B.Sc. SEMESTER – II
PHYSICS COURSE: USO2CPHY01
UNIT – 4: SPECIAL THEORY OF RELATIVITY

INTRODUCTION

- Einstein's special theory of relativity deals with the physical law as determined in two references frames moving with constant velocity relative to each other.
- ***Event* :** An event is something that happens at a particular point in space and at a particular instant of time, independent of the reference frame. Which we may use to described it.
- A collision between two particles, an explosion of bomb or star and a sudden flash of light are the examples of event.
- ***Oserver* :** An observer is a person or equipment meant to observe and take measurement about the event. The observer is supposed to have with him scale, clock and other needful things to observe that event.

FRAME OF REFERENCE (INERTIAL AND NON-INERTIAL FRAMES OF REFERENCE):

- An object, either at rest or in motion, can be located with reference to some co-ordinate system called the frame of reference.
- A frame of reference is any coordinate system. For example in Cartesian coordinate system the frame S is denoted by S[O-XYZ] as shown in Figure (a).

- If the coordinates [x, y, z] of all points of a body do not change with respect to time and frame of reference, the body is said to be at rest.

Fig. (a)

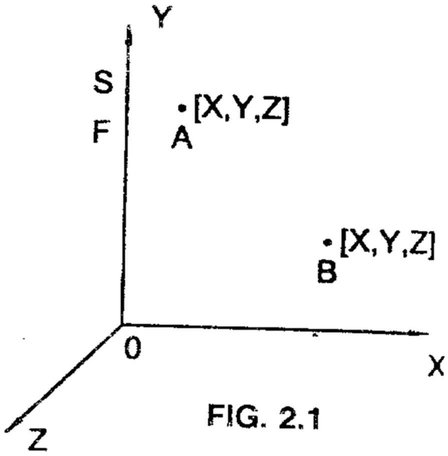


FIG. 2.1

Fig. (b)

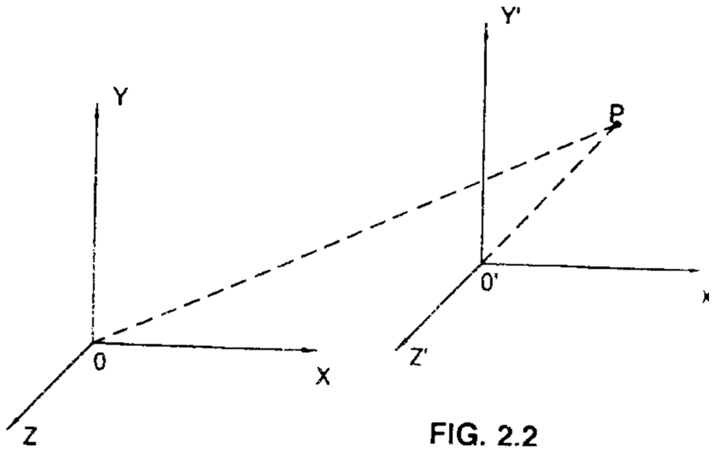


FIG. 2.2

- If the coordinates of a point of the body change with time and with respect to the frame of reference, the body is said to be in motion.

- As shown in the figure (a), consider a body at point A having coordinates [x, y, z] in the frame of reference S. If the body always remains at A, it will be at rest relative to the frame of reference S. But if it moves to point B having coordinates [x_1, y_1, z_1], in certain time duration, then it is said to be in motion relative to the frame of reference S.

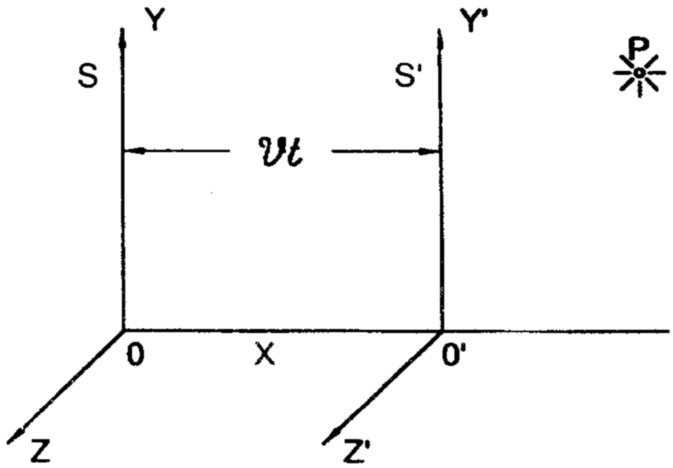
- Suppose motion of the particle is observed by observers O and O' as shown in Figure (b). If O and O' are at rest with respect to each other, they will observe the same motion of P. But if O and O' are in relative motion their observation of motion of P would certainly differ.

- Any object can be located or any event can be described using a coordinate system. This coordinate system is called the ***Frame of Reference***.

- ***Inertial Frame*** **:** An inertial frame is defined as a reference frame in which the law of inertia holds true. i.e. Newton's first law. Such a frame is also called un-accelerated frame. e.g. a distant star can be selected as slandered inertial frame of reference.

- ***Non-inertial Frame*:** It is defined a set of coordinates moving with acceleration relative to some other frame in which the law of inertia does not hold true. It is an accelerated frame. e.g., applications of brakes to a moving train makes it an accelerated(decelerated) frame. So it becomes a non-inertial frame.

GALILEAN TRANSFORMATION EQUATIONS



- As shown in the figure consider two inertial reference frames S[O-XYZ] and S'[O'-X'Y'Z'].
- At time t = 0, O and O' coincide with each other.
- Suppose S' frame with observer O' moves with the velocity v along positive X-axis.
- Some event occurs at a point P whose space coordinates and time coordinates are recorded by both the observers in their respective inertial frames.

- The observes O in S frame of reference records coordinates (x,y,z) and time t for the event P is S – frame.

- The observer O' in S' frame of reference records coordinates (x',y',z') and time t' for the same event at P in S' - frame.

- According to classical physics, motion does not affect the length so we have

$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

- Also according to the concept of absolute nature or universal nature of time we have

$$t' = t$$

- Then the following set of equations

$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

$$t' = t$$

is called the Galilean transformation equations.

LUMINIFEROUS ETHER

- The electromagnetic wave theory of light established the fact that light waves are transverse waves and can be polarized.

- Since transverse waves require some medium for propagation, it was assumed that light propagates through a medium called ***Ether***.
- Maxwell put forward the idea of ether with following **properties** :

  (1) The space in the entire universe is filled up with the medium called ether, which is **difficult to conceive**.
  (2) It possesses **zero density** and **perfectly transparent**.
  (3) It possesses very **high elasticity**.
  (4) **Penetrates** all the **matter** and **fills** the whole **space**.

EINSTEIN'S SPECIAL THEORY OF RELATIVITY

- Einstein proposed the special theory of relativity in 1905. This theory deals with the problems of mechanics in which one frame moves with constant velocity relative to the other frame.
- The **two postulates** of the **Special Theory of Relativity** are :

1. The laws of physics are the same in all inertial systems. No preferred inertial system exists.
2. The speed of light(c) in free space has the same value in all the inertial systems.

MICHELSON-MORLEY EXPERIMENT

- Michelson and Morley performed experiment during 1881-1887 to detect the luminiferous ether.

- A parallel beam of monochromatic light is divided into two parts by half silvered plate A. One portion of light beam travels towards M_1 and is reflected back to A. The other refracted portion of light travels to towards M_2 and is also reflected back to A.

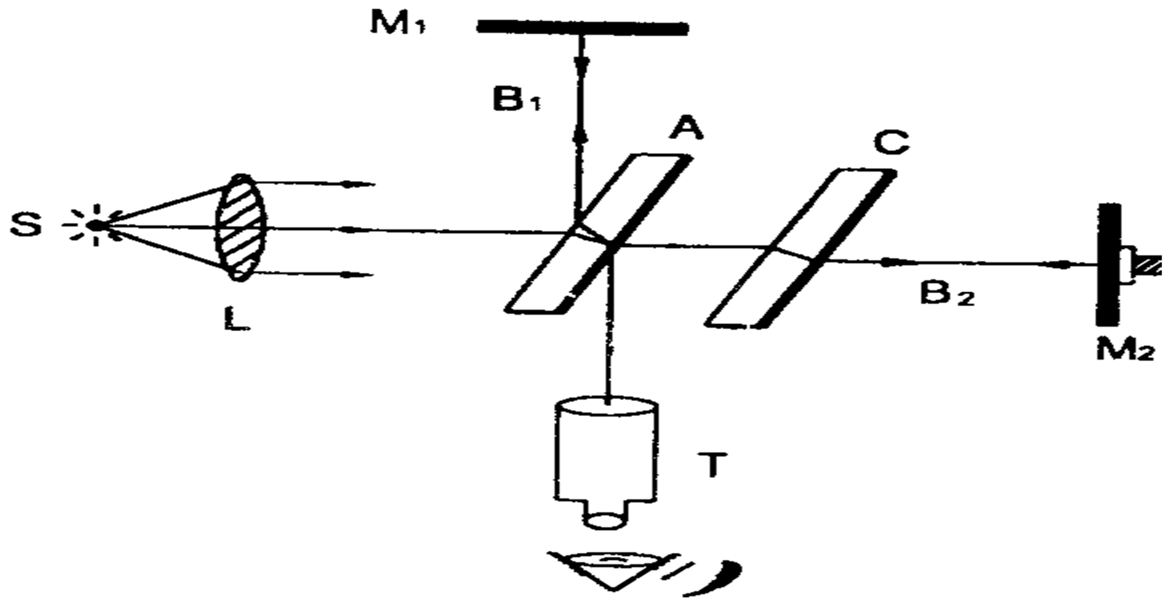
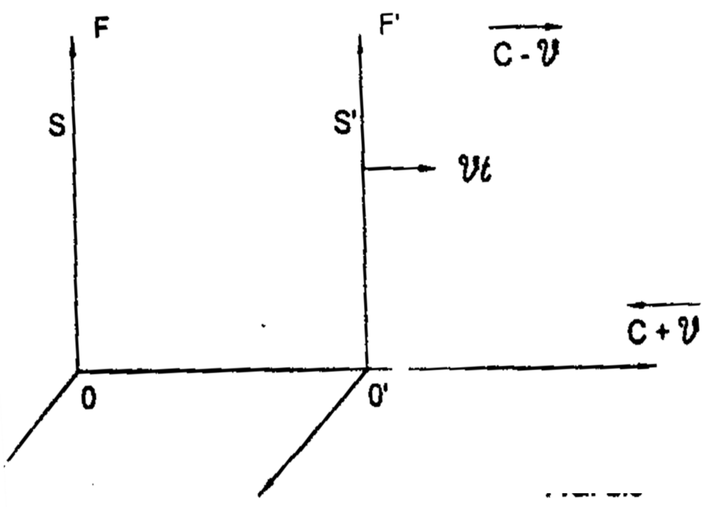


Fig. (a)

- Both beams B_1 and B_2 interfere with each other and the interference fringes formed can be viewed by the telescope. It is arranged to move along the direction of the earth's orbit round the sun. The speed of apparatus is equal to the speed of earth v in its orbit.



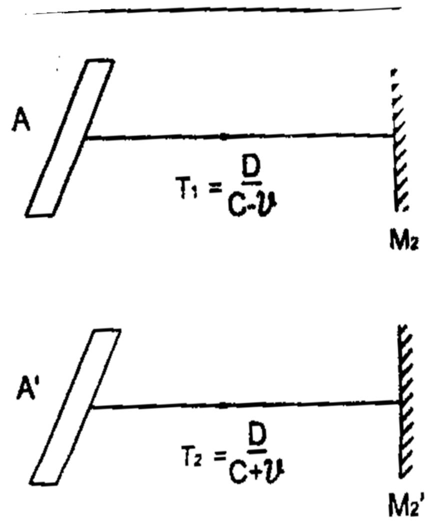


Fig. (b) **Fig. (c)**

- According to Galilean frame of reference, F is a fixed frame of reference corresponding to the ether medium. The speed of light relative to F is c. F' is the frame moving with speed v in the direction of the earth along with the interferometer around the sun.
- The velocity of light in the direction of frame F' is equal to (c – v) and in the opposite direction is equal to (c + v).
- Let T_1 be the time taken by light to travel AM_2 distance and T_2 be the time taken by light to travel $M_2'A'$ distance.

$$AM_2 = M_2{}'A = D$$

- Total time taken by light for its to and fro journey is

$$T = T_1 + T_1 \quad = \frac{D}{c-v} + \frac{D}{c+v}$$

Where the Velocity of light $c = \frac{D}{T}$

$$T = \frac{2Dc}{c^2 - v^2}$$

- The total distance traveled by the light in this time T is

$$x_1 = Tc = \frac{2Dc^2}{c^2 - v^2}$$

$$x_1 = 2D\left[1 - \frac{v^2}{c^2}\right]^{-1}$$

- Simplifying we get

$$x_1 = 2D\left[1 + \frac{v^2}{c^2}\right]$$

- For B_1 part of the light the geometrical arrangement of the moving plate A and mirror M_1 is shown below in figure. Here mirror M_1 is shifted to M_1' and the plate A is shifted to P in time T'.

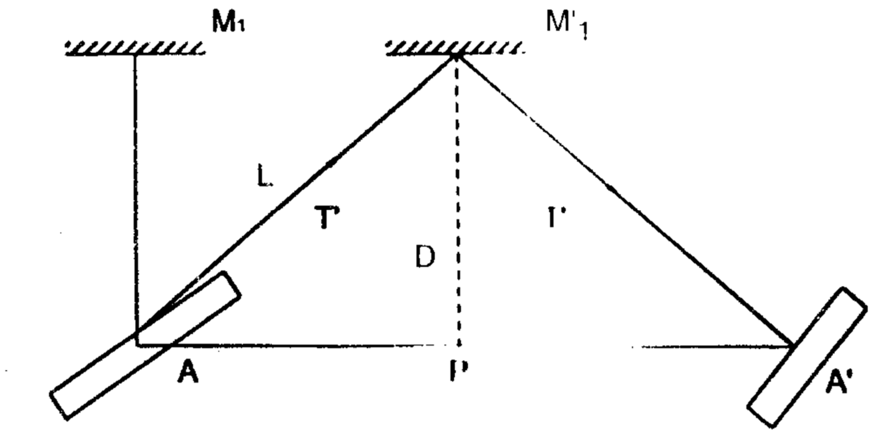


Fig. (d)

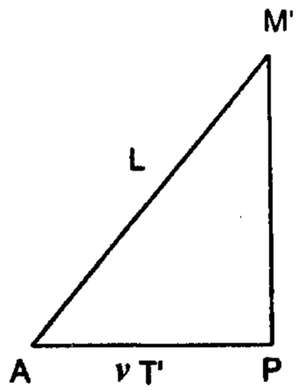


Fig. (e)

- Here

$$AP = vT'$$

$$But\ T' = \frac{L}{c} \qquad so\ AP = v\left(\frac{L}{c}\right)$$

- From Δ APM₁' We have $(AM_1')^2 = (M_1'P)^2 + (AP)^2$

$$L^2 = D^2 + \left(\frac{vL}{c}\right)^2$$

$$L^2 - \frac{v^2L^2}{c^2} = D^2$$

$$L^2\left[1 - \frac{v^2}{c^2}\right] = D^2$$

$$L^2 = \frac{D^2}{\left[1 - \frac{v^2}{c^2}\right]}$$

$$L^2 = D^2\left[1 - \frac{v^2}{c^2}\right]^{-1}$$

$$L = D\left[1 - \frac{v^2}{c^2}\right]^{-\frac{1}{2}}$$

- Simplifying we get

$$L = D\left[1 + \frac{1}{2}\frac{v^2}{c^2}\right]$$

- The total distance traveled by the light in time T for its journey from A to M_1' and back from M_1' to A is

$$x_2 = 2L = 2D\left[1 + \frac{1}{2}\frac{v^2}{c^2}\right]$$

- Then the path difference is

$$x_1 - x_2 = 2D\left[1 + \frac{v^2}{c^2}\right] - 2D\left[1 + \frac{1}{2}\frac{v^2}{c^2}\right]$$

$$x_1 - x_2 = \frac{Dv^2}{c^2}$$

- This equation gives path difference between two parts of the beams B_1 and B_2.

- If the apparatus is turned through 90^0, path difference should become (- $\frac{Dv^2}{c^2}$) and the corresponding value of the fringe shift should be about 0.4 of a finger width.

- When the same experiment was repeated at various locations and at different time it always yielded the same negative result that there was no change in the position of the fringes.

<u>Outcome (Conclusions) Of Michelson-Morley Experiment :</u>

- This result pointed out at the following two facts :

(1) The **velocity of light** is invariant and **remains constant** in all the directions. It is independent of the motion of source and the observer.

(2)The **ether does not exist** and if at all it exists, it is **undetectable**.

LORENTZ TRANSFORMATIONS

- Consider two frames of references A and B as shown in the Figure (a). As shown in the figure, A is fixed and B is moving along the direction of the X-axis with a constant velocity v.
- After time 't' the frame of reference B has moved a distance OO' = vt.
- For the point P in space the coordinates are (x, y, z) with reference to the frame A and (x', y', z') with reference to the frame B.

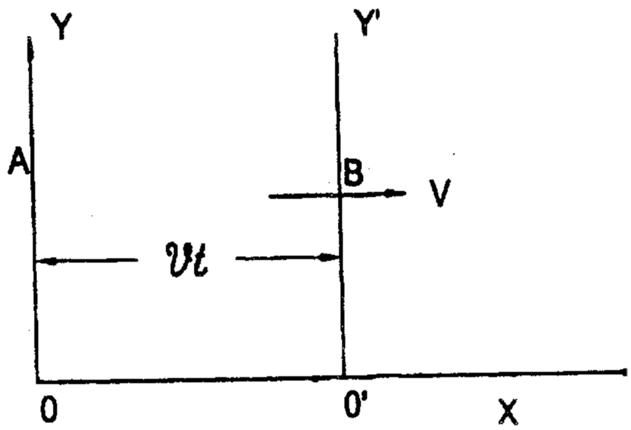


Fig. (a)

- According to Galilean transformation equations,

$$x' = x - vt$$

$$y' = y$$

$$z' = z$$

$$t' = t \qquad (1)$$

- Differentiating the (1) equation

$$\frac{dx'}{dt'} = \frac{dx}{dt} - v$$

$$c' = c - v$$

- This equation says if a person is moving in a spaceship the speed of the passing light will be $(c - v)$.
- But according to the postulates of the special theory of relativity the velocity of light remains constant in free space.

- This suggests that the Galilean transformations are not in accordance with the special theory of relativity. So the need for the new transformation equations is there.
- However, the equation $x' = x - vt$ is in accordance with the ordinary laws of mechanics. So the new transformation for the x coordinates must be similar to this equation. The simplest possible form of this can be

$$x' = k(x - vt) \qquad (2)$$

- Where k depends only on the value of v and doesn't depend upon the values of x and t. The above equation is linear and x' has only one value for given value of x.
- According to the first postulate of the special theory of relativity observation made in the frame of reference B must be identical to those made in A expect for a change in the sign of v and having the same value for the constant of proportionality k.

$$x = k(x' + vt') \qquad (3)$$

- Since the relative motion of A and B is combined to only x

$$y' = y$$

$$z' = z$$

$$t' = t$$

- The value of x' from equation (2) can be substituted in equation (3)

$$x = k\,[k(x - vt) + vt']$$

$$x = k^2(x - vt) + kvt'$$

$$kvt' = x - k^2(x - vt)$$

$$t' = \frac{x - k^2 x + k^2 vt}{kv}$$

$$t' = \frac{x - k^2 x}{kv} + \frac{k^2 vt}{kv} = \frac{x(1-k^2)}{kv} + \frac{k^2 vt}{kv}$$

$$t' = kt + \frac{x(1-k^2)}{kv} \qquad (4)$$

- To find the value k, consider two reference frames A and B. The spaceship in reference frame A measures the time t and the spaceship in reference frame B measure the time t'.

$$x = ct \qquad (5)$$

$$x' = ct' \qquad (6)$$

- Substituting the value of x' and t' from equations (2) and (4) in equation (6)

$$k(x - vt) = c\left[kt + \frac{x(1-k^2)}{kv}\right]$$

$$kx - kvt = c\,kt + cx\frac{(1-k^2)}{kv}$$

$$kx - cx\frac{(1-k^2)}{kv} = c\,kt + kvt$$

$$x\left[k - c\frac{(1-k^2)}{kv}\right] = c\,kt\left[1 + \frac{v}{c}\right]$$

$$x = \frac{c\,kt\left[1+\frac{v}{c}\right]}{\left[k - c\frac{(1-k^2)}{kv}\right]} = \frac{c\,kt\left[1+\frac{v}{c}\right]}{k\left[1-\frac{c}{v}\left(\frac{1}{k^2}-1\right)\right]}$$

$$x = c\,t\frac{\left[1+\frac{v}{c}\right]}{\left[1-\frac{c}{v}\left(\frac{1}{k^2}-1\right)\right]} \qquad (7)$$

- Then substituting the value of x from equation (5) into (7) we get

$$ct = c\,t\frac{\left[1+\frac{v}{c}\right]}{\left[1-\frac{c}{v}\left(\frac{1}{k^2}-1\right)\right]}$$

$$1 - \left(\frac{c}{v}\right)\left(\frac{1}{k^2} - 1\right) = 1 + \frac{v}{c}$$

$$-\left(\frac{c}{v}\right)\left(\frac{1}{k^2} - 1\right) = \frac{v}{c}$$

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

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

$$k^2 = \frac{1}{1 - \frac{v^2}{c^2}} \tag{8}$$

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

- The value of k when substituted in equation (2) we get

$$x' = k(x - vt)$$

$$\boldsymbol{x' = \frac{(x - vt)}{\sqrt{1 - \frac{v^2}{c^2}}}} \tag{9}$$

$$\boldsymbol{y' = y} \tag{10}$$

$$\boldsymbol{z' = z} \tag{11}$$

- Now we can rewrite the equation (4) as

$$t' = kt + \frac{x(1-k^2)}{kv} = kt + \frac{x}{kv} - k\left(\frac{x}{v}\right)$$

$$t' = kt + \frac{x}{kv} - k\frac{x}{v} = kt + \frac{x}{v}\left[\frac{1}{k} - k\right]$$

$$t' = kt + k\frac{x}{v}\left[\frac{1}{k^2} - 1\right]$$

$$t' = k\left[t + \frac{x}{v}\left[\frac{1}{k^2} - 1\right]\right] = \frac{t + \frac{x}{v}\left[1 - \frac{v^2}{c^2} - 1\right]}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- Then substituting the value of k and k^2 in above equation from equations (9) and (8), we get

$$t' = k\left[t + \frac{x}{v}\left[\frac{1}{k^2} - 1\right]\right] = \frac{t+\frac{x}{v}\left[1-\frac{v^2}{c^2}-1\right]}{\sqrt{1-\frac{v^2}{c^2}}}$$

t'

$$\boldsymbol{t' = \frac{t-\frac{xv}{c^2}}{\sqrt{1-\frac{v^2}{c^2}}}} \qquad (12)$$

- The equations (9), (10), (11) and (12) are called ***Lorentz transformation equations***.
- These equations give the conversions for the measurements of time and space made in the stationary frame A to B.
- The ***Inverse Lorentz transformation*** for measurements of space and time made in frame in B to A**.**

$$\boldsymbol{x = \frac{x'+vt'}{\sqrt{1-\frac{v^2}{c^2}}}} \qquad (13)$$

$$\boldsymbol{y' = y} \qquad (14)$$

$$\boldsymbol{z' = z} \qquad (15)$$

$$\boldsymbol{t = \frac{t'-\frac{vx'}{c^2}}{\sqrt{1-\frac{v^2}{c^2}}}} \qquad (16)$$

LORENTZ-FITZERALD CONTRACTION

- Measurement of space and time are not absolute but depend on the relative motion of the observer and the observed objects.
- Consider a rod of length L_o parallel to the X-axis and having co-ordinates x_1 and x_2 in the frame A.
- An observer in the reference frame A measures the length of the rod as $L_o = x_2 - x_1$.
- Also consider a second reference frame B moving with a velocity v along the x axis with respect to the reference frame A.
- An observer in the reference frame B measures the length of the rod as $L = x_2' - x_1'$.
- The relation between x_1 and x_1' and also between x_2 and x_2' according to the Inverse Lorentz Transformations will be

$$x_1 = \frac{x_1' + vt'}{\sqrt{1-\frac{v^2}{c^2}}} \quad x_1 = \frac{x_1' + vt'}{\sqrt{1-\frac{v^2}{c^2}}} \text{ and } x_1 = \frac{x_2' + vt'}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$L_o = x_2 - x_1$$

$$L_o = \frac{x_2' + vt'}{\sqrt{1-\frac{v^2}{c^2}}} - \frac{x_1' + vt'}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$L_o = \frac{x_2' - x_1'}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{L}{\sqrt{1-\frac{v^2}{c^2}}}$$

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

- This equation shows that the length of stationary object with respect to an observer in motion appears to be shorter than length measured by an observer at rest.

- Similarly when an object is in motion with respect to a stationary observer, again the object appears to be shortened in length.

- This relativistic result is true for both the cases, i.e whether object is in motion or the observer is in motion the object appears to be contracted or shortened in length. This phenomenon is called ***Lorentz-Fitzerald Constraction***.

- Lorentz –Fitzerald contraction is appreciable only when the velocity, v is comparable to the velocity of light c.

- Let consider a rod of length L moving with a velocity which is equal to 0.6c. Then its length as measured from another frame is given by L_0. Here we have $v = 0.6\,c$

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

$$\mathrm{L} = \mathrm{L_o}\sqrt{1 - 0.36}$$

$$\mathrm{L} = 0.8\ \mathrm{L_o}$$

The contraction in length = $\mathrm{L} - \mathrm{L_o} = 0.2\ \mathrm{L_o}$

- Instead if the velocity of the body is negligibly small as compared to c, the contraction the length is also negligible i.e., $\mathrm{L} = \mathrm{L_o}$

- Suppose $v = 0.01\,c$

$$\mathrm{L} = \mathrm{L_o}\sqrt{1 - (10)^{-4}}$$
$$\mathrm{L} = 0.9999\,\mathrm{L_o}$$

$$L = L_o$$

TIME DILATION

- According to the special theory of relativity the time intervals are also affected by the relative motion between two frames of references.
- Let's consider two frames of references A and B such that B is moving along x axis with respect to A with a constant velocity v. The duration of an event taking place at a point in space is measured from both the frames of references.
- The observers in both the frames measure the time instants of beginning of the event and then the time instants of the ending of the event.
- Suppose the event begins at time t_1 in frame A and at time t_1' in frame B. The event ends at time t_2 in frame A and at time t_2' in frame B. If the time interval measured in A is t and in B it is t_0, then we have

  $$t_0 = t_2' - t_1' \qquad (1)$$

  and

  $$t = t_2 - t_1 \qquad (2)$$

- Then according to the Lorentz transformation equation

$$t_1 = \frac{t_1' + \frac{x'v}{c^2}}{\sqrt{1 - v^2/c^2}} \quad \text{and} \quad t_2 = \frac{t_2' + \frac{x'v}{c^2}}{\sqrt{1 - v^2/c^2}} \qquad (3)$$

Then,

$$t = t_2 - t_1$$

$$= \frac{t_2' + \frac{x'v}{c^2}}{\sqrt{1 - v^2/c^2}} - \frac{t_1' + \frac{x'v}{c^2}}{\sqrt{1 - v^2/c^2}}$$

$$= \frac{t_2' - t_1'}{\sqrt{1 - v^2/c^2}}$$

$$\therefore\ t = \frac{t_0}{\sqrt{1 - v^2/c^2}} \qquad (4)$$

- Thus from equation (4) we can say that the interval of time t_0 measured in the moving frame B is smaller than that in stationary frame A.
- It shows that the moving clock appears to go slower than the stationary clock.
- So to a moving observer time appears to be expanded. This phenomenon is called Time Dilation.

MASS ENERGY EQUIVALENCE

- In relativity, work done by a force = $\int \vec{F}\ \overrightarrow{ds}$
- Relativistic kinetic energy k is given by

$$k = \int_{u=0}^{u=d} F\ ds = \int_{u=0}^{u=d} \frac{d}{dt}(mu)\frac{ds}{dt}\ dt$$

- Since $\frac{ds}{dt} = u$

$$k = \int_{u=0}^{u=d} u\frac{d}{dt}(mu)\ dt = \int_{u=0}^{u=d} u\, d(mu)$$

- Now, the relativistic mass formula is

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

$$m^2 = \frac{{m_0}^2}{\frac{c^2 - u^2}{c^2}}$$

$$m^2(c^2 - u^2) = {m_0}^2c^2$$

$$m^2c^2 - m^2u^2 = {m_0}^2c^2$$

- Taking differentiation on both sides

$$2mc^2dm - m^2 2udu - u^2 2mdm\ = 0$$

- Dividing the equation by 2m , we get

$$\frac{2mc^2dm}{2m} - \frac{m^2 2udu}{2m} - \frac{u^2 2mdm}{2m} = 0$$

$$\frac{2mc^2dm}{2m} = \frac{m^2 2udu}{2m} + \frac{u^2 2mdm}{2m}$$

$$u\,d\,(mu) = mu\,du + u^{\,2}dm = c^2 dm$$

$$k = \int_{u=0}^{u=d} u\,d(mu) = \int_{u=0}^{u=d} c^2 dm = c^2 \int_{u=0}^{u=d} dm \quad = mc^2 - m_0c^2$$

$$k = mc^2 - m_0c^2 = \frac{m_0}{\sqrt{1-\frac{u^2}{c^2}}}(c^2 - m_0c^2) = m_0c^2\left[\frac{1}{\sqrt{1-\frac{u^2}{c^2}}} - 1\right]$$

$$k = m_0c^2\left[\frac{1}{\sqrt{1-\frac{u^2}{c^2}}} - 1\right] = m_0c^2\left[\left(1-\frac{u^2}{c^2}\right)^{-\frac{1}{2}} - 1\right]$$

Using the Binomial expansion of u/c all get

$$k = m_0c^2\left[1 + \frac{1}{2}\left(\frac{u}{c}\right)^2 + \frac{3}{8}\left(\frac{u}{c}\right)^4 + \cdots \; - 1\right]$$

$$k = m_0c^2\left[1 + \frac{1}{2}\left(\frac{u}{c}\right)^2\right]$$

$$k = m_0c^2\,\frac{1}{2}\left(\frac{u}{c}\right)^2$$

$$k = \frac{1}{2}m_0u^2$$

- Which is the classical result obtained by neglecting higher order terms

$$E = m_0c^2 + \frac{1}{2}m_0u^2$$

- This equation represents the equivalence of mass and energy.

Energy Momentum Relation:

- If a body of mass m is moving with velocity v, its momentum, energy and mass are given by

$$p = mv,\ \ E = mc^2 \text{ and } m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$E^2 - c^2p^2 = m^2c^4 - m^2c^2v^2$$

$$E^2 - c^2p^2 = \frac{m_0c^2}{\sqrt{1-\frac{v^2}{c^2}}} - \frac{m_0c^2v^2}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$E^2 - c^2p^2 = \frac{{m_0}^2c^4}{\left[1-\frac{v^2}{c^2}\right]} - \frac{{m_0}^2c^2v^2}{\left[1-\frac{v^2}{c^2}\right]}$$

$$E^2 - c^2p^2 = \frac{{m_0}^2c^4\left[1-\frac{v^2}{c^2}\right]}{\left[1-\frac{v^2}{c^2}\right]}$$

$$E^2 - c^2p^2 = {m_0}^2c^4$$

$$E^2 = {m_0}^2c^4 + c^2p^2 \qquad \textbf{or} \qquad \mathrm{E} = \sqrt{\mathrm{m_0}^2\mathrm{c}^4 + \mathrm{c}^2\mathrm{p}^2}$$

QUESTION BANK

MULTIPLE CHOICE QUESTIONS

(1) According to the special theory of relativity, something that happens at a particular point in space at a particular instant of time is called _____.

(a) Event (b) Phenomenon (c) Incident (d) Happening

(2) According to the special theory of relativity, a person or equipment meant to observe and take measurement about the event is called ____.

(a) supervisor **(b) observer** (c) examiner (d) invigilator

(3) A frame of reference is specified by a

(a) observer (b) decimal system
(c) coordinate system (d) metric system

(4) The frame of reference in which the law of inertia is satisfied is called ______ frame of reference.

(a) Einstein's (b) Newton's (c) non-inertial **(d) inertial**

(5) The frame of reference in which the law of inertia is **not** satisfied is called _____ frame of reference.

(a) Einstein's (b) Newton's **(c) non-inertial** (d) inertial

(6) A car moving with a constant velocity represents ____ frame of reference.

(a) Einstein's **(b) inertial** (c) non-inertial (d) Newton's

(7) The special theory of relativity deals with the motion of objects in _____frame of references.

(a) inertial (b) Newton's (c) Einstein's (d) non-inertial

(8) According to the special theory of relativity the speed of light is ____.

(a) zero **(b) constant** (c) infinite (d) not predictable

(9) Any object can be located or any event can be described using a coordinate system. This coordinate system is called _____.

(a) coordinate frame (b) reference system
(c) ***reference frame*** (d) coordinate frame

(10) Which one of the following is **NOT** a property of Ether?

(a) zero density (b) perfectly transparent

(c) high elasticity **(d) zero elasticity**

(11) The Special theory of relativity deals with problems of mechanics in which one frame moves with ____ velocity relative to the other frame

(a) greater (b) infinite **(c) constant** (d) lesser

(12) The Michelson-Morley experiment was performed to verify the presence of _____ .

(a) matter **(b) ether** (c) aliens (d) flying objects

(13) The Michelson-Morley experiment established the fact that the ether

(a) does not exist (b) exists

(c) is breakable (d) is unbreakable

(14) The Michelson-Morley experiment established the fact that the velocity of light is

(a) constant and dependent of the frame of reference

(b) constant and independent of the frame of reference

(c) variable and independent of the frame of reference

(d) variable and dependent of the frame of reference

(15) The instrument that was used in Michelson-Morley experiment was

(a) Jamin refractometer (b) Rayleigh refractometer

(c) Michelson's interferometer (d) Fabry-Perot interferometer

(16) The equations representing an event in one frame of reference can be transformed to other frame of reference using _____ equations.

(a) cosmological (b) continuity

(c) canonical **(d) transformation**

(17) In Galilean transformation acceleration is _____.

(a) variant (b) very high **(c) invariant** (d) infinite

(18) Lorentz transformations are converted into Galilean transformation for ____ particle.
(a) large mass **(b) Small velocity**
(c) large velocity (d) small mass

(19) According to the special theory of relativity a moving clock always go
(a) slow (b) down (c) up (d) fast

(20) The energy momentum relation in special theory of relativity is given by
(a) $E = \sqrt{m_0^2 c^4 + c^2 p^2}$ (b) $E = \sqrt{m_0^4 c^4 + c^4 p^4}$
(c) $E = \sqrt{m_0^2 c^4 - c^2 p^2}$ (d) $E = \sqrt{m_0 c^2 + c^2 p^2}$

SHORT QUESTIONS (TWO MARKS EACH)

1. Define : Event and Observer
2. Define : Inertial Frame of reference and Non-Inertial frame of reference.
3. Define : Frame of Reference and Ether.
4. Enlist the properties of ether.
5. Write a short note on luminiferous ether.
6. State the two postulates of Special Theory of Relativity.
7. Discuss the major conclusions of Michelson-Morley experiment.
8. Write the equations for the Galilean transformation equations.
9. Write the equations for the Lorentz transformation equations.
10. With the help of an example explain why Lorentz Fitzgerald length contraction is not applicable to the objects which are not moving with relativistic speed.

11. Derive the energy-momentum relationship for a particle moving at relativistic speed.

LONG QUESTIONS

1. Define frame of reference and discuss the inertial and non-inertial frames of references with the help of necessary diagrams. **(3)**
2. Discuss the Galilean transformation equations in detail. **(3/4)**
3. Explain the concept of luminiferous ether and state the postulates of theory of relativity. **(3)**
4. What is luminiferous ether? Discuss the Michelson-Morley experiment for the search of ether, derive the necessary equations and state its major conclusions. **(10/8)**
5. With the help of necessary diagram discuss the Michelson-Morley experiment and enlist its major outcomes. **(6/7)**
6. Explain the failure of Galilean transformation equations and derive the Lorentz transformation equation with the help of necessary diagrams and equations. **(8-10)**
7. Discuss the phenomenon of Lorentz-Fitzerald length contraction along with an example. **(6)**
8. Write a detailed note on Time Dilation. **(5)**
9. Explain why a moving clock (at a relativistic speed) appears to go slow. **(5)**
10. Derive the expression for the kinetic energy of a particle moving at relativistic speed and hence establish the relationship showing the equivalence of its mass and energy. **(5/6)**
11. Obtain the energy-momentum relationship for a particle moving at relativistic speed. **(3)**

Δ • Δ • Δ • Δ • Δ • Δ