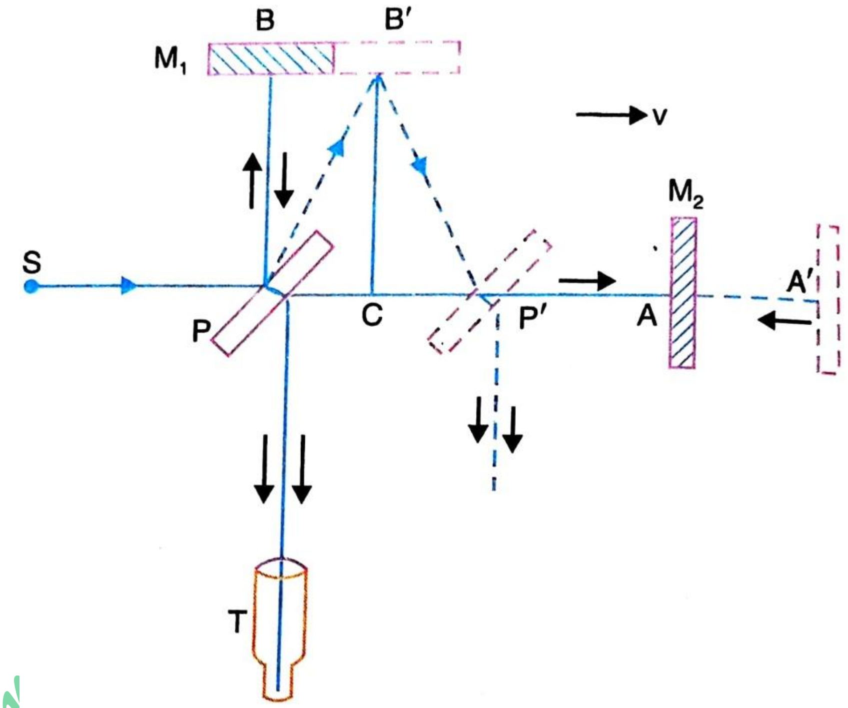
THEORY OF RELATIVITY

The Michelson-Morley Experiment:

A beam of light from a monochromatic source S falls on a half-silvered glass plat P, placed at an angle of 45^o to the beam. The incident beam is split up into two parts by P (below figure). The reflected portion travels in a direction at right angles to the incident beam, falls normally at B on the plane mirror M_1 and is reflected back to P. It gets refracted through P and enters the telescope T. The transmitted portion travels along the direction of the initial beam, falls normally on mirror M_2 at A and is reflected back to P. After reflection from the back surface of P, it enters the telescope T. The two reflected beams interfere and the interference fringes are viewed with the help of the telescope T. The beam reflected upwards to M_1 traverses the thickness of plate P thrice whereas the beam refracted on to mirror M_2 traverses P only once. The effective distance of the mirrors M_1 and M_2 from the plate P is made to be the same by the use of a compensating plate not shown in figure.



The whole apparatus was floating on mercury. One arm (PA) was pointed in the direction of earth's motion round the sun and the other (PB) was pointed perpendicular to this motion. The paths of the two beams and the positions of their reflections from M_1 and M_2 will be as shown by the dotted lines.

Assume that the velocity of the apparatus (or earth) relative to fixed ether is v in the direction PA. The relative velocity of a light ray travelling along PA is (c – v) while its value would be (c + v) for the returning ray. Let PA = PB =d.

Time taken by light to travel from P to A = d/(c – v)

Time taken by light to travel from A to P = d/(c + v)

∴ Total time taken by light to travel from P to A and back

$$\mathbf{t} = \frac{\mathbf{d}}{\mathbf{C - v}} + \frac{\mathbf{d}}{\mathbf{c + v}} = \frac{\mathbf{2cd}}{\mathbf{c^2 - v^2}} = \frac{\mathbf{2dc}}{\mathbf{c^2\left(1 - \frac{v^2}{c^2}\right)}} = \frac{\mathbf{2d}}{\mathbf{c\left(1 - \frac{v^2}{c^2}\right)}} = \frac{\mathbf{2d}}{\mathbf{c}}\left(\mathbf{1} - \frac{\mathbf{v^2}}{\mathbf{c^2}}\right)^{-1}$$

Expand by using Binomial theorem, neglecting all terms involving second and higher powers of $\frac{v^2}{c^2}$ we get

$$\mathbf{t} = \frac{2d}{c}\left(1 + \frac{v^2}{c^2}\right) \qquad \dots.(1)$$

Now, consider the ray moving upwards from P to B. It will strike the mirror M_1 not at B but at B' due to the motion of the earth. If t_1 is the time taken by the ray starting from P to reach M_1, then PB' = ct_1 and BB' = vt_1.

The total path of the ray until it returns to P = PB'P'.

Now PB'P' = PB' + B'P' = 2PB', since PB' = B'P'.

$$(PB)^2 = (PC)^2 + (CB)^2 = (BB)^2 + PB^2$$

i.e. $c^2v_1^2 = v^2t_1^2 + d^2$

$$\therefore \qquad t_1 = \frac{d}{\sqrt{c^2 - v^2}}$$

∴ Total time taken by the ray to travel the whole path PB'P'

$$\mathbf{t' = 2t_1} = \frac{\mathbf{2d}}{\sqrt{\mathbf{c^2 - v^2}}} = \frac{\mathbf{2d}}{\mathbf{c}\sqrt{\mathbf{1 - (v^2/c^2)}}} = \frac{\mathbf{2d}}{\mathbf{c}}\left(\mathbf{1} - \frac{\mathbf{v^2}}{\mathbf{c^2}}\right)^{-1/2}$$

Expand by using Binomial theorem, neglecting all terms involving second and higher powers of $\frac{v^2}{c^2}$ we get

$$t' = \frac{2d}{c}\left(1 + \frac{v^2}{2c^2}\right) \qquad \dots.(2)$$

Clearly, t' <t. The time difference

$$\Delta t = t - t' = \frac{2d}{c}\left(1 + \frac{v^2}{c^2}\right) - \frac{2d}{c}\left(1 + \frac{v^2}{2c^2}\right) = \frac{2d}{c}\ x\ \frac{v^2}{2c^2} = \frac{dv^2}{c^3}$$

The distance travelled by light in time $\Delta \mathbf{t} = \mathbf{c\ x\ \Delta t} = \frac{\mathbf{dv^2}}{\mathbf{c^2}}$

This is the path difference between the two parts of the incident beam. If the apparatus is turned through 90°, the path difference between the two beams becomes $\frac{\mathbf{dv^2}}{\mathbf{c^2}}$. Michelson and Morley expected a fringe shift of about 0.4 in their apparatus when it was rotated through 90°. But, in the experiment no displacement of the fringes was observed. This negative result suggests that it is impossible to measure the speed of the earth relative to the ether. Therefore, the effects of ether are undetectable. Thus, all attempts to make ether as a fixed frame of reference failed.

Interpretation to explain negative results:

- The earth might drag little ether along with it near its surface. To overcome this difficulty, the experiment was repeated in the mountain laboratory at suitable site projecting out of the drifting ether but no fringe shift could be detected.
- As the earth moves in different directions at different times of the year, the earth at the time of the experiment might be at rest relative to the ether. If it was so, the situation must change after six months. But the experiment at the same place at interval of six months again yielded null results.
- A brilliant suggestion to explain the negative results of the Michelson-Morley Experiment was given by Lorentz and Fitzgerald. They proposed that the dimensions of all material bodies get contracted by a factor $\sqrt{1-\frac{v^2}{c^2}}$ in a direction parallel to the relative velocity. In Michelson-Morley Experiment, the Fitzgerald contraction means that when the apparatus is in motion, the distance travelled by the beam PM_1 is not d but d$\sqrt{1-\frac{v^2}{c^2}}$. Substituting this in equation (2) the t and t^1 are same, thus observing no fringe shift.
- The proper explanation for negative result of the Michelson-Morley Experiment was given by Einstein. He concluded that the velocity of light in free space is a universal constant.

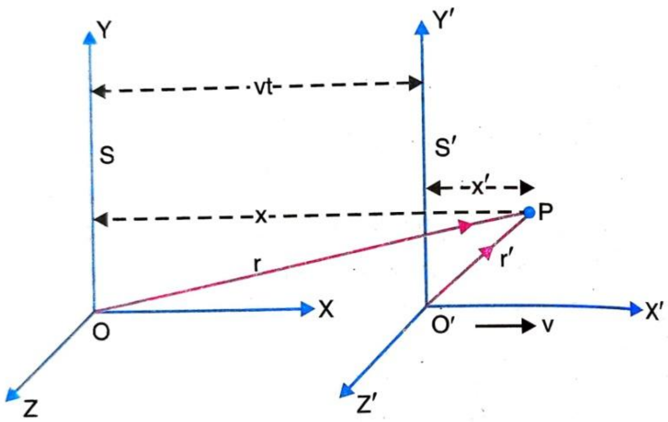
Postulates of special theory of relativity

1. ***The laws of Physics are same in all inertial frames of reference.***
2. ***The velocity of light in free space is constant. It is independent of the relative motion of the source and the observer.***

The Lorentz Transformation Equations:

We have to introduce new transformation equations which are consistent with the new concept of the invariance of light velocity in free space. The new transformation equations were discovered by Lorentz and are known as "**Lorentz transformations**".

Derivation: Consider two observers O and O^1 in two systems S and S^1. System S^1 is moving with a constant velocity v relative to system S along the positive X-axis. Suppose we make measurements of time from the instant when the origins of S and S^1 just coincide. i.e., t = 0 when O and O^1 coincide. Suppose a light pulse is emitted when O and O^1 coincide. The light pulse produced at t = 0 will



spread out as a growing sphere. The radius of the wave-front produced in this way will grow with speed c. After a time t, the observer O will note that the light has reached a point P(x, y, z) as shown in Figure. For him, the distance of point P is given by r = ct. From figure $r^2 = x^2 + y^2 + z^2$.

Hence, $$\mathbf{x^2 + y^2 + z^2. = c^2t^2} \qquad \textbf{.....(1)}$$

Similarly, the observer O' will note that the light has reached the same point P in a time t' with the same velocity c. So r' = ct'.

∴ $$\mathbf{x'^2 + y'^2 + z'^2. = c^2t'^2} \qquad \textbf{.....(2)}$$

Now, equations (1) and (2) must be equal since both the observers are at the centre of the same expanding wavefront.

∴ $$\mathbf{x^2 + y^2 + z^2 - c^2t^2 = x'^2 + y'^2 + z'^2 - c^2t'^2} \qquad \textbf{...(3)}$$

Since there is no motion in the Y and Z directions, y' = y and z' = z.

∴ Equation (3) becomes,

$$\mathbf{x^2 - c^2t^2 = x'^2 - c^2t'^2} \qquad \textbf{...(4)}$$

The transformation equation relating to x and x' can be written as

$$\mathbf{x' = k(x - vt)} \qquad \textbf{...(5)}$$

where k is a constant.

The reason for trying the above relation is that, the transformation must reduce to Galilean transformation for low speed (v<<c).

Similarly, let us assume that

$$\mathbf{t' = a(t - bx)} \qquad \textbf{...(6)}$$

where a and b are constants.

Substituting these values for x' and t' in equation (4), we have,

$$x^2 - c^2 t^2 = k^2 (x - vt)^2 - c^2 a^2 (t - bx)^2$$

$$\mathbf{i.e., x^2 - c^2t^2 = (k^2 - c^2a^2b^2)x^2 - 2(k^2v - c^2a^2b)xt - \left(a^2 - \frac{k^2v^2}{c^2}\right)c^2t^2} \qquad \textbf{......(7)}$$

Equating the coefficients of corresponding terms in equation (7),

$$k^2 - c^2a^2b^2 = 1 \qquad \ldots.(8)$$

$$k^2v - c^2a^2b = 0 \qquad \ldots.(9)$$

$$a^2 - \frac{k^2v^2}{c^2} = 1 \qquad \ldots.(10)$$

Solving the above equations for k, a and b, we get

$$\boldsymbol{k = a = \frac{1}{\sqrt{1-(v^2/c^2)}}} \qquad \ldots.(\mathbf{11}) \qquad \text{and} \qquad \boldsymbol{b = \frac{v}{c^2}} \qquad \textbf{.....(12)}$$

Substituting these values of k, a and b in (5) and (6) we have,

$$\mathbf{x' = \frac{x - vt}{\sqrt{1 - (v^2/c^2)}} \quad and \quad t' = \frac{t - (vx/c^2)}{\sqrt{1 - (v^2/c^2)}}}$$

Therefore, **the Lorentz transformation equations are**

$$x' = \frac{\mathbf{x - vt}}{\sqrt{\mathbf{1 - (v^2/c^2)}}}\ ;\ \mathbf{y' = y}\ ;\ \mathbf{z' = z} \qquad \text{and} \quad \mathbf{t'} = \frac{\mathbf{t - (vx/c^2)}}{\sqrt{\mathbf{1 - (v^2/c^2)}}} \qquad \ldots.(\mathbf{13})$$

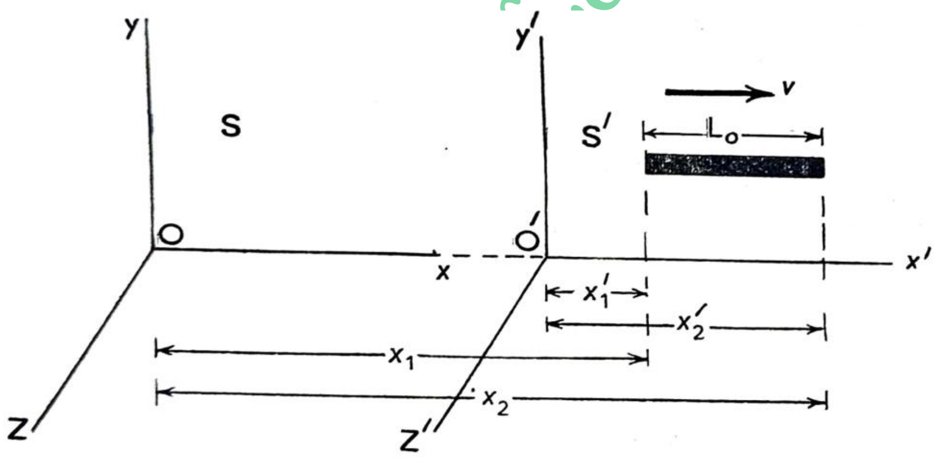
The inverse **Lorentz transformation equations** are obtained by interchanging the coordinates and replacing v by – v in the above.

$$\mathbf{x} = \frac{\mathbf{x' - vt'}}{\sqrt{\mathbf{1 - (v^2/c^2)}}}\ ;\quad \mathbf{y = y'}\ ;\quad \mathbf{z = z'}\ \text{and}\ \ \mathbf{t} = \frac{\mathbf{t' - (vx'/c^2)}}{\sqrt{\mathbf{1 - (v^2/c^2)}}} \qquad \ldots.(\mathbf{14})$$

These equations convert measurements made in frame S' into those in frame S.

The apparent length contraction:

As mentioned earlier, in order to explain the negative results of Michelson-Morley experiment, Fitzgerald had made an ad hoc assumption that the length of a body set into relative motion with a constant velocity v shortens in the direction of motion by the factor $\sqrt{1 - v^2/c^2}$. Fitzgerald contraction postulate easily follows from the theory of relativity. Let us again consider a reference frame S' moving with a constant velocity v relative to the frame S in the positive x-direction.



Let us consider a rod lying parallel to the X' axis in the moving frame S' and let its length as measured by an observer in S' be L_0 (figure). We propose to determine the length of the moving rod as it appears to an observer in S.

Since the rod is at rest with respect to the frame S', its ends have fixed coordinates such that

$$\mathbf{x'_2 - x'_1 = L_0} \quad \text{------------} \quad \mathbf{(1)}$$

Let the coordinates of the ends of the rod as measured by an observer in the reference frame S at exactly the same instant be x_1 and x_2 and L be the length of the rod as it appears to him. Then we have

$$\mathbf{x_2 - x_1 = L} \quad \text{--------------}\mathbf{(2)}$$

From Lorentz transformation equations,

$x_1{}' = \frac{\mathbf{x_1 - vt}}{\sqrt{\mathbf{1-(v^2/c^2)}}}$ **and** $x_2{}' = \frac{\mathbf{x_2 - vt}}{\sqrt{\mathbf{1-(v^2/c^2)}}}$ Substracting

$$x'_2 - x'_1 = \frac{\mathbf{x_2 - x_1}}{\sqrt{\mathbf{1-(v^2/c^2)}}}$$

$$L_0 = \frac{\mathbf{L}}{\sqrt{\mathbf{1-(v^2/c^2)}}} \quad \text{or}$$

$$\boldsymbol{L = L_0\sqrt{1 - v^2/c^2}} \quad \ldots\ldots\ (3)$$

Eq(3) shows that the length of an object in motion as measured by an observer appears to him to be shorter than when it is at rest with respect to him, this phenomenon being known as **Lorentz-Fitzgerald contraction.**

Time dilation: Apparent slowing of moving clocks.

Time intervals between two events are also affected by relative motion. Let us consider one of the reference frame S with origin O to be at rest and the other reference frame S$'$ with origin O$'$ moving relative to O with a uniform velocity v along the positive X-direction

Let us suppose that at a certain position x' in the moving frame S', a light flash is produced at time t'_1, and another flash is produced in the same position at time t'_2. The time interval between these events as measured by a clock in the frame S' is given by

$$\mathbf{t_0 = t'_2 - t'_1} \quad \text{--------------}\mathbf{(1)}$$

To an observer in S, let these two flashes appear to occur at t_1 and t_2. The time interval between the two flashes as measured by a clock in reference frame S is given by

$$\mathbf{t = t_2 - t_1} \quad \text{--------------}\mathbf{(2)}$$

From inverse Lorentz transformation, we have

$$t_1 = k\left(t_1' + \frac{v}{c^2}\,.x'\right)$$

and $$t_2 = k\left(t_2' + \frac{v}{c^2}\,.x'\right)$$

Subtracting, we have

$$(t_2 - \ \ t_1) = k(t_1' - t_2')$$

or $$t = kt_0$$

or $$\boldsymbol{t} = \frac{\boldsymbol{t_0}}{\sqrt{\mathbf{1}-\boldsymbol{v^2/c^2}}} \ \ldots\ldots\ldots\ldots(\mathbf{3}) \qquad \text{Since} \quad \boldsymbol{k} = \frac{\mathbf{1}}{\sqrt{\mathbf{1}-\boldsymbol{v^2/c^2}}}$$

Which shows that $t > t_0$. Eq. (3) shows that a stationary clock measures a longer time interval between two events occurring in a moving frame than that measured by a clock placed in a moving frame. In other words, a clock moving with respect to an observer appears to him to run slower than it does when at rest with respect to him. This effect is called **time dilation**.

Relativity of Simultaneity: Consider two events –explosion of a pair of time bombs-that occur at the same time t_o for an observer O in a reference frame S. Let the two events occur at different locations x_1 and x_2. Consider another observer O^1in S^1 moving with a uniform relative speed v with respect to S in the positive X- direction.

To O^1, the explosion at x_1 and t_0 occurs at the time $\quad t_1^1 = \frac{t_0 - (\frac{v}{c^2})x_1}{\sqrt{1-v^2/c^2}}$

and the explosion at x_2 and t_0 occurs at the time $\quad t_2^1 = \frac{t_0 - (\frac{v}{c^2})x_2}{\sqrt{1-v^2/c^2}}$

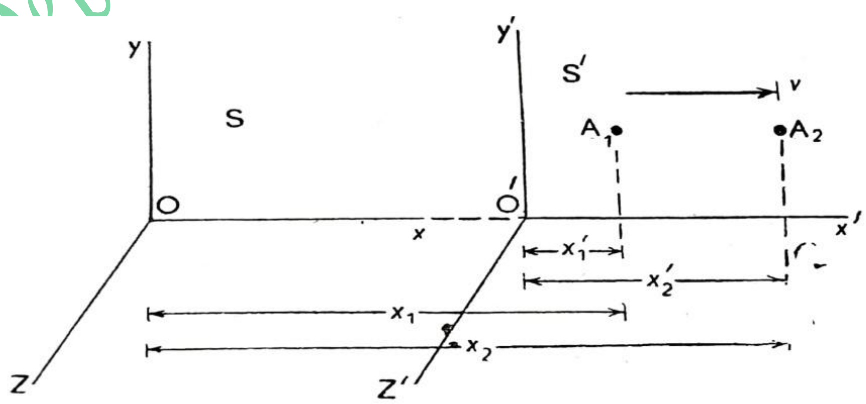
∴ The time interval between the two events as observed by the observer O^1

$$= t^1 = t_2^1 - t_1^1 = \frac{(x_2 - x_1)\left(\frac{v}{c^2}\right)}{\sqrt{1 - v^2/c^2}}$$

This is not zero. This indicates that two events at x_1 and x_2, which are simultaneous to the observer in S, do not appear so to the observer in S^1. Therefore, the concept of simultaneity has only a relative and not an absolute meaning**.**

The relativistic velocity transformation (Velocity Addition Theorem):

The Lorentz space time transformation equation easily enables us to transform the velocity from one frame of reference to another. Let us consider one of the reference frame S with origin O to be at rest and the other reference frame S' with origin O' moving relative to O with a uniform velocity v along the positive X-direction



Let us consider an object, like a bird in flight also moving along the positive direction of X-axis. Suppose that the observer at O in the reference frame S finds the bird flying from the position A_1 at the time t_1 to the position A_2 at time $t_2$where as the observer O in the frame S' finds the same bird flying from the position A_1 at time t'_1 to the position A_2 at time t'_2. Let the coordinates of A_1 and A_2 with respect to O be x_1 and x_2 and those with respect to O' be x'_1 and x'_2. If u and u' are the velocities of the birds with reference to the observers at O and O' respectively, we evidently have

$$u = \frac{(x_2 - x_1)}{(t_2 - t_1)} \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

and $$u' = \frac{(x'_2 - x'_1)}{(t'_2 - t'_1)} \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

Expressing u' in terms of the quantities relative to the frame S by using Lorentz transformation equations, we have

$$u' = \frac{k(x_2 - vt_1) - k\,(x_1 - vt_1)}{k\left(t_2 - \frac{vx_2}{c^2}\right) - k\left(t_1 - \frac{vx_1}{c^2}\right)}$$

$$= \frac{(x_2 - x_1) - (t_2 - t_1)v}{(t_2 - t_1) - (x_2 - x_1)v/c^2}$$

Divided throughout by $(t_2 - t_1)$, we have

$$u' = \frac{\left[\frac{(x_2 - x_1)}{(t_2 - t_1)}\right] - v}{1 - \left[\frac{(x_2 - x_1)}{(t_2 - t_1)}\right] v/c^2} \quad \textbf{or} \quad \boldsymbol{u' = \frac{u - v}{1 - (uv/c^2)}} \qquad \ldots\ldots. (3)$$

The inverse velocity transformation equation can be obtained by changing the sign of v as before. We thus have $$\boldsymbol{u = \frac{u' + v}{1 + \left(\frac{u'v}{c^2}\right)}} \qquad \ldots\ldots\ldots\ldots (\mathbf{4})$$

Variation of mass with velocity

Another very significant result of theory of relativity is that a mass of a body does not remain constant but varies with its velocity. The mass transformation formula can be derived by considering the following speculative experiment involving the collision between the two bodies.

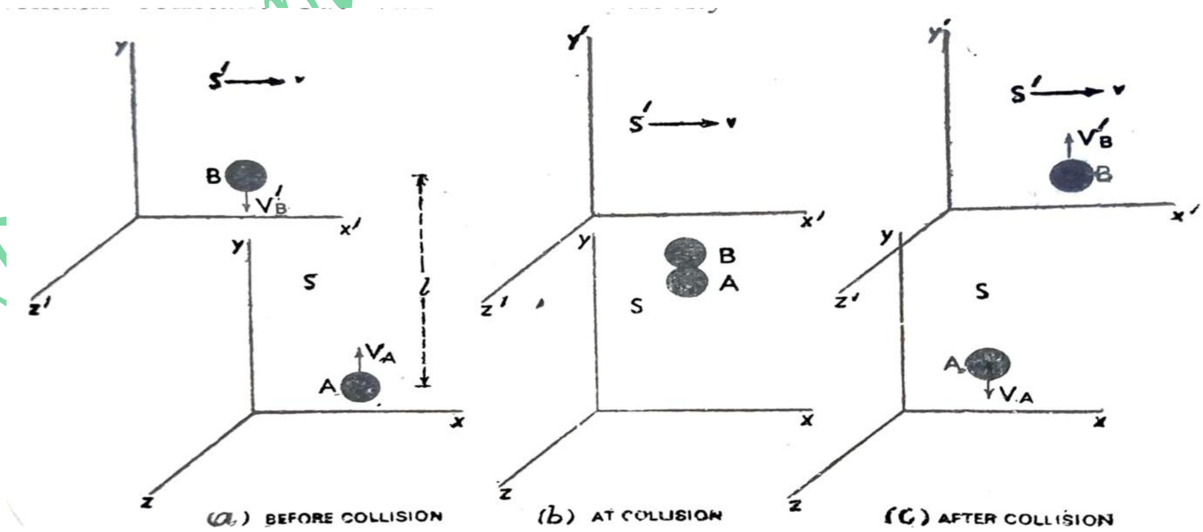


Figure (1)

Consider two frames of reference S and S^1, S is at rest and S^1 is moving with a constant velocity v relative to S. Let us consider an elastic collision (A collision in which both momentum and K.E remain conserved) between two exactly identical balls A & B as seen by observer in two frames. Suppose that the moving frame S^1 not yet passed the frame S and the ball A is thrown along +y direction and B along –y direction with same velocity (Fig 1a). let the time of thrown is such that the two balls collides exactly when the two observers are opposite to each other (Fig 1b) and then bounce back to move in opposite directions (fig 1c).The apparent motion of ball B as it appears to the observer in the frame S and vice versa are shown separately in figure (2a) and (2b).

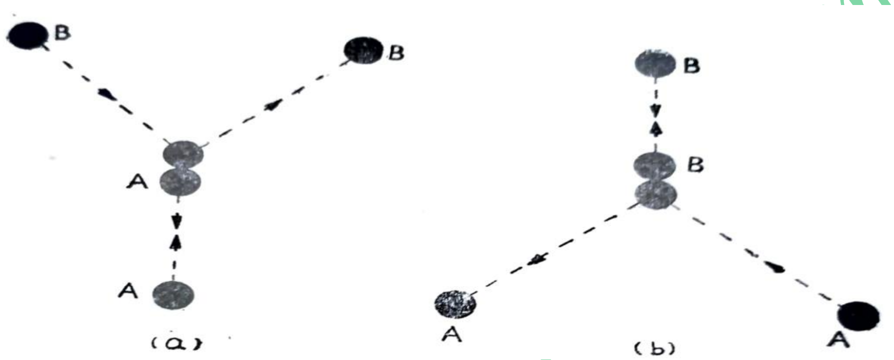


Figure (2)

Let the velocity of ball A in the + y direction relative to the frame S be V_A and the velocity of ball B in the - y direction relative to the frame S^1 be V_B^1. As assumed above $V_A = V_B^1$. The behavior of A as seen from S is exactly the same as the behavior of B as seen from S^1. After collision, A rebounds along –y direction with velocity V_A relative to S whereas B rebounds along +y direction with velocity V_B^1 relative to S^1. Let l be the initial distance along y axis between the balls when they were thrown. An observer in S finds that the collision to occur at $y = \frac{l}{2}$ and that in S^1 finds it to occur at $y^1 = \frac{l}{2}$

The round trip time t_0 for ball A as measured in the frame S is given by

$$t_0 = \frac{l}{V_A} \qquad \text{---------------------------- (1)}$$

The same is the round trip time for ball B as measured in the frame S^1 I, e

$$t_0 = \frac{l}{V_B^1} \qquad \text{----------------------------(2)}$$

Let m_A and m_B be the masses of the two balls A and B as measured by the observer in the frame S. Further, letr V_B be the velocity of ball B as it appears to an observer in S.

The change in momentum of the ball A relative to the observer in S = 2 $m_A V_A$

Similarly, the change in momentum of the ball B also relative to the observer in S = 2 $m_B V_B$

Since momentum must remain constant

$$2\, m_A V_A = 2\, m_B V_B \quad \text{Or} \quad \frac{V_B}{V_A} = \frac{m_A}{m_B} \text{ -----------------(3)}$$

Further, let the observer in S finds that the ball B completing its round trip in time't' which for observer in S^1 is t_0.

$$V_B = \frac{l}{t}$$

But according to time transformation formula,

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

$$\therefore\ V_B = \frac{l}{t_0}\sqrt{1-\frac{v^2}{c^2}}$$

$$V_B = V_A\sqrt{1-\frac{v^2}{c^2}} \qquad \left(\text{Since } \frac{l}{t_0} = V_A\right)$$

$$\therefore \quad \frac{V_B}{V_A} = \sqrt{1-\frac{v^2}{c^2}} \quad \text{---------- ---- (4)}$$

Equating equations (3) and (4)

$$\frac{m_A}{m_B} = \sqrt{1-\frac{v^2}{c^2}} \quad \text{Or}$$

$$\mathbf{m_A = m_B\sqrt{1-\frac{v^2}{c^2}}} \text{ -------------------(5)}$$

As said above, m_A is the mass of the ball A relative to the observer in S and m_B is mass of an exactly identical ball B placed in the moving frame S^1 and measured by the observer in S. If therefore, the measurements are made relative to frame S : m_A can be replaced by m_0 (**called the rest mass** of the ball) and m_B can be replaced by m (**called the relativistic mass**) , Thus

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

$$\text{or} \quad \boldsymbol{m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}}$$

EINSTEIN'S MASS ENERGY RELATIONSHIP

As we know, the kinetic energy of a body is measured by the amount of work done to accelerate the body from its state of rest to required state of motion with velocity v. If a force F acting on a body displaces it through a small distance dx along its direction of application, then

The work done by the force = F.dx , which is stored in the body as its kinetic energy dE_k Thus,

$$\mathbf{dE_k = F.dx} \quad \dots\dots\dots\dots..(1)$$

From Newton's second law of motion, the force equals to rate of change of momentum, I,e

$$F = \frac{d(mv)}{dt} \qquad \text{since both m and v are variable ,we have}$$

$$\boldsymbol{F = m.\frac{dv}{dt} + v.\frac{dm}{dt}}$$

Substituting this in equation (1) ,we have

$$dE_k = \left(m.\frac{dv}{dt} + v.\frac{dm}{dt}\right).dx$$

$$= m\left(\frac{dx}{dt}\right)dv + v(\frac{dx}{dt}).dm$$

$$dE_k = mvdv + v^2dm \qquad since \quad \frac{dx}{dt} = v$$

Now according to mass transformation equation.

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \qquad \text{Squaring on both sides} \qquad m^2 = \frac{m_0^2c^2}{c^2 - v^2}$$

$$m^2c^2 = m^2v^2 + m_0^2c^2 \qquad \dots\dots\dots\dots\dots\dots.(3)$$

Differentiating equation (3) and noting that both m_0 and c are constant, we have

$$2mdmc^2 = 2mdmv^2 + 2m^2vdv$$

$$c^2\,dm = mvdv + v^2dm \qquad .\dots\dots\dots(4)$$

Compare equations (2) and (4) we have

$$dE_k = c^2\,dm \qquad \dots\dots\dots\dots\dots\dots(5)$$

If mass of the body changes from m_0 to m and the corresponding change in kinetic energy is E_k

we have on integration $\int_0^{E_k} dE_{k} = c^2 \int_{m_0}^{m} dm$

$$E_k = (m - m_0)c^2 \qquad \textbf{Or}$$

$$E_k = (\Delta m)c^2 \dots\dots\dots\dots\dots\dots\dots(6)$$

Where Δm is the increase in mass.

Equation (6) shows that the K.E of the moving body is equal to the increase in mass as a result of its relative motion multiplied by square of the speed of light. Due to high value of c^2 (ie $9\text{x}10^{16}\text{ms}^{-1}$) even a small Δm is equivalent to a large amount of energy.

The mass m_0 is often termed as **rest mass** of the body and the term m_0c^2as **rest mass energy** of the body. This rest mass energy is regarded as a form of internal energy inherent in the nature of the particles constituting the matter.

Since the total energy possessed by a moving body is the sum of the kinetic energy due to its motion and energy stored as internal energy (rest mass energy) , we have

$$E = E_k + m_0\,c^2 = (m - m_0)c^2 + m_0\,c^2 = mc^2 + m_0\,c^2 + m_0\,c^2$$

$$E = mc^2$$

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