

15a. Einstein's Special Relativity

1. "On the Electrodynamics of Moving Bodies"
2. The Principle of Relativity
3. The Light Postulate
4. Reconciliation: Relativity of Simultaneity



Albert Einstein
(1879-1955)

"I am more and more convinced that the electrodynamics of moving bodies, as it is presented today, does not agree with the truth, and that it should be possible to present it in a simpler way. The introduction of the name 'ether' into the electric theories has led to the notion of a medium of whose motion one could speak of without being able, I believe, to associate a physical meaning to this statement." (1899.*)

"I believe that electric forces can be directly defined only for empty space... Further, electric currents will have to be regarded not as 'the vanishing of electric polarization in time' but as motion of true electric masses, whose physical reality seems to result from the electrochemical equivalents... Electrodynamics would then be the science of the motions in empty space of moving electricities and magnetisms." (1899.)



*Letter to Mileva Maric. Quoted in Darrigol, O. (2005) 'The Genesis of the Theory of Relativity', *Poincare Seminar 2005*, pg. 21.

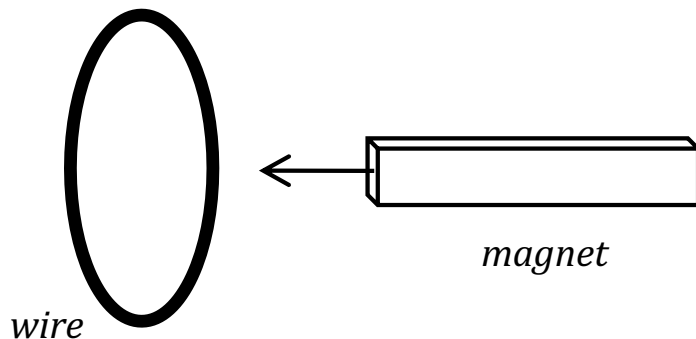
1. "On the Electrodynamics of Moving Bodies" (1905)

- Central Motivation:

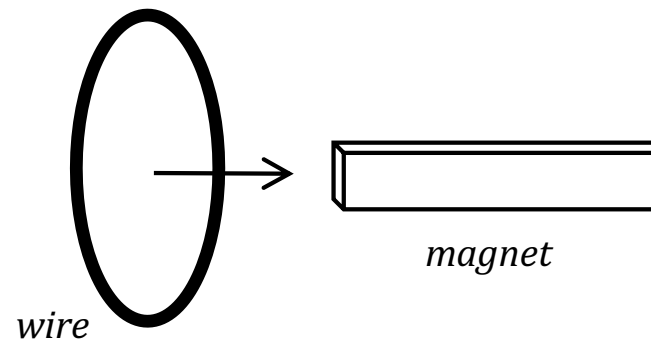


"It is known that Maxwell's electrodynamics--as usually understood at the present time [*i.e.*, Lorentz's theory]--when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena."

- When a magnet moves through a stationary conducting coil, or when the coil moves about the stationary magnet, the induced current is the same.
- But: The theoretical explanation is different!
 - First case: Moving magnet induces electric field in coil (Faraday's Law). Electric force makes electrons move in coil
 - Second case: Lorentz force due to magnetic field of magnet causes electrons to move in coil.



$$\nabla \times \mathbf{e} = -c^{-1} \partial \mathbf{b} / \partial t$$



$$\mathbf{f} = \rho [c^{-1} \mathbf{v} \times \mathbf{b}]$$



"Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the 'light medium' suggest..."

1st Postulate ("Principle of Relativity"):

"The same laws of electrodynamics and optics will be valid in all frames of reference for which the equations of mechanics hold good." "



2nd Postulate (Light Postulate):

"Only apparently irreconcilable with [the relativity postulate]."

"Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body."



2. The Principle of Relativity

"The same laws of electrodynamics and optics will be valid in all frames of reference for which the equations of mechanics hold good."

- Conceptual desire to avoid theoretical "asymmetries" in electrodynamics leads Einstein to reject the aether (the source of such asymmetries).
- "Frames for which the equations of mechanics hold good" = inertial frames = frames moving at constant velocity with respect to each other.
- Thus: The P. of R. says: There is no privileged aether frame in which the laws of electrodynamics and optics (*i.e.*, the Maxwell-Lorentz equations) hold; rather, these laws hold in all inertial frames.
- What this means: The laws of electrodynamics *and* optics *and* mechanics (*i.e.*, the laws of physics at the time) cannot distinguish one inertial frame from another.
 - *All inertial frames are physically indistinguishable with respect to the laws of physics.*

3. The Light Postulate

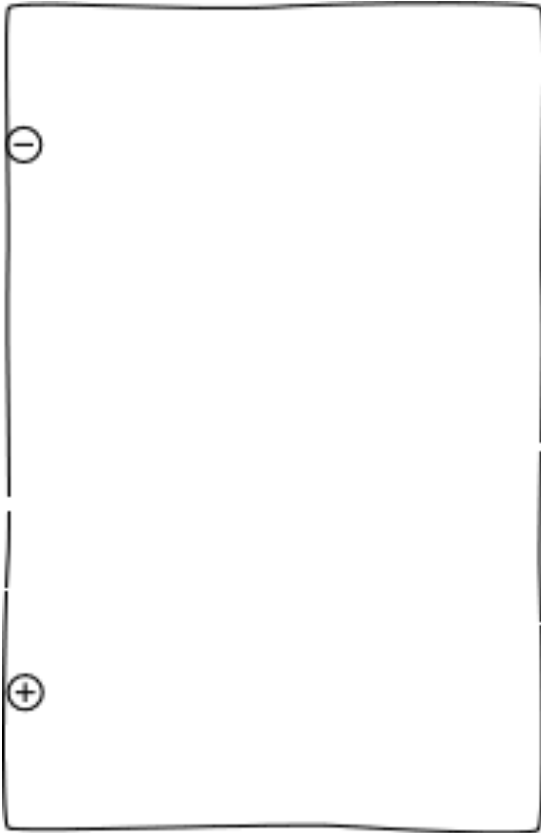
"Light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body."

- According to Maxwell-Lorentz electrodynamics, light is always propagated *in the aether* with a definite velocity c which is independent of the state of motion of the emitting body.
 - *Light Postulate rephrases this in terms of "empty space".*
- Why state this as a postulate?
 - "The constancy of the velocity of light no longer resulted from the existence of the aether, and had to be postulated separately." (Darrigol, pg. 23.)
 - *It's the essential feature of electrodynamics that Einstein thought would survive in a theory describing light quanta...*
- Why is it "apparently irreconcilable" with the Principle of Relativity?
 - *Principle of Relativity and Light Postulate entail:*

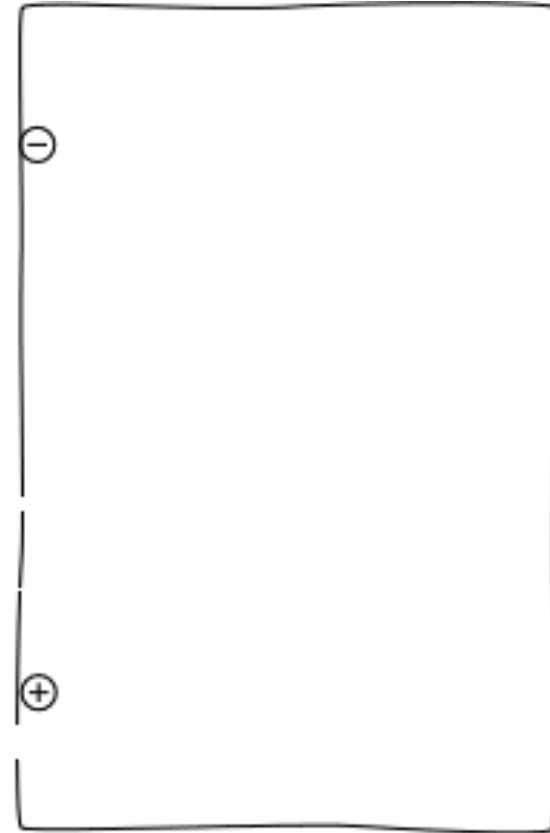
The speed of light is the same in all inertial reference frames.

This violates the way of adding velocities on both emission and aether theories of light!

- *Emission Theories*: The speed of light is a constant c with respect to its source, *not* to the aether.
- *Aether Theories*: The speed of light is a constant c with respect to the aether.

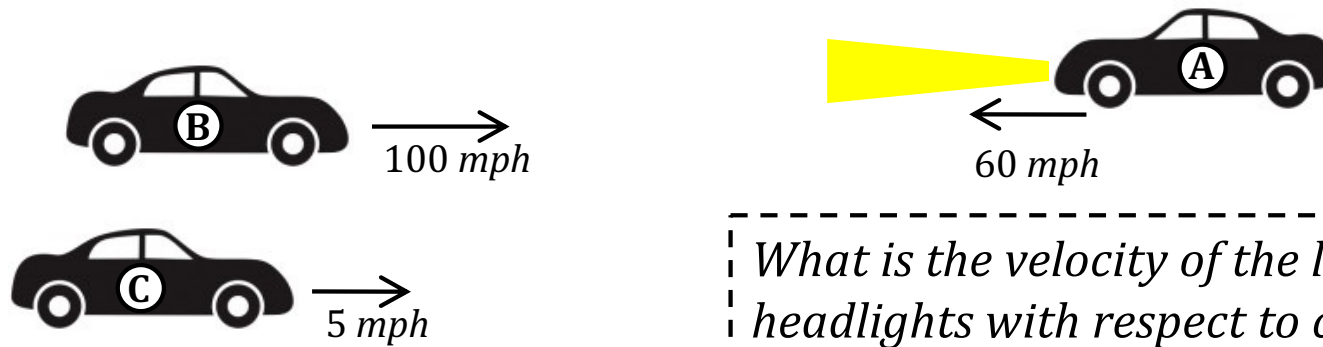


Aether theory



Emission theory

Consider three cars on a highway:



What is the velocity of the light of car A's headlights with respect to cars B and C?

Emission theory: Velocity of light depends on velocity of its source.

- Car B says velocity of light from car A's headlights is $c + 60 \text{ mph} + 100 \text{ mph}$.
- Car C says velocity of light from car A's headlights is $c + 60 \text{ mph} + 5 \text{ mph}$.

Aether theory: Velocity of light with respect to aether is c , independent of its source.

- Car B says velocity of light from car A's headlights is $c + 100 \text{ mph}$.
- Car C says velocity of light from car A's headlights is $c + 5 \text{ mph}$.

Einstein's theory: Velocity of light is c in all inertial frames.

- Car B says velocity of light from car A's headlights is c .
- Car C says velocity of light from car A's headlights is c .

- Einstein's two postulates entail that B and C measure the same velocity for light, even though they are moving with respect to each other!

4. Reconciliation: Relativity of Simultaneity

How to reconcile the two postulates?

- Spring 1905. In conversation with Michele Besso, Einstein considers redefinition of the concept of time...
- Influenced by Poincaré's *Science and Hypothesis*:



"There is no absolute time. To say two durations are equal is an assertion which has by itself no meaning and which can acquire one only by convention. Not only have we no direct intuition of the equality of two durations, but we have not even direct intuition of the simultaneity of two events occurring in different places..."

"The simultaneity of two events or the order of their occurrence, and the equality of two time intervals must be defined so that the expression of the laws of physics should be the simplest possible; in other words, all those rules and definitions [conventions for time measurement] only are the fruits of an unconscious opportunism."



- To reconcile the Light Postulate with the Principle of Relativity, require that inertial observers measure time in different ways.
- Relativity of simultaneity: Events are simultaneous only with respect to an inertial frame.

"Most of the components of Einstein's paper appeared in others' anterior works on the electrodynamics of moving bodies... None of these authors, however, dared to reform the concepts of space and time. None of them imagined a new kinematics based on two postulates. None of them derived the Lorentz transformations on this basis. None of them fully understood the physical implications of these transformations. It all was Einstein's unique feat." (Darrigol, pg. 25.*)