motion of an object through the ether with velocity v generated its shortening in the direction of velocity by the factor

$$R = \sqrt{1 - v^2/c^2} \tag{3}$$

This conjecture could explain the negative result of the Michelson-Morley experiment. The idea of a contraction due to motion was not so far-fetched as it might seem. Using classical physics, Lorentz was able to prove that the movement of an electric charge through ether modifies its electric field by squeezing it towards a plane perpendicular to the direction of motion, and that the degree of squeezing increases with velocity. It follows that an electron bound to a moving proton no longer forms a regular hydrogen atom, but an atom with internal motion taking place on an orbit squeezed similarly to the field. Moreover, the period of the electronic motion turns out to be modified, actually increased for the observer watching the atom move. One must therefore expect that every object (made of atoms) be shortened in its dimension parallel to the direction of motion, and that in every moving clock the pace of advancement of the hands be slowed down.

The first to conclude that a clock must change its pace when in motion was Voigt in 1887. He found, however, an incorrect dependence of period on velocity. In 1900 Larmor considered a system "composed of two electrons of opposite charge" (one would say today: composed of an electron-positron pair), neglected irradiation, and assumed circular orbits round the common centre of mass of the two particles. Assuming also that the whole system was in motion through ether, he proved that the velocity dependent deformation of the electric fields predicted by classical physics generated in the bound system exactly the contraction postulated by Fitzgerald and Lorentz. Furthermore Larmor found that the orbital period was necessarily increased by R^{-1}, where R is given by (3). This was the first correct formulation of the idea of a velocity dependent retardation of clocks.

Today the slowing down of moving clocks is an experimentally very well ascertained phenomenon, to the point that it can be said that one is dealing with a property of nature. One of the most precise and convincing experiments was performed in 1977 when the lifetimes of positive and negative muons were measured at the CERN muon storage ring. Muons with a velocity of $0.9994c$, corresponding to a factor $R^{-1} = 29.33$, were circling in a ring with diameter of 14 m, with a centripetal acceleration equal to $10^{18}\,g$. The lifetime τ was measured and found in excellent agreement with the formula $\tau = \tau_0 / R$ where τ_0 is the lifetime of muons at rest.

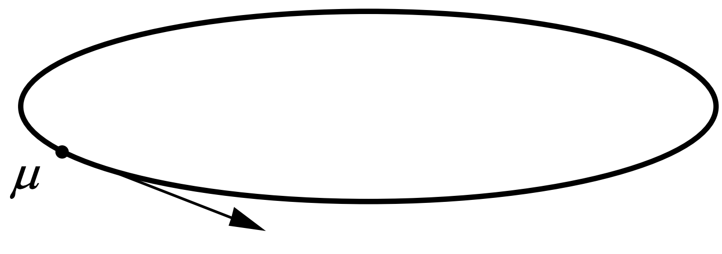


Figure 1. In the CERN storage ring unstable particles ("muons") circulated with a speed smaller than that of light by only six parts over ten thousand. It was observed that muons disintegrated after a lifetime 29,33 times larger than for muons at rest.

The lesson learnt from this experiment concerns the transformation of time: the laboratory time interval τ_0 between two events taking place in the same position of the moving system (injection and decay of the muon) is observed to be dilated according to $\tau_0 = \tau / R$ if compared with the corresponding time interval τ measured by the observer in motion. Besides this experiment, there is rich evidence of another kind, but with the same meaning: measurements made with rectilinear beams of unstable particles showed that the average lifetime (before spontaneous disintegration) also depends on velocity according to $\tau_0 = \tau / R$. These experiments have been repeated so many times, and with such accuracy, that no reasonable doubt remains about the conclusion that the slowing down of moving clocks is a true property of nature, and not a fancy of the physicists' imagination.

In the 1972 experiment with macroscopic clocks by the two American physicists Hafele and Keating six accurately synchronized Cesium atomic clocks were used, and:

1) two were carried by ordinary commercial jets in a full eastbound tour around the planet;

2) other two were carried by ordinary commercial jets in a full westbound tour around the planet;

3) the last two remained on the ground.

It was observed that with respect to the latter clocks, those on board the westbound trip had undergone a loss of 59 ± 10 nanosec., while the clocks on the eastbound trip had undergone an advancement of 273 ± 7 nanosec.. These results were in excellent agreement with the usual formula $\tau_0 = \tau R^{-1}$, if:

a) one used three different factors R^{-1} for the three pairs of clocks. The largest (smallest) factor was that of clocks that traveled eastward (westward) for which the Earth rotation velocity added to (subtracted from) the jet velocity. That is, it was necessary to refer movements not to the Earth surface, but to a reference frame with origin in the Earth centre and axes oriented toward fixed directions of the sky;

b) one kept into account the effect of the Earth gravitational field that varies with altitude and therefore modifies the rates of traveling clocks differently from those left on the ground.

The Hafele-Keating experiment has been criticized because not all parameters were under control during the flights. However its results have been finally and irreversibly confirmed by the GPS (*Global Positioning System*) system of satellites [OQ, pp. 81-90]. This system consists of a network of 24 satellites in roughly 12-hour orbits, each carrying atomic clocks on board. The orbital radius of the satellites is about four Earth radii. The orbits are nearly circular, with eccentricities of less than 1%. Orbital inclinations to the Earth equator are about 55°. The satellites have orbital speeds of about 3.9 km / sec in a frame centered on the Earth and not rotating with respect to the stars. Every satellite has on board four atomic clocks marking time with an error of a few nanoseconds per day ($\mathrm{ns / day}$). From every point of the Earth surface at least four satellites are visible at any time. Initially conceived for military aims, the GPS was subsequently used for telecommunications, satellite navigation, meteorology.

The theory of general relativity predicts that clocks in a stronger gravitational field will tick at a slower rate. Thus the atomic clocks on board the satellites at GPS orbital altitudes will tick faster by about 45.900 $\mathrm{ns / day}$ because they are in a weaker gravitational field than atomic clocks on the Earth surface. The velocity effect predicts that atomic clocks moving at GPS orbital speeds will tick slower by about 7.200 $\mathrm{ns / day}$ than stationary ground clocks. Therefore the global prediction is a gain of about 38.700 $\mathrm{ns / day}$. Rather than having clocks with such large rate differences, the satellite clocks were reset in rate before launch (slowing them down by 38.700 $\mathrm{ns / day}$) to compensate for these predicted effects. The very rich data show that the on board atomic clock rates do indeed agree with ground clock rates to the predicted extent. Thus the theoretical predictions are confirmed, in particular the slowdown of the clock rate due to the orbital velocity: from this point of view there is full agreement between the GPS satellites and the CERN muons!

We can then state the following second fundamental conclusion:

C2. A clock in motion with velocity v undergoes a slowdown of the pace with which it marks the time by a factor R given by (3).

We left in vagueness the question of the reference frame with respect to which v should be calculated. Anyhow, in the next section we will take C1. and C2. as fundamental empirical facts and get rid the vagueness by making a precise assumption: its validity will be corroborated by the success of the ensuing theory.

5. The new theory

According to Mansouri and Sexl [MS] the Lorentz transformations contain a purely conventional term, the coefficient of x in the transformation of time. Reconsidering the whole matter I reformulated the transformation of the space and time variables between inertial systems [FS] starting from very general assumptions. I obtained the "equivalent transformations" containing an indeterminate term, e_1, the coefficient of x in the transformation of time: see Eq.s (4) below.

The structure of the reasoning leading to the equivalent transformations is as follows. Given the inertial frames S_0 and S one can set up Cartesian coordinates (see Fig. 2) and make the following standard assumptions:

(i) Space is homogeneous and isotropic and time homogeneous, at least from the point of view of observers at rest in S_0;

(ii) In the isotropic system S_0 the velocity of light is "c" in all directions, so that clocks have to be synchronized in S_0 with the Einstein method and the one way velocities relative to S_0 can be measured ;

(**iii**) The origin of S, observed from S_0, is seen to move with velocity $v < c$ parallel to the $+x_0$ axis, that is according to the equation $x_0 = v\, t_0$;

(**iv**) The axes of S and S_0 coincide for $t = t_0 = 0$;

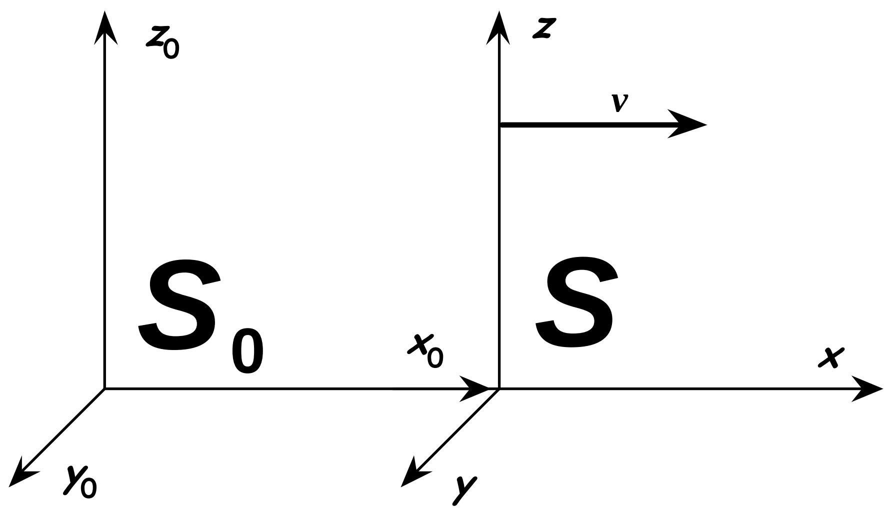


Figure 2. An inertial system S having coordinates $(x,\ y,\ z)$ moves with velocity $v < c$ with respect to the isotropic inertial system S_0 having coordinates $(x_0,\ y_0,\ z_0)$. The two sets of coordinates overlap perfectly at $t_0 = t = 0$.

The geometrical configuration is thus the usual one of the Lorentz transformations.

The assumptions (i) and (ii) are not exposed to objections both from the point of view of the TSR and of any plausible theory based on a privileged system; for the TSR they hold in all inertial systems, in the second case they are taken to hold in the privileged system itself.

Now we add two points discussed in the previous section which, as we saw, are based on solid empirical evidence:

(**v**) The two way velocity of light is the same in all directions and in all inertial systems;

(**vi**) Clock retardation takes place with the usual factor R when clocks move with respect to S_0. Notice that we have now eliminated ambiguities by specifying that R in the formula $\tau = \tau_0 / R$ has to be calculated in S_0.

These conditions were shown [FS] to reduce the transformations of the space and time variables from S_0 to S to the form

$$\begin{cases} x = \dfrac{x_0 - v\,t_0}{R} \\ y = y_0 \qquad ; \qquad z = z_0 \\ t = R\,t_0 + e_1\left(x_0 - v\,t_0\right) \end{cases} \tag{4}$$

with R given by (3). From (4) one can easily see that the "delay" $t - t_0$ of a clock in S, with respect to the clock in S_0 which is passing by, in general depends not only on t_0, but also on the point x of S in which the former clock is placed. Only if $e_1 = 0$ such a complication is absent. Therefore the physically free parameter e_1 can be fixed conventionally by defining in S the simultaneity of distant events, or, which is the same, by choosing a clock synchronization method in S. Clearly, then, the denomination appropriate for e_1 is "synchronization parameter".

The Lorentz transformations of the TSR are a particular case, obtained for $e_1 = -v / Rc^2$, value introducing a certain symmetry between space variables and time, forcing the latter to a geometrical role in a four dimensional space. With Minkowski's words: "The views of space and time which I wish to lay before you ... are radical. Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality." [EL, p. 75].

Different values of e_1 imply different theories of space and time that are empirically equivalent to a very large extent. I checked with explicit calculations [FS] that the empirical data are very often insensitive to the choice of e_1 (Römer, Bradley, Fizeau, Michelson-Morley, Doppler, etc.). Thus there are infinitely many theories explaining equally well the results of these experiments. It is remarkable that all such theories are based on the existence of a privileged frame, the only exception being the TSR.

The previous conclusion would seem to agree with the conventionality idea of clock synchronization. There are however experimental situations of a different type (linear accelerations, rotating platforms, superluminal signals) allowing one to determine the unique synchronization allowed by nature (which is not the one of the TSR, but is based on $e_1 = 0$). Obviously this is a very important point, but we cannot present it here for reasons of space. All the necessary arguments are given in detail in the last chapter of my book [FS].

I proposed that the Eq.s (4) with $e_1 = 0$ be called inertial transformations. They imply a complete liberation of time from the merely geometrical role to which it had been forced in the Minkowski space and predict that the velocity of light relative to an inertial system S moving with respect to the privileged one S_0 be not isotropic. A corresponding anisotropy is predicted for Reichenbach's parameter ε.

6. Energy and relativism

The last six sections, starting from the present one, are devoted to as many sectors of physics that the TSR does not describe satisfactorily. Only in one case (Sagnac effect) one can talk of impossibility to deduce from the TSR a formula in agreement with experiments, while in the other cases one has to do with the impossibility to give to the mathematical symbols a reasonable physical meaning. We start from the mass-energy equivalence.

The theory of relativity led to the conclusion that an arbitrary object, whose quantity of matter is measured by mass, and pure motion, measured by energy, are transformable into one another and must be considered different forms of a unique reality. This conclusion has been confirmed in an enormous number of experiments of nuclear and subnuclear physics, so that it can now be considered an irreversible conquest of science. The mass-energy equivalence is expressed by the famous formula

$$E = mc^2$$

The reciprocal transformability of energy and mass was so described: "A further consequence of the (special) theory of relativity is the connection between mass and energy. Mass is energy and energy has mass. The two conservation laws of mass and energy are combined by the relativity theory into one, the conservation law of mass-energy." [EI, p. 132]

The new discovery was full of consequences, for example it implied a full continuity between that form of energy diffused in space which is called "field" and the material sources generating it: "From the relativity theory we know that matter represents vast stores of energy and that energy represents matter. We cannot, in this way, distinguish qualitatively between mass and field, since the distinction between mass and energy is not a qualitative one. We could therefore say: Matter is where the concentration of energy is great, field where the concentration of energy is small. But if this is the case, then the difference between matter and field is a quantitative rather than a qualitative one. [...] In the light of the equivalence of matter and energy the division in matter and field is something artificial and not well defined. [...] Matter is where the concentration of energy is high, field is where the concentration of energy is low. But if this is the case, the difference between matter and field is quantitative and not qualitative." [EI, p. 116]

From the practical point of view the mass-energy equivalence means that a material object can be transformed into pure motion (that is, into kinetic energy) of other objects and, *viceversa*, that it is possible to create matter at the expenses of motion. These transformations take place according to the rigorous laws of conservation of energy and momentum. These are absolutely concrete processes: it is possible to make two protons with high enough kinetic energy collide to produce in the final state the same two protons with identical properties (mass, electric charge, etc.) and, additionally, one or several new pieces of matter, for example some π mesons, which were born from nothingness during the collision. That is, they appear to be born from nothingness to a person believing that matter can neither be created nor destroyed. Actually, if one compares the kinetic energies of the initial and final state one finds that exactly the quantity of kinetic energy has disappeared that is necessary to produce the new mass of the final state. Let us consider the following reaction as an example:

$$P + P \rightarrow P + P + \pi^0$$

that reads as follows: two colliding protons ($P + P$) give rise to ($\rightarrow$) a new physical state including two protons and a neutral π meson ($P + P + \pi^0$). The meson π is a quantum of nuclear forces and has a rest mass 264 times that of the electron.

Also the inverse processes exist, in which energy is created at the expenses of mass. Of this type are the uranium fission reactions. In this way one sees how false is the belief of the past that matter can neither be created nor destroyed. In reality there is no law of conservation of matter: what is conserved under all circumstances is energy together with its vectorial daughter, the quantity of motion. These are the fundamental quantities of reality, whereas the stability of matter is pure appearance, born from the fact that we live in a low energy world: let the energy increase and matter will start to disappear! In fact at the center of the Sun there is a temperature of 15-20 million degrees, the kinetic energy of thermal agitation is correspondingly high and every second four million tons of matter are transformed into radiant energy.

It is out of doubt that the conquests of relativity on the just described mass-energy relationship belong to the philosophical field of realism. Positivism, however, did not disappear, on the contrary it tried to force its domination to the very notion of energy, as we will see next.

Energy has all the right properties to be considered a kind of fundamental substance of the universe: it is indestructible, it enters in all dynamical processes and matter itself has to be considered a localized form of energy. Naturally this "energetic materialism" is very different from the anti-atomistic energetism proposed by Ostwald towards the end of the XIXth century. However, the TSR itself negates sharply a fundamental role to the energy. It does so with its relativism. Every inertial observer assigns a different velocity, and thus a different energy, to any given particle. The relativistic formula of the total energy E (kinetic energy plus rest mass energy) of a particle having rest mass m and velocity u relative to a frame of reference S is

$$E = \frac{mc^2}{\sqrt{1 - u^2/c^2}}$$

where c is the velocity of light, as usual. The previous equation holds in all inertial systems S, S', S'', ... provided one uses the particle velocity u, u', u'', ... relative to each of them. If one asks which is the real value of energy, the TSR answers that all observers are equivalent, so that their answers are all equally valid. And since each of them attributes to the particle energy a different value, in the impossibility of choosing one of these as "more true" than others, one is forced to conclude that a real value of energy does not exist. In this way energy, possible substratum of the universe, is stripped of the most important property, a well defined numerical value.

In 1943 J. Jeans used a similar argument against the objectivity of forces. For him the essence of all physical explanation is that each particle of a system experiences a real and definite force. This force should be objective as regards both quantity and quality, so that its measure should always be the same, whatever means of measurement are employed to measure it - just as a real object must always weigh the same, whether it is weighed on a spring balance or on a weighing beam. But the TSR shows that if motions are attributed to forces, these forces will be differently estimated, as regards both quantity and quality, by observers moving at different speeds, and furthermore that all their estimates have an equal claim to be considered right. Thus - Jeans concludes - the forces cannot have a real objective existence; they are mere mental concepts that we make for ourselves in our efforts to understand the workings of nature. [JJ, p. 14] Naturally Jeans was able to generalize his argument to all physical quantities: force, energy, momentum, and so on. With his words: "But the physical theory of relativity has now shown ... that electric and magnetic forces are not real at all; they are mere mental constructs of our own, resulting from our rather misguided efforts to understand the motions of the particles. It is the same with the Newtonian force of gravitation, and with energy, momentum and other concepts which were introduced to help us understand the activities of the world - all prove to be mere mental constructs, and do not even pass the test of objectivity. If the materialists are pressed to say how much of the world they now claim as material, their only possible answer would seem to be: Matter itself. Thus their whole philosophy is reduced to a tautology, for obviously matter must be material. But the fact that so much of what used to be thought to possess an objective physical existence now proves to consist only of subjective mental constructs must surely be counted a pronounced step in the direction of mentalism." [JJ, p. 200] With a start of this kind it is no surprise that Jeans arrives to the most genuine philosophical idealism: "Today there is a wide measure of agreement, which on the physical side of science approaches almost to unanimity, that the stream of knowledge is heading towards a non-mechanical reality. The universe begins to look more like a great thought than like a great machine. Mind no longer appears as an accidental intruder into the realm of matter. We ought rather to hail it as the creator and governor of the real of matter." [PF, p. 235]

For escaping from these conclusions there is only one way, giving up relativism which in the TSR arises from the symmetry of the Lorentz transformations and constitutes the most natural interpretation of the Einsteinian theory. The retrieval of the objectivity of energy and of the other physical quantities should rather aim at the inequivalence of the different reference frames. But such lack of equivalence is achieved with the inertial transformations, based on the existence of a privileged system, which give back to the mass-energy equivalence all its great conceptual importance [FS]. Energy can take up its fundamental role, its true value being the one relative to the privileged isotropic inertial system.

7. Einstein's relativistic ether

We will now discuss the famous "abolition" of the ether, which accompanied the birth of the two relativistic theories. For example, in the 1905 paper Einstein stated that the introduction of a luminiferous ether could be considered superfluous, given that the new theory needed neither an absolutely stationary space endowed with particular properties, nor a medium in which electromagnetic processes, such as the propagation of light, could take place.

In the years of the transition from positivism to realism, Einstein started to reconsider the whole question of the ether [LK] and admitted that, after all, it was still possible to think it as existing, even if only to designate particular properties of space. He stated that during the evolution of science the word "ether" had changed its meaning several times and that anyway, after the birth of the theory of relativity, it could not anymore indicate a medium composed of particles. A self critical position was ripe by then, and in fact in 1919 Einstein wrote to Lorentz : "It would have been more correct if I had limited myself, in my earlier publications, to emphasizing only the nonexistence of an ether velocity, instead of arguing the total nonexistence of the ether, for I can see that with the word *ether* we say nothing else than that space has to be viewed as a carrier of physical qualities." [Quoted in LK, p. 2]

As one could expect, Einstein's change of opinion started with the criticism of the Machian philosophy that influenced him so much in the formulation of the TSR and brought him to believe that space and time were chiefly metaphysical and antiscientific ideas. He later described the reasons of his change with these words: "I see Mach's greatness in his incorruptible skepticism and independence; in my younger years, however, Mach's epistemological position also influenced me very greatly, a position which today appears to me to be essentially untenable. For he did not place in the correct light the essentially constructive and speculative nature of thought and more especially of scientific thought; in consequence of which he condemned theory on precisely those points where its constructive-speculative character unconcealably comes to light, as for example in the kinetic atomic theory."[AB, p. 8]. At this point Einstein rediscovered all the importance of the arguments in favor of the existence of an ethereal medium, such as the existence in every point of space of well defined inertial reference systems, or, which is the same, the genesis of the inertial forces in the accelerated systems. To explain this fundamental phenomenon he would not invoke an action at a distance of the fixed stars (as done by Mach), but rather resorted to well defined properties of space itself, eventually generated by all the matter of the universe, but anyhow active here and now. Therefore he wrote: "On the other hand there is a weighty argument to be adduced in favor of the ether hypothesis. To deny the existence of the ether means, in the last analysis, denying all physical properties to empty space. But such a view is inconsistent with the fundamental facts of mechanics." [AR]

Einstein thought that ether should not be conceived as different from the four dimensional space with real physical properties. In his opinion it did not make much sense to suppose that an absolutely empty geometrical space preexisted and that a substance, the ether, could fill it and endow it with physical properties. Therefore: “Physical space and the ether are only different terms for the same thing; fields are physical states of space. If no particular state of motion can be ascribed to the ether, there does not seem to be any ground for introducing it as an entity of a special sort alongside space.” [Quoted in LK, p. 123] Considering the mechanical nature of the Lorentz ether, Einstein stated, almost joking, that the TSR (reconsidered in the new approach based on ether) had given rise to a radical change, consisting just of depriving the ether of its last mechanical property that Lorentz had still left it, that of immobility: “More careful reflection teaches us, however, that this denial of the existence of the ether is not demanded by the special principle of relativity. We may assume the existence of an ether; only we must give up ascribing a definite state of motion to it, i.e., we must by abstraction take away from it the last mechanical characteristic that Lorentz had still left it.” [AR] The idea was confirmed with the following words: “As to the mechanical nature of the Lorentzian ether, it may be said of it, in a somewhat playful spirit, that immobility is the only mechanical property of which it has not been deprived by H.A. Lorentz. It may be added that the whole change in the conception of the ether, which the special theory of relativity brought about, consisted of taking away from the ether its last mechanical quality, namely, its immobility.” [AR]

Also in general relativity Einstein’s ether was deprived of all types of motion, then also of the possibility of being motionless. In short, it had radically new properties that prevented to imagine it composed of parts or particles in any state of motion. This new description was unavoidable if the ether had to look exactly the same in all inertial reference systems. Thus was born the idea of an ether compatible with the TSR, of a relativistic ether. After all this idea can be considered an attempt of compromise between the positivism of the TSR and the realism of the ether. But this time nobody took seriously the great physicist: many liked positivism, a few liked realism, but it seems that they all agreed that the two philosophies should not be mixed together.

What can one say, today, about Einstein’s relativistic ether? Well, in the first place that the return to the ether is an operation dictated by what we called above good sense: an empty space endowed with physical properties, such as that we live in, can very well be called ether, a war on words being of no interest in physics. In the second place one should however add that it is strange and unpleasant to deprive the ether of all states of motion. This must have been considered inevitable to Einstein who wanted to defend the interpretation of the TSR based on relativism, but today it is not anymore so. Thanks to the inertial transformations, which admit the existence of a privileged inertial system, a full retrieval of the Lorentz ether becomes finally possible [FS].

8. The twin paradox

Let us repeat the famous "twin paradox" which was formulated by Langevin to illustrate the peculiar properties of time predicted by special relativity. It should always be kept in mind that one has to do in reality with a fact of nature ascertained beyond all reasonable doubt, more than with a paradox. There are two twins, **F** and **G**, and the former decides to become a space voyager by performing an interstellar trip, while the latter remains on Earth to await his return. The departure takes place when the twins are twenty years old. The spaceship of **F** accelerates rapidly until it reaches a velocity equal to 99% of that of light, then it travels until arriving near Mira Ceti, a famous variable star 32 light years away from Earth. When **F** reaches his destination, he stops, takes rapidly some pictures of that stellar system, then accelerates back toward Earth, soon reaching again the constant speed of $0.99\ c$. How long later will he be back? The calculation is easy for twin **G**, it is about 64.6 years (the brief time spent in accelerating is neglected). The situation is different for **F** who undergoes both technologically and biologically the slowing down of all physical processes. On the moving spaceship everything is slower, from the clocks to the computers and to the heartbeats of the space travelers. One can almost say that time itself slows down by the usual factor R which for **F** is $R \cong 0.141$. For twin **F**, thus, the voyage in reality lasts $64.6 \times 0.141 \cong 9$ years. When at the end of the voyage **F** meets again **G** he is still young (he is 29 years old), while **G** is an octagenarian.

In this argument, the only paradoxical element is that no one has ever experienced anything of the kind, but this is natural since the maximum velocities ever reached by man are terribly small if compared with c and give practically $R = 1$. Nevertheless, a real experiment using concretely "human" travels, was performed by Hafele and Keating, as we saw, and their results were fully confirmed by the GPS satellites. It has to be said that all these real or ideal results are in excellent agreement with the relativistic equations, but very little with the foundational relativism of the TSR. In physics one should always pay attention to the fact that there are two logics present, the mathematical one of the equations and the qualitative one of the meaning of the used symbols. A numerical agreement might not be enough if the meaning of the theoretical prediction is not what it should be.

In fact, the difference between the times shown by the atomic clocks on board the two flights of the Hafele-Keating experiment could be explained by assuming that in the eastward flight the airplane velocity added to the Earth rotational velocity, while in the westward flight the two velocities subtracted. In this way one considered that *with respect to the surrounding space* one flight was faster. Relativism would instead require that only motions relative to the Earth surface be considered, but from such a point of view the eastward and westward flights should produce equal physical effects on the clocks, contrary to observations. To state that the results of these experiments are in good agreement with the TSR, as done by several authors, one has to forget the relativism of the theory, and thoughtlessly calculate with respect to the inertial frame in which the Earth center is instantaneously at rest.

The problem disappears with the inertial transformations which are not based on relativism and require one to consider that light propagates isotropically only with respect to the privileged inertial system [FS]. Similarly, in the case of the twin paradox considered above the troubles arise from considering the movements symmetrical, as required by relativism. In a theory with a privileged system the twin ageing less is always the one who feels the effects of a larger absolute velocities and no problem arises.

9. The aberration of light

The phenomenon of aberration of the star light, discovered by Bradley in 1725, is very important in relativistic physics, so much that Einstein discussed it in his first article on the TSR, the famous one of 1905. From the angular deviation of the light of a star, observed during a year, it is possible to deduce the velocity of light. But the star light follows a one way path towards the Earth and one could believe that aberration allows one to measure the one way velocity of light. Actually it is not so, as all the equivalent transformation predict exactly the same aberration angle even though the one way velocity is different for different equivalent transformations.

Consider a localized light pulse P from the point of view of the privileged reference system S_0 of the equivalent theories, relative to which the velocity of light is the same in all directions. If θ_0 is the inclination with respect to the x_0 axis of the trajectory of P and θ is the inclination of the same trajectory as judged in S, one can prove [FS] an aberration formula identical to the one of relativity, namely:

$$\tan\theta = \frac{cR\,\mathrm{sen}\theta_0}{c\cos\theta_0 - v} \tag{5}$$

Al the quantities entering in the right hand side of (5) are relative to the isotropic system S_0 for which all equivalent theories accept the same velocity of light, and thus the same synchronization of clocks. Clearly all the equivalent transformations agree on the numerical values of θ_0 and v. Therefore they predict exactly the same aberration angle θ for an arbitrary reference system S. Even though we are unable to identify S_0 the previous conclusion is obviously enough for concluding that we have so obtained a complete explanation of aberration from the point of view of the equivalent transformations, based on the existence of a privileged system: if the absolute aberration angle is the same for all S, also the aberration angle observed between two moving systems S and S' has to be the same!

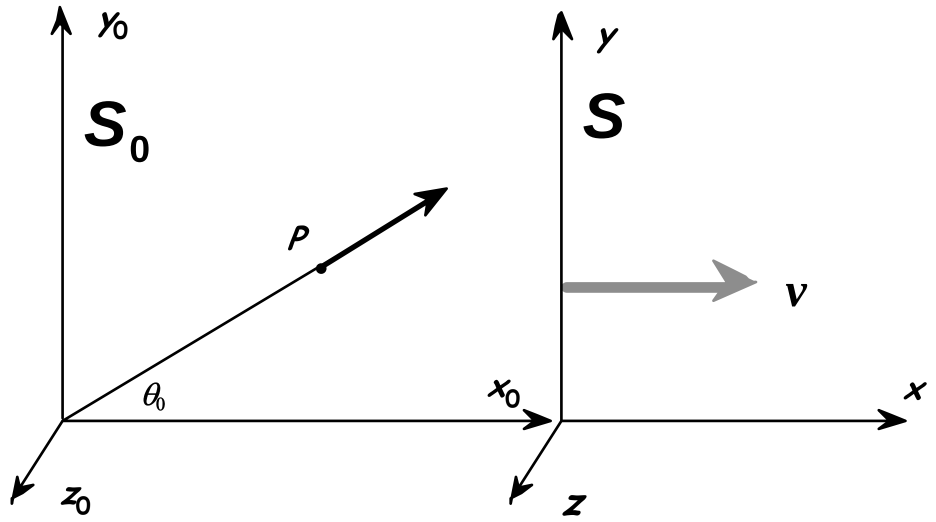


Figure 3. A localized light pulse P propagates in the isotropic inertial system S_0, relative to which the velocity of light is the same in all directions. One seeks the description of the motion of P in the different inertial system S.

The above explanation of aberration in terms of absolute motion provides the resolution of a longstanding problem of the relativistic approach. Einstein deduced the aberration formula (5) from the idea that v is the *relative* velocity of the star-Earth system. This idea was repeated by many authors, e.g. by Møller, clearly because the use of the relative velocity is the most natural thing to do in a theory, such as the TSR, based on the philosophy of relativism. If, however, we imagine the stars as molecules of a gas in random motion, we have to admit that the velocity relative to the Earth varies from star to star. This conclusion contradicts the fact that the observed angle of aberration is the same for all stars. In 1950 Ives stressed that the existence of binary stars gives rise to the same difficulty for the TSR, noting that there are spectroscopic binaries with known orbital parameters and velocities around their center of mass similar to the Earth orbital velocity. Therefore the components of such a binary system at some times can have velocities relative to the Earth very different from one another; nevertheless it is well known that these components exhibit always the same aberration angle. The argument was developed by Eisner and Hayden, who strengthened Ives' conclusions.

The aberration problem is completely solved by the inertial transformations predicting that the v in (5) is the Earth absolute velocity and that aberration is due to the variations of v generated by the orbital motion of our planet.

10. The Sagnac effect

In the Sagnac 1913 experiment a circular platform rotated uniformly around a vertical axis. In an interferometer mounted on the platform, two interfering light beams, reflected by four mirrors, propagated in opposite directions along a closed horizontal circuit defining a certain area A. The rotating system included also the luminous source and a detector (a photographic plate recording the interference fringes). On the pictures obtained during clockwise and counterclockwise rotations the interference fringes were observed to be in different positions.

This fringe displacement is strictly tied to the time delay with which a light beam reaches the detector with respect to the other one and turns out to depend on the disk angular velocity. Sagnac observed a shift of the interference fringes every time the rotation was modified. Considering his experiment conceptually similar to the Michelson-Morley one, he informed the scientific community with two papers (in French) bearing the titles "*The existence of the luminiferous ether demonstrated by means of the effect of a relative ether wind in an uniformly rotating interferometer*" and "*On the proof of reality of the luminiferous ether with the experiment of the rotating interferometer.*"

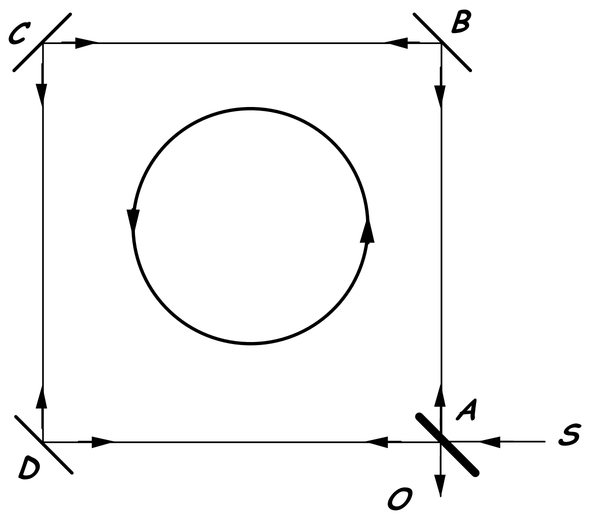


Figure 4. Simplified configuration of the Sagnac apparatus. Light from the source S is split in two parts by the semitransparent mirror A. The first part moves on the path $ABCDAO$ concordant with disk rotation, the second part moves on $ADCBAO$ discordant from rotation. The two parts interfere in O.

The experiment was repeated in different ways, with the full confirmation of the Sagnac results. The 1925 repetition by Michelson and Gale used large dimensions of the optical interference system (a rectangle about 650m x 360m); in this case the disk was the Earth itself at the latitude concerned. The light propagation times were not the same, as evidenced by the resulting fringe shift. Full consistency was found with the Sagnac formula if the angular velocity of the Earth rotation was used.

Surprisingly theoreticians were little interested in the Sagnac effect. As far as I know Einstein's publications never mentioned it. A first discussion by Langevin came only 7-8 years later and was as much formally self-assured as substantially weak. One of the opening statements is this: "I will show how the theory of general relativity explains the results of Sagnac's experiment in a quantitative way." Langevin argues that Sagnac's is a first order experiment, on which all theories (relativistic or pre-relativistic) must agree qualitatively and quantitatively, given that the experimental precision does not allow one to detect second order effects: therefore it cannot produce evidence for or against any theory. Then he goes on to show that *Galilean* kinematics explains the empirical observations!

The impression that Langevin, beyond words, could not be satisfied with his explanation is reinforced by his second article of 1937 in which two relativistic treatments are presented. The first one is still that of 1921, this time deduced from the strange idea that the time to be adopted everywhere on the platform is that of the rotational centre (which is motionless in the laboratory). The second one is to define "time" in such a way as to enforce a velocity of light constant and equal to c by starting from a non total differential, falling so flatly in the problem of the discontinuity for a tour around the disk that I discuss in the book [FS].

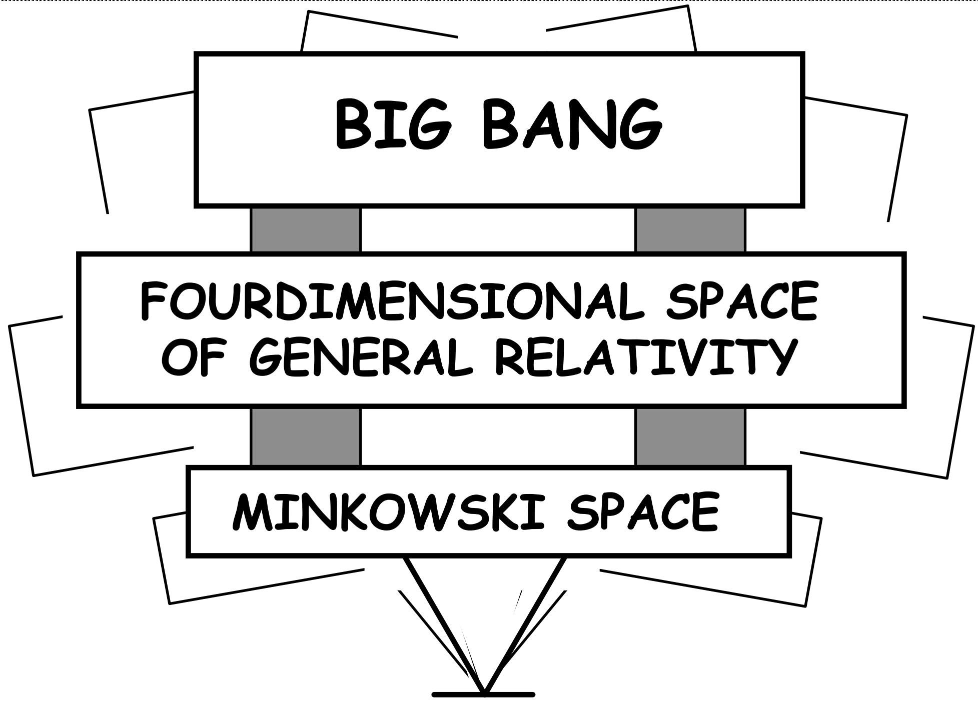
In 1963 was published an influential review paper by Post, who seems to agree with the idea that two relativistic proofs of the Sagnac effect are better than one. The first proof (in the main text) uses arbitrarily the laboratory to platform transformation of time $t' = tR$ where R is the usual square root factor of relativity, here written with the rotational velocity. The second proof (in an appendix) starts from the Lorentz transformation $t' = \left(t + \vec{v} \cdot \vec{r} / c^2\right) / R$, but it hastens to let the second term disappear with the (arbitrary) choice of $\vec{r}$ perpendicular to $\vec{v}$. The tendency to cancel the space variables in the transformation of time, common to Langevin and Post, shows the great difficulty in explaining the physics of the rotating platform with the TSR. The result can only be a great confusion, to the point that Hasselbach and Nicklaus, describing their own experiment, list about twenty "explanations" of the Sagnac effect and comment: "This great variety (if not disparity) in the derivation of the Sagnac phase shift constitutes one of the several controversies ... that have been surrounding the Sagnac effect since the earliest days."

The tendency by Langevin and Post to get rid of x in the transformation of time somehow anticipates the approach based on the inertial transformations, the only ones among the equivalent transformations, which provide a rigorous qualitative and quantitative explanation of the Sagnac effect [FS].

11. The cosmological question

A much used method for providing an intuitive understanding of *big bang* is based on the analogy between the universe and the surface of an inflating rubber balloon covered with dots, adding that the real world is however the three dimensional surface of a four dimensional sphere. The use of the four dimensions (4D) is essential. In fact, in the ordinary space with three dimensions (3D) the *big bang* would be a great explosion producing matter, throwing it in all directions and generating galaxies with different velocities. Seen globally the cosmos would be an irregular structure composed of an empty central region, the "crater of the explosion", an intermediate region containing the galaxies and an external part containing only radiation. Whatever our position could be in the intermediate region, we would see a vault of heaven very different from the basically isotropic one disclosed by the great telescopes. No structure in the 3D space, born from an explosion occurred 10-20 billion years ago, could resemble the universe we observe.

For this reason all the theoretical models of *big bang* find it absolutely necessary to introduce 4D. We should then stress that from a conceptual point of view these models have a very unstable equilibrium, based as they are on the 4D space of general relativity, in turn derived from the Minkowski space of the TSR. Thus the *big bang* depends strongly on the mixing of space with time of the TSR. In other words, it is in great danger if one modifies the fourth Lorentz transformation. But this is exactly what we did by adopting the inertial transformations and giving up the Lorentz ones! In the inertial transformations time is independent of space and in this way a conception of reality is introduced in which no room is left for a 4D space.



$$c\,t' = \frac{c\,t - \beta x}{\sqrt{1 - \beta^2}}$$

Figure 5. The unstable equilibrium of the *big bang* model. The model is built on the four dimensional space of general relativity, in turn based on the Minkowski space of special relativity which is entirely dependent on the Lorentz transformation of time.

In the idea of time separated from space, flowing from a not modifiable past to a future not yet existing, but to be built, there is no place for 4D in which to dip and bend our 3D universe. Forced from the experimental evidence to re-appropriate a space with 3D and without curvature, we have to agree that the *big bang* theory cannot be true. No structure of the 3D space, originated from an explosion 10-20 billion year old, could represent a universe similar to the one we observe. The *big bang* never happened!

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