37

Special Theory of Relativity

BRIEF REVIEW

Michelson–Morley experiment discarded the ether theory. Thus, it was established that no medium is required for light or *em* waves to propagate in the space.

A body at rest on the earth's surface is not really in an inertial frame because it is accelerated due to earth's rotation about its axis and revolution about the sun.

Einstein's postulates

1. The laws of physics are same in every inertial frame of reference.
2. The speed of light in vacuum is the same in all inertial frames of reference and is independent of motion of the source. The speed of light in free space is c.

Einstein's 2nd Postulate implies It is impossible for an inertial observer to travel at c, the speed of light in vacuum.

Gallilean Transformation If s and s' be two frames of reference with s' moving with a velocity v along positive x-direction with respect to s then co-ordinates of an event (x, y, z, t) in s frame are related to the co-ordinates (x', y', z', t') of the same event in s' frame as

$x' = x - vt, y = y', z = z', t = t'$

These transformations violate both the postulates of special theory of relativity.

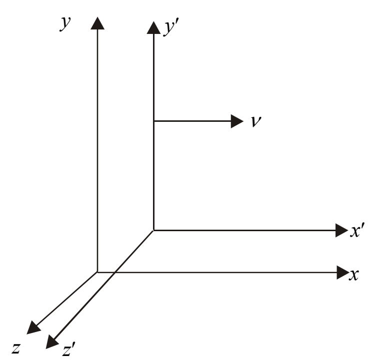

Fig. 37.1

Relativity of Simultaneity Whether or not two events at different x-axis locations are simultaneous depends on the state of motion of the observer. That is, time interval between two events may be different in differnet frames of reference.

Proper time is the time interval between two events that occur at the same point.

Lorentz Transformation

$$x' = \frac{x - vt}{\sqrt{1-\frac{v^2}{c^2}}}\ ; \qquad x = \frac{x' - vt'}{\sqrt{1-\frac{v^2}{c^2}}}\ ;$$

$$y' = y, z' = z$$

$$t' = \frac{t - \frac{v}{c^2}x}{\sqrt{1-\frac{v^2}{c^2}}}\ ; \qquad t = \frac{t' + \frac{v}{c^2}x'}{\sqrt{1-\frac{v^2}{c^2}}}$$

Length contraction $L = L_o\sqrt{1-\frac{v^2}{c^2}}$ where L_o is original length.

Mass variation $m^* = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$ where m_o is rest mass.

Time dilation $t = \frac{\tau}{\sqrt{1-\frac{v^2}{c^2}}}$, i.e., a moving clock appears to run slow. The time interval t appears to be lengthened or dilated.

Relative Velocity $V_{rel} = \frac{u-v}{1-\frac{uv}{c^2}}$

$$KE = mc^2 - m_o c^2 = m_o c^2\left[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right]$$

Relativistic momentum $p = mv = \frac{m_o v}{\sqrt{1-\frac{v^2}{c^2}}}$

Relativistic force $F = \frac{dp}{dt} = \frac{ma}{\left(1-\frac{v^2}{c^2}\right)^{3/2}}$ ($\vec{F}$ and $\vec{v}$ act along same line).

Relation between momentum and total energy

$E^2 = m_o^2 c^4 + p^2 c^2$

Doppler effect $f = \sqrt{\frac{c-v}{c+v}}\, f_o$ when the source is receding.

$$v = \frac{\left(f/f_o\right)^2 - 1}{\left(f/f_o\right)^2 + 1}\, c$$

or $f = \sqrt{\frac{c+v}{c-v}}\, f_o$ when the source is approaching.

If v is extremely small, then, $\frac{\Delta f}{f} = \frac{v}{c}$.

Cerenkov radiation travels with speed $> c$. Tachyons are hypothetical particles assumed to travel with a speed $> c$.

SHORT CUTS AND POINTS TO NOTE

1. **Proper frame:** It is common practice to speak of the frame in which the object is at rest as proper frame of the object. The length of the object in this frame is called proper length. The time as measured by the clock attached to this frame is called proper time. Proper time interval may be regarded as the time interval between two events occuring at the same point in s' frame or the time interval as measured by a single clock situated at the same point in s' frame.

   Lorentz transformation supports the postulates of special theory of relativity. According to this transformation, length contraction occurs if the body tries to move with a speed comparable to speed of light.

2. $L = L_o\sqrt{1-\frac{v^2}{c^2}}$; $L \to 0$ as $v \to c$

3. Time dilation $t = \frac{\tau}{\sqrt{1-\frac{v^2}{c^2}}}$

   if $v \to c, t \to \infty$ and $z \to 0$

4. At high speeds mass varies as $m^* = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$

   when $v \to c$, $m^* \to \infty$

5. Law of conservation of momentum is valid in special theory of relativity.

6. Relativistic momentum $p = mv = \frac{m_o v}{\sqrt{1-\frac{v^2}{c^2}}}$.

7. Force $F = \frac{d}{dt}(p) = \frac{d}{dt}\frac{m_o v}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{m_o v}{\left(1-\frac{v^2}{c^2}\right)^{3/2}}$ $\vec{F}$ and $\vec{v}$ act and along same direction.

   $a = \frac{F}{m}\left(1-\frac{v^2}{c^2}\right)^{3/2}$ Note that as speed increases a decreases and if $v \to c$, $a \to 0$

8. $KE = mc^2 - m_o c^2$

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

9. **Relative Velocity** $v_{rel} = \dfrac{u-v}{1-\dfrac{vu}{c^2}}$

10. Relativistic relation between total energy E and momentum p

$E^2 = m_o^{\,2} c^4 + p^2 c^2$

11. Relativistic relation between KE and momentum

$$KE = m_o c^2 \left[1 + \frac{p^2}{m_o^2 c^2} - 1 \right]$$

(xii) Doppler effect $f = f_o \sqrt{\dfrac{c-v}{c+v}}$ when source is receding

and $f = f_o \sqrt{\dfrac{c+v}{c-v}}$ when the source is approaching.

CAUTION

1. Considering that relativistic mechanics or special theory of relativity can be applied when a particle/body is moving with c (speed of light).

⇒ Whenever velocity is high ($\geq 10^7\ ms^{-1}$) relativistic conditions hold true.

2. Considering that energy possessed by a body cannot exceed $m_o c^2$.

⇒ Particle can have energy > $m_o c^2$. But velocity will be less than c. At very large velocities ($v \to c$) mass increases as $m^* = \dfrac{m_o}{\sqrt{1-\dfrac{v^2}{c^2}}}$.

3. Considering when two photons are moving in opposite direction or two electrons are moving in opposite direction with 0.9 c, then relative velocity is 2c and 1.8c respectively.

⇒ Apply relativistic mechanics rule. Remember v can never exceed c according to Einstein theory of relativity. Some exceptions have been found Cerenkov radiations and some other travel with a speed around 1.1 or 1.2 c. However, not much work has been done on these radiations.

4. Considering 1 MeV electron has speed $\sqrt{2}\,c$.

⇒ As $v \to c$, $m \to m^* = \dfrac{m_o}{\sqrt{1-\dfrac{v^2}{c^2}}}$ and $v < c$. Therefore

apply the relation $m^* c^2 = m_o c^2 + KE$

Then, to find v use $m^* = \dfrac{m_o}{\sqrt{1-\dfrac{v^2}{c^2}}}$.

SOLVED PROBLEMS

1. An electron is moving opposite to an electric field of magnitude $E = 5 \times 10^5$ N/C. Find the magnitude of momentum and acceleration when speed is 0.99 c.

(a) 1.9×10^{-19} kg ms^{-1}, 7.3×10^{15} ms^{-2}.

(b) 1.9×10^{-19} kg ms^{-1}, $2.5 \times 10^{+14}$ ms^{-2}.

(c) 2.7×10^{-24} kg ms^{-1}, 2.5×10^{15} ms^{-2}.

(d) none of these.

Solution (b) $p = \dfrac{m_o v}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{9.1\times10^{-31}\times.99\times3\times10^8}{\sqrt{1-.98}}$

$= (7.07)(9.1 \times 10^{-23})\,2.97$

$= 1.9 \times 10^{-19}$ kg ms^{-1}

$$a = \frac{F}{m}\left(\sqrt{1-\frac{v^2}{c^2}}\right)^3 = \frac{qE}{m}(1-.98)^3$$

$$= \frac{1.6\times10^{-19}\times5\times10^5}{9.1\times10^{-31}} \times \sqrt{8\times10^{-6}}$$

$$= \frac{8\times10^{-14}}{9.1\times10^{-31}} \times 2\sqrt{2} \times 10^{-3} = 2.5 \times 10^{14}\ \text{ms}^{-2}$$

2. The blue light observed from a jet has a frequency 6.66×10^{14} Hz. In the reference frame of the jet its frequency is 5.55×10^{13} Hz. Find the speed of jet.

(a) 0.9 c (b) 0.932 c

(c) 0.945 c (d) 0.986 c

Solution (d) $v = \dfrac{\left(\dfrac{f}{f_o}\right)^2 - 1}{\left(\dfrac{f}{f_o}\right)^2 + 1}\, c = \dfrac{12^2-1}{12^2+1}\, c = 0.986\, c$

3. Spaceship moving with a speed 0.9 c with reference to earth fires a robot space probe in the direction of its motion. With a speed 0.7 c relative to the spaceship. Find the velocity of robot with respect to earth.

(a) 0.961 c (b) 0.938 c
(c) 0.964 c (d) 0.982 c

Solution (d) $v = \dfrac{0.7c + 0.9c}{1 + \dfrac{0.9 \times 0.7c^2}{c^2}} = 0.982\, c$

4. The observers on earth are 56.4 m apart. How far apart a crew on spaceship moving with 0.99 c will measure them to be ?

(a) 5.64 m (b) 7.96 m
(c) 16.2 m (d) 54.2 m

Solution (b) $l = l_o \sqrt{1 - \dfrac{v^2}{c^2}}$

$= (56.4)\ \sqrt{1 - (.99)^2}$

$= 56.4\ \sqrt{.02} = 7.96$ m

5. A student found $\dfrac{e}{m}$ using thomson method and found $\dfrac{2}{3}$ of the actual value. She claimed to commit no mistake. The possible reason of such a result is

(a) she did experiment wrong.
(b) she used quarks instead of electrons.
(c) She was telling a lie.
(d) The electron was moving with a speed 0.743 c.

Solution (d) $\dfrac{3}{2} m_o = \dfrac{m_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}$

or $1 - \dfrac{v^2}{c^2} = \dfrac{4}{9}$ or $v = \dfrac{\sqrt{5}c}{3}$

6. Two protons are moving in opposite direction with 0.8 c then, their relative velocity is

(a) 0.978 c. (b) 0.95 c.
(c) 1.28 c. (d) 1.6 c.

Solution (a) $v = \dfrac{.8c + .8c}{1 + (.8)(.8)} = \dfrac{1.6c}{1.64} = 0.978\, c$

7. Find the velocity of electron accelerated by 5 MV.

(a) 0.981 c (b) 0.99 c
(c) 0.996 c (d) 0.972 c

Solution (c) $E = \dfrac{mc^2}{\sqrt{1 - \dfrac{v^2}{c^2}}} = m_o c^2 + \text{eV}$

or $m^* c^2 = m_o c^2 + \text{eV} = (.51 + 5.0)$ MeV

$m^* = \dfrac{m_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ or $\dfrac{v^2}{c^2} = \dfrac{120}{121}$

or $v = 0.996\, c$

TYPICAL PROBLEMS

8. An alien spacecraft is flying overhead of a great distance as you stand in your backyard. You see its search light blink for 0.19 s. The officer in the spacecraft measures the search light is ON for 12 ms. Which is the proper time? At what speed the spacecraft is flying.

Solution The proper time is 0.19 s

using $t = \dfrac{\tau}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ or $\dfrac{\tau}{t} = \dfrac{12 \times 10^{-13}}{.19}$

$= \sqrt{1 - \dfrac{v^2}{c^2}} = \dfrac{12}{190} = \dfrac{6}{95}$.

$v^2 = \left(\dfrac{1.36}{9025}\right) c^2$ or $v = 0.998\, c$

9. By what minimum amount does the mass of 4 kg of ice increase when the ice melts at 0°C to form water at 0°C.

(a) 1.48×10^{-11} kg (b) 1.48×10^{-12} kg
(c) 1.48×10^{-10} kg (d) 1.48×10^{-13} kg

Solution (a) $\Delta m_o c^2 = E = mL$

$\Delta m_o = \dfrac{4 \times 10^3 \times 80 \times 4.2}{(3 \times 10^8)^2} = \dfrac{32 \times 4.2 \times 10^{-12}}{9}$

$= 1.48 \times 10^{-11}$ kg

10. Two particles created in a high energy accelerator move in opposite directions. The speed of one particle as measured in the lab is 0.65 c and their relative speed is 0.95 c. Find the speed of the other particle.

(a) 0.3 c (b) 0.652 c

(c) 0.784 c (d) 0.842 c

Solution (c) $0.95\,c = \dfrac{0.65c+u}{1+\dfrac{0.65cu}{c^2}}$ or $0.95\,c + 0.95\,(.65\,u)$

$= 0.65\,\text{c} + u\,0.30\,c = u\,(1-0.6175)$

or $u = \dfrac{0.30c}{0.3825} = 0.784\,c$

11. The average life time of pion (π^-) is $2.6 \times 10^{-8}\ s$ as measured in the proper frame and $4.2 \times 10^{-7}\ s$ in the laboratory frame. Find the speed of π^- and distance covered by π^- during its average life time.

(a) 0.95 c, 124 m (b) 0.996 c, 126 m

(c) 0.89 c, 108 m (d) 0.91 c, 114 m

Solution (b) $t = \dfrac{\tau}{\sqrt{1-\dfrac{v^2}{c^2}}}$ or $1 - \dfrac{v^2}{c^2} = \left(\dfrac{\tau}{t}\right)^2$ or

$$v = c\sqrt{1-\left(\frac{\tau}{t}\right)^2} = c\sqrt{1-\left(\frac{2.6\times10^{-8}}{4.2\times10^{-7}}\right)^2}$$

$= 0.996\ \text{c}$

$x = 0.996 \times 3 \times 10^8 \times 4.2 \times 10^{-7} = 126$ m

12. If KE Vs speed graph is plotted then which of the following is correct.

(a) 1 (b) 2

(c) 3 (d) 4

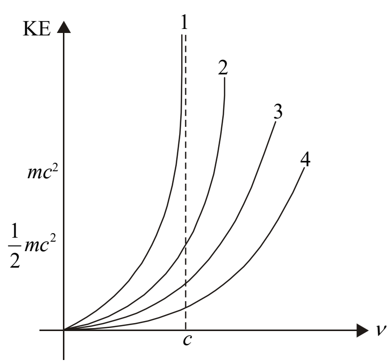

Fig. 37.2

Solution (a) KE can exceed mc^2 but velocity cannot exceed c.

13. Find the magnitude of the force to be given to a 0.145 kg base ball if it is moving with 0.9 c. Acceleration to be given is 1 ms^{-2}.

(a) 0.145 N (b) $2.4\sqrt{3}\ N$

(c) 12.72 N (d) 1.776 N

Solution (d) $F = \dfrac{ma}{\left(1-\dfrac{v^2}{c^2}\right)^{3/2}} = \dfrac{.145\times1}{(1-.81)^{3/2}} = 1.776$ N

14. How much work be done to increase the speed of a particle of mass m to increase from 0.9 c to 0.99 c?

Solution $K = \dfrac{mc^2}{\sqrt{1-\dfrac{v^2}{c^2}}} - mc^2,$

$$\Delta K = mc^2\left[\frac{1}{\sqrt{1-(.99)^2}} - \frac{1}{\sqrt{1-(.9)^2}}\right]$$

$$= mc^2\left[\frac{1}{\sqrt{.02}} - \frac{1}{\sqrt{.19}}\right] = mc^2\,[7.07-2.32]$$

$= 4.75\ mc^2$

PASSAGE 1

Read the following passage and answer the questions given at the end.

Relativity does not contradict the older mechanics but generalizes it. After all, Newton's law rest on a very solid base of experimental evidence, and it would be very strange indeed to advance a new theory in consistent, with this evidence. So, it always is with the development of physical theory. Whenever a new theory is in partial conflict with an older, established theory, it never-the-less must yield the same predictions as the old in areas where the old theory is supported by experimental evidence. Every new physical theory must pass this test, called the correspondence principle, which has come to be regarded as a fundamental procedural rule in all physical theory. There are many problems for which Newtonian mechanics is clearly inadequate, including all situations where particle speeds approach that of light or there is direct conversion of mass to energy. But there is still a large area, including nearly all the behavior of macroscopic bodies in mechanical systems, in which Newtonian mechanics is still perfectly adequate.

1. In which field other than mentionted in paragraph the Newtonian/classical mechanics fails?

(a) moleculor particles. (b) atomic particles.

(c) bosons. (d) fermions.

(e) subatomic particles.

2. Neutron follows

(a) Bose–Einstein statistics.

(b) Fermi–Dirac statistics.

(c) Pauli's exclusion principle.

(d) Maxwell Boltzmann's statistics.

3. The law which is respected in both classical and quantum machanics is

(a) conservation of force.

(b) conservation of energy.

(c) conservation of momentum.

(d) conservation of spin.

Solution **1.** (e)

Solution **2.** (b), (c)

Solution **3.** (c)

QUESTIONS FOR PRACTICE

1. A spaceship in space will have

(a) clocks running slower than a stationary clock by a factor $\sqrt{1-\frac{v^2}{c^2}}$

(b) its length shrunk in the direction of relative motion by a factor of $\sqrt{1-\frac{v^2}{c^2}}$

(c) its mass increased by a factor of $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

(d) all the above

2. Einstein's mass energy relation (E = mc^2) shows that

(a) mass disappears to reappear as energy.

(b) energy disappears to reappear as energy.

(c) mass and energy are two different forms of the same entity.

(d) all the statements are correct.

3. A rod of length L_0 moving with a velocity of 0.8c in a direction inclined at 60° to its own length. The apparent length along the direction of motion will be

(a) 0.1 L_0 (c) 0.2 L_0

(c) 0.3 L_0 (d) 0.4 L_0

4. In the above problem, the apparent length perpendicular to the direction of motion will be

(a) $\frac{3}{2}L_0$ (b) $\frac{\sqrt{3}}{2}L_0$

(c) $\frac{5}{2}L_0$ (d) $\frac{\sqrt{5}}{2}L_0$

5. In Q. 3, the apparent length of the moving rod will be

(a) 0.916 L_0 (b) L_0

(c) 1.021 L_0 (d) none of these

6. In Q. 3, the percentage contraction in the rod will be

(a) 0.84% (b) 8.4%

(c) 84% (d) none of these

7. A beam of particles of half life 2.8 × 10^{-6}s travels in the laboratory with v = 0.96c. The apparent lifetime of the particles will be

(a) 1 × 10^{-6}s (b) 1 × 10^{-5}s

(c) 1 × 10^{-4}s (d) 1 × 10^{-3}s

8. In the above problem, the distance traveled by the beam before the flux fails to half its initial value, will be

(a) 2.88 × 10^{3}m (b) 2.88 × 10^2 m

(c) 2.88 × 10^{1}m (d) 2.88 × 10^0 m

9. If l_0^3 is the rest volume of a cube, then the volume viewed from a reference frame moving with uniform velocity v parallel to an edge of the cube, will be

(a) $l_0^3\left(1-\frac{v^2}{c^2}\right)^{3/2}$ (b) $l_0^3\left(1-\frac{v^2}{c^2}\right)$

(c) $l_0^3\sqrt{1-\frac{v^2}{c^2}}$ (d) none of these

10. At what speed should a clock be moved so that it may appear to lose 1 minute in each hour ?

(a) 1.9 × 10^{7}m/s (b) 2.7 × 10^{7}m/s

(c) 5.4 × 10 m/s (d) none of these

11. A space ship, moving away from earth with speed 0.9c, fires a missile in the same direction as its motion, with a speed 0.9c relative to space ship. What will be its speed relative to earth ?

(a) 0.745c (b) 0.859c

(c) 0.994 c (d) c

12. The energy equivalent to amu in MeV will be

(a) 0.931 MeV (b) 9.31 MeV

(c) 93.1 MeV (d) 931 MeV

13. A body of specific heat 0.2 kilocal/ $\mathrm{kg}^{-1}\,{}^{\circ}\mathrm{C}^{-1}$ is heated through 100°C, the percentage increase in its mass will be

(a) 9.3×10^{-8} % (b) 9.3×10^{-9} %
(c) 9.3×10^{-10}% (d) 9.3×10^{-11} %

14. The velocity of π-mesons, whose observed mean life is 2.5×10^{-7} s and proper life is
(a) 0.795 c (b) 0.895 c
(c) 0.995 c (d) none of these

15. A certain particle called μ-mesons has a life time 2×10^{-6} sec. If it is traveling with a speed of 2.994×10^8m then its mean life time will be
(a) 31.7×10^{-6}s (b) 3.17×10^{-6}s
(c) 0.317×10^{-6}s (d) none of these

16. In the above problem, how far does the particle go during one mean life ?
(a) 6770 m (b) 9510 m
(c) 1850 m (d) none of these

17. In Q. 15, what distance would be travelled by the particle without relativistic effects ?
(a) 598.8 m (b) 5988 m
(c) 59.88 m (d) 5.988 m

18. A charged particle shows an acceleration of 4.2×10^{10} m/s^2 under an electric field at low speed. The acceleration of the particle under the same field when its speed becomes 2.88×10^8 m/s will be
(a) 4.2×10^{10} m/s^2 (b) 1.176×10^{10}m/s^2
(c) 2.88×10^8 m/s^2 (d) none of these

19. The mass of an electron having kinetic energy 1.5 MeV will be
(a) 9.1×10^{-31} kg. (b) 3.58×10^{-31} kg.
(c) 35.8×10^{-31} kg. (d) none of these.

20. In the above problem, the velocity of electron will be
(a) 3×10^8m/s. (b) 2.9×10^8 m/s.
(c) 2.8×10^8 m/s. (d) 2.7×10^8 m/s.

21. An electron is moving with a speed 0.99c. Its relativistic mass will be
(a) 9.1×10^{-31} kg. (b) 64.5×10^{-31} kg.
(c) 98.5×10^{-31} kg. (d) none of these.

22. In the above problem, the total energy of electron will be
(a) 5.8×10^{-11} Joule. (b) 5.8×10^{-12} Joule.
(c) 5.8×10^{-13} Joule. (d) none of these.

23. In Q. 21, the ratio of Newtonian kinetic energy to the relativistic energy will be
(a) 0.05 (b) 0.06
(c) 0.07 (d) 0.08

24. At what velocity the kinetic energy of a particle is equal to the rest mass of energy?
(a) $\sqrt{5}/2$ (b) $\sqrt{3}/2c$
(c) $c/2$ (d) none of these

25. The e/m measured by an experimenter is 1/3rd of the usual value. The electron is moving with a speed
(a) 0.842 c (b) 0.724 c
(c) 0.866 c (d) 0.943 c

26. At what speed the mass of a body will be almost doubled?
(a) 0.77 c (b) 0.87 c
(c) 0.97 c (d) none of these

27. Which of the following is not assumed to be absolute in newtonian mechanics?
(a) mass. (b) state of rest or motion.
(c) space. (d) time.

28. An electron is moving with speed 0.99 c. The total energy of electron will be
(a) 5.8×10^{-13} J (b) 5.8×10^{-12} J
(c) 5.8×10^{-11} J (d) none of these

29. A rod of length L_0 moving with a velocity of 0.8 c in a direction inclined at 60° to its own length. The apparent length along the direction of motion will be
(a) 0.4 L_0 (b) 0.3 L_0
(c) 0.2 L_0 (d) 0.1 L_0

30. One kilogran of mass is completely converted in to heat energy. The heat produced in kilocalories will be
(a) 2.1×10^{16} (b) 2.1×10^{13}
(c) 2.1×10^{10} (d) none of these

31. A beam of particles of half-life 2.8×10^{-6} s travels in the laboratory with $v = 0.96\ c$. The apparent life time of the particles will be
(a) 1×10^{-3} s (b) 1×10^{-4} s
(c) 1×10^{-5} s (d) 1×10^{-6} s

32. The energy equivalent to amu in MeV will be
(a) 0.931 MeV (b) 931 MeV
(c) 9.31 MeV (d) 93.1 MeV

33. The velocity of an electron having kinetic energy of 1.5 MeV will be
(a) 2.7×10^8 ms^{-1} (b) 2.8×10^8 ms^{-1}
(c) 2.9×10^8 ms^{-1} (d) 3×10^8 ms^{-1}

34. The mass of an electron having kinetic energy of 1.5 MeV will be
(a) 3.58×10^{-31} kg (b) 9.1×10^{-31} kg
(c) 35.8×10^{-31} kg (d) none of these

35. A certain particle called μ-mesons has a life time 2×10^{-6} s. If it is travelling with a speed of 2.994×10^8 ms^{-1}. Then its mean life time will be

(a) 0.317×10^{-6} s (b) 3.17×10^{-6} s
(c) 31.7×10^{-6} s (d) none of these

36. An electron is being chased by a photon. The speed of the electron is 0.9 *c*. Their relative velocity is
(a) *c*. (b) 0.9 *c*.
(c) 0.1 *c*. (d) none of these.

37. An electron is moving with speed 0.99 *c*. The ratio of newtonium kinetic energy to the relativistic energy will be
(a) 0.08. (b) 0.07.
(c) 0.06. (d) 0.04.

38. A charged particle shows an acceleration of 4.2×10^{10} ms^{-2} under an electric field at low speed. The acceleration of the particle under the same field when its speed becomes 2.88×10^8 ms^{-1} will be
(a) 2.88×10^8 ms^{-2}. (b) 1.176×10^{10} ms^{-2}.
(c) 4.2×10^{10} ms^{-2}. (d) none of these.

39. A charged particle of π meason whose observed life 2.5×10^{-7} s and proper life is 3.5×10^{-7} s is
(a) 0.7 *c*. (b) 0.841 *c*.
(c) 0.795 *c*. (d) 1.95 *c*.

40. Two photons recede from each other. Their relative velocity will be
(a) $c/2$. (b) *c*.
(c) 2 *c*. (d) zero.

41. A body of specific heat 0.2 $kcalkg^{-1}$ $°C^{-1}$ is heated through 100°C. The percentage increase in its mass will be
(a) 9.3×10^{-10}%. (b) 9.3×10^{-11}%.
(c) 9.3×10^{-8}%. (d) 9.3×10^{-9}%.

42. An electron is moving with a speed 0.99 *c*. Its relativistic mass will be
(a) 98.5×10^{-31} kg. (b) 64.5×10^{-31} kg.
(c) 9.1×10^{-31} kg. (d) none of these.

43. Two photons approach each other. Their relative velocity will be
(a) slightly less than *c*. (b) $c/2$.
(c) *c*. (d) $c - v$.

44. A beam of light moves towards right with speed *c*. If earth also moves towards right with speed *v*, then the speed of beam of light relative to earth will be?
(a) $\sqrt{c^2 + v^2}$ (b) *c*
(c) $c + v$ (d) $c - v$

45. Whose experimental work proved that the velocity of light is a universal and natural constant?
(a) Lorentz. (b) Einstein.
(c) Maxwell. (d) Michelson.

46. On the annihilation of a particle and its antiparticle the energy released is *E*. The mass of each particle will be
(a) E/c. (b) $E/2c$.
(c) E/c^2. (d) $\frac{E}{2c^2}$.

47. Special theory of relativity deals with the events in the frames of reference which move with constant
(a) acceleration. (b) momentum.
(c) space interval. (d) time interval.

48. A proton has a charge *q* when at rest. When it acquires a velocity $c/2$, its charge becomes
(a) $q\sqrt{1-(1/2)^2}$. (b) *q*.
(c) $\frac{q}{\sqrt{1-(1/2)^2}}s$. (d) infinity.

49. Einstein proposed the general theory of relativity in
(a) 1916. (b) 1905.
(c) 1904. (d) 1900.

50. At what speed should a clock be moved so that it may appear to lose 1 minute in each hour?
(a) 5.4×10^7 ms^{-1}. (b) 2.7×10^7 ms^{-1}.
(c) 1.9×10^7 ms^{-1}. (d) none of these.

Answers to Questions for Practice

1.	(d)	2.	(d)	3.	(c)	4.	(b)	5.	(a)	6.	(b)	7.	(b)
8.	(a)	9.	(c)	10.	(c)	11.	(c)	12.	(d)	13.	(d)	14.	(c)
15.	(a)	16.	(b)	17.	(a)	18.	(b)	19.	(c)	20.	(b)	21.	(b)
22.	(c)	23.	(d)	24.	(b)	25.	(d)	26.	(b)	27.	(b)	28.	(a)
29.	(b)	30.	(b)	31.	(c)	32.	(b)	33.	(c)	34.	(c)	35.	(c)
36.	(a)	37.	(a)	38.	(b)	39.	(a)	40.	(b)	41.	(b)	42.	(b)
43.	(c)	44.	(b)	45.	(d)	46.	(d)	47.	(b)	48.	(b)	49.	(a)
50.	(a)												

EXPLANATION

28. (a) $m^* = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}} = 7.1\ m_0; E = 7.1\ m_0c^2.$

29. (b) $L = \left[L_0\sqrt{1-\dfrac{v^2}{c^2}}\right]\cos 60° = 0.3\ L_0$

30. (b) $H = \dfrac{m_0c^2}{4200} = \dfrac{1\times 9\times 10^{16}}{4.2\times 10^3} = 2.1\times 10^3$ kcal.

35. (c) $t = \dfrac{\tau}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{20\times 10^{-6}}{\sqrt{1-(0.998)^2}} = 31.7\times 10^{-6}$ s

38. (b) $m^* = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}} = \dfrac{m_0}{\sqrt{1-(0.96)^2}} = \dfrac{m_0}{0.28}$

$$a_{\text{new}} = 0.28(4.2\times 10^{10})$$
$$= 1.176\times 10^8\ \text{ms}^{-2}.$$

39. (a) $\dfrac{2.5}{3.5} = \sqrt{\dfrac{1-v^2}{c^2}}$

or $1-\dfrac{25}{49} = \dfrac{v^2}{c^2}$

or $v = \dfrac{\sqrt{24}}{7}c = 0.7\,c.$