The Special Theory of Relativity
(2nd Lecture)
Emergence of Special Relativity

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Recapitulation

1. **Basic aspects of Newtonian Mechanics & Electrodynamics**
2. **Contradiction between the concepts of Newtonian Mechanics & Electrodynamics**
3. **Classical Relativity: Galilean Transformation**
4. **Galilean Concept of relativity**
5. **Invariance of Newtonian Mechanics Under Galilean Transformation**
6. **Newton's concept of absolute space interval and time interval**
7. **Inconsistency of electrodynamics in Galilean transformation.**
8. **Speed of light in free space is different in different inertial coordinate system.**
9. **Contradicts with the observed phenomena.**
10. **Concept of luminoferous ether**
11. **Michelson Morley Experiment to detect presence of ether: failed to detect.**
12. **Speed of light in free space is a Universal Constant**
13. **Emergence of Special Theory of Relativity.**

THE SPECIAL THEORY OF RELATIVITY

The constancy of the speed of light in all inertial frames stands in contradiction with the Galilean transformations.

In 1905, Albert Einstein presented a revolutionary proposal which resolved this contradiction.

Rather than modifying electromagnetic theory, he rejected the ether hypothesis and generalized Galilean principle of relativity.

In his paper "On the Electrodynamics of Moving Bodies", Einstein formulated the two postulates of the special theory of relativity

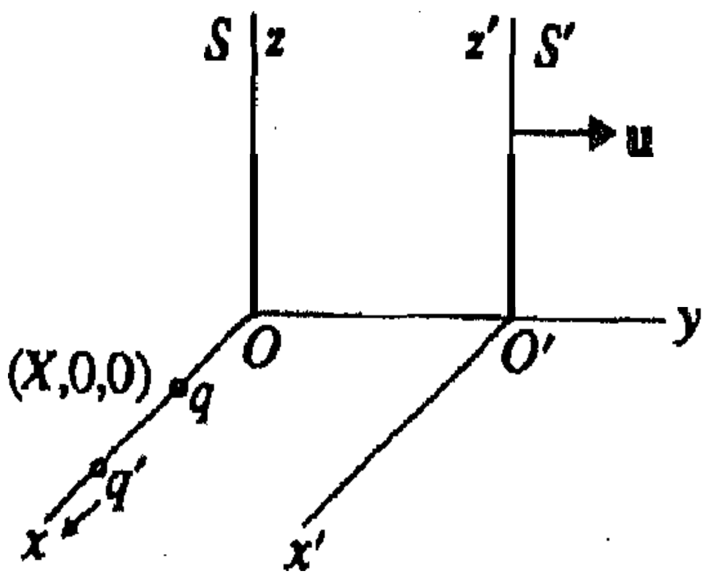
Postulate 1 - The Principle of Relativity
The laws of physics are the same in all inertial frames of reference.

Postulate 2 - The Principle of Constancy of Speed of Light
The speed of light (in vacuum) has the same constant value in all inertial reference frames

The Principle of Relativity

the Galilean principle of relativity which applied to the Newtonian laws of mechanics only has now been generalized to all laws of physics –

any law of physics that is true in one inertial frame will also be true in all other inertial frames.



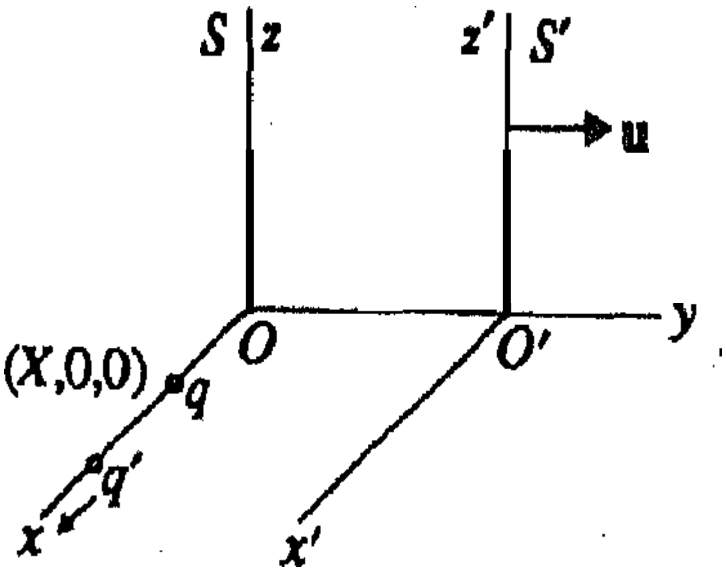
A positive electric charge *q* was fixed at a point (X, 0, 0) in a stationary inertial frame *S.*

Another positive charge *q′* was released at some point on the x-axis.

It would accelerated away from the fixed charge at x = X.

We could experimentally determine the *x* component of the acceleration of the moving charge as a function of its distance from the fixed charge.

The Principle of Relativity



For a charged particle moving away from a fixed charge

$$\frac{d^2x}{dt^2} = \frac{k}{(x - X)^2} \quad (k = constant)$$

Another observer is stationed in an inertial reference frame S' moving with respect to *S* with a constant velocity u.

The principle of relativity tells us that if the above equation is really a law of physics, then the observer in the S' frame should find that

$$\frac{d^2x\prime}{dt\prime^2} = \frac{k\prime}{(x\prime - X\prime)^2} \quad (\mathrm{X}' \Rightarrow \text{position of the fixed charge q on the x}'\text{axis of the S}'\text{ frame})$$

Thus, even though the values of x', t', X' and the constant k' are different from x, t, X, and k, the relationship between them is of the same form

The Principle of Relativity

any equation that cannot be written in the same form in all Inertial Frames cannot be a law of physics.

The principle of relativity also allows us *to* determine which relationships (or equations) can or cannot be laws of physics

In summary, the principle of relativity implies that the laws of nature do not depend upon the choice of an inertial frame of reference or the position or motion of an observer – they will always retain their form in any inertial frame of reference.

The measurements of various quantities, like the positions, times, velocities, energies, momenta, electric and magnetic fields may be different in different inertial frames.

The relationships between these quantities governed by various laws would remain the same in all inertial frames.

In philosophical terms, we can say that the principle of relativity underscores the objective character of the laws of nature and not the relativity of knowledge.

The Principle of Relativity

The laws of physics do not allow us to distinguish between different inertial frames.

In other words, you will not be able to distinguish through any experiment whether you are at rest or in a state of uniform motion.

If there were such an experiment, it would mean that the laws of physics depended in some way on your velocity and were different from the laws of physics when you were at rest.

The principle of relativity does not claim that all inertial frames are the same in all respects.

The Principle of Relativity

Consider two different spacecraft, each travelling with a different constant velocity with respect to S.

The two frames cannot be distinguished as far as the laws of physics are concerned.

However, if one could look outside each spacecraft through a window, it would be easy to know that they are moving at different velocities, relative to S.

Does this contradict the principle of relativity?

No, because the velocity of the spacecraft relative to S is not determined by a law of physics.

Besides, in formulating this form of the principle of relativity the essential condition was that the space crafts were completely isolated.

The Principle of Constancy of Speed of Light

The basic premise of Newtonian mechanics was that the same time scale applied lo all inertial frames of reference. (recall the equation $t' = t$ in Galilean transformation).

Using this universal time scaled we must be able to give ,meaning to statement such as "Events A and *B* occurred at the same time, without referring to any inertial frame of reference."

When we say that a train arrives at 7 o'clock, what we mean is this: The pointing of the clock hand to 7 and the arrival of the train are simultaneous events.

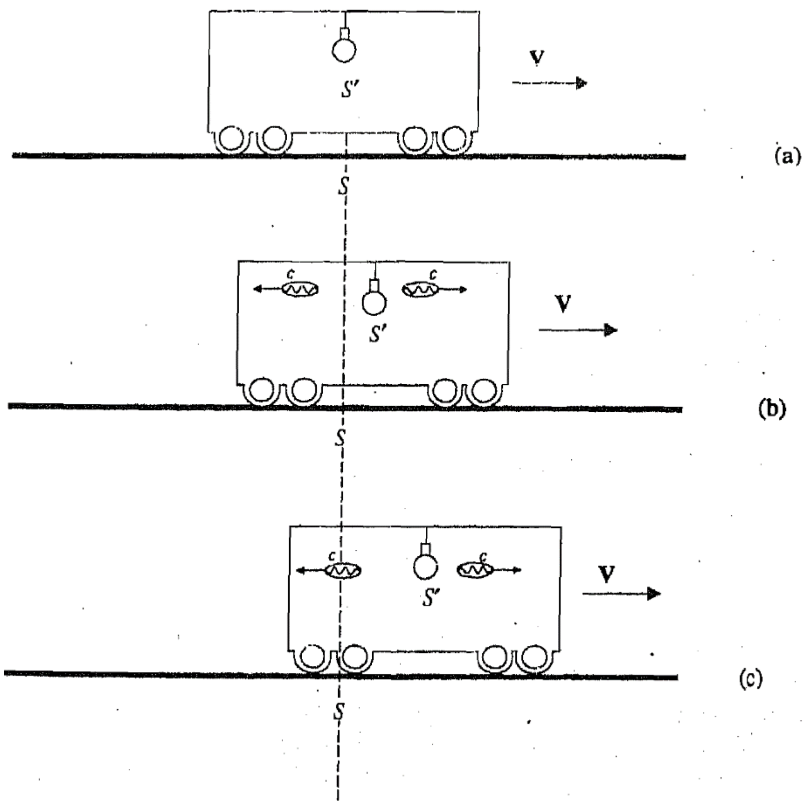
Assigning of time to events involves judging whether they are simultaneous or not.

So, if all observers, independent of their position and velocity, that two events (e.g., the arrival of the train at the station and the pointing of the clock hand to 7) are simultaneous, we could certainly say that the absolute, Newtonian time scale existed.

The Principle of Constancy of Speed of Light

There will be no absolute time scale if different inertial observers disagree about two events being simultaneous.

This is precisely what happens if we uphold the constancy of the speed of light.

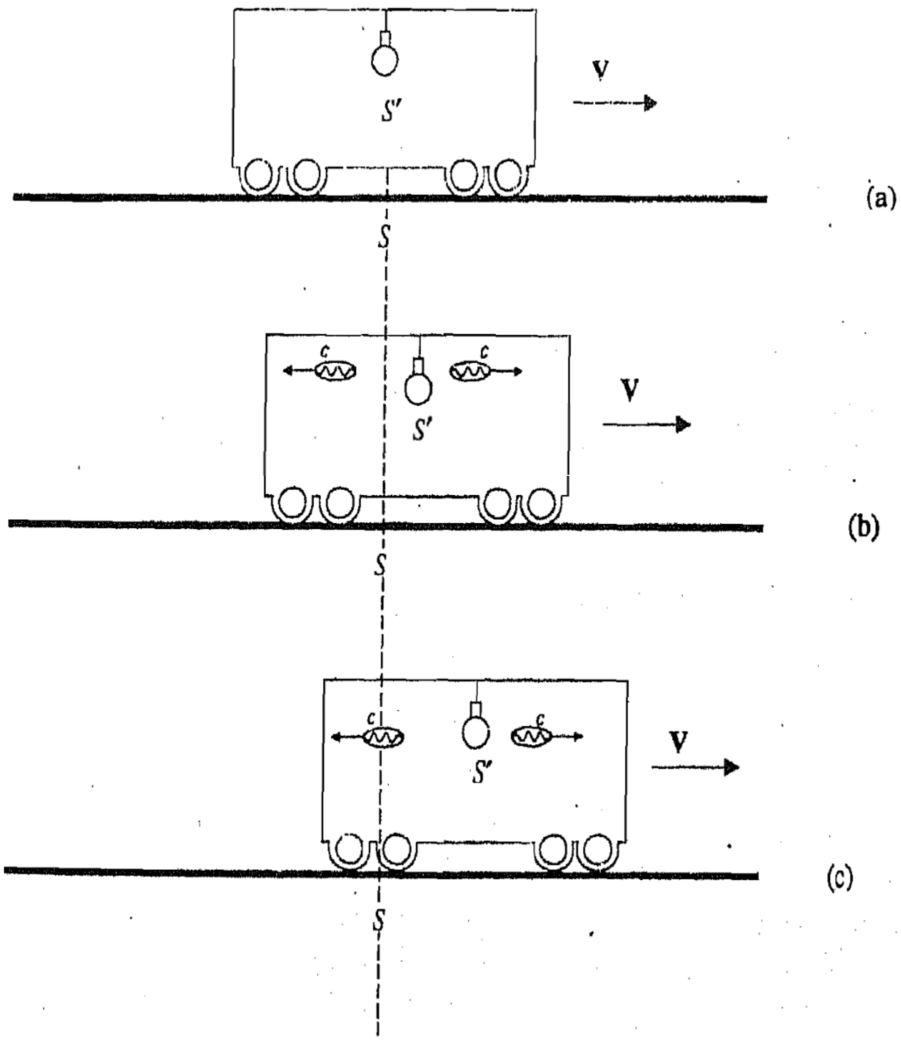


Consider a train compartment travelling at a very high constant velocity V to the right of an observer *S* at rest on the earth.

A high speed flashbulb is situated at the exact center of the compartment. It sends out light pulses to the right and left when it flashes.

There *are* photocells at each end of the compartment, so that an observer *S',* in the compartment can detect when the light pulses strike its ends.

The Principle of Constancy of Speed of Light



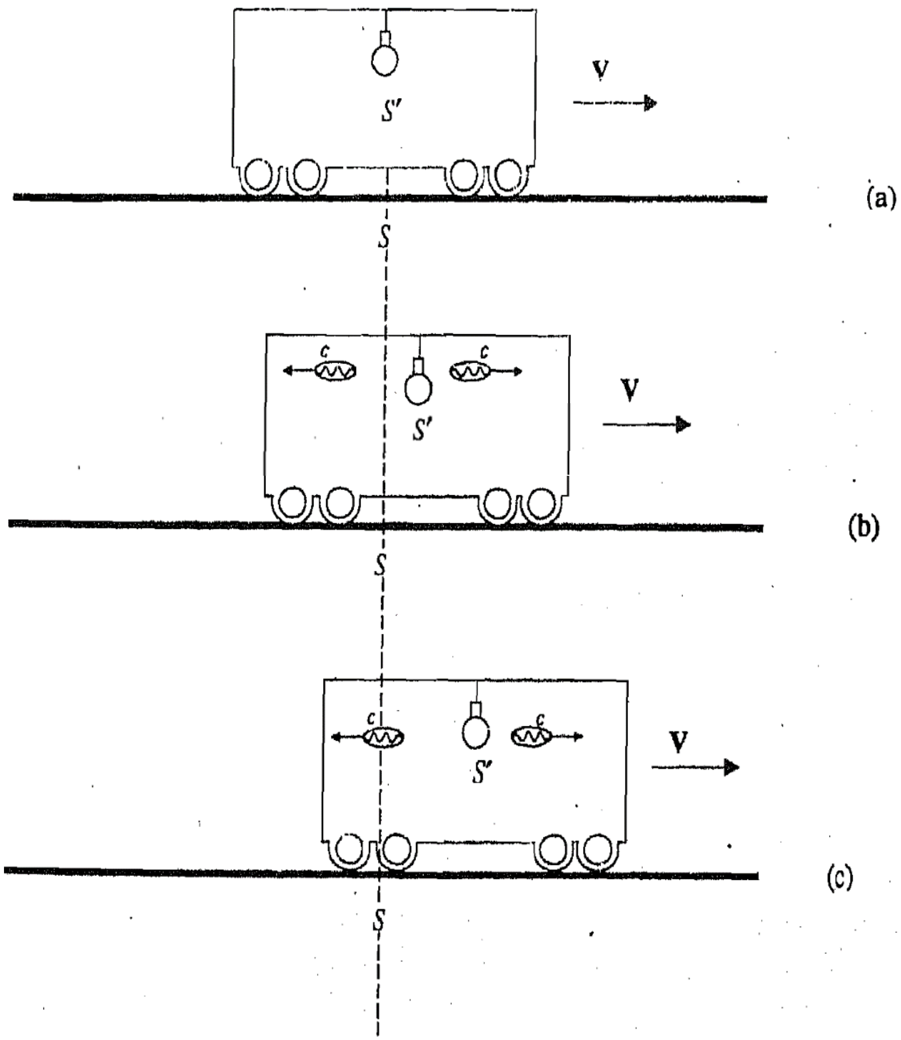
Let the positions of *S* and *S′* coincide with that of the bulb when it flashes.

The flashbulb is at rest relative lo the observer S' in the compartment.

Since it is at the center, when the bulb flashes, two light pulses travel equal distances to the two ends of the compartment in equal times.

To the *S′* observer: light pulses hit the two ends of the compartment at the same time.

The Principle of Constancy of Speed of Light



What will be the observation of S observer?

The light pulses travel equal distances to the right and left in equal time.

In the frame of S the compartment is moving to the right.

the distance between the point of bulb flashing and the left end is shorter than that of the right end.

To S light pulse strikes the left end before the other pulse strikes the opposite end.

Hence In S frame light pulses do not hit the two ends of the compartment at the same time.

The Principle of Constancy of Speed of Light

As per of Newtonian mechanics the light wavers will travel different distances to the two ends in the frame S.

Now the speed of light measured by S would be different in the two directions lower speed (c - V) to the left (opposite to the direction of the train's motion) and the pulse travelling to the right would travel a greater distance but *at* a greater speed of (c + V).

Thus, S would measure both the times to be equal and conclude that the two pulses hit the ends of the compartment at the same time.

But the *speed* of light is constant. Hence in the S frame the two events (the light, pulses hitting the two ends of the compartment) do not occur simultaneously.

This signifies a major break with the older ideas of absolute time. Different

observers do not agree on what is the same time.

The point to be noted here that the events are occurring at different locations (the two ends of the compartment for instance).

In the next unit we shall come back to this discussion and also consider events occurring simultaneously at the same point in space.

To sum up, we can conclude that the notion of absolute time is contradicted by the second postulate because events (occurring at different points in space) that are simultaneous in one inertial system may not be simultaneous in another.

This conclusion is termed the relativity of simultaneity, It is the fundamental difference between Newtonian relativity and special relativity.

In Newtonian relativity, observers in S and S' always agree everywhere about events occurring at the same time.

This is also the origin of other features of space and time that follow from the special theory of relativity, namely, the phenomena of length contraction, time dilation, twin paradox, etc.

Thank you