Special Theory of Relativity

PH101

Lec-1

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Background

➢ Modern Physics is based on the three major theories :

I. Relativity (space, time and gravity)
II. Quantum Mechanics (subatomic particles)
III. Thermodynamics (relationship between heat and other forms of energy)

What is unique about these three theories ?

- ✓ Distinct from say the theory of electromagnetism.
- ✓ More general : based on general principles which all more specialized or more specific theories are required to satisfy.
- ✓ These theories lead to general conclusions which apply to all physical systems, and hence are of enormous power !

Fundamentally significant

The role of relativity ?

- ✓ It specify the properties of space and time, the arena in which all physical processes take place.

Background !

- Until the end of the 19th century it was believed that Newton's three Laws of Motion and the associated ideas about the properties of space and time provided a basis on which the motion of matter could be completely understood.

- However, the formulation by Maxwell of a unified theory of electromagnetism disrupted this comfortable state of affairs – the theory was extraordinarily successful, yet at a fundamental level it seemed to be inconsistent with certain aspects of the Newtonian ideas of space and time

✓Ultimately, a radical modification of these concepts was found to be necessary.

It was Albert Einstein who, by combining the experimental results and physical arguments of others with his own unique insights, first formulated the new principles in terms of which space, time, matter and energy were to be understood.

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Special Theory of Relativity ⇒ General Theory of Relativity → Theory of Gravity

Background !

- ❑ Most basic concept of "relativity" is as old as Galilean and Newtonian Mechanics. it is:

  ✓ *The Laws of Physics* are the *same in all* inertial *frames* of reference !

  ✓ Newtonian Relativity: Concerned only with the mechanical behavior of the moving objects !

  ✓ In Einstein's Relativity: This applies to **all Laws of Physics !**

- ❑ When applied to all laws, difficult issues arise.

  ✓ Implications seem to violate intuition

  ❖ masses increase, lengths are shortened, time expands

- ❑ Recall: Newton's Laws are valid only in an "inertial" frame

  ✓ Issues in Basic Newtonian mechanics :

A state of a system is specified at some time t_o by giving position coordinates (x_o, y_o, z_o) and velocity (v_{ox}, v_{oy}, v_{oz}) at t_o. We can calculate position (x,y,z) and velocity (v_x, v_y, vz) at a later time t by knowing all forces acting on the system and applying Newton's laws.

✓ Often desirable to specify such a state in terms of a new set of coordinate axes, which is moving with respect to the first !

Background !

- ❑ Therefore, the important and useful questions are:
  - ✓ How do the state transform from the old to the new frame?
  - ✓ What happens to Newton's Laws under this "transformation"?
  - ✓ What happens to Electromagnetic theory (Maxwell's Equations)?

Theory of Relativity concerns itself with these questions

- ❑ Albert Einstein formulated the modern Theory of Relativity.
  - ✓ He proposed **two such theories:**

(1) The Special Theory of Relativity:

- Deals with the case of an inertial frame of reference moving with constant velocity with respect to another inertial frame !
  - ✓ Its consequences are most important as the velocity $v \rightarrow c$

(2) The General Theory of Relativity :

- Deals with the case of an inertial frame of reference accelerating with respect to another inertial frame.

Principle of relativity

- *The laws of physics take the same mathematical form in all frames of reference moving with constant velocity with respect to one another.*

  ✓ Consider a collection of experimenters, each based in laboratories moving at constant velocities with respect to one another, and each undertaking a series of experiments designed to lead to a mathematical statement of a particular physical law, such as the response of a body to the application of a force.

  ✓ According to the principle of relativity, the final form of the equations derived (in this case, Newton's laws) will be found to have exactly the same form for all experimenters.

  - Actual data obtained by each experimenter will not necessarily be numerically the same.

Given two observers A and B moving at a constant velocity with respect to one another, it is not possible by any experiment whatsoever to determine which of the observers is 'at rest' or which is 'in motion'.

Frames of reference

- ✓ Physical processes either directly or indirectly involve the dynamics of particles and/or fields moving or propagating through space and time.
  - Almost all of the fundamental laws of physics involve position and time.
- ✓ We have at hand some way of measuring or specifying or labelling each point in space and different instants in time.

In order to describe in a quantitative fashion the multitude of physical processes that occur in the natural world, one of the important requirements is that we should be able to specify where and when events take place in space and time.

Something that occurs at an instant in time at a point in space, or, more colloquially, over a localized interval in time, and in a localized region in space.

The combination of a means of measuring the position of events, and the time at which they occur, constitutes what is referred to as a frame of reference.

Suppose in one frame of reference a particle is observed to be at a position at a time t (as indicated by the clock at (x, y, z)), we can summarize this information by saying that the particle was observed to be at the point (x, y, z, t) in space-time.