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Where Minds Pollinate

Class 11
Physics

Chapter 13

Handwritten Notes

Chapter 13 RELATIVITY

Frame of referance:-

A co-ordinate system with respect to which an observer/experimenter measures position, displacement, velocity and time of a physical event/Phenomenon is called frame of referance.

Types of Frame of Referame:-

There are two types of frame of referance.

Inertial frame of referance.

Non-Inertial frame of referance.

Inertial frame of reference:-

A frame of referance which is at rest or moving with uniform velocity along a straight line is called a inertial frame of referance.

It is non-accelerated frame of referance.

Newton's first law of motion holds in inertial frame of referance.

e.g:-

Room in which we are sitting and a car moving with uniform velocity along a straight line. are example of inertial frame of referance.

Non-Inertial frame of referance:-

An accelerated frame of referance is called non-Inertial frame of referance. It is moving with some acceleration. Newton's first law of motion does not act/apply in non-inertial frame of referance.

e.g:-

A car moving with variable velocity on a road is an example of non-Inertial frame of referance.

Postulates of Special Theory of Relativity

Special theory of relativity is based on two postulates:-

A- Principle of Relativity:-

All laws of physics remain same in all inertial frames of referances. All inertial frame of referances are equivalent. All laws of physics are same and givive same results in all inertial frame of referances. On the basis of results of an experiment, we cannot diff b/w any two inertial frame of referances.

B- Constancy of speed:-

Speed of light in vaccume/air measured of all inertial referance frames remain constant and appears as $C = 299,792,458\ m/s$ (or)

$C = 3 \times 10^8\ m/s$.

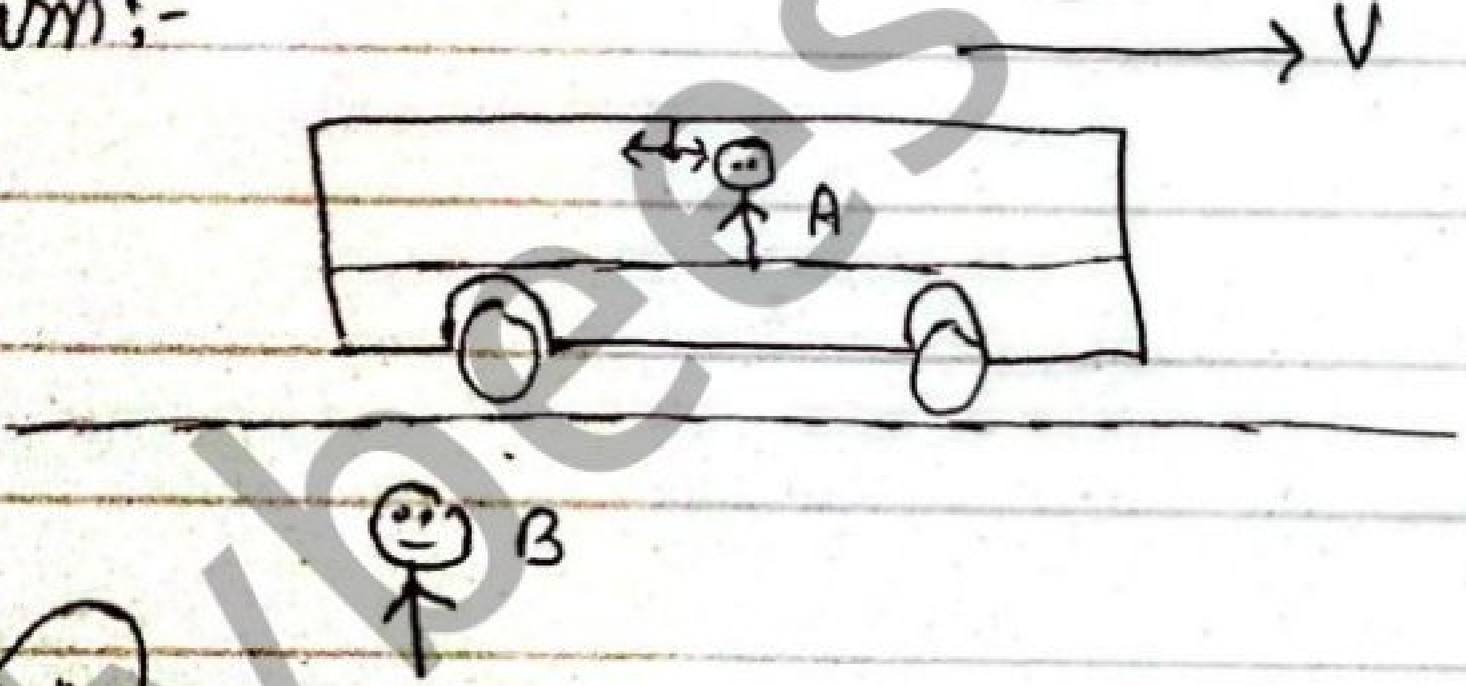
It does not depend upon the relative motion b/w source of light and observer.

Consequences of Special Theory of Relativity :-

1- Relativity of Simultaniety :-

According to this, two events that are simultaneous in one frame of referance, may not be simultaneous in another frame of referance. It means that, simultaniety is not absolute but relative.

Diagram:-



Explanation:-

According to the observer "A" present inside the train, both photons of light reach the opposite end at the same. Hence, events are simultaneous according to observer "A".

But, according to observer "B", present outside the train, left photon reaches left side earlier than the right photon reaches the right sides. For observer "B", both events are not simultaneous. Hence, Simultaneously is relative.

Mass Energy equivalence:-

According to Einstein, mass of an object is the condense form of energy. It means that, mass and energy are equivalent. Mass can be converted into energy and energy can be converted mass.

Rest mass energy:-

Energy equivalent to mass of an object at rest is called rest mass energy. It is represent by E_0 and is given by.

$$E_0 = m_0c^2 \quad \cdots (1)$$

When object is in motion, then:

$$E = mc^2 \quad \cdots (2)$$

Subtracting (1) and (2)

$$E - E_0 = mc^2 - m_0c^2$$

$$\Delta E = (m - m_0)c^2$$

$$\Delta E = \Delta mc^2$$

$$\Delta m = \frac{\Delta E}{c^2}.$$

This is the increase in mass of an object due to its motion. Increase in mass is very small and not noticeable in daily life scenario.

Length Conduction:-

Definition:

Length of an object measured in a moving frame is less than the length of same object measured in a frame in which object is at rest. This effect is called length conduction.

Mathematically:-

Relationship b/w rest length (proper length) and moving length (improper length) is.

$$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}.$$

Proper length/rest length (l_0):-

length of object measured in a frame in which object is at rest is called rest/proper length. It is represented by l_0. It is longest length.

Improper length/Moving length(l):-

length of object measured by a moving frame or by a frame in which object is moving is called improper length.

It is represented by l.

It is shorter than proper length.

Mass Variation:-

Mass of a moving object is greater than the mass of object at rest. This means that, when an object moves, its mass increases.

This effect is called mass variation.

Mathematically:-

Relationship b/w rest mass (proper mass) and moving mass (improper mass) is

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

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Proper mass / Rest mass:-
Mass of an object in a frame in which object is at rest is called rest/ proper mass. It is represented by m_0. It is the least amount of mass.

Improper length:-
Mass of an object measured by a moving frame or in a frame in which object is moving is called improper mass.
It is represented by "m".
It is greater than the rest mass.

5 Time dilation:-
Time interval b/w two events depends upon the frame of referance in which it is being measured. It is not same this effect is called time dilation.

Mathematically:-
Relationship b/w proper time interval and improper time interval is given by

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}.$$

Proper time interval (t_0):-
Time interval b/w two events measured in a frame in which both events took place at same ~~time~~ point of space is called proper time interval.

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It is represented by "t_o".
It is the least value of time interval.
Improper time interval:- (t)
Time interval b/w two events measured in a frame in which both events took place at diff points of space is called improper time interval. It is represented by "t".
It is longer then proper time interval.

Example 13.1

If a 0.5kg body is moving with a speed equivalent to 90% of the speed of light. What will be its mass in this situation?

Given data:-

$v = 90\%$ of $c = 0.9c$ and $m_o = 0.5kg$

To find:-

$m = ?$

Solution:-

using the relation

$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{0.5}{\sqrt{1 - \frac{(0.9)^2}{c^2}}}$$

$m = 1.15kg$.

Example 13.2

At what speed would the mass of the proton be tripled? The rest mass of a proton is 1.673×10^{-27} kg.

Given data:-

$m = 3m_0$, $m_0 = 1.673 \times 10^{-27}$ kg.

To prove:- v

$v = ?$

Solution:-

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} , \quad 3m_0 = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$3 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{1}{3}$$

Sq. both sides we get.

$$1 - \frac{v^2}{c^2} = \frac{1}{9}$$

$$\frac{v^2}{c^2} = 1 - \frac{1}{9}$$

$$v^2 = \frac{8}{9} c^2$$

$$v = \frac{\sqrt{8}}{3} c , \quad v = 0.9428c$$

Assignment 17.1

What is the speed of a rod relatives to the observer, if the length of rod is measured to be half of its proper length?

~~Solution:~~

Given data

$$l_0 = l_0 \quad , \quad l = \frac{l_0}{2}$$

To find

$$V = ?$$

Calculation

we know that.

$$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}.$$

putting all values we get

$$\frac{l_0}{2} = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$\frac{1}{2} = \sqrt{1 - \frac{v^2}{c^2}}$$

taking sq on b/s.

$$\frac{1}{4} = 1 - \frac{v^2}{c^2}$$

$$\frac{v^2}{c^2} = 1 - \frac{1}{4} = \frac{3}{4}$$

$$\frac{v}{c} = \sqrt{\frac{3}{4}}$$

$$V = 0.86\,c$$

$$V = 0.86 \times (3 \times 10^8 \, m/s)$$

$$V = 2.6 \times 10^8 \, m/s.$$

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Assignment 17.1.2

The time period of a pendulum is measured to be 3s in inertial terms of the pendulum. What is the period when measured by an observer moving with a speed of 0.95c with respect to the pendulum?

Given data:

$t_0 = 3s$, $V = 0.95c$

To find:

$t = ?$

Calculations:

$$t = \frac{t_0}{\sqrt{1 - \frac{V^2}{c^2}}}$$

$$t = \frac{3}{\sqrt{1 - (0.95)^2}}$$

$$t = 9.6s.$$

NUMERICALS PROBLEMS

1.1 **Calculate the equivalent energy of an electron having rest mass 9.11×10^{-31} Kg.**

ol: <u>Given data:</u>

Rest mass of electron: $m_e = 9.11 \times 10^{-31} kg$

Speed of light: $c = 3 \times 10^8 ms^{-1}$

Equivalent energy of (e^-): $E = ?$

<u>Formula:</u>

$$E = mc^2$$

$$E = (9.11 \times 10^{-31}) \times (3 \times 10^8)^2 = 8.2 \times 10^{-14} J \qquad \because 1eV = 1.602 \times 10^{-19} J$$

$$E_{(eV)} = \frac{8.2 \times 10^{-14}}{1.602 \times 10^{-19}} = 5.12 \times 10^5 eV = 0.512 MeV$$

3.2 **The length of a spaceship is 100 m long. What will be its length if the spaceship moves with a speed of 0.99c?**

ol: <u>Given Data:</u>

Rest length of spaceship: $L = 100m$

Velocity of the spaceship: $v = 0.99c$

Length contraction: $L' = ?$

<u>Formula</u>:

$$L' = L_o\sqrt{1 - \frac{v^2}{c^2}}$$

$$L' = (100) \times \sqrt{1 - \frac{(0.99c)^2}{c^2}} = 100 \times \sqrt{1 - 0.9801}$$

$$L' = 14m$$

13.3 **Particles called π-mesons are produced by accelerator beams. If these particles travel at 2.70×10⁸ m/s and live 2.60×10⁻⁸ s when at rest relative to an observer. How long do they live as viewed in the laboratory?**

Sol: Given data:

Velocity of π-meson: $v = 2.70\times10^{8}\,ms^{-1}$

Lifetime of π-meson at rest: $t = 2.60\times10^{-8}\,s$

Speed of light: $c = 3\times10^{8}\,ms^{-1}$

Observed lifetime in laboratory frame: $t' = ?$

Formula:

$$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$t' = \frac{2.60\times10^{-8}}{\sqrt{1-\frac{\left(2.70\times10^{8}\right)^2}{\left(3\times10^{8}\right)^2}}} = 5.96\times10^{-8}\,s$$

13.4 **A neutral π-mesons lives 1.40×10⁻¹⁶ s as measured in the laboratory, and 0.840×10⁻¹⁶ s when at rest relative to an observer, what is its velocity relative to the laboratory?**

Sol: Given data:

Lifetime in the laboratory: $t' = 1.40\times10^{-16}\,s$

Lifetime at rest: $t = 0.84\times10^{-16}\,s$

Speed of light: $c = 3\times10^{8}\,ms^{-1}$

Velocity of π-meson: $v = ?$

Formula:

$$t' = \frac{t}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\sqrt{1-\frac{v^2}{c^2}} = \frac{t}{t'}$$

$$1-\frac{v^2}{c^2} = \left(\frac{t}{t'}\right)^2$$

$$\frac{v^2}{c^2} = 1-\left(\frac{t}{t'}\right)^2$$

$$\frac{v^2}{c^2} = 1-\left(\frac{0.84\times10^{-16}}{1.40\times10^{-16}}\right)^2$$

$$\frac{v^2}{c^2} = 1-0.36$$

$$v^2 = 0.64c^2$$

$$v = \sqrt{0.64c^2} = 0.800c$$