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Wikipedia unable to deal with Relativity

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Wikipedia has problems with clearly stating what Einstein's relativity "is". It has articles that contradict each other on relativity. Since wikipedia is in a continual state of change I can only deal with what it says about relativity at this time of 2011-02-17. Physics has become ambiguous thanks to Einstein. The issue however is so vast that I can only highlight some of the ambiguities.

(SR = Special relativity, GR = General relativity)

The two articles in wikipedia I shall be referring to are: "Special relativity (alternative formulations) (SRAF article) and "Lorentz ether theory" (LET article). I will be contrasting what they both say and have them as Appendices to show what they say at 2011-02-17

There is a great deal more in wikipedia with problems as regards relativity, so this is just illustrative of the whole mess.

Also since wikipedia is in process of continual change, they might try to hide this mess later under further layers of confusion; so be warned of that and when later claims are made and modifications are made to the claims made at 2011-02-17 – one should ask for what evidence do they have for those changes rather than just docilely accept.

The wiki article "Special relativity (alternative formulations" (SRAF article) starts:

"As formulated by Albert Einstein in 1905, the theory of special relativity was based on two main postulates:

1. The principle of relativity — The form of a physical law is the same in any inertial frame.
2. The speed of light is constant — In all inertial frames, the speed of light c is the same whether the light is emitted from a source at rest or in motion. (Note this does not apply in non-inertial frames, indeed between accelerating frames

the speed of light cannot be constant.[1] Although it can be applied in non-inertial frames if an observer is confined to making local measurements.)

"There have been various alternative formulations of **special relativity** over the years. Some of these formulations are equivalent to the original formulation whereas others result in modifications."

me: So the things to note here are that Einstein formed SR in 1905. That there are alternative formulations of SR to Einstein and there are formulations that are different to Einstein's.

I draw your attention to the word "original"; it says the "original formulation". One might naively think that the original formulation of SR is what Einstein gave in 1905.

However as we glance down this article it says:

"Hendrik Lorentz and Henri Poincaré developed their version of special relativity in a series of papers from about 1900 to 1905. They used Maxwell's equations and the principle of relativity to deduce a theory that is mathematically equivalent to the theory later developed by Einstein."

me: Note that Lorentz and Poincare were developing their theory before Einstein 1905. So the issue is whether the "original formulation" is Poincare- Lorentz not Einstein 1905. (Highlighted further by the wiki article saying it is their version of SR.)

However the article tries to reassure us that Poincare-Lorentz theory is mathematically equivalent to Einstein 1905, so we might naively think all is safe and that we can accept either Poincare-Lorentz or Einstein 1905 as original formulation of SR with no difficulties. (Naively – in the sense that we are to be shocked it is otherwise.)

So let us now look at the wiki article on "Lorentz ether theory" (LET article), it starts:

"What is now often called **Lorentz Ether theory** ("LET") has its roots in Hendrik Lorentz's "Theory of electrons", which was the final point in the development of the classical aether theories at the end of the 19th and at the beginning of the 20th century.

"Lorentz's initial theory created in 1892 and 1895 was based on a completely motionless aether."

me: Hold on a minute—it's now giving us new dates!

SRAF article gave us: 1900 to 1905 for the Poincare-Lorentz theory. Now this LET article tells us Lorentz started his theory 1892- 1895. Obviously Poincare later came on board and the theory developed further from that.

But now we have the initial form of the theory as 1892-1895, this is long before the time of Einstein 1905. So is the “original formulation” of SR in the form of the theory of Lorentz 1892-1895? Answer Wiki has now suddenly hit a barrier of conflict of interests. I remind you of what it said in SRAF article:

“There have been various alternative formulations of **special relativity** over the years. Some of these formulations are equivalent to the original formulation whereas others result in modifications.”

me: The “original formulation” of SR theory could be Lorentz theory1892-1895.

The SRAF article is trying to gloss over the problem of what is the original formulation of SR, it does not state what that formulation “is”, it wants the reader to just assume that it is Einstein 1905, but there is theory before that!

The problem of the “original formulation” gets worse, as the LET article continues and tells us:

“Eventually, it was Henri Poincaré who in 1905 corrected the errors in Lorentz's paper and actually incorporated non-electromagnetic forces (incl. Gravitation) within the theory, which he called "The New Mechanics".”

me: So Lorentz 1892-1895 theory was changed in 1905 to become Poincare-Lorentz theory; and this theory incorporated gravity. Something that Einstein did not claim for his SR, and he had to develop GR to add gravity.

LET article continues and says:

“Many aspects of Lorentz's theory were incorporated into special relativity (SR) with the works of Albert Einstein and Hermann Minkowski.”

me: So Lorentz’s theory presumably of 1892-1895 is not Einstein’s 1905 theory.

I remind you what SRAF article says about SR:

“Hendrik Lorentz and Henri Poincaré developed their version of special relativity in a series of papers from about 1900 to 1905. They used Maxwell's equations and the principle of relativity to deduce a theory that is mathematically equivalent to the theory later developed by Einstein.”

me: i.e. whatever SRAF article means by “mathematically equivalent” now does not make sense, because LET article points out Lorentz 1892-1895 theory is not Einstein 1905 theory, and Poincare-Lorentz theory is not Einstein 1905 theory because Poincare includes gravity while Einstein does not!

i.e. we have conflict of what these two articles in wiki are saying. And it all centres upon when SRAF article says:

"There have been various alternative formulations of **special relativity** over the years. Some of these formulations are equivalent to the original formulation whereas others result in modifications."

me: SRAF article avoids saying what the "original formulation" "is" and left everything ambiguous, it hopes that the reader just falls into the trap of assuming the "original formulation" is Einstein 1905 theory and then deluding oneself for the rest of the SRAF article that this formulation is the same as the Poincare-Lorentz theory. When in LET article it clearly points out that Poincare-Lorentz theory is not Einstein 1905 theory.

A conflict of interests between the two articles and the facts do not tie together.

If the "original formulation" is Poincare-Lorentz theory then it's not Einstein 1905 theory that should be the basis of modern physics, and the Poincare-Lorentz theory is better than Einstein 1905 because it includes gravity.

Thus look out for the changes that wiki might try to make to unify these articles; to try to bodge the facts, because mainstream wants Einstein 1905 as basis of modern physics, and so does not want to admit an Einstein-type relativity theory before Einstein 1905. Mainstream wants Einstein 1905 as its start, and it wants this so badly - it is prepared to alter its version of the history from what actually happened to conform to Einstein 1905 as being the basis of modern physics.

The LET article continues:

"Today LET is often treated as some sort of "Lorentzian" or "neo-Lorentzian" interpretation of special relativity. The introduction of length contraction and time dilation for all phenomena in a "preferred" frame of reference (which plays the role of Lorentz's immobile aether), leads to the complete Lorentz transformation. Because of the same mathematical formalism it is not possible to distinguish between LET and SR by experiment."

me: So if LET is the "original formulation" can't tell the difference between it and Einstein 1905 theory. (An issue I will get back to anon.)

The LET article comes up with a contrived reason for why LET is dismissed in favour of Einstein 1905 theory.

"However, in LET the existence of undetectable ether is assumed and the validity of the relativity principle seems to be only coincidental, which is one reason why SR is commonly preferred over LET."

me: However Einstein in 1920s was saying ether existed, so if LET was original formulation then Einstein himself went back to that as the original formulation.

The LET article then says:

“Another important reason for preferring SR is that the new understanding of space and time was also fundamental for the development of general relativity.”

me: But when we look at Eddington and Einstein they were treating GR as an ether theory. (see my previous articles). So the supposed reason for rejecting LET in favour of Einstein 1905 theory was Einstein 1905 theory did not have ether no longer makes sense. Because Einstein brought back ether for GR, it seems LET was more compatible with GR than Einstein 1905 theory so contrary to what is being said about preferring Einstein 1905 theory because of link to GR, it would be better to prefer LET with GR because both linked by accepting ether.

So back to when wiki says: “ .. not possible to distinguish between LET and SR by experiment. “ – that is an error, it is possible because LET has ether same as GR and GR accepted by experiment. Of course with Einstein and Eddington accepting GR as ether theory, those relativists that have come after them are - no doubt confused over whether GR is now an ether theory.

And as I have pointed out in previous articles – GR is really Newtonian physics once the mistakes are corrected with GR.

Appendices:

Special relativity (alternative formulations)

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As formulated by Albert Einstein in 1905, the theory of special relativity was based on two main postulates:

1. The principle of relativity — The form of a physical law is the same in any inertial frame.
2. The speed of light is constant — In all inertial frames, the speed of light c is the same whether the light is emitted from a source at rest or in motion. (Note this does not apply in non-inertial frames, indeed between accelerating frames the speed of light cannot be constant.[1] Although it can be applied in non-inertial frames if an observer is confined to making local measurements.)

There have been various alternative formulations of **special relativity** over the years. Some of these formulations are equivalent to the original formulation whereas others result in modifications.

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[edit] "Single postulate" approaches

Equivalent to the original ? Yes.

According to some references,[1][2][3][4] the theory of special relativity can be derived from a single postulate: the principle of relativity. This claim can be misleading because actually these formulations rely on various unsaid assumptions such as isotropy and homogeneity of space.[5] The question here is not about the exact number of postulates. The phrase "single postulate" is just used in comparison with the original "two postulate" formulation. The real question here is whether universal lightspeed can be deduced rather than assumed.

The Lorentz transformations, up to a nonnegative free parameter, can be derived without first postulating the universal lightspeed. Experiment rules out the validity of the Galilean transformations and this means the parameter in the Lorentz transformations is nonzero hence there is a finite maximum speed before anything has been said about light. Combining this with Maxwell's equations shows that light travels at this maximum speed. The numerical value of the parameter in these transformations is determined by experiment, just as the numerical values of the parameter pair c and the permittivity of free space are left to be determined by experiment even when using Einstein's original postulates. When the numerical values in both Einstein's and these other approaches have been found then these different approaches result in the same theory. So the end result of the interlocking trio of theory+Maxwell+experiment is the same either way. This is the sense in which universal lightspeed can be deduced rather than postulated.

For some historical information, see: History of special relativity#Spacetime physics and the section "Lorentz transformation without second postulate" for the approaches of Ignatowski and Frank/Rothe. However, according to Pauli (1921), Resnick (1967), and Miller (1981), those models were insufficient. But the constancy of the speed of light is contained in Maxwell's equations. That section includes the phrase "Ignatowski was forced to recourse to electrodynamics to include the speed of light.". So, the trio of "principle of relativity+Maxwell+numerical values from experiment" gives special relativity and this should be compared with "principle of relativity+second postulate+Maxwell+numerical values from experiment". Since Einstein's 1905 paper is all about electrodynamics he is assuming Maxwell's equations, and the theory isn't practically applicable without numerical values. When compared like with like, from the point of view of asking what is knowable, the second postulate can be deduced. If you restrict your attention to just the standalone theory of relativity then yes you need the postulate. But given all the available knowledge we don't need to postulate it. In other words different domains of knowledge are overlapping and thus taken together have more information than necessary.

This can be summarized as follows:

1. Experimental results rule out the validity of the Galiliean transformations.
2. That just leaves the Lorentz transformations with a finite maximal speed V.
3. Given a maximal speed V, the only consistent way of combining PofR with Maxwell's equations is to identify Maxwell's parameter : $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$. with the aforementioned maximal speed V.
4. We are now at the same starting point as if we had postulated the constancy of light, so we proceed to develop all the usual results of special relativity.

There are references which discuss in more detail the principle of relativity[6][7]

[edit] Lorentz ether theory

Main article: Lorentz ether theory

Equivalent to the original ? Yes.

Hendrik Lorentz and Henri Poincaré developed their version of special relativity in a series of papers from about 1900 to 1905. They used Maxwell's equations and the principle of relativity to deduce a theory that is mathematically equivalent to the theory later developed by Einstein.

[edit] Minkowski spacetime

Main article: Minkowski space

Equivalent to the original ? Yes.

Minkowski space (or Minkowski spacetime) is a mathematical setting in which special relativity is conveniently formulated. Minkowski space is named for the German mathematician Hermann Minkowski, who around 1907 realized that the theory of special relativity (previously developed by Poincaré and Einstein) could be elegantly described using a four-dimensional spacetime, which combines the dimension of time with the three dimensions of space.

Mathematically there are a number of ways in which the four-dimensions of Minkowski spacetime are commonly represented: as a four-vector with 4 real coordinates, as a four-vector with 3 real and one complex coordinate, or using tensors.

[edit] Test theories of special relativity

Main article: Test theories of special relativity

Equivalent to the original ? No.

Test theories of special relativity are flat space-time theories which differ from special relativity by having a different postulate about light concerning one-way speed of light vs two-way speed of light. Different postulates on light result in different notions of time simultaneity. There is Robertson's test theory (1949) which predicts different experimental results from Einstein's special relativity, and then there is Edward's theory (1963) which cannot be called a test theory because it is physically equivalent to special relativity, and then there is the Mansouri-Sexl theory (1977) which is equivalent to Robertson's theory.[8]

[edit] Curvilinear coordinates and non-inertial frames

Equivalent to the original ? Curvilinear is a generalization, but the original SR can be applied locally.

There can be misunderstandings over the sense in which SR can be applied to accelerating frames.

> The confusion here results from trying to describe *three* different things with just *two* labels. The three things are:

- A description of physics without gravity using just "inertial frames", i.e. non-accelerating Cartesian coordinate systems. These coordinate systems are all related to each other by the linear Lorentz transformations. The physical laws may be described more simply in these frames than in the others. This is "special relativity" as usually understood.
- A description of physics without gravity using arbitrary curvilinear coordinates. This is non-gravitational physics plus general covariance. Here one sets the Riemann-Christoffel tensor to zero instead of using the Einstein field equations. This is the sense in which "special relativity" can handle accelerated frames.
- A description of physics including gravity governed by the Einstein field equations, i.e. full general relativity.

Special relativity cannot be used to describe a **global** frame for non-inertial i.e. accelerating frames. However general relativity implies that special relativity *can* be applied **locally** where the observer is **confined to making local measurements**. For example an analysis of Bremsstrahlung does not require general relativity, SR is sufficient. For examples see Can Special Relativity handle accelerations?, Differential aging from acceleration, an explicit formula and SR treatment of arbitrarily accelerated motion.

The key point is that you can use special relativity to describe all kinds of accelerated phenomena, and also to predict the measurements made by an accelerated observer who's **confined to making measurements at one specific location only**. If you try to build a complete frame for such an observer, one that is meant to cover all of spacetime, you'll run into difficulties (there'll be a horizon, for one).

The problem is that you cannot derive from the postulates of special relativity that an acceleration will not have a non-trivial effect. E.g. in case of the twin paradox, we know that you can compute the correct answer of the age difference of the twins simply by integrating the formula for time dilation along the trajectory of the travelling twin.[9] This means that one assumes that at any instant, the twin on its trajectory can be replaced by an inertial observer that is moving at the same velocity of the twin. This gives the correct answer, as long as we are computing effects that are local to the travelling twin. The fact that the acceleration that distinguishes the local inertial rest frame of the twin and the true frame of the twin does not have any additional effect follows from general relativity (it has, of course, been verified experimentally).

In 1943, Moller obtained a transform between an inertial frame and a frame moving with constant acceleration, based on Einstein's vacuum eq and a certain postulated time-independent metric tensor, although this transform is of limited applicability as it does not reduce to the Lorentz transform when a=0.

Throughout the 20th century efforts were made in order to generalize the Lorentz transformations to a set of transformations linking inertial frames to non-inertial frames with uniform acceleration. So far, these efforts failed to produce satisfactory results that are both consistent with 4-dimensional symmetry and to reduce in the limit a=0 to the Lorentz transformations. Hsu and Hsu[1] claim that they have finally come up with suitable transformations for constant linear acceleration (uniform acceleration). They call these transformations: Generalized Moller-Wu-Lee Transformations. They also say: "But such a generalization turns out not to be unique from a theoretical viewpoint and there are infinitely many generalizations. So far, no established theoretical principle leads to a simple and unique generalization."

[edit] de Sitter relativity

Main article: de Sitter relativity

Equivalent to the original ? No.

According to[4][10] and the references therein, if you take Minkowski's ideas to their logical conclusion then not only are boosts non-commutative but translations are also non-commutative. This means that the symmetry group of space time is a de Sitter group rather than the Poincare group. This results in spacetime being slightly curved even in the absence of matter or energy. This residual curvature is caused by a cosmological constant to be determined by observation. Due to the small magnitude of the constant, then special relativity with the Poincaré group is more than accurate enough for all practical purposes, although near the big bang and inflation de Sitter relativity may be more useful due to the cosmological constant being larger back then. Note this is not the same thing as solving Einstein's field equations for general relativity to get a de Sitter Universe, rather de Sitter relativity is about getting a de Sitter Group for special relativity which neglects gravity.

[edit] Taiji relativity

Equivalent to the original ? Yes.

This section is based on the work of Jong-Ping Hsu and Leonardo Hsu.[1][11][12][13] They decided to use the word *Taiji* which is a Chinese word meaning the ultimate principles that existed before the creation of the world. In SI units, time is measured in seconds, but taiji time is measured in units of metres — the same units used to measure space. Their arguments about choosing what units to measure time in, lead them to say that they can develop a theory of relativity which is experimentally indistinguishable from special relativity, but without using the second postulate in their derivation. Their claims have been disputed.[14][15] There is a discussion of taiji relativity in the book.[16]

The transformations that they derive involve the factor $\frac{1}{\sqrt{1-\beta^2}}$ where β is the velocity measured in metres per metre (a dimensionless quantity). This looks the same as (but should NOT be conceptually confused with) the velocity as a fraction of light v/c that appears in some expressions for the Lorentz transformations. Expressing time in metres has previously been done by other authors: Taylor and Wheeler in *Spacetime Physics*[17] and Moore in *Six Ideas that Shaped Physics*.[18]

The transformations are derived using just the principle of relativity and have a maximal speed of 1, which is quite unlike "single postulate" derivations of the Lorentz transformations in which you end up with a parameter that may be zero. So this is not the same as other "single postulate" derivations. However the relationship of taiji time "w" to standard time "t" must still be found, otherwise it would not be clear how an observer would measure taiji time. The taiji transformations are then combined with Maxwell's equations to show that the speed of light is independent of the observer and has the value 1 in taiji speed (i.e. it has the maximal speed). This can be thought of as saying: a time of 1 metre is the time it takes for light to travel 1 metre. Since we can measure the speed of light by experiment in m/s to get the value c, we can use this as a conversion factor. i.e. we have now found an operational definition of taiji time: w=ct.

So we have: w metres = (c m/s) * t seconds

Let r= distance. Then taiji speed = r metres / w metres = r/w dimensionless.

But it is not just due to the choice of units that there is a maximum speed. It is the principle of relativity, that Hsu&Hsu say, when applied to 4d spacetime, implies the invariance of the 4d-spacetime interval $s^2 = w^2 - r^2$ and this leads to the coordinate transformations involving the factor $\frac{1}{\sqrt{(1-\beta^2)}}$ where beta is the magnitude of the velocity between two inertial frames. The difference between this and the spacetime interval $s^2 = c^2t^2 - r^2$ in Minkowski space is that $s^2 = w^2 - r^2$ is invariant purely by the principle of relativity whereas $s^2 = c^2t^2 - r^2$ requires both postulates. The "principle of relativity" in spacetime is taken to mean invariance of laws under 4-dimensional transformations.

Hsu&Hsu then explore other relationships between w and t such as w=bt where b is a function. They show that there are versions of relativity which are consistent with experiment but have a definition of time where the "speed" of light is not constant. They develop one such version called *common relativity* which is more convenient for performing calculations for "relativistic many body problems" than using special relativity.

[edit] Very special relativity

Main article: Very special relativity

Equivalent to the original ? No, but it is compatible.

Ignoring gravity, experimental bounds seem to suggest that special relativity with its Lorentz symmetry and Poincare symmetry describes spacetime. Surprisingly, Cohen and Glashow[19] have demonstrated that a small subgroup of the Lorentz group is sufficient to explain all the current bounds.

The minimal subgroup in question can be described as follows: The stabilizer of a null vector is the special Euclidean group SE(2), which contains T(2) as the subgroup of parabolic transformations. This T(2), when extended to include either parity or time reversal (i.e. subgroups of the orthochronous and time-reversal respectively), is sufficient to give us all the standard predictions. Their new symmetry is called **Very Special Relativity** (VSR).

[edit] Doubly special relativity

Main article: Doubly special relativity

Equivalent to the original ? No.

Doubly-special relativity (DSR) is a modified theory of special relativity in which there is not only an observer-independent maximum velocity (the speed of light), but an observer-independent minimum length (the Planck length).

The motivation to these proposals is mainly theoretical, based on the following observation: The Planck length is expected to play a fundamental role in a theory of Quantum Gravity, setting the scale at which Quantum Gravity effects cannot be neglected and *new* phenomena are observed. If Special Relativity is to hold up exactly to this scale, different observers would observe Quantum Gravity effects at different scales, due to the Lorentz-FitzGerald contraction, in contradiction to the principle that all inertial observers should be able to describe phenomena by the same physical laws.

A drawback of the usual doubly special relativity models is that they are valid only at the energy scales where ordinary special relativity is supposed to break down, giving rise to a patchwork relativity. On the other hand, de Sitter relativity is found to be invariant under a simultaneous re-scaling of mass, energy and momentum, and is consequently valid at all energy scales.

[edit] Analytic hyperbolic geometry with gyrovectors

Main article: Gyrovector space

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2011-02-17

Lorentz ether theory

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What is now often called **Lorentz Ether theory** ("LET") has its roots in Hendrik Lorentz's "Theory of electrons", which was the final point in the development of the classical aether theories at the end of the 19th and at the beginning of the 20th century.

Lorentz's initial theory created in 1892 and 1895 was based on a completely motionless aether. It explained the failure of the negative aether drift experiments to first order in v/c by introducing an auxiliary variable called "local time" for connecting systems at rest and in motion in the aether. In addition, the negative result of the Michelson-Morley experiment led to the introduction of the hypothesis of length contraction in 1892. However, other experiments also produced negative results and (guided by Henri Poincaré's principle of relativity) Lorentz tried in 1899 and 1904 to expand his theory to all orders in v/c by introducing the Lorentz transformation. In addition, he assumed that also non-electromagnetic forces (if they exist) transform like electric forces. However, Lorentz's expression for charge density and current were incorrect, so his theory did not fully exclude the possibility of detecting the aether. Eventually, it was Henri Poincaré who in 1905 corrected the errors in Lorentz's paper and actually incorporated non-electromagnetic forces (incl. Gravitation) within the theory, which he called "The New Mechanics". Many aspects of Lorentz's theory were incorporated into special relativity (SR) with the works of Albert Einstein and Hermann Minkowski.

Today LET is often treated as some sort of "Lorentzian" or "neo-Lorentzian" interpretation of special relativity. The introduction of length contraction and time dilation for all phenomena in a "preferred" frame of reference (which plays the role of Lorentz's immobile aether), leads to the complete Lorentz transformation. Because of the same mathematical formalism it is not possible to distinguish between LET and SR by experiment. However, in LET the existence of an undetectable ether is assumed and the validity of the relativity principle seems to be only coincidental, which is one reason why SR is commonly preferred over LET. Another important reason for preferring SR is that the new understanding of space and time was also fundamental for the development of general relativity.

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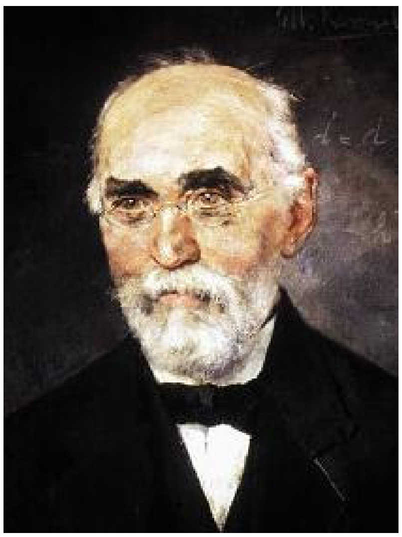
[edit] Historical development

[edit] Basic concept



Hendrik Antoon Lorentz

This theory, which was developed mainly between 1892 and 1906 by Lorentz and Poincaré, was based on the aether theory of Augustin-Jean Fresnel, Maxwell's equations and the electron theory of Rudolf Clausius.[B 1] Lorentz introduced a strict separation between matter (electrons) and ether, whereby in his model the ether is completely motionless, and it won't be set in motion in the neighborhood of ponderable matter. As Max Born later said, it was natural (though not logically necessary) for scientists of that time to identify the rest frame of the Lorentz ether with the absolute space of Isaac Newton.[B 2] The condition of this ether can be described by the electric field E and the magnetic field H, where these fields represent the "states" of the ether (with no further specification), related to the charges of the electrons. Thus an abstract electromagnetic ether replaces the older mechanistic ether models. Contrary to Clausius, who accepted that the electrons operate by actions at a distance, the electromagnetic field of the ether appears as a mediator between the electrons, and changes in this field can propagate not faster than the speed of light. Lorentz theoretically explained the Zeeman effect on the basis of his theory, for which he received the Nobel Prize in Physics in 1902. Joseph Larmor found a similar theory simultaneously, but his concept was based on a mechanical ether. A fundamental concept of Lorentz's theory in 1895[A 1] was the "theorem of corresponding states" for terms of order v/c. This theorem states that a moving observer makes the same observations as an observer in the stationary system.

[edit] Length contraction

A big challenge for this theory was the Michelson–Morley experiment in 1887. According to the theories of Fresnel and Lorentz a relative motion to an immobile ether had to be determined by this experiment, however, the result was negative. Michelson himself thought that the result confirmed the aether drag hypothesis, in which the aether is fully dragged by matter. However, other experiments like the Fizeau experiment and the effect of aberration disproved that model.

A possible solution came in sight, when in 1889 Oliver Heaviside derived from the Maxwell's equations that the magnetic vector potential field around a moving body is altered by a factor of $\sqrt{1-v^2/c^2}$. Based on that result and to bring the hypothesis of an immobile ether in accordance with the Michelson–Morley experiment, George FitzGerald in 1889 (qualitatively) and independently of him Lorentz in 1892[A 2] (already quantitatively) suggested that not only the electrostatic fields, but also the molecular forces are affected in such a way that the dimension of a body in the line of motion is less by the value $v^2 / (2c^2)$ than the dimension perpendicularly to the line of motion. However, an observer co-moving with the earth would not notice this contraction, because all other instruments contract at the same ratio. In 1895[A 1] Lorentz proposed three possible explanation for this relative contraction:[B 3]

- The body *contracts* in the line of motion and preserves its dimension perpendicularly to it.
- The dimension of the body remains the same in the line of motion, but it *expands* perpendicularly to it.
- The body contracts in the line of motion, and expands at the same time perpendicularly to it.

Although the possible connection between electrostatic and intermolecular forces was used by Lorentz as a plausibility argument, the contraction hypothesis was soon considered as purely ad hoc. It is also important that this contraction only affected the space between the electron but not the electrons themselves, therefore the name "intermolecular hypotheses" was sometimes used of this effect. The so called Length contraction without expansion perpendicularly to the line of motion and by the precise value $l = l_0 \cdot \sqrt{1-v^2/c^2}$ (where l_0 is the length at rest in the ether) was given by Larmor in 1897 and by Lorentz in 1904. In the same year Lorentz also argued that also electrons themselves are affected by this contraction.[B 4] For further development of this concept, see the section #Lorentz transformation.[A 3]

[edit] Local time

An important part of the theorem of corresponding states in 1892 and 1895 [A 1] was the local time $t' = t - vx / c^2$, where t is the time coordinate for an observer resting in the ether, and t' is the time coordinate for an observer moving in the ether. (Woldemar Voigt had previously used the same expression for local time in 1887 in connection with the Doppler effect and an incompressible medium.) With the help of this concept Lorentz could explain the aberration of light, the Doppler effect and the Fizeau experiment (i.e. measurements of the Fresnel drag coefficient) by Hippolyte Fizeau in moving and resting liquids as well. While for Lorentz length contraction was a real physical effect, he considered the time transformation only as a heuristic working hypothesis and a mathematical stipulation to simplify the calculation from the resting to a "fictitious" moving system. Contrary to Lorentz, Poincaré saw more than a mathematical trick in the definition of local time, which he called Lorentz's "most ingenious idea".[A 4] In The Measure of Time he wrote in 1898:[A 5]

> “ We do not have a direct intuition for simultaneity, just as little as for the equality of two periods. If we believe to have this intuition, it is an illusion. We helped ourselves with certain rules, which we usually use without giving us account over it [...] We choose these rules therefore, not because they are true, but because they are the most convenient, and we could summarize them while saying: „The simultaneity of two events, or the order of their succession, the equality of two durations, are to be so defined that the enunciation of the natural laws may be as simple as possible. In other words, all these rules, all these definitions are only the fruit of an unconscious opportunism.“[C 1] ”

In 1900 Poincaré interpreted local time as the result of a synchronization procedure based on light signals. He assumed that 2 observers *A* and *B* which are moving in the ether, synchronize their clocks by optical signals. Since they believe to be at rest they must consider only the transmission time of the signals and then crossing their observations to examine whether their clocks are synchronous. However, from the point of view of an observer at rest in the ether the clocks are not synchronous and indicate the local time $t' = t - vx / c^2$. But because the moving observers don't know anything about their movement, they don't recognize this.[A 6] In 1904 he illustrated the same procedure in the following way: *A* sends a signal at the time 0 to *B*, which arrives at the time *t*. B also sends a signal at the time 0 to *A*, which arrives at the time *t*. If in both cases *t* has the same value the clocks are synchronous, but only in the system in which the clocks are at rest in the ether. So according to Darrigol[B 5] Poincaré understood local time as a physical effect just like length contraction - in contrast to Lorentz, who used the same interpretation not before 1906. However, contrary to Einstein, who later used a similar synchronisation procedure which was called Einstein synchronisation, he still was the opinion that only clocks resting in the ether are showing the „true“ time.[A 4]

However, at the beginning it was unknown that local time includes what is now known as time dilation. This effect was first noticed by Larmor (1897), who wrote that "*individual electrons describe corresponding parts of their orbits in times shorter for the [ether] system in the ratio* $\varepsilon^{-1/2}$ *or* $(1 - (1/2)v^2/c^2)$". And in 1899[A 7] also Lorentz noted for the frequency of oscillating electrons "*that in S the time of vibrations be* $k\varepsilon$ *times as great as in* S_0", where S_0 is the ether frame, S the mathematical-fictitious frame of the moving observer, k is $\sqrt{1 - v^2/c^2}$, and ε is an undetermined factor. [B 6]

[edit] Lorentz transformation

Further information: History of Lorentz transformations

While *local time* could explain the negative aether drift experiments to first order to v/c, it was necessary — due to other unsuccessful ether drift experiments like the Trouton–Noble experiment — to modify the hypothesis to include second order effects. The mathematical tool for that is the so called Lorentz transformation. It was Voigt in 1887 who already derived a similar set of equations (however, with a different scale factor). Afterwards, Larmor in 1897 and Lorentz in 1899[A 7] derived equations in a algebraically equivalent form to those, which are used up to this day (however, Lorentz used an undetermined factor *l* in his transformation). In his paper Electromagnetic phenomena in a system moving with any velocity smaller than that of light (1904)[A 3] Lorentz attempted to create such a theory, according to which *all* forces between the molecules are affected by the Lorentz transformation (in which Lorentz set the factor *l* to unity) in the same manner as electrostatic forces. In other words, Lorentz attempted to create a theory in which the relative motion of earth and aether is (nearly or fully) undetectable. Therefore he generalized the contraction hypothesis and argued that not only the forces between the electrons, but also the electrons themselves are contracted in the line of motion. However, Max Abraham (1904) quickly noted a defect of that theory: Within a purely electromagnetic theory the contracted electron-configuration is unstable and one has to introduce non-electromagnetic force to stabilize the electrons - Abraham himself questioned the possibility of including such forces within the theory of Lorentz.

So it was Poincaré (1905) on 5 June 1905[A 8] who introduced the so called "Poincaré stresses" to solve that problem. Those stresses were interpreted by him as an external, non-electromagnetic pressure, which stabilize the electrons and also served as an explanation for length contraction.[B 7] Although he argued that Lorentz succeeded in creating a theory which complies to the postulate of relativity, he showed that Lorentz's equations of electrodynamics were not fully Lorentz covariant. So by pointing out the group characteristics of the transformation Poincaré demonstrated the Lorentz covariance of the Maxwell-Lorentz equations and corrected Lorentz's transformation formulae for charge density and current density. He went on to sketch a model of gravitation (incl. gravitational waves) which might be compatible with the transformations. Poincaré used for the first time the term "Lorentz transformation", and he gave them a form which is used up to this day. (Where ℓ is an arbitrary function of ε, which must be set to unity to conserve the group characteristics. He also set the speed of light to unity.)

$$x' = k\ell\left(x + \varepsilon t\right), \qquad y' = \ell y, \qquad z' = \ell z, \qquad t' = k\ell\left(t + \varepsilon x\right)$$
$$k = \frac{1}{\sqrt{1-\varepsilon^2}}$$

A substantially extended work (the so called „Palermo paper“)[A 9] was submitted by Poincaré on 23 July 1905, but was published on January 1906, because the journal only appeared two times in a year. He spoke literally of "the postulate of relativity", he showed that the transformations are a consequence of the principle of least action; he demonstrated in more detail the group characteristics of the transformation, which he called Lorentz group, and he showed that the combination $x^2 + y^2 + z^2 - c^2t^2$ is invariant. While elaborating his gravitational theory he noticed that the Lorentz transformation is merely a rotation in four-dimensional space about the origin by introducing $ct\sqrt{-1}$ as a fourth imaginary coordinate, and he used an early form of four-vectors. However, Poincaré later said the translation of physics into the language of four-dimensional metry would entail too much effort for limited profit, and therefore he refused to work out the consequences of this notion. This was later done by Minkowski, see "The shift to relativity".[B 8]

[edit] Electromagnetic mass and energy

[edit] Rest mass and energy

It was recognized by J. J. Thomson in 1881 that a charged body—due to its electromagnetic Self-energy—is harder to set in motion than an uncharged body, which was worked out on more detail by Heaviside (1889) and George Frederick Charles Searle (1896). So the electrostatic energy behaves as having some sort of electromagnetic mass, which can increase the normal mechanical mass of the bodies. This was discussed in connection with the proposal of the electrical origin of matter, and Wilhelm Wien (1900), Max Abraham (1902), and Lorentz (1904)[A 3] came to the conclusion that the total mass of the bodies is identical to its electromagnetic mass. And because the em-mass depends on the em-energy, the formula for the energy-mass-relation given by Thomson (1893) and Wien (1900) was $m = (4 / 3)E / c^2$ (Abraham and Lorentz used similar expressions). Wien stated, that if it is assumed that gravitation is an electromagnetic effect too, then there has to be a proportionality between em-energy, inertial mass and gravitational mass. However, it was not recognized that energy can *transport* inertia from one body to another and that mass can be *converted* into energy, which was explained by Einstein's mass–energy equivalence.

The idea of an electromagnetic nature of matter had to be given up, however, in the course of the development of relativistic mechanics. Abraham (1904) argued (as described in the preceding section #Lorentz transformation), that non-electrical binding forces were necessary within Lorentz's electrons model. But Abraham also noted that different results occurred, dependent on whether the em-mass is calculated from the energy or from the momentum. To solve those problems, Poincaré in 1905[A 8] and 1906[A 9] introduced some sort of pressure of non-electrical nature, which contributes the amount $-(1 / 3)E / c^2$ to the energy of the bodies, and therefore explains the 4/3-factor in the expression for the electromagnetic mass-energy relation. However, while Poincaré's expression for the energy of the electrons was correct, he erroneously stated that only the em-energy contributes to the mass of the bodies. Max von Laue showed in 1910 that Poincaré's model is formally correct, but it is only one of many possible and equivalent mechanisms to guarantee that the electron configuration form a "closed system".[B 9]

[edit] Mass and speed

Thomson, Heaviside and Searle also noticed that inertia depends on the speed of the bodies as well. In 1899 Lorentz calculated that the ratio of the electron masses of the moving frame and the ether frame is $k^3\varepsilon$ parallel to the direction of motion and $k\varepsilon$

perpendicular to the direction of motion, where $k=\sqrt{1-v^2/c^2}$ and ε is an undetermined factor. Lorentz wrote in 1899 by using the term „ions“ for the basic constituents of matter:[A 7]

> [p. 442]: states of motion, related to each other in the way we have indicated, will only be possible if in the transformation of S_0 into S the masses of the ions change; even this must take place in such a way that the same ion will have different masses for vibrations parallel and perpendicular to the velocity of translation.

This theory was further developed by Abraham (1902), who first used the terms longitudinal and transverse mass for Lorentz's two masses. However, Abraham's expressions were more complicated than those of Lorentz. Lorentz himself expanded his 1899 ideas in his famous 1904 paper, where he set the factor ε to unity.[A 3] So, according to this theory no body can reach the speed of light because the mass becomes infinitely large at this velocity. The predictions of those theories were supported by the experiments of Walter Kaufmann (1901), but the experiments were not precise enough, to distinguish between them.

In 1904 Paul Langevin illustrated this kind of inertia by a body which moves in a liquid. If the body changes the direction it suffers resistance, afterwards it moves in straight lines, because the resistance is compensated by some sort of wake (in that case the electromagnetic fields). And Poincaré wrote in 1904, that because of the variability of mass the conservation of mass and the action/reaction principle aren't valid anymore. [A 4] In a later edition of his book *Science and Hypothesis* in 1906 he concluded that in case matter is of electromagnetic origin, and because matter and mass are inseparably connected, matter doesn't exist at all and electrons are only concavities in the ether. [A 10]

The mass concept of Lorentz (incl. longitudinal and transverse mass) was incorporated into special relativity by Einstein (1905)[A 11] and Max Planck (1906). In 1905 Kaufmann conducted another series of experiments, which confirmed Abraham's theory, but contradicted what Kaufmann called the "Lorentz-Einstein theory". However, in the following years experiments by Alfred Bucherer (1908), Neumann (1914) and others seemed to confirm Lorentz's mass formula. However, it was later pointed out, that the Bucherer-Neumann experiments were also not precise enough to distinguish between the theories. So Abraham's theory was disproved not before 1940. [B 10] Later a similar concept was also used as relativistic mass by reputable physicists like Max Born[B 11] and Wolfgang Pauli[B 12] and is sometimes used in physics textbooks up to this day, although the term is not is not preferred. The term 'mass' is now normally considered to refer to invariant mass.

[edit] Inertia of energy

James Clerk Maxwell (1874) and Adolfo Bartoli (1876) found out that the existence of tensions in the ether like the radiation pressure follows from the electromagnetic theory. Lorentz recognized in 1895[A 1] that this is also the case in his theory. So if the ether is able to set bodies in motion, the action/reaction principle demands that the ether must be set in motion by matter as well. However, Lorentz pointed out that any tension in the ether requires the mobility of the ether parts, which in not possible in his immobile ether. This represents a violation of the reaction principle which was accepted by Lorentz consciously. He continued by saying, that one can only speak about *fictitious* tensions, since they are only mathematical models in his theory to ease the description of the electrodynamic interactions.

In 1900[A 6] Poincaré studied the conflict between the action/reaction principle and Lorentz's theory. He tried to determine whether the center of gravity still moves with a uniform velocity when electromagnetic fields are included. He noticed that the action/reaction principle does not hold for matter alone, but that the electromagnetic field has its own momentum. The electromagnetic field energy behaves like a fictitious fluid („fluide fictif“) with a mass density of E / c^2 (in other words $m = E / c^2$). If the center of mass frame (COM-frame) is defined by both the mass of matter *and* the mass of the fictitious fluid, and if the fictitious fluid is indestructible - it's neither created or destroyed - then the motion of the center of mass frame remains uniform. But electromagnetic energy is not indestructible and can be converted into other forms of energy, and therefore loses its mass (which was the reason why Poincaré regarded em-energy as a "fictitious" fluid rather than a "real" fluid). So Poincaré assumed that there exists a non-electric energy fluid at each point in the ether, into which electromagnetic energy can be transformed and which also carries a mass proportional to the energy. In this way, the motion of the COM-frame (incl. matter, em-energy and non-electrical energy) remains uniform. Poincaré said that one should not be too surprised by these assumptions, since they are only mathematical fictions.

But Poincaré's resolution led to a paradox when changing frames: if a Hertzian oscillator radiates in a certain direction, it will suffer a recoil from the inertia of the fictitious fluid. In the framework of Lorentz's theory Poincaré performed a Lorentz boost to the frame of the moving source. He noted that energy conservation holds in both frames, but that the law of conservation of momentum is violated. This would allow perpetual motion, a notion which he abhorred. The laws of nature would have to be different in the frames of reference, and the relativity principle would not hold. Therefore he argued that also in this case there has to be another compensating mechanism in the ether.[B 13][B 14]

Poincaré came back to this topic in 1904.[A 4] This time rejected his own solution that motions in the ether can compensate the motion of matter, because any such motion is unobservable and therefore scientifically worthless. He also abandoned the concept that energy carries mass and wrote in connection to the above mentioned recoil:

> “ The apparatus will recoil as if it were a cannon and the projected energy a ball, and that contradicts the principle of Newton, since our present projectile has no mass; it is not matter, it is energy. ”

Besides this radiation paradox (1) he also discussed two other problematic effects: (2) non-conservation of mass implied by Abraham's and Lorentz's theory of variable mass, and Kaufmann's experiments on the mass of fast moving electrons and (3) the non-conservation of energy in the radium experiments - however, for the latter he cited William Ramsay's proposal that radium is *transformed* because it contains an enormous amount of energy. Those problems were later solved through Einstein's mass–energy equivalence - see "The shift to relativity".

Following Poincaré, Abraham introduced the term „electromagnetic momentum" to maintain the reaction principle, whereby the field density per cm^3 is E / c^2 and E / c per cm^2. Contrary to Lorentz and Poincaré, who considered that momentum as a fictitious force, he argued that it is a real physical entity. In 1904, Friedrich Hasenöhrl concluded that radiation contributes to the inertia of bodies, and inertia depends on temperature as well. He derived the formula $m = (8 / 3)E / c^2$, where m is the "apparent mass" due to radiation. This was corrected in 1905 by Abraham and him to $m = (4 / 3)E / c^2$ (the same formula as for the electromagnetic mass, see section „Rest mass and energy").[B 15]

[edit] Gravitation

[edit] Lorentz's theories

In 1900[A 12] Lorentz tried to explain gravity on the basis of the Maxwell equations. He first considered a Le Sage type model and argued that there possibly exists a universal radiation field, consisting of very penetrating em-radiation, and exerting a uniform pressure on every body. Lorentz showed that an attractive force between charged particles would indeed arise, if it is assumed that the incident energy is entirely absorbed. This was the same fundamental problem which had afflicted the other Le Sage models, because the radiation must vanish somehow and any absorption must lead to an enormous heating. Therefore Lorentz abandoned this model.

In the same paper, he assumed like Ottaviano Fabrizio Mossotti and Johann Karl Friedrich Zöllner that the attraction of opposite charged particles is stronger than the repulsion of equal charged particles. The resulting net force is exactly what is known as universal gravitation, in which the speed of gravity is that of light. This leads to a conflict with the law of gravitation by Isaac Newton, in which it was shown by Pierre Simon Laplace that a finite speed of gravity leads to some sort of aberration and therefore makes the orbits unstable. However, Lorentz showed that the theory is not concerned by Laplace's critique, because due to the structure of the Maxwell equations only effects in the order v^2/c^2 arise. But Lorentz calculated that the value for the perihelion advance of Mercury was much too low. He wrote:

> “ The special form of these terms may perhaps be modified. Yet, what has been said is sufficient to show that gravitation may be attributed to actions which are propagated with no greater velocity than that of light. ”

In 1908[A 13] Poincaré examined the gravitational theory of Lorentz and classified it as compatible with the relativity principle, but (like Lorentz) he criticized the inaccurate indication of the perihelion advance of Mercury. Contrary to Poincaré, Lorentz in 1914 considered his own theory as incompatible with the relativity principle and rejected it.[A 14]

[edit] Lorentz-invariant gravitational law

Poincaré argued in 1904 that a propagation speed of gravity which is greater than c is contradicting the concept of local time and the relativity principle. He wrote: [A 4]

> “ What would happen if we could communicate by signals other than those of light, the velocity of propagation of which differed from that of light? If, after having regulated our watches by the optimal method, we wished to verify the result by means of these new signals, we should observe discrepancies due to the common translatory motion of the two stations. And are such signals inconceivable, if we take the view of Laplace, that universal gravitation is transmitted with a velocity a million times as great as that of light? ”

However, in 1905 and 1906 Poincaré pointed out the possibility of a gravitational theory, in which changes propagate with the speed of light and which is Lorentz covariant. He pointed out that in such a theory the gravitational force not only depends on the masses and their mutual distance, but also on their velocities and their position due to the finite propagation time of interaction. On that occasion Poincaré introduced four-vectors.[A 8] Following Poincaré, also Minkowski (1908) and Arnold Sommerfeld (1910) tried to establish a lorentz-invariant gravitational law.[B 16] However, these attempts were superseded because of Einstein's theory of general relativity, see "The shift to relativity".

[edit] Principles and conventions

Henri Poincaré

[edit] Constancy of light

Already in his philosophical writing on time measurements (1898)[A 5] Poincaré wrote that astronomers like Ole Rømer, in determining the speed of light, simply assume that light has a constant speed, and that this speed is the same in all directions. Without this postulate it would not be possible to infer the speed of light from astronomical observations, as Rømer did based on observations of the moons of Jupiter. Poincaré went on to note that Rømer also had to assume that Jupiter's moons obey Newton's laws, including the law of gravitation, whereas it would be possible to reconcile a different speed of light with the same observations if we assumed some different (probably more complicated) laws of motion. According to Poincaré, this illustrates that we adopt for the speed of light a value that makes the laws of mechanics as simple as possible. (This is an example of Poincaré's conventionalist philosophy.) Poincaré also noted that the propagation speed of light can be (and in practice often is) used to define simultaneity between spatially separate events. However, in that paper he did not go on to discuss the consequences of applying these "conventions" to multiple relatively moving systems of reference. This next step was done by Poincaré in 1900,[A 6] when he recognized that synchronization by light signals in earth's reference frame leads to Lorentz's local time.[B 17][B 18] (See the section on "local time" above). And in 1904 Poincaré wrote:[A 4]

> “ From all these results, if they were to be confirmed, would issue a wholly new mechanics which would be characterized above all by this fact, that there could be no velocity greater than that of light, any more than a temperature below that of absolute zero. For an observer, participating himself in a motion of translation of which he has no suspicion, no apparent velocity could surpass that of light, and this would be a contradiction, unless one recalls the fact that this observer does not use the same sort of timepiece as that used by a stationary observer, but rather a watch giving the “local time.[..] Perhaps, likewise, we should construct a whole new mechanics, of which we only succeed in catching a glimpse, where inertia increasing with the velocity, the velocity of light would become an impassable limit. The ordinary mechanics, more simple, would remain a first approximation, since it would be true for velocities not too great, so that we should still find the old dynamics under the new...I hasten to say in conclusion we are not yet there, and as yet nothing proves that the principles [of ordinary mechanics] will not come forth from the combat victorious and intact.” ”

[edit] Principle of relativity

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In 1895[A 15][B 19] Poincaré argued that experiments like that of Michelson-Morley show that it seems to be impossible to detect the absolute motion of matter or the relative motion of matter in relation to the ether. And although most physicists had other views, Poincaré in 1900[A 16] stood to his opinion and alternately used the expressions "principle of relative motion" and "relativity of space". He criticized Lorentz by saying, that it would be better to create a more fundamental theory, which explains the absence of any ether drift, than to create one hypothesis after the other. In 1902[A 17] he used for the first time the expression "principle of relativity". In 1904[A 4] he appreciated the work of the mathematicians, who saved what he now called the "principle of relativity" with the help of hypotheses like local time, but he confessed that this venture was possible only by an accumulation of hypotheses. And he defined the principle in this way (according to Miller[B 20] based on Lorentz's theorem of corresponding states): *"The principle of relativity, according to which the laws of physical phenomena must be the same for a stationary observer as for one carried along in a uniform motion of translation, so that we have no means, and can have none, of determining whether or not we are being carried along in such a motion."*

Referring to the critique of Poincaré from 1900, Lorentz wrote in his famous paper in 1904, where he extended his theorem of corresponding states:[A 3] *"Surely, the course of inventing special hypotheses for each new experimental result is somewhat artificial. It would be more satisfactory, if it were possible to show, by means of certain fundamental assumptions, and without neglecting terms of one order of magnitude or another, that many electromagnetic actions are entirely independent of the motion of the system."*

One of the first assessments of Lorentz's paper was by Paul Langevin in May 1905. According to him, this extension of the electron theories of Lorentz and Larmor led to "the physical impossibility to demonstrate the translational motion of the earth". However, Poincaré noticed in 1905 that Lorentz's theory of 1904 was not perfectly "Lorentz invariant" in a few equations such as Lorentz's expression for current density (it was admitted by Lorentz in 1921 that these were defects). As this required just minor modifications of Lorentz's work, also Poincaré asserted [A 8] that Lorentz had succeeded in harmonizing his theory with the principle of relativity: *"It appears that this impossibility of demonstrating the absolute motion of the earth is a general law of nature. [..] Lorentz tried to complete and modify his hypothesis in order to harmonize it with the postulate of* complete *impossibility of determining absolute motion. He has succeeded in doing so in his article [Lorentz, 1904b]."*[C 2]

In his Palermo paper (1906), Poincaré called this "the postulate of relativity“, and although he stated that it was possible this principle might be disproved at some point (and in fact he mentioned at the paper's end that the discovery of magneto-cathode rays by Paul Ulrich Villard (1904) seems to threaten it[B 21]), he believed it was interesting to consider the consequences if we were to assume the postulate of relativity was valid without restriction. This would imply that all forces of nature (not just electromagnetism) must be invariant under the Lorentz transformation.[A 9] In 1921 Lorentz credited Poincaré for establishing the principle and postulate of relativity and wrote:[A 18] *"I have not established the principle of relativity as rigorously and universally true. Poincaré, on the other hand, has obtained a perfect invariance of the electro-magnetic equations, and he has formulated 'the postulate of relativity', terms which he was the first to employ."*[C 3]

[edit] Ether

Poincaré wrote in the sense of his conventionalist philosophy in 1889: [A 19] *"Whether the ether exists or not matters little - let us leave that to the metaphysicians; what is essential for us is, that everything happens as if it existed, and that this hypothesis is found to be suitable for the explanation of phenomena. After all, have we any other reason for believing in the existence of material objects? That, too, is only a* *convenient hypothesis; only, it will never cease to be so, while some day, no doubt, the ether will be thrown aside as useless."*

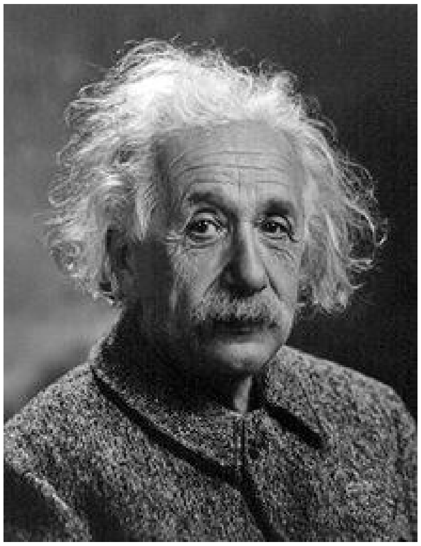
He also denied the existence of absolute space and time by saying in 1901:[A 20] *"1. There is no absolute space, and we only conceive of relative motion ; and yet in most cases mechanical facts are enunciated as if there is an absolute space to which they can be referred. 2. There is no absolute time. When we say that two periods are equal, the statement has no meaning, and can only acquire a meaning by a convention. 3. Not only have we no direct intuition of the equality of two periods, but we have not even direct intuition of the simultaneity of two events occurring in two different places. I have explained this in an article entitled "Mesure du Temps" [1898]. 4. Finally, is not our Euclidean geometry in itself only a kind of convention of language?"*

However, Poincaré himself never abandoned the ether hypothesis and stated in 1900:[A 16] *"Does our ether actually exist ? We know the origin of our belief in the ether. If light takes several years to reach us from a distant star, it is no longer on the star, nor is it on the earth. It must be somewhere, and supported, so to speak, by some material agency."* And referring to the Fizeau experiment, he even wrote: *"The ether is all but in our grasp."* He also said the ether is necessary to harmonize Lorentz's theory with Newton's third law. Even in 1912 in a paper called "The Quantum theory", Poincaré ten times used the word "ether", and described light as *"luminous vibrations of the ether"*.[A 21]

And although he admitted the relative and conventional character of space and time, he believed that the classical convention is more "convenient" and continued to distinguish between "true" time in the ether and "apparent" time in moving systems. Addressing the question if a new convention of space and time is needed he wrote in 1912:[A 22] *"Shall we be obliged to modify our conclusions? Certainly not; we had adopted a convention because it seemed convenient and we had said that nothing could constrain us to abandon it. Today some physicists want to adopt a new convention. It is not that they are constrained to do so; they consider this new convention more convenient; that is all. And those who are not of this opinion can legitimately retain the old one in order not to disturb their old habits, I believe, just between us, that this is what they shall do for a long time to come."*

Also Lorentz argued during his lifetime that in all frames of reference this one has to be preferred, in which the ether is at rest. Clocks in this frame are showing the "real" time and simultaneity is not relative. However, if the correctness of the relativity principle is accepted, it is impossible to find this system by experiment.[A 23]

[edit] The shift to relativity



Albert Einstein

[edit] Special relativity

Main article: History of special relativity

In 1905, Albert Einstein published his paper on what is now called special relativity.[A 11] In this paper, by examining the fundamental meanings of the space and time coordinates used in physical theories, Einstein showed that the "effective" coordinates given by the Lorentz transformation were in fact the inertial coordinates of relatively moving frames of reference. From this followed all of the physically observable consequences of LET, along with others, all without the need to postulate an unobservable entity (the ether). Einstein identified two fundamental principles, each founded on experience, from which all of Lorentz's electrodynamics follows:

1. The laws by which physical processes occur are the same with respect to any system of inertial coordinates (the principle of relativity)
2. In empty space light propagates at an absolute speed c in any system of inertial coordinates (the principle of the constancy of light)

Taken together (along with a few other tacit assumptions such as isotropy and homogeneity of space), these two postulates lead uniquely to the mathematics of special relativity. Lorentz and Poincaré had also adopted these same principles, as necessary to achieve their final results, but didn't recognize that they were also *sufficient*, and hence that they obviated all the other assumptions underlying Lorentz's initial derivations (many of which later turned out to be incorrect [C 4]). Therefore, special relativity very quickly gained wide acceptance among physicists, and the 19th century concept of a luminiferous ether was no longer considered useful.[B 22][B 23]

Einstein's 1905 presentation of special relativity was soon supplemented, in 1907, by Hermann Minkowski, who showed that the relations had a very natural interpretation[C 5] in terms of a unified four-dimensional "spacetime" in which absolute intervals are seen to be given by an extension of the Pythagorean theorem. (Already in 1906 Poincaré anticipated some of Minkowski's ideas, see the section

"Lorentz-transformation").[B 24] The utility and naturalness of the representations by Einstein and Minkowski contributed to the rapid acceptance of special relativity, and to the corresponding loss of interest in Lorentz's ether theory.

In 1907 Einstein criticized the "ad hoc" character of Lorentz's contraction hypothesis in his theory of electrons, because according to him it was only invented to rescue the hypothesis of an immobile ether. Einstein thought it necessary to replace Lorentz's theory of electrons by assuming that Lorentz's "local time" can simply be called "time", and he stated that the immobile ether as the theoretical fundament of electrodynamics was unsatisfactory.[A 24] And in 1910[A 25] and 1912[A 26] Einstein explained that he borrowed the principle of the constancy of light from Lorentz's immobile ether, but he recognized that this principle together with the principle of relativity makes the ether useless and leads to special relativity. Minkowski ironically said that for Lorentz the contraction hypothesis is only a "gift from above". And although Lorentz's hypothesis is "completely equivalent with the new concept of space and time", Minkowski held that it becomes much more comprehensible in the framework of the new spacetime physics. However, Lorentz disagreed that it was "ad-hoc" and he argued in 1913 that there is little difference between his theory and the negation of a preferred reference frame, as in the theory of Einstein and Minkowski, so that it is a matter of taste which theory one prefers.[A 23].

[edit] Mass–energy equivalence

It was derived by Einstein (1905) as a consequence of the relativity principle, that inertia of energy is actually represented by E / c^2, but in contrast to Poincaré's 1900-paper, Einstein recognized that matter itself loses or gains mass during the emission or absorption.[A 27] So the mass of any form of matter is equal to a certain amount of energy, which can be converted into and re-converted from other forms of energy. This is the mass–energy equivalence, represented by $E = mc^2$. So Einstein didn't have to introduce "fictitious" masses and also avoided the perpetual motion problem, because according to Darrigol[B 25] , Poincaré's radiation paradox can simply be solved by applying Einstein's equivalence. If the light source loses mass during the emission by E / c^2, the contradiction in the momentum law vanishes without the need of any compensating effect in the ether.

Similar to Poincaré, Einstein concluded in 1906 that the inertia of (electromagnetic) energy is a necessary condition for the center of mass theorem to hold in systems, in which electromagnetic fields and matter are acting on each other. Based on the mass–energy equivalence he showed that emission and absorption of em-radiation and therefore the transport of inertia solves all problems. On that occasion, Einstein referred to Poincaré's 1900-paper and wrote:[A 28]

> “ Although the simple formal views, which must be accomplished for the proof of this statement, are already mainly contained in a work by H. Poincaré [Lorentz-Festschrift, p. 252, 1900], for the sake of clarity I won't rely on that work.[C 6] ”

Also Poincaré's rejection of the reaction principle due to the violation of the mass conservation law can be avoided through Einstein's $E = mc^2$, because mass conservation appears as a special case of the energy conservation law.

[edit] General relativity

Main article: History of general relativity

The attempts of Lorentz and Poincaré (and other attempts like those of Abraham and Gunnar Nordström) to formulate a theory of gravitation, were superseded by Einstein's theory of general relativity.[B 26] This theory is based on principles like the equivalence principle, the general principle of relativity, the principle of general covariance, geodesic motion, local Lorentz covariance (the laws of special relativity apply locally for all inertial observers), and that spacetime curvature is created by stress-energy within the spacetime.

In 1920 Einstein compared Lorentz's ether with the "gravitational ether" of general relativity. He said that immobility is the only mechanical property of which the ether has not been deprived by Lorentz, but contrary to the luminiferous and Lorentz's ether the ether of general relativity has no mechanical property, not even immobility:[A 29]

> “ The ether of the general theory of relativity is a medium which is itself devoid of all mechanical and kinematical qualities, but helps to determine mechanical (and electromagnetic) events. What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with the matter and the state of the ether in neighbouring places, which are amenable to law in the form of differential equations; whereas the state of the Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same. The ether of the general theory of relativity is transmuted conceptually into the ether of Lorentz if we substitute constants for the functions of space which describe the former, disregarding the causes which condition its state. Thus we may also say, I think, that the ether of the general theory of relativity is the outcome of the Lorentzian ether, through relativization. ”

[edit] Priority

Some claim that Poincaré and Lorentz are the true founders of special relativity, but not Einstein. For more Details see the article on Relativity priority dispute.

[edit] Later activity and Current Status

Viewed as a theory of elementary particles, Lorentz's electron/ether theory was superseded during the first few decades of the 20th century, first by quantum mechanics and then by quantum field theory. As a general theory of dynamics, Lorentz and Poincare had already (by about 1905) found it necessary to invoke the principle of relativity itself in order to make the theory match all the available empirical data. By this point, the last vestiges of a substantial ether had been eliminated from Lorentz's "ether" theory, and it became both empirically and deductively equivalent to special relativity. The only difference was the metaphysical[C 7] postulate of a unique absolute rest frame, which was empirically undetectable and played no role in the physical predictions of the theory. As a result, the term "Lorentz ether theory" is sometimes used today to refer to a neo-Lorentzian interpretation of special relativity. The prefix "neo" is used in recognition of the fact that the interpretation must now be applied to physical entities and processes (such as the standard model of quantum field theory) that were unknown in Lorentz's day.

Subsequent to the advent of special relativity, only a small number of individuals have advocated the Lorentzian approach to physics. Many of these, such as Herbert E. Ives (who, along with G. R. Stilwell, performed the first experimental confirmation of time dilation) have been motivated by the belief that special relativity is logically inconsistent, and so some other conceptual framework is needed to reconcile the relativistic phenomena. For example, Ives wrote "*The 'principle' of the constancy of the velocity of light is not merely 'ununderstandable', it is not supported by 'objective matters of fact'; it is untenable...*"[C 8]. However, the logical consistency of special relativity (as well as its empirical success) is well established, so the views of such individuals are considered unfounded within the mainstream scientific community.

A few physicists, while recognizing the logical consistency of special relativity, have nevertheless argued in favor of the absolutist neo-Lorentzian view. Some (like John Stewart Bell) have asserted that the metaphysical postulate of an undetectable absolute rest frame has pedagogical advantages [B 27], while others have suggested that a neo-Lorentzian interpretation would be preferable in the event that any evidence of a failure of Lorentz invariance were ever detected.[C 9] However, no evidence of such violation has ever been found (despite strenuous efforts) → see Test theories of special relativity.

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[edit] Notes

Notes on primary sources

1. ^ a b c d Lorentz (1895)
2. ^ Lorentz (1892)
3. ^ a b c d e Lorentz (1904b)
4. ^ a b c d e f g Poincaré (1904); Poincaré (1905a), Ch. 8
5. ^ a b Poincaré (1898); Poincaré (1905a), Ch. 2
6. ^ a b c Poincaré (1900b)
7. ^ a b c Lorentz (1899)
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12. ^ Lorentz (1900)
13. ^ Poincaré (1908a); Poincaré (1908b) Book 3, Ch. 3
14. ^ Lorentz (1914) primary sources
15. ^ Poincaré (1895)
16. ^ a b Poincaré (1900a); Poincaré (1902), Ch. 9-10
17. ^ Poincaré (1902), Ch. 13
18. ^ Lorentz (1921), pp. 247-261
19. ^ Poincaré (1889); Poincaré (1902), Ch. 12
20. ^ Poincaré (1901a); Poincaré (1902), Ch. 6
21. ^ Poincaré 1912; Poincaré 1913, Ch. 6
22. ^ Poincaré (1913), Ch. 2
23. ^ a b Lorentz (1913), p. 75
24. ^ Einstein (1907)
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1. ^ Whittaker (1951), 386ff
2. ^ Born (1964), 172ff
3. ^ Brown (2001)
4. ^ Miller (1981), 70-75,
5. ^ Darrigol (2005), 10-11
6. ^ Janssen (1995), Chap. 3.5.4
7. ^ Janssen/Mecklenburg (2007)
8. ^ Walter (2007), Kap. 1
9. ^ Janssen/Mecklenburg (2007)
10. ^ Miller (1981), 334-352
11. ^ Born (1964), 238
12. ^ Pauli (1921), 634-636

13. ^ Miller (1981), 41ff
14. ^ Darrigol (2005), 18-21
15. ^ Miller (1981), 359-360
16. ^ Walter (2007)
17. ^ Galison (2002)
18. ^ Miller (1981), 186-189
19. ^ Katzir (2005), 275-288
20. ^ Miller (1981), 79
21. ^ Walter (2007), Chap. 1
22. ^ Darrigol (2005), 15-18
23. ^ Janssen (1995), Kap. 4
24. ^ Walter (1999)
25. ^ Darrigol (2005), 18-21
26. ^ Walter 2007
27. ^ J. Bell, How to Teach Special Relativity

Other notes and comments

1. ^ French original: *Nous n'avons pas l'intuition directe de la simultanéité, pas plus que celle de l'égalité de deux durées. Si nous croyons avoir cette intuition, c'est une illusion. Nous y suppléons à l'aide de certaines règles que nous appliquons presque toujours sans nous en rendre compte. [...] Nous choisissons donc ces règles, non parce qu'elles sont vraies, mais parce qu'elles sont les plus commodes, et nous pourrions les résumer en disant: « La simultanéité de deux événements, ou l'ordre de leur succession, l'égalité de deux durées, doivent être définies de telle sorte que l'énoncé des lois naturelles soit aussi simple que possible. En d'autres termes, toutes ces règles, toutes ces définitions ne sont que le fruit d'un opportunisme inconscient. »*
2. ^ French original: *Il semble que cette impossibilité de démontrer le mouvement absolu soit une loi générale de la nature [..] Lorentz a cherché à more compléter et à more modifier son hypothèse de façon à la mettre en concordance avec le postulate de l' impossibilité complète de la détermination du mouvement absolu. C'est ce qu'il a réussi dans son article intitulé [Lorentz, 1904b]*
3. ^ French original: *je n'ai pas établi le principe de relativité comme rigoureusement et universellement vrai. Poincaré, au contraire, a obtenu une invariance parfaite des équations de l'électrodynamique, et il a formule le « postulat de relativité » , termes qu'il a été le premier a employer.*
4. ^ The three best known examples are (1) the assumption of Maxwell's equations, and (2) the assumptions about finite structure of the electron, and (3) the assumption that all mass was of electromagnetic origin. Maxwell's equations were subsequently found to be invalid and were replaced with quantum electrodynamics, although one particular feature of Maxwell's equations, the invariance of a characteristic speed, has remained. The electron's mass is now regarded as a pointlike particle, and Poincaré already showed in 1905 that it is not possible for all the mass of the electron to be electromagnetic in origin. This is how relativity invalidated the 19th century hopes for basing all of physics on electromagnetism.
5. ^ See Whittaker's History of the Aether, in which he writes "the great advances made by Minkowski were connected with his formulation of physics

in terms of a four-dimensional manifold... in order to represent natural phenomena without introducing contingent elements, it is necessary to abandon the customary three-dimensional system of coordinates and to operate in four dimensions". See also Pais's Subtle is the Lord, in which it says of Minkowski's interpretation "Thus began the enormous simplification of special relativity". See also Miller's "Albert Einstein's Special Theory of Relativity" in which it says "Minkowski's results led to a deeper understanding of relativity theory".

6. ^ German original: *Trotzdem die einfachen formalen Betrachtungen, die zum Nachweis dieser Behauptung durchgeführt werden müssen, in der Hauptsache bereits in einer Arbeit von H. Poincaré enthalten sind [Lorentz-Festschrift, p. 252, 1900], werde ich mich doch der Übersichtlichkeit halber nicht auf jene Arbeit stützen.*
7. ^ Lorentz commented that the difference between his and Einstein's view was purely metaphysical, and could be left to the metaphysicians.
8. ^ Herbert E. Ives, "Revisions of the Lorentz Transformations", October 27, 1950
9. ^ It should also be mentioned that the flexibility of the neo-Lorentzian interpretation is regarded as a weakness, rather than a strength, according to the usual view that equates the strength of a scientific theory with its falsifiability. A theory that can be easily modified to accommodate any contingency is considered weaker than one that could be strictly falsified by any of a large number of empirical tests (and of course that passes all those tests).

[edit] External links

- Mathpages: Corresponding States, The End of My Latin, Who Invented Relativity?, Poincaré Contemplates Copernicus, Whittaker and the Aether, Another Derivation of Mass-Energy Equivalence