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NEET | JEE ESSENTIALS

Class XI

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Unit 5 GRAVITATION

THE UNIVERSAL LAW OF GRAVITATION

- According to Newton's law of gravitation, each body attracts other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
- Let m_1 and m_2 be the masses of two bodies and r be the separation between them.

$$F \propto \frac{m_1 m_2}{r^2}$$

$$\Rightarrow \quad F = \frac{G m_1 m_2}{r^2}$$

Here, G is the constant of proportionality which is called universal gravitational constant. The value of G is 6.67×10^{-11} N m^2 kg^{-2}.

The direction of the force F is along the line joining the two particles.

- The gravitational force between two particles is independent of the presence of other bodies or the properties of the intervening medium.
- Gravitational force is a conservative force therefore work done in displacing a body from one place to another is independent of the path followed. It depends only on the initial and final positions.
- The gravitational force obeys Newton's third law *i.e.* $F_{12} = -F_{21}$
- Principle of superposition of gravitation : It states that the resultant gravitational force $\vec{F}$ acting on a particle due to number of other particles is equal to vector sum of the gravitational forces exerted by individual particle on the given particle.

i.e., $\vec{F} = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + \ldots + \vec{F}_{0n}$

$$= \sum_{i=1}^{n} \vec{F}_{0i}$$

where $\vec{F}_{01}, \vec{F}_{02}, \vec{F}_{03}, \ldots, \vec{F}_{0n}$ are the gravitational forces on a particle of mass m_0 due to particles of masses $m_1, m_2, \ldots, m_n$ respectively.

GRAVITY

- It is defined as the force of attraction exerted by the earth towards its centre on a body lying on or near the surface of the earth.
- It is merely a special case of gravitation and is also called as earth's gravitational pull.
- It is the measure of weight of the body. The weight of the body
  = mass (m) × acceleration due to gravity (g) = mg.
- The unit of weight of the body will be the same as that of force. It is a vector quantity. It is always directed towards the centre of the earth.

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☞ VARIATION OF ACCELERATION DUE TO GRAVITY

- Acceleration due to gravity on the surface of the earth is given by, $g = \frac{GM_e}{R_e^2}$
- **Effect of altitude :** Now, consider the body at a height h above the surface of the earth, then the acceleration due to gravity at height h given by

$$g_h = \frac{GM_e}{(R_e + h)^2} = g\left(1 + \frac{h}{R_e}\right)^{-2}$$

$$\simeq g\left(1 - \frac{2h}{R_e}\right) \text{ when } h << R_e$$

- The decrease in the value of g at the height h

$$= g - g_h = \frac{2gh}{R_e}.$$

- Then percentage decrease in the value of g

$$= \frac{g - g_h}{g} \times 100 = \frac{2h}{R_e} \times 100\%$$

- **Effect of depth :** The gravitational pull on the surface is equal to its weight *i.e.*

$$mg = \frac{GM_e m}{R_e^2}$$

$$\therefore \quad mg = \frac{G \times \frac{4}{3}\pi R_e^3 \rho m}{R_e^2}$$

$$\text{or} \quad g = \frac{4}{3}\pi G R_e \rho \qquad \text{...(i)}$$

When the body is taken to a depth d, the mass of the sphere of radius $(R_e - d)$ will only be effective for the gravitational pull and the outward shell will have no resultant effect on the mass. If the acceleration due to gravity on the surface of the solid sphere is g_d, then

$$g_d = \frac{4}{3}\pi G(R_e - d)\rho \qquad \text{...(ii)}$$

By dividing equation (ii) by equation (i), we get

$$\Rightarrow \quad g_d = g\left(1 - \frac{d}{R_e}\right)$$

- **Effect of the position on the earth's surface :** The equatorial radius is about 21 km longer than its polar radius.

We know, $g = \frac{GM_e}{R_e^2}$, hence $g_{pole} > g_{equator}$. The weight of the body increases as the body taken from the equator to the pole.

- **Effect of rotation of the earth :** The earth rotates about its axis with angular velocity ω. Consider a particle of mass m at latitude θ. The angular velocity of the particle is also ω.

According to parallelogram law of vector addition, the resultant force acting on mass m along PQ is

$$F = [(mg)^2 + (m\omega^2 R_e\cos\theta)^2 + \{2mg \times m\omega^2 R_e\cos\theta\} \cos(180° - \theta)]^{1/2}$$

$$= [(mg)^2 + (m\omega^2 R_e\cos\theta)^2 - (2m^2 g\omega^2 R_e\cos\theta)\cos\theta]^{1/2}$$

$$= mg\left[1 + \left(\frac{R_e\omega^2}{g}\right)^2 \cos^2\theta - 2\frac{R_e\omega^2}{g}\cos^2\theta\right]^{1/2}$$

- At pole θ = 90° ⇒ $g_{pole} = g$,
- At equator θ = 0°

$$\Rightarrow g_{equator} = g\left[1 - \frac{R_e\omega^2}{g}\right].$$

Hence $g_{pole} > g_{equator}$

- If the body is taken from pole to the equator, then change in acceleration due to gravity

$$\Delta g = \frac{R_e\omega^2}{g}$$

- Hence % change in weight of a body

$$= \frac{mg - mg\left(1 - \frac{R_e\omega^2}{g}\right)}{mg} \times 100 = \frac{mR_e\omega^2}{mg} \times 100$$

$$= \frac{R_e\omega^2}{g} \times 100$$

KEPLER'S LAWS OF PLANETARY MOTION

- **First law (law of orbits) :** All planets move in elliptical orbits with the sun situated at one of the foci of the ellipse.
- **Second law (law of areas) :** The radius vector drawn from the sun to the planet sweeps out equal areas in equal intervals of time *i.e.* the areal velocity of the planet (or the area swept out by the planet per unit time) around the sun is constant *i.e.*, areal velocity $= \frac{d\vec{A}}{dt} =$ a constant, for a planet.
  - Angular momentum $(\vec{L})$ of a planet is related with areal velocity $\left(\frac{d\vec{A}}{dt}\right)$ by the relation
    $$\vec{L} = 2m\left(\frac{d\vec{A}}{dt}\right)$$
  - Kepler's second law follows from the law of conservation of angular momentum.
  - The area covered by the radius vector in dt seconds $= \frac{1}{2} r^2\, d\theta$.
    The areal velocity $= \frac{1}{2} r^2 \frac{d\theta}{dt} = \frac{1}{2} r^2 \omega = \frac{1}{2} rv$.
  - According to Kepler's second law, the speed of the planet is maximum, when it is closest to the sun and is minimum when the planet is farthest from the sun.
- **Third law (law of periods) :** The square of the time period of revolution of a planet around the sun is directly proportional to the cube of semi major axis of the elliptical orbit *i.e.* $T^2 \propto a^3$ where a is the semi major axis of the elliptical orbit of the planet around the sun.

GRAVITATIONAL FIELD

- The space around a material body in which its gravitational pull can be experienced is called its gravitational field.
- The intensity of the gravitational field of a body at a point in the field is defined as the force experienced by a body of unit mass placed at that point provided the presence of unit mass does not disturb the original gravitational field. It is denoted by symbol E.
- The intensity of gravitational field at a point due to a body of mass M, at a distance r from the centre of the body is
  $$E = -\frac{GM}{r^2}$$
  where negative sign shows that the gravitational intensity is of attractive force.
- Intensity of gravitational field is a vector quantity. Its dimensional formula is $[M^0LT^{-2}]$.
- Unit of intensity of gravitational field in SI system is N kg^{-1} and in CGS system is dyne g^{-1}.

GRAVITATIONAL POTENTIAL

- The gravitational potential at a point in the gravitational field of a body is defined as the amount of work done in bringing a unit mass from infinity to that point. It is denoted by symbol V.
- The gravitational potential at a point in the gravitational field due to a body of mass M at a distance r from the centre of the body is given by
  $$V = -\frac{GM}{r}$$
- Gravitational potential is a scalar quantity. Its dimensional formula is $[M^0L^2T^{-2}]$.
- Unit of gravitational potential in SI system is J kg^{-1} and in CGS system is erg g^{-1}.
- Gravitational potential (V) is related with gravitational field intensity (E) by a relation
  $$E = -\frac{dV}{dr}$$

GRAVITATIONAL FIELD AND POTENTIAL OF SOME CONTINUOUS MASS DISTRIBUTIONS

- Uniform ring of mass M and radius R
  - Gravitational field on the axis,
    $$E = -\frac{GMx}{(R^2 + x^2)^{3/2}}$$
  - Gravitational potential on the axis,
    $$V = -\frac{GM}{(R^2 + x^2)^{1/2}}$$
- Uniform disc of mass M and radius R
  - Gravitational field on the axis,
    $$E = -\frac{2GM}{R^2}\left[1 - \frac{x}{\sqrt{R^2 + x^2}}\right]$$
  - Gravitational potential on the axis,
    $$V = -\frac{2GM}{R^2}[x - \sqrt{R^2 + x^2}]$$

- Thin spherical shell of mass M and radius R
  - Gravitational field at a distance r from centre:

(i) Inside the shell,

$$E(r < R) = 0$$

(ii) On the surface of the shell,

$$E(r = R) = -\frac{GM}{R^2}$$

(iii) Outside the shell,

$$E(r > R) = -\frac{GM}{r^2}$$

  - Gravitational potential at a distance r from centre:

(i) Inside the shell,

$$V(r < R) = -\frac{GM}{R}$$

(ii) On the surface of shell,

$$V(r = R) = -\frac{GM}{R}$$

(iii) Outside the shell,

$$V(r > R) = -\frac{GM}{r}$$

Note that field intensity inside the shell is zero. Field intensity and potential on the surface or outside points can be calculated by assuming the entire mass of the shell to be concentrated at its centre

- A solid sphere of mass M and radius R, with uniform mass density
  - Gravitational field at a distance r from centre:

(i) Inside the solid sphere,

$$E(r < R) = -\frac{GMr}{R^2}$$

(ii) On the surface of the sphere,

$$E(r = R) = -\frac{GM}{R^2}$$

(iii) Outside the sphere,

$$E(r > R) = -\frac{GM}{r^2}$$

  - Gravitational potential at a distance r from the centre:

(i) Inside the sphere,

$$V(r < R) = -\frac{GM}{2R^3}(3R^2 - r^2)$$

(ii) On the surface of the sphere,

$$V(r = R) = -\frac{GM}{R}$$

(iii) Outside the sphere,

$$V(r > R) = -\frac{GM}{r}$$

(iv) At the centre of the sphere,

$$V(r = 0) = -\frac{3}{2}\frac{GM}{R}$$

GRAVITATIONAL POTENTIAL ENERGY

- The gravitational potential energy of a body at a point in a gravitational field of another body is defined as the amount of work done in bringing the given body from infinity to that point.

  Gravitational potential energy

  = Gravitational potential × mass of the body

- The gravitational potential energy of mass m in the gravitational field of mass M at a distance r from it is

$$U = -\frac{GMm}{r}$$

  where, r is the distance between M and m.

- The gravitational potential energy of a mass m at a distance r ($> R_e$) from the centre of the earth is

$$U = mV = -\frac{GM_e m}{r}$$

- Gravitational potential energy of a mass at infinite distance from the earth is zero.
- Gravitational potential energy is a scalar quantity. Its dimensional formula is $[ML^2T^{-2}]$ and SI unit is J.
- Gravitational potential energy of a body of mass m at height h above the earth's surface is given by

$$U_h = \frac{-GM_e m}{(R_e + h)}$$

- Gravitational potential energy of a body of mass m on the earth's surface is given by

$$U_s = \frac{-GM_e m}{R_e}$$

- The change in potential energy when a body of mass m is moved vertically upwards through a height h from the earth's surface is given by

$$\Delta U = U_h - U_s = GM_e m\left[\frac{1}{R_e} - \frac{1}{R_e + h}\right]$$

$$= \frac{GM_e mh}{R_e^2\left(1 + \frac{h}{R_e}\right)} = \frac{mgh}{\left(1 + \frac{h}{R_e}\right)} \quad \left(\because\ g = \frac{GM_e}{R_e^2}\right)$$

  - For $h << R_e$, $\Delta U = mgh$.

SATELLITE

- Satellite is natural or artificial body describing orbit around a planet under its gravitational attraction. Moon is a natural satellite while INSAT-1B is an artificial satellite of the earth.
- Orbital speed of the satellite, when it is revolving around the earth at a height h is given by

$$v_o = \sqrt{\frac{GM_e}{r}} = \sqrt{\frac{GM_e}{R_e + h}}$$

$$= R_e\sqrt{\frac{g}{R_e + h}} \qquad \left(\text{As } g = \frac{GM_e}{R_e^2}\right)$$

  - When the satellite is orbiting close to the earth's surface, *i.e.*, $h << R_e$, then

$$v_o = R_e\sqrt{\frac{g}{R_e}} = \sqrt{gR_e}$$

$$v_o = \sqrt{9.8 \times 6.4 \times 10^6} = 7.92 \times 10^3 \text{ m s}^{-1}$$

$$\approx 8 \text{ km s}^{-1}$$

  - The orbital speed of the satellite is independent of the mass of the satellite.
  - The orbital speed of the satellite depends upon the mass and radius of the earth/planet around which the revolution of satellite is taking place.
  - The direction of orbital speed of the satellite at an instant is along the tangent to the orbital path of satellite at that instant.

- **Time period of a satellite :** It is the time taken by satellite to complete one revolution around the earth and it is given by

$$T = \frac{2\pi r}{v_o} = 2\pi\sqrt{\frac{r^3}{GM_e}} = 2\pi\sqrt{\frac{(R_e + h)^3}{GM_e}}$$

$$= \frac{2\pi}{R_e}\sqrt{\frac{(R_e + h)^3}{g}}$$

  - For a satellite orbiting close to the earth's surface *i.e.* $h << R_e$

$$T = 2\pi\sqrt{\frac{R_e}{g}} = 84.6 \text{ min.}$$

  - The period of revolution of the satellite depends upon its height above earth's surface. Larger is the height of the satellite, the greater will be its time period of revolution.

- Height of satellite above the earth's surface

$$h = \left(\frac{T^2 R_e^2 g}{4\pi^2}\right)^{1/3} - R_e$$

- Kinetic energy of a satellite

$$K = \frac{1}{2}mv_o^2 = \frac{1}{2}\frac{GM_e m}{r} = \frac{1}{2}\frac{GM_e m}{(R_e + h)}$$

- Potential energy of a satellite

$$U = -\frac{GM_e m}{r} = -\frac{GM_e m}{R_e + h}$$

- Total energy (mechanical) of a satellite

$$E = K + U = -\frac{GM_e m}{2r} = -\frac{GM_e m}{2(R_e + h)}$$

  - For satellite orbiting very close to the surface of earth *i.e.*, $h << R_e$ then $E = -\frac{GM_e m}{2R_e}$.

- Kinetic energy of a satellite is equal to negative of total energy while potential energy is equal to twice the total energy.
  i.e. $K = -E$, $U = 2E$
- Binding energy of a satellite

$$E_B = -E = \frac{GM_e m}{2r} = \frac{GM_e m}{2(R_e + h)}.$$

- Angular momentum of a satellite

$$L = mv_o r = mr\sqrt{\frac{GM_e}{r}} = [m^2 rGM_e]^{1/2}$$

  - Angular momentum of a satellite depends on both, mass of the satellite (m) and mass of the earth (M_e). It also depends upon the radius of the orbit (r) of the satellite.
  - Angular momentum is conserved in the motion of satellite.

ESCAPE SPEED

- The escape speed on earth (or any planet) is defined as the minimum speed with which a body has to be projected vertically upwards from the surface of earth (or any other planet) so that it just crosses the gravitational field of earth (or of that planet) and never returns on its own. Escape speed v_e is given by

$$v_e = \sqrt{\frac{2GM}{R}}$$

where M = Mass of the earth/planet
R = Radius of the earth/planet

$$v_e = \sqrt{\frac{2G \times \text{volume} \times \text{density}}{R}}$$

$$\text{or} \quad v_e = \sqrt{\frac{2G}{R} \times \frac{4}{3}\pi R^3 \rho} = \sqrt{\frac{8\pi\rho G R^2}{3}}$$

For earth, $v_e = 11.2$ km s^{-1}.

- The escape speed depends upon the mass and radius of the earth/planet from the surface of which the body is to be projected.
- The escape speed is independent of the mass and direction of projection of the body from the surface of earth/planet.
- For a point close to earth's surface the escape speed and orbital speed are related as
  $v_e = \sqrt{2}\, v_o$
- A given planet will have atmosphere if the root mean square speed of molecules in its atmosphere (*i.e.*, $v_{rms} = \sqrt{3RT / M}$) is smaller than the escape speed for that planet.
- Moon has no atmosphere because the r.m.s. speed of gas molecules there, are greater than the escape speed of moon.

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SPEED PRACTICE

1. A satellite is moving in a circular orbit at a certain height above the earth's surface. It takes 5.26×10^3 s to complete one revolution with a centripetal acceleration equal to 9.32 m s^{-2}. The height of the satellite orbit above the earth's surface is (Radius of earth = 6.37×10^6 m)

(a) 70 km (b) 160 km
(c) 190 km (d) 220 km

2. A synchronous satellite goes around the earth once in every 24 h. What is the radius of orbit of the synchronous satellite in terms of the earth's radius? (Given mass of the earth, $M_e = 5.98 \times 10^{24}$ kg, radius of the earth, $R_e = 6.37 \times 10^6$ m, universal constant of gravitation, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}).

(a) 2.4 R_e (b) 3.6 R_e (c) 4.8 R_e (d) 6.6 R_e

3. A particle of mass M is situated at the centre of a spherical shell of same mass and radius a. The gravitational potential at a point situated at distance $\frac{a}{2}$ from the centre, will be

(a) $-\frac{3GM}{a}$ (b) $-\frac{2GM}{a}$
(c) $-\frac{GM}{a}$ (d) $-\frac{4GM}{a}$

4. In the solar system, sun is in the focus of system for sun-earth binding system. Then the binding energy for the system will be
(Given that the radius of the earth orbit round the sun is 1.5×10^{11} m, mass of the earth is 6×10^{24} kg, mass of the sun is 10^{30} kg)

(a) 2.7×10^{33} J (b) 1.3×10^{33} J
(c) 2.7×10^{30} J (d) 1.3×10^{30} J

5. A saturn year is 29.5 times the earth year. How far is the saturn from the sun if the earth is 1.5×10^8 km away from the sun?

(a) 1.2×10^9 km (b) 1.3×10^9 km
(c) 1.4×10^9 km (d) 1.5×10^9 km

6. Two satellites of earth, S_1 and S_2 are moving in the same orbit. The mass of S_1 is four times the mass of S_2. Which one of the following statements is true?

(a) The potential energies of earth and satellite in the two cases are equal.
(b) S_1 and S_2 are moving with the same speed.
(c) The kinetic energies of the two satellites are equal.
(d) The time period of S_1 is four times that of S_2.

7. The escape velocity of a body from the surface of earth is 11.2 km s^{-1}. A body is projected with a velocity of 22.4 km s^{-1}. Velocity of the body at infinite distance from the centre of the earth would be

(a) 11.2 km s^{-1} (b) zero
(c) $11.2\sqrt{3}$ km s^{-1} (d) $11\sqrt{2}$ km s^{-1}

8. Figure shows the variation of energy E with the orbital radius r of a satellite in a circular motion. Mark the correct statement.

(a) A shows the kinetic energy, B shows the total energy and C the potential energy of the satellite.
(b) A and B are the kinetic energy and potential energy respectively and C the total energy of the satellite.
(c) A and B are the potential energy and kinetic energy respectively and C the total energy of the satellite.
(d) C and A are the kinetic and potential energies and B the total energy of the satellite.

9. A ball is thrown vertically upwards with a velocity equal to half the escape velocity from the surface of the earth. The ball rises to a height h above the surface of the earth. If the radius of the earth is R_e, then the ratio $\frac{h}{R_e}$ is

(a) $\frac{1}{2}$ (b) $\frac{1}{3}$ (c) 2 (d) 3

10. If r denotes the distance between the sun and the earth, then the angular momentum of the earth around the sun is proportional to

(a) $r^{3/2}$ (b) r (c) $\sqrt{r}$ (d) r^2

11. Two satellites of masses m_1 and m_2 ($m_1 > m_2$) are revolving around the earth in a circular orbit of radii r_1 and r_2 ($r_1 > r_2$) respectively. Which of the following statements is true regarding their speeds v_1 and v_2?

(a) $v_1 = v_2$ (b) $v_1 > v_2$

(c) $v_1 < v_2$ (d) $\frac{v_1}{r_1} = \frac{v_2}{r_2}$

12. Four particles each of mass M, are located at the vertices of a square with side L. The gravitational potential due to this at the centre of the square is

(a) $-\sqrt{32}\frac{GM}{L}$ (b) $-\sqrt{64}\frac{GM}{L^2}$

(c) zero (d) $\sqrt{32}\frac{GM}{L}$

13. Starting from the centre of the earth having radius R, the variation of g(acceleration due to gravity) is shown by

[NEET Phase II 2016]

14. A satellite of mass m is orbiting the earth (of radius R) at a height h from its surface. The total energy of the satellite in terms of g_0 the value of acceleration due to gravity at the earth's surface is

(a) $\frac{mg_0R^2}{2(R+h)}$ (b) $-\frac{mg_0R^2}{2(R+h)}$

(c) $\frac{2mg_0R^2}{R+h}$ (d) $-\frac{2mg_0R^2}{R+h}$

[NEET Phase II 2016]

15. The ratio of escape velocity at earth (v_e) to the escape velocity at a planet (v_p) whose radius and mean density are twice as that of earth is

(a) $1:4$ (b) $1:\sqrt{2}$ (c) $1:2$ (d) $1:2\sqrt{2}$

[NEET Phase I 2016]

16. A black hole is an object whose gravitational field is so strong that even light cannot escape from it. To what approximate radius would earth (mass = 5.98×10^{24} kg) have to be compressed to be a black hole?

(a) 10^{-9} m (b) 10^{-6} m (c) 10^{-2} m (d) 100 m

[AIPMT 2014]

17. A satellite is revolving in a circular orbit at a height 'h' from the earth's surface (radius of earth R; $h << R$). The minimum increase in its orbital velocity required, so that the satellite could escape from the earth's gravitational field, is close to : (Neglect the effect of atmosphere.)

(a) $\sqrt{2gR}$ (b) $\sqrt{gR}$

(c) $\sqrt{gR/2}$ (d) $\sqrt{gR}\left(\sqrt{2}-1\right)$

[JEE Main Offline 2016]

18. Figure shows elliptical path *abcd* of a planet around the sun S such that the area of triangle *csa* is $\frac{1}{4}$ the area of the ellipse. (See figure) With *db* as the semi-major axis, and *ca* as the semi-minor axis. If t_1 is the time taken for planet to go over path *abc* and t_2 for path taken over *cda* then

(a) $t_1 = 4t_2$
(b) $t_1 = 2t_2$
(c) $t_1 = 3t_2$
(d) $t_1 = t_2$

[JEE Main Online 2016]

19. An astronaut of mass m is working on a satellite orbiting the earth at a distance h from the earth's surface. The radius of the earth is R, while its mass is M. The gravitational pull F_G on the astronaut is

(a) Zero since astronaut feels weightless

(b) $\frac{GMm}{(R+h)^2} < F_G < \frac{GMm}{R^2}$

(c) $F_G = \frac{GMm}{(R+h)^2}$

(d) $0 < F_G < \frac{GMm}{R^2}$

[JEE Main Online 2016]

20. From a solid sphere of mass M and radius R, a spherical portion of radius $\frac{R}{2}$ is removed, as shown

in the figure. Taking gravitational potential $V = 0$ at $r = \infty$, the potential at the centre of the cavity thus formed is
(G = gravitational constant)

(a) $\frac{-2GM}{3R}$ (b) $\frac{-2GM}{R}$

(c) $\frac{-GM}{2R}$ (d) $\frac{-GM}{R}$

[JEE Main Online 2015]

SOLUTIONS

1. (b): Time period of revolution of satellite

$$T = 2\pi\sqrt{\frac{(R_e+h)^3}{GM_e}}$$

or $$\frac{T^2}{4\pi^2} = \frac{(R_e+h)^3}{GM_e} \quad ...(i)$$

Centripetal acceleration, $a = \frac{GM_e}{(R_e+h)^2}$

or $$\frac{(R_e+h)^2}{GM_e} = \frac{1}{a} \quad ...(ii)$$

Divide (i) by (ii), we get

$$(R_e+h) = \frac{T^2}{4\pi^2}\times a = \left(\frac{5.26\times10^3}{2\pi}\right)^2 \times 9.32$$

$R_e + h = 6.53 \times 10^6$ m

$h = 6.53 \times 10^6$ m $- 6.37 \times 10^6$ m $= 0.16 \times 10^6$ m

$= 160 \times 10^3$ m $= 160$ km

2. (d): Time period of revolution of satellite

$$T = 2\pi\sqrt{\frac{R^3}{GM_e}}$$

Also, $g = \frac{GM_e}{R_e^2}$ ...(i)

$\therefore \quad T^2 = \frac{4\pi^2R^3}{gR_e^2}$ (Using (i))

Substituting the given values in above equation, we get

$$(24\times60\times60)^2 = \frac{4\times(3.14)^2R^3}{9.8R_e^2}$$

$R = 4.22\times10^7$ m

$$\frac{R}{R_e} = \frac{4.22\times10^7}{6.37\times10^6} = 6.6$$

or $R = 6.6R_e$

3. (a): Gravitational potential due to the shell of radius a at any point inside it $= -\frac{GM}{a}$

Gravitational potential due to the particle at the centre at a point P distant $\frac{a}{2}$ from the centre

$$= -\frac{GM}{a/2} = -\frac{2GM}{a}$$

$\therefore$ Net gravitational potential at P

$$= -\frac{GM}{a} - \frac{2GM}{a} = -\frac{3GM}{a}$$

4. (b): Binding energy = – total energy of system

$$= \frac{GM_sM_e}{2R}$$

Mass of sun, $M_s = 10^{30}$ kg

Mass of earth, $M_e = 6 \times 10^{24}$ kg

Radius, $R = 1.5 \times 10^{11}$ m

Binding energy of the system

$$= \frac{6.67\times10^{-11}\times10^{30}\times6\times10^{24}}{2\times1.5\times10^{11}} = 1.3\times10^{33}\text{ J}$$

5. (c): Here, $T_s = 29.5\ T_e$ and $R_e = 1.5 \times 10^8$ km

According to Kepler's third law, $T^2 \propto R^3$

$$\therefore \frac{T_s^2}{T_e^2} = \frac{R_s^3}{R_e^3} \quad \text{or} \quad R_s = R_e\left(\frac{T_s}{T_e}\right)^{2/3}$$

$$R_s = 1.5\times10^8\left(\frac{29.5\,T_e}{T_e}\right)^{2/3} = 1.4 \times 10^9 \text{ km}$$

6. (b): Both, orbital speed of satellite $v_o = \sqrt{GM_e/r}$ and time period of revolution of satellite, $T = \left[\frac{4\pi^2r^3}{GM_e}\right]^{1/2}$ are independent of mass of satellite. Therefore orbital speed and time period of revolution of both the satellites are same.

Hence option (b) is correct.

The kinetic energy of a satellite, $K = \frac{GM_em}{2r}$ and potential energy of a satellite, $U = -\frac{GM_em}{r}$ both depend on the mass of satellite.

7. (c): Total energy at earth's surface = Energy at infinity

$$\frac{1}{2}mv_i^2 - \frac{GM_em}{R_e} = \frac{1}{2}mv_f^2$$

If v is the velocity of the body at infinite distance from the centre of the earth and u is the velocity of projection of body, then

$$\frac{1}{2}mu^2 - \frac{1}{2}mv_e^2 = \frac{1}{2}mv^2$$

$$v^2 = u^2 - v_e^2$$

or $\quad v = \sqrt{u^2 - v_e^2} = \sqrt{(22.4)^2 - (11.2)^2}$

$$= 11.2\sqrt{3}\ \text{km s}^{-1}$$

8. (b): K.E $= \frac{GMm}{2r}$; P.E. $= -\frac{GMm}{r}$

T.E. $= -\frac{GMm}{2r}$

$\therefore$ K.E. is always positive and K.E. $\propto \frac{1}{r}$

P.E. is always negative and P.E. $\propto \frac{1}{r}$

T.E. is also negative and T.E. $\propto \frac{1}{r}$

Also T.E. < P.E.

Thus the curve *A* represents K.E., curve *B* represents P.E. and curve *C* represents T.E. of the satellite.

9. (b): Here, $\frac{1}{2}mv^2 - \frac{GM_e m}{R_e} = -\frac{GM_e m}{(R_e + h)}$

or $\quad v^2 = \frac{2GM_e}{R_e}\left(\frac{h}{R_e + h}\right)$ ...(i)

The escape velocity, $v_e = \left(\frac{2GM_e}{R_e}\right)^{1/2}$

and $v = \frac{v_e}{2}$ (given)

Using these in eqn. (i), we get

$$\frac{1}{4}\frac{2GM_e}{R_e} = \frac{2GM_e}{R_e}\left(\frac{h}{R_e + h}\right)$$

or $\quad h = \frac{R_e}{3}$ $\quad$ or $\quad \frac{h}{R_e} = \frac{1}{3}$

10. (c): Angular momentum of the earth around the sun is

$$L = M_e v_o r$$

$$= M_e\sqrt{\frac{GM_s}{r}}\, r \qquad \left(\because\ v_o = \sqrt{\frac{GM_s}{r}}\right)$$

$$\therefore\ L = \left[M_e^2 GM_s r\right]^{1/2}$$

where, M_e = mass of the earth

M_s = mass of the sun

r = distance between the sun and the earth

$\therefore\ L \propto \sqrt{r}$

11. (c): The speed of a satellite of mass m revolving around the earth in a circular orbit of radius r is given by

$v = \sqrt{\frac{GM_e}{r}}$ where M_e is the mass of the earth.

It does not depend upon the mass of the satellite.

Since,

$$v \propto \frac{1}{\sqrt{r}} \quad \therefore \quad \frac{v_1}{v_2} = \sqrt{\frac{r_2}{r_1}}$$

As $r_1 > r_2$

$$\therefore\ \frac{v_1}{v_2} < 1 \text{ or } v_1 < v_2$$

12. (a): Gravitational potential at the centre is

$$U = -4\left(\frac{GM}{L/\sqrt{2}}\right)$$

$$= -\frac{4\sqrt{2}\,GM}{L}$$

$$= -\sqrt{2\times 16}\,\frac{GM}{L}$$

$$= -\sqrt{32}\,\frac{GM}{L}$$

13. (b): Acceleration due to gravity

$$g = \begin{cases} \frac{GM}{R^3}x & ;\ x < R \\ \frac{GM}{x^2} & ;\ x \geq R \end{cases}$$

14. (b): Total energy of satellite at height h from the earth surface,

E = PE + KE

$$= -\frac{GMm}{(R+h)} + \frac{1}{2}mv^2 \qquad \text{...(i)}$$

Also, $\frac{mv^2}{(R+h)} = \frac{GMm}{(R+h)^2}$

or, $\quad v^2 = \frac{GM}{R+h}$ ...(ii)

From eqns. (i) and (ii),

$$E = -\frac{GMm}{(R+h)} + \frac{1}{2}\frac{GMm}{(R+h)} = -\frac{1}{2}\frac{GMm}{(R+h)}$$

$$= -\frac{1}{2}\frac{GM}{R^2}\times\frac{mR^2}{(R+h)}$$

$$= -\frac{mg_0R^2}{2(R+h)} \qquad \left(\because\ g_0 = \frac{GM}{R^2}\right)$$

15. (d): As escape velocity,

$$v = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2G}{R}\cdot\frac{4\pi R^3}{3}\rho} = R\sqrt{\frac{8\pi G}{3}\rho}$$

$$\therefore \quad \frac{v_e}{v_p} = \frac{R_e}{R_p}\times\sqrt{\frac{\rho_e}{\rho_p}}$$

$$= \frac{1}{2}\times\sqrt{\frac{1}{2}} = \frac{1}{2\sqrt{2}} \quad (\because R_p = 2R_e \text{ and } \rho_p = 2\rho_e)$$

16. (c) : The earth will become black hole if the escape velocity on earth is equal to the velocity of light.

i.e., $v_e = c$

or $\sqrt{\frac{2GM}{R}} = c$ or $R = \frac{2GM}{c^2}$

$$R = \frac{2\times6.67\times10^{-11}\text{ N m}^2\text{ kg}^{-2}\times5.98\times10^{24}\text{ kg}}{(3\times10^8\text{ m s}^{-1})^2}$$

$$= 8.86\times10^{-3}\text{ m} \approx 10^{-2}\text{ m}$$

17. (d): Orbital velocity of the satellite,

$$v_o = \sqrt{\frac{GM}{R+h}}, \quad v_o \approx \sqrt{\frac{GM}{R}} \qquad (\because h << R)$$

Let v_e be the minimum velocity required by the satellite to escape from its orbit.

$$\therefore \quad \frac{1}{2}mv_e^2 = \frac{GmM}{R+h}$$

$$\Rightarrow \quad v_e = \sqrt{\frac{2GM}{R+h}} \approx \sqrt{\frac{2GM}{R}} \qquad (\because h << R)$$

so, required increment in the orbital velocity

$$= v_e - v_o = \sqrt{\frac{2GM}{R}} - \sqrt{\frac{GM}{R}}$$

$$= \sqrt{\frac{GM}{R}}(\sqrt{2}-1) = \sqrt{gR}(\sqrt{2}-1)$$

18. (c) : Let the area of the ellipse be A.

As per Kepler's 2nd law, areal velocity of a planet around the sun is constant, *i.e.*, $\frac{dA}{dt}$ = constant.

$$\therefore \quad \frac{t_1}{t_2} = \frac{\text{Area of } abcsa}{\text{Area of } adcsa} = \frac{\frac{A}{2}+\frac{A}{4}}{\frac{A}{2}-\frac{A}{4}} = \frac{\frac{3A}{4}}{\frac{A}{4}} = 3$$

$$\Rightarrow \quad t_1 = 3t_2$$

Note : Here db is the major axis of the ellipse, not semi-major axis and ca is the minor axis of the ellipse, not semi-minor axis.

19. (c) : Gravitational pull on the astronaut

$$F_G = \frac{GMm}{(R+h)^2}$$

Net force on the astronaut is zero.

20. (d): Potential at point P (centre of cavity) before removing the spherical portion,

$$V_1 = \frac{-GM}{2R^3}\left(3R^2 - \left(\frac{R}{2}\right)^2\right)$$

$$= \frac{-GM}{2R^3}\left(3R^2 - \frac{R^2}{4}\right)$$

$$= \frac{-11GM}{8R}$$

Mass of spherical portion to be removed, $M' = \frac{MV'}{V}$

$$= \frac{M\frac{4\pi}{3}\left(\frac{R}{2}\right)^3}{\frac{4\pi}{3}R^3} = \frac{M}{8}$$

Potential at point P due to spherical portion to be removed

$$V_2 = \frac{-3GM'}{2R'} = \frac{-3G(M/8)}{2(R/2)} = \frac{-3GM}{8R}$$

$\therefore$ Potential at the centre of cavity formed

$V_P = V_1 - V_2$

$$= \frac{-11GM}{8R} - \left(\frac{-3GM}{8R}\right) = \frac{-GM}{R}$$

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the nobel prize in physics 2016

Three UK-born scientists won the 2016 Nobel Prize in physics on Tuesday 4th October for revealing unusual states of matter, leading to advances in electronics and development on future quantum computers.

David J. Thouless, F. Duncan M. Haldane and J. Michael Kosterlitz, alumni of the ancient university of Cambridge who all now work at US universities, will share the prize for their discoveries on abrupt changes in the properties, or phases of ultrathin materials such as superconductors, superfluids or thin magnetic films. Their research centres on topology, a branch of mathematics involving step-wise changes like making a series of holes in an object.

David J. Thouless

In the early 1970s, Kosterlitz and Thouless demonstrated that superconductivity could occur at low temperatures and also explained the mechanism, phase transition, that makes superconductivity disappear at higher temperatures. In the 1980s, Thouless showed that the integers by which the conductivity of electricity could be measured were topological in their nature. Around that time, Haldane discovered how topological concepts could be used to understand the properties of chains of small magnets found in some materials. "We now know of many topological phases, not only in thin layers and threads, but also in ordinary three-dimensional materials," the committe said.

F. Duncan M. Haldane

"Thanks to their pioneering work, the hunt is now on for new and exotic phases of matter," the Royal Swedish Academy of Sciences said while awarding the 8 million Swedish crown ($937,000) prize to the trio. "Many people are hopeful of future applications in both material science and electronics."Thouless was awarded half the prize, with the other half divided between Haldane and Kosterlitz. "Suddenly, people are realising that the topological effects in quantum mechanics are just a tremendously rich subject," said 65-year-old Haldane.

At a news conference in Stockholm, Thors Hans Hansson, a member of the Nobel physics committee, used a bagel, a pretzel and a cinnamon bun to explain topology . While the items vary across many variables, a topologist focuses only on the holes: The pretzel has two, the bagel has one, and the bun has none. "Things like taste or shape or deformation can change continuously, but the number of holes -something that we call the topological invariant -can only change by integers, like 1, 2, 3, 0," he said. Andy Schofield, a professor of theoretical physics t the University of Birmingham, where Kosterlitz and Thouless carried out their early work, said the new understanding of phase states was particularly promising in computing. "One of the most exciting technological implications is in insulators that don't carry electricity normally but can be forced to carry electrical current at the surface," he said.

J. Michael Kosterlitz

"That's a very robust state, which gives a stability that is essential to quantum computing." There had been speculation this year's prize might be awarded for the first detection of gravitational waves. The ancient university of Cambridge on Tuesday hailed three of its alumni named as winners of the 2016 Nobel Prize for physics, making them the 93rd, 94th and 95th Nobel affiliates in its history of more than 800 years.

Announcing the physics prize, the Nobel committee said: “This year’s Laureates opened the door on an unknown world where matter can assume strange states. They have used advanced mathematical methods to study unusual phases, or states of matter, such as superconductors, superfluids or thin magnetic films.

☺☺

CLASS XI Series 5

ACE YOUR WAY CBSE

Mechanical Properties of Fluids
Thermal Properties of Matter

Time Allowed : 3 hours
Maximum Marks : 70

GENERAL INSTRUCTIONS

(i) All questions are compulsory.
(ii) Q. no. 1 to 5 are very short answer questions and carry 1 mark each.
(iii) Q. no. 6 to 10 are short answer questions and carry 2 marks each.
(iv) Q. no. 11 to 22 are also short answer questions and carry 3 marks each.
(v) Q. no. 23 is a value based question and carries 4 marks.
(vi) Q. no. 24 to 26 are long answer questions and carry 5 marks each.
(vii) Use log tables if necessary, use of calculators is not allowed.

SECTION-A

1. Animals curl into a ball, when they feel very cold why?

2. Water rises to a height of 20 mm in a capillary. If the radius of the capillary is made $\frac{1}{3}$ rd of its previous value, to what height will the water now rise in the tube?

3. Why iron rings are heated red hot before being put on the cart wheels ?

4. What is the basic condition for Newton's law of cooling to be obeyed?

5. The temperature gradient in a rod 0.5 m long is 40° C per metre. The temperature of the hotter end is 30° C. What is the temperature of its colder end?

SECTION-B

6. A bubble having surface tension S and radius R is formed on a ring of radius b ($b<<R$). Air is blown inside the tube with velocity v as shown. The air molecule collides perpendicularly with the wall of the bubble and stops. Calculate the radius at which the bubble separates from the ring.

7. Explain the effect of (a) density (b) temperature and (c) pressure on the viscosity of liquids and gases.

8. The stream of water flowing at high speed from a garden hose pipe tends to spread like a fountain when held vertically up, but tends to narrow down when held vertically down. Explain how?

9. Iceberg floats in water with part of it submerged. What is the fraction of the volume of iceberg submerged if the density of ice is $\rho_i = 0.917$ g cm^{-3}?

OR

Two exactly identical rain drops falling with terminal velocity of $2^{1/3}$ m s^{-1} coalesce to form a bigger drop. Find the new terminal velocity of the bigger drop.

10. These days people use steel utensils with copper bottom. This is supposed to be good for uniform heating of food. Explain this effect using the fact that copper is the better conductor.

SECTION-C

11. If a drop of liquid breaks into smaller droplets, it results in lowering of temperature of the droplets. Let a drop of radius R, break into N small droplets each of radius r. Estimate the drop in temperature.

12. Two narrow bores of diameters 3.0 mm and 6.0 mm are joined together to form a U-tube open at both ends. If the U-tube contains water, what is the difference in its levels in the two limbs of the tube? Surface tension of water at the temperature of the experiment is 7.3×10^{-2} N m^{-1}. Take the angle of contact to be zero and density of water to be 1.0×10^3 kg m^{-3} ($g = 9.8$ m s^{-2}).

13. A rail track made of steel having length 10 m is clamped on a railway line at its two ends. On a summer day due to rise in temperature by 20 °C, it is deformed as shown in figure. Find x (displacement of the centre) if coefficient of linear expansion of steel is, $\alpha_{steel} = 1.2 \times 10^{-5}$ °C^{-1}.

14. The cylindrical tube of a spray pump has a cross-section of 8.0 cm^2 on one end of which has 40 fine holes each of diameter 1.0 mm. If the flow of liquid inside the tube is 1.5 m min^{-1}, what is the speed of ejection of the liquid through the holes?

15. A sphere is dropped under gravity through a fluid of viscosity η. Taking the average acceleration as half of the initial acceleration, show that the time to attain the terminal velocity is independent of the fluid density.

16. The coefficient of cubical expansion of glass and mercury being 25×10^{-6} °C^{-1} and 18×10^{-5} °C^{-1} respectively, what fraction of the whole volume of glass vessel should be filled with mercury in order that the volume of the empty part should remain constant when the glass and mercury are heated to the same temperature?

17. An electric drill of output 0.2 hp is used to drill a hole in 100 g of iron. It takes 20 s to drill the hole. Assuming that all the energy spent is absorbed by the iron, calculate its rise in temperature. Given specific heat of iron = 450 J kg^{-1} °C^{-1}, 1 hp = 750 W.

18. Water is boiled in a rectangular steel tank of thickness 2 cm by a constant temperature furnace. Due to vaporisation, water level falls at a steady rate of 1 cm in 9 minutes. Calculate the temperature of furnace. Given k for steel = 0.2 cgs units.

19. In a test experiment on a model aeroplane in a wind tunnel, the flow speeds on the upper and lower surfaces of the wing are 70 m s^{-1} and 63 m s^{-1} respectively. What is the lift on the wing if its area is 2.5 m^2? Take the density of air to be 1.3 kg m^{-3}.

OR

A U-shaped wire is dipped in a soap solution, and removed. The thin soap film formed between the wire and the light slider supports a weight of 1.5×10^{-2} N (which includes the small weight of the slider). The length of the slider is 30 cm. What is the surface tension of the film?

20. Find out the increase in moment of inertia I of a uniform rod (coefficient of linear expansion α) about its perpendicular bisector when its temperature is slightly increased by ΔT.

21. Derive an expression for rate of flow of fluid as measured by venturimeter.

22. Figure shows a system of two concentric spherical shells of radii r_1 and r_2 and kept at temperatures T_1 and T_2 respectively. Find the radial rate of flow of heat through a substance of thermal conductivity K filled in the space between the two shells.

SECTION-D

23. Having found his mother suffering from fever Ram took her to the doctor for treatment. While checking the status, the doctor used a thermometer to know the temperature of the body. He kept the thermometer in the mouth of the patient and noted the reading as 102 °F. Doctor gave the necessary medicines. After coming home, Ram asked his mother, why mercury is used in thermometer when there are so many liquids. Then his mother explained the reason.

(a) Comment upon the values of the mother.
(b) Why mercury is used in thermometer?
(c) What is Ram's mother temperature in °C?

SECTION-E

24. An iron bar (L_1 = 0.1 m, A_1 = 0.02 m^2, K_1 = 79 W m^{-1} K^{-1}) and a brass bar (L_2 = 0.1 m, A_2 = 0.02 m^2, K_2 = 109 W m^{-1} K^{-1}) are soldered end to end as shown in figure. The free ends of the iron bar and brass bar are maintained at 373 K and 273 K respectively. Obtain expressions for and hence compute (a) the temperature of the junction of the two bars, (b) the equivalent thermal conductivity of the compound bar, and (c) the heat current through the compound bar.

OR

A cylindrical tank 1 m in radius rests on a platform of height 5 m. Initially the tank is filled with water upto a height 5 m. A plug whose area is 10^{-4} m^2 is removed from the orifice in the side of the tank at the bottom. Calculate : (a) initial speed with which water flows from the orifice (b) speed with which the water strikes the ground and (c) time taken to empty the tank to half of its original volume.
Take g = 10 m s^{-2}.

25. A hot air balloon is a sphere of radius 8 m. The air inside is at a temperature of 60 °C. How large a mass can the balloon lift when the outside temperature is 20 °C? (Assume air is an ideal gas,
R = 8.314 J mole^{-1}K^{-1}, 1 atm. = 1.013 × 10^5 Pa; the membrane tension is 5 N m^{-1}.)

OR

(a) Pressure decreases as one ascends the atmosphere. If the density of air is ρ, what is the change in pressure dP over a differential height dh?
(b) Considering the pressure P to be proportional to the density, find the pressure P at a height h if the pressure on the surface of the earth is P_0.
(c) If P_0 = 1.013 × 10^5 N m^{-2}, ρ_0 = 1.29 kg m^{-3} and g = 9.8 m s^{-2}, at what height will the pressure drop to (1/10) the value at the surface of the earth? [Given that log(1/10) = –2.30]
(d) This model of the atmosphere works for relatively small distances. Identify the underlying assumption that limits the model.

26. According to Stefan's law of radiation, a black body radiates energy σT^4 from its unit surface area every second where T is the surface temperature of the black body and σ = 5.67 × 10^{-8} W m^{-2} K^{-4} is known as Stefan's constant. A nuclear weapon may be thought of as a ball of radius 0.5 m. When detonated, it reaches temperature of 10^6 K and can be treated as a black body.
(a) Estimate the power it radiates.
(b) If surrounding has water at 30 °C, how much water can 10% of the energy produced evaporate in 1 s?
[c_w = 4186.0 J kg^{-1} K^{-1} and L_v = 22.6 × 10^5 J kg^{-1}]
(c) If all this energy U is in the form of radiation, corresponding momentum is $p = U/c$. How much momentum per unit time does it impart on unit area at a distance of 1 km?

OR

We would like to make a vessel whose volume does not change with temperature. We can use brass and iron (γ_B = 6 × 10^{-5} K^{-1} and γ_I = 3.55 ×10^{-5} K^{-1}) to create a volume of 100 cc. How do you think you can achieve this?

SOLUTIONS

1. When the animals feel cold, they curl their bodies into the ball so as to decrease the surface area of their bodies. As total energy radiated by a body varies directly as the surface area of the body, the loss of heat due to radiation would be reduced.

2. As $h \propto \frac{1}{R}$

$$\therefore \quad \frac{h'}{h} \propto \frac{R}{R'} \quad \text{or} \quad h' = \frac{Rh}{R'}$$

For a capillary tube of radius $\frac{R}{3}$, we have

$$h' = \frac{R}{\frac{1}{3}R} h = 3 \times 20 \text{ mm} = 60 \text{ mm}$$

3. The iron ring to be put on the rim of a cart wheel is always of slightly smaller diameter than that of the wheel. When the iron ring is heated to become red hot, it expands and slips on to the wheel easily. When it is cooled, it contracts and grips the wheel firmly.

4. Newton's law of cooling will be obeyed if the temperature difference between body and surrounding is small, *i.e.,* not more than 40 °C.

5. As temperature gradient $= \dfrac{T_1 - T_2}{x}$,

where, $T_1 = 30$ °C, $x = 0.5$ m, $T_2 = ?$

Temperature of colder end = 30 – 0.5 × 40 = 10 °C

6. The bubble will separate from the ring when

$$2\pi b \times 2S \sin\theta = \rho A v^2$$

or $\quad 4\pi bS \times \dfrac{b}{R} = \rho \times \pi b^2 \times v^2$ or $R = \dfrac{4S}{\rho v^2}$

7. (a) In case of liquids, viscosity increases with increase in density and for gases, it decreases with increases in density.

(b) With the rise in temperature, the viscosity of liquid decreases while that of gases increases.

(c) With the increase in pressure, the viscosity of liquids (except water) increases while that of gases is practically independent of pressure. The viscosity of water decreases with the increase in pressure.

8. As the stream falls, its speed v will increase and hence its area of cross-section a will decrease, according to equation of continuity, *i.e.,* av = constant. That is why the stream will become narrow.

When the stream will go up, its speed will decrease, hence its area of cross-section will increase, *i.e.,* it will become broader and spreads out like a fountain.

9. Here, $\rho_i = 0.917$ g cm^{-3}, $\rho_w = 1$ g cm^{-3}

Let V_i = Volume of iceberg

V_w = Volume of water displaced by iceberg;

Weight of iceberg, $W = \rho_i V_i g$

Upthrust, $F_B = \rho_w V_w g$

At equilibrium, $W = F_B$

$\Rightarrow \quad \rho_i V_{i\,G} = \rho_w V_w G$

$\Rightarrow \quad \dfrac{V_w}{V_i} = \dfrac{\rho_i}{\rho_w} = \dfrac{0.917}{1} = 0.917$

OR

Volume of a bigger drop = (Volume of raindrop) × 2

$$\frac{4\pi}{3}R^3 = 2\left(\frac{4\pi}{3}r^3\right) \text{ or } R = 2^{1/3}r$$

Terminal velocity of each small drop is given by

$$v = \frac{2}{9}\frac{r^2}{\eta}(\rho - \rho')g \quad \text{...(i)}$$

Terminal velocity of a bigger drop is given by

$$V = \frac{2}{9}\frac{R^2}{\eta}(\rho - \rho')g \quad \text{...(ii)}$$

Dividing equation (ii) by (i), we get

$\dfrac{V}{v} = \dfrac{R^2}{r^2}$, But $R = 2^{1/3}r$ and $v = 2^{1/3}$ m s^{-1}

$$\therefore \quad V = \frac{v \times R^2}{r^2} = \frac{2^{2/3}\,r^2}{r^2}.2^{1/3} = 2 \text{ m s}^{-1}$$

10. Since copper has a high conductivity compared to steel, the junction of copper and steel gets heated quickly but steel does not conduct as quickly, thereby allowing food inside to get heated uniformly.

11. Volume of liquid drop of radius R

= (Volume of liquid droplet of radius r) × N

$$\Rightarrow \quad \frac{4}{3}\pi R^3 = N \times \frac{4}{3}\pi r^3 \Rightarrow r = \frac{R}{(N)^{1/3}} \quad \text{...(i)}$$

Let, surface energy = T

Change in the internal energy,

$$\Delta U = T \times \Delta A = T[4\pi R^2 - N(4\pi r^2)]$$
$$= 4\pi T(R^2 - Nr^2)$$

As $\quad \Delta U = mc\Delta T$

$$\Delta T = \frac{\Delta U}{mc} = \frac{4\pi T(R^2 - Nr^2)}{\left(\frac{4}{3}\pi R^3\right)\rho c}$$

[$\because$ ρ = density of liquid]

$$\Rightarrow \quad \Delta T = \frac{3T}{\rho c}\left(\frac{1}{R} - N\frac{r^2}{R^3}\right)$$

$$\Rightarrow \quad \Delta T = \frac{3T}{\rho c}\left(\frac{1}{R} - \frac{1}{r}\right) \quad \text{[Using eqn. (i)]}$$

$$\because \quad R > r \Rightarrow \frac{1}{R} < \frac{1}{r} \Rightarrow \left(\frac{1}{R} - \frac{1}{r}\right) < 0$$

$\therefore$ ΔT will be negative. Hence, temperature of droplet falls.

12. Here, $S = 7.3 \times 10^{-2}$ N m^{-1};

$\rho = 1.0 \times 10^3$ kg m^{-3}; $\theta = 0°$

For narrow tube, $2r_1 = 3.00$ mm $= 3 \times 10^{-3}$ m

or $r_1 = 1.5 \times 10^{-3}$ m

For wider tube, $2r_2 = 6.00$ mm $= 6 \times 10^{-3}$ m

or $r_2 = 3 \times 10^{-3}$ m

Let h_1, h_2 be the heights to which water rises in narrow tube and wider tube respectively

Then, $h_1 = \dfrac{2S\cos\theta}{r_1\rho g}$ and $h_2 = \dfrac{2S\cos\theta}{r_2\rho g}$

$\therefore$ Difference in levels of water in two limbs of U tube is,

$$h_1 - h_2 = \frac{2S\cos\theta}{\rho g}\left[\frac{1}{r_1} - \frac{1}{r_2}\right]$$

$$= \frac{2\times 7.3\times 10^{-2}\times\cos 0°}{10^3\times 9.8}\times\left[\frac{1}{1.5\times 10^{-3}} - \frac{1}{3\times 10^{-3}}\right]$$

$= 4.97 \times 10^{-3}$ m

13. From figure,

$$x^2 = \left(\frac{L+\Delta L}{2}\right)^2 - \left(\frac{L}{2}\right)^2$$

$$\Rightarrow \quad x = \sqrt{\left(\frac{L+\Delta L}{2}\right)^2 - \left(\frac{L}{2}\right)^2}$$

$$= \sqrt{\left(\frac{L}{2}\right)^2 + \frac{2L\Delta L}{4} + \left(\frac{\Delta L}{2}\right)^2 - \left(\frac{L}{2}\right)^2}$$

Since ΔL is a small quantity, the term with ΔL^2 being very very small can be neglected.

$$\therefore \quad x = \sqrt{\frac{L\Delta L}{2}} = \sqrt{\frac{L(L\alpha\Delta T)}{2}} = L\sqrt{\frac{\alpha\Delta T}{2}}$$

Given, $L = 10$ m, $\alpha = 1.2 \times 10^{-5}$ °C^{-1}, $\Delta T = 20$ °C

$$\text{Hence, } x = 10\sqrt{\frac{1.2\times 10^{-5}\times 20}{2}}$$

$= 10 \times 1.1 \times 10^{-2}$ m $= 0.11$ m $= 11$ cm

14. Here, cross-section of the tube,

$a_1 = 8.0$ cm^2 $= 8.0 \times 10^{-4}$ m^2;

The speed of liquid in the tube,

$$v_1 = 1.5 \text{ m min}^{-1} = \frac{1.5}{60} \text{ m s}^{-1} = 0.025 \text{ m s}^{-1}$$

diameter of a hole, $D = 1.0$ mm $= 10^{-3}$ m

Therefore, cross-section of a hole,

$$\frac{\pi D^2}{4} = \frac{\pi}{4}\times(10^{-3})^2 = \frac{\pi}{4}\times 10^{-6} \text{ m}^2$$

Therefore, total cross-section of 40 holes,

$$a_2 = \frac{\pi}{4}\times 10^{-6}\times 40 \text{ m}^2$$

If v_2 is the speed of ejection of the liquid through the holes, then $a_1v_1 = a_2v_2$

$$\text{or} \quad v_2 = \frac{a_1v_1}{a_2} = \frac{8.0\times 10^{-4}\times 0.025}{(\pi/4)\times 10^{-6}\times 40} = 0.637 \text{ m s}^{-1}$$

15. Let, r = radius of the sphere

ρ, σ = densities of the sphere and fluid respectively

a = initial acceleration of the sphere when it just enters the fluid

v_t = terminal velocity of the sphere

Net downward force (F) acting on the sphere as it just enters the fluid = weight of the sphere – weight of the fluid displaced by the sphere

$$i.e., \quad F = \frac{4\pi}{3}r^3\rho g - \frac{4\pi}{3}r^3\sigma g = \frac{4\pi}{3}r^3 g(\rho-\sigma)$$

$$\text{Thus, } a = \frac{F}{m} = \frac{\frac{4}{3}r^3 g(\rho-\sigma)}{\frac{4\pi}{3}r^3\rho} = \frac{(\rho-\sigma)g}{\rho}$$

When the sphere attains terminal velocity its acceleration becomes zero. Thus,

$$\text{average acceleration} = \frac{a+0}{2} = \frac{a}{2}$$

Let t be the time taken by the sphere to attain terminal velocity (v_t).

From $v = v_0 + at$, $\quad v_t = \dfrac{at}{2}$

(as initial velocity v_0 of the sphere is zero, $v = v_t$)

$$\text{or} \quad t = \frac{2v_t}{a} = \frac{2\left(\frac{2r^2(\rho-\sigma)g}{9\eta}\right)}{(\rho-\sigma)g/\rho}$$

$$t = \frac{4r^2\rho}{9\eta}$$

Clearly, t is independent of σ (the fluid density)

16. Here, $\gamma_g = 25 \times 10^{-6}$ °C^{-1}

$\gamma_m = 18 \times 10^{-5}$ °C^{-1}

Let V_0 be the total internal volume of the glass vessel at 0 °C and v be the volume filled with mercury.

At t °C, the volume of the vessel $= V_0(1 + \gamma_g t)$

At t °C, the volume of the mercury $= v(1 + \gamma_m t)$

Volume of the empty part at t °C

$= V_0(1 + \gamma_g t) - v(1 + \gamma_m t)$

$= (V_0 - v) + (V_0\gamma_g - v\gamma_m)t$

As the volume of the empty part ($V_0 - v$) is to remain constant,

$$(V_0\,\gamma_g - v\,\gamma_m)t = 0$$

Thus, the required fraction,

$$\frac{v}{V_0} = \frac{\gamma_g}{\gamma_m} = \frac{25\times10^{-6}\ °C^{-1}}{18\times10^{-5}\ °C^{-1}} = 0.139$$

17. Power of the drill,

$$P = 0.2\ \text{hp} = (0.2)\ (750\ \text{W}) = 150\ \text{W}$$

Work done (W) by the drill in 20 second = $P \times 20$ s (as P = work/time)

or $W = (150\ \text{W})\ (20\ \text{s}) = 3000\ \text{J}$ ...(i)

Mass of iron, $m = 100\ \text{g} = 0.1\ \text{kg}$

Specific heat of iron, $c = 450\ \text{J kg}^{-1}\ °\text{C}^{-1}$

If ΔT is the rise in temperature of iron,

$$Q = mc\,\Delta T$$
$$= 0.1\ \text{kg} \times 450\ (\text{J kg}^{-1}\ °\text{C}^{-1}) \times \Delta T\ (°\text{C}^{-1})$$
$$= (45\ \Delta T)\ \text{J} \quad ...(ii)$$

From eqns. (i) and (ii), $(45\ \Delta T)\ \text{J} = 3000\ \text{J}$

or $45\ \Delta T = 3000$

or $\Delta T = \dfrac{3000}{45}\ °\text{C} = 66.7\ °\text{C}$

18. Let A cm^2 be the surface area of the bottom of the tank which is in contact with the furnace.

Volume of water evaporating in a time t (9 minute = 540 s)

= area × thickness of water layer

$= (A\ \text{cm}^2)\ (1\ \text{cm}) = A\ \text{cm}^3$

Mass of water evaporating in the time t

$= (A\ \text{cm}^3)\ (1\ \text{g cm}^{-3}) = A\ \text{g}$

Amount of heat required to evaporate A g of water, *i.e.*,

$$Q = AL = (A\ \text{g})\ (540\ \text{cal g}^{-1})$$

[As L, latent heat of steam = 540 cal g^{-1}]

$= 540\ A$ cal ...(i)

Let T_1 be the temperature of the furnace and T_2 that of boiling water. Therefore, $T_1 - T_2 = (T_1 - 100)$

Thickness of the tank, $x = 2$ cm

As $Q = \dfrac{kA(T_1 - T_2)t}{x}$, ...(ii)

From eqns. (i) and (ii),

$$\frac{kA(T_1 - T_2)t}{x} = 540A$$

or $(T_1 - T_2) = \dfrac{540Ax}{kAt} = \dfrac{540x}{kt}$

or $T_1 - 100 = \dfrac{540\times2}{0.2\times540} = 10$

or $T_1 = (100 + 10)\ °\text{C} = 110\ °\text{C}$

19. Let v_1 and v_2 be the speeds on the upper and lower surfaces of the wings of the aeroplane respectively, P_1 and P_2 be the pressures on the upper and lower surfaces of the wings respectively.

Here, $v_1 = 70\ \text{m s}^{-1}$; $v_2 = 63\ \text{m s}^{-1}$; $\rho = 1.3\ \text{kg m}^{-3}$

The level of the upper and lower surfaces of the wings from the ground may be taken same.

$\therefore\ h_1 = h_2$

Area of wing, $A = 2.5\ \text{m}^2$

Thus from Bernoulli's theorem,

$$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2$$

or $P_2 - P_1 = \dfrac{1}{2}\rho(v_1^2 - v_2^2)$ ...(i)

This pressure difference provides the lift to the aeroplane.

If F be the lift on the wing, then

$$F = (P_2 - P_1) \times A = \frac{1}{2}\rho(v_1^2 - v_2^2)\times A$$

[by using (i)]

$$= \frac{1}{2}\times1.3\times(70^2 - 63^2)\times2.5$$
$$= \frac{1}{2}\times1.3\times931\times2.5 = 1512.9\ \text{N}$$
$$= 1.5 \times 10^3\ \text{N}$$

OR

We know that a soap film has two free surfaces, so total length of the film, $l = 2 \times 30$ cm

or $l = 60\ \text{cm} = 0.60\ \text{m}$

Let S = Surface tension of the film

If F = Total force on the slider due to surface tension, then

$$F = S \times 2l = T \times 0.6\ \text{N}$$
$$W = 1.5 \times 10^{-2}\ \text{N}$$

In equilibrium position, the force F on the slider due to surface tension must be balanced by the weight (W) supported by the slider.

i.e., $F = W = mg$

or $T \times 0.6 = 1.5 \times 10^{-2}$

$\therefore\ T = \dfrac{1.5\times10^{-2}}{0.6} = 2.5\times10^{-2}\ \text{N m}^{-1}$

20. Let M = Mass of rod, L = Length of rod

Moment of inertia of a uniform rod about its perpendicular bisector,

$$I = \frac{1}{12}ML^2$$

ΔT = Increase in the temperature of the rod.

$\therefore$ Changed length, $L' = L(1 + \alpha\Delta T)$ ...(i)

$\therefore$ New moment of inertia of rod,

$$I' = \frac{ML'^2}{12} = \frac{M}{12}[L(1+\alpha\Delta T)]^2 \qquad \text{[Using (i)]}$$

$$= \frac{ML^2}{12}[1+2\alpha\Delta T+\alpha^2(\Delta T)^2]$$

$\therefore$ $I' = I[1 + 2\alpha\Delta T]$ $\quad (\because \alpha^2(\Delta T)^2$ is very small)

$\therefore$ Increase in moment of inertia,

$= I' - I = I[1 + 2\alpha\Delta T] - I = 2\alpha I\Delta T$

21. Let the liquid velocities be v_1 and v_2 at the wider and the narrow portions. Let P_1 and P_2 be the liquid pressures at these regions. By the equation of continuity,

$$a_1 v_1 = a_2 v_2 \quad \text{or} \quad \frac{a_1}{a_2} = \frac{v_2}{v_1}$$

If the liquid has density ρ and is flowing horizontally, then from Bernoulli's equation.

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

$$\text{or} \quad P_1 - P_2 = \frac{1}{2}\rho(v_2^2 - v_1^2) = \frac{1}{2}\rho v_1^2\left(\frac{v_2^2}{v_1^2} - 1\right)$$

$$= \frac{1}{2}\rho v_1^2\left(\frac{a_1^2}{a_2^2} - 1\right) \qquad \left[\because \frac{v_2}{v_1} = \frac{a_1}{a_2}\right]$$

$$= \frac{1}{2}\rho v_1^2\left(\frac{a_1^2 - a_2^2}{a_2^2}\right)$$

If h is the height difference in the two arms of the manometer tube, then

$P_1 - P_2 = h\rho_m g$

$$\therefore \quad h\rho_m g = \frac{1}{2}\rho v_1^2\left(\frac{a_1^2 - a_2^2}{a_2^2}\right)$$

$$\therefore \quad v_1 = \sqrt{\frac{2h\rho_m g}{\rho} \times \frac{a_2^2}{a_1^2 - a_2^2}}$$

Volume of the liquid flowing out per second,

$$Q = a_1 v_1 = a_1 a_2\sqrt{\frac{2h\rho_m g}{r(a_1^2 - a_2^2)}}$$

22. Consider a thin concentric shell of radius r and thickness dr. The radial rate of flow of heat through this elementary shell will be

$$H = -KA\frac{dT}{dr} = -K\,4\pi r^2\frac{dT}{dr} \quad \text{or} \quad H\frac{dr}{r^2} = -4\pi K\,dT$$

Integrating both sides between the limits of radii and temperatures of the two shells, we get

$$H\int_{r_1}^{r_2} r^{-2}dr = -4\pi K\int_{T_1}^{T_2} dT$$

$$\text{or} \quad H\left[\frac{r^{-1}}{-1}\right]_{r_1}^{r_2} = -4\pi K[T]_{T_1}^{T_2}$$

$$\text{or} \quad H\left[-\frac{1}{r}\right]_{r_1}^{r_2} = 4\pi K[-T]_{T_1}^{T_2}$$

$$\text{or} \quad H\left[\frac{1}{r_1} - \frac{1}{r_2}\right] = 4\pi K(T_1 - T_2)$$

$$\text{or} \quad H = \frac{4\pi K\, r_1 r_2(T_1 - T_2)}{(r_2 - r_1)}$$

23. (a) Mother has interest in educating her son. She is a kind and loving mother. She has a good knowledge of science.

(b) Mercury has got the following properties for being used in thermometers.

(i) The expansion of Mercury is fairly regular and uniform.

(ii) It is opaque and shining, hence can be easily seen through the glass tube.

(iii) Mercury is a good conductor of heat and has low thermal capacity,

(iv) Mercury does not wet the sides of the glass tube in which it is filled.

(c) $\dfrac{t_F - 32}{180} = \dfrac{t_C}{100}$

Here, $t_F = 102$ °F

$$\Rightarrow \quad t_C = \left(\frac{102 - 32}{180}\right)\times 100 = 38.9\,°\text{C}$$

24. (a) Here,

$L_1 = L_2 = L = 0.1$ m, $A_1 = A_2 = A = 0.02$ m^2,
$K_1 = 79$ W m^{-1} K^{-1}, $K_2 = 109$ W m^{-1} K^{-1},
$T_1 = 373$ K, and $T_2 = 273$ K

In the steady state,

Heat current through = Heat current through
iron bar brass bar

or $H_1 = H_2 = H$ (say)

or $\dfrac{K_1A_1(T_1 - T_0)}{L_1} = \dfrac{K_2A_2(T_0 - T_2)}{L_2}$

or $\dfrac{K_1A(T_1 - T_0)}{L} = \dfrac{K_2A(T_0 - T_2)}{L}$

or $K_1(T_1 - T_0) = K_2(T_0 - T_2)$

Thus the junction temperature T_0 of the two bars is $T_0 = \dfrac{(K_1T_1 + K_2T_2)}{(K_1 + K_2)}$

Using this value of T_0, the heat current through either bar will be

$$H = \frac{K_1A(T_1 - T_0)}{L} = \frac{K_1A}{L}\left(T_1 - \frac{K_1T_1 + K_2T_2}{K_1 + K_2}\right)$$

$$= \frac{K_1K_2A}{K_1 + K_2} \cdot \frac{T_1 - T_2}{L}$$

Thus, the heat current H' through the compound bar of length $L_1 + L_2 = 2L$ and the equivalent thermal conductivity K', of the compound bar are given by $H' = H$

or $\dfrac{K'A(T_1 - T_2)}{2L} = \dfrac{K_1K_2A}{K_1 + K_2} \cdot \dfrac{T_1 - T_2}{L}$

or $K' = \dfrac{2K_1K_2}{K_1 + K_2}$

(a) $T_0 = \dfrac{(K_1T_1 + K_2T_2)}{(K_1 + K_2)}$

$$= \frac{(79\,\text{W m}^{-1}\,\text{K}^{-1})(373\,\text{K}) + (109\,\text{W m}^{-1}\,\text{K}^{-1})(273\,\text{K})}{79\,\text{W m}^{-1}\,\text{K}^{-1} + 109\,\text{W m}^{-1}\,\text{K}^{-1}}$$

$= 315$ K

(b) $K' = \dfrac{2K_1K_2}{K_1 + K_2}$

$$\frac{2 \times (79\,\text{W m}^{-1}\,\text{K}^{-1}) \times (109\,\text{W m}^{-1}\,\text{K}^{-1})}{79\,\text{W m}^{-1}\,\text{K}^{-1} + 109\,\text{W m}^{-1}\,\text{K}^{-1}}$$

$= 91.6\ \text{m}^{-1}\,\text{K}^{-1}$

(c) $H' = H = \dfrac{K'A(T_1 - T_2)}{2L}$

$$= \frac{(91.6\,\text{W m}^{-1}\,\text{K}^{-1}) \times (0.02\,\text{m}^2) \times (373\,\text{K} - 273\,\text{K})}{2(0.1\,\text{m})}$$

$= 916.1$ W

OR

(a) Initial speed with which water flows from orifice,

i.e., $v_0 = \sqrt{2gh_0} = \sqrt{2 \times 10 \times 5}\ \text{m s}^{-1} = 10\ \text{m s}^{-1}$

(b) Speed with which water strikes the ground *i.e.*,

$v = \sqrt{2g(h_0 + H)}$

$= \sqrt{2 \times 10\,(5 + 5)}\ \text{m s}^{-1} = 14.1\ \text{m s}^{-1}$

(c) Let h be the height of water inside the tank at any instant t.

Speed of efflux of water through the hole at the bottom at the instant, t, *i.e.*, $v' = \sqrt{2gh}$

Volume of water flowing through the hole in time dt, *i.e.*, $dV = (av')\,dt = (a\sqrt{2gh})\,dt$

If the level of water in the tank is lowered by dh, volume of the liquid that flows out in time dt, *i.e.*,

$dV = -A\,dh$ (negative sign shows decrease in h)

or $(a\sqrt{2gh})dt = -A\,dh$

or $dt = -\left(\dfrac{A}{a\sqrt{2g}}\right)\dfrac{dh}{\sqrt{h}}$ ...(ii)

$$T = \frac{A}{a}\sqrt{\frac{2}{g}}\int_{h_0/2}^{h_0}\frac{dh}{\sqrt{h}}$$

$$= \frac{A}{a}\sqrt{\frac{2}{g}}(\sqrt{h_0} - \sqrt{h_0/2})$$

$$= \left[\frac{\pi \times (1)^2}{10^{-4}}\sqrt{2/10}(\sqrt{5} - \sqrt{5/2})\right]\text{s}$$

$$= \left[\pi\left(1 - \frac{1}{\sqrt{2}}\right) \times 10^4\right]\text{s} = 9194\ \text{s} = 2\ \text{h}\ 33\ \text{min},\ 14\ \text{s}$$

25. For n_i moles of air inside the balloon,

$P_iV = n_iRT_i$

or $n_i = \dfrac{P_iV}{RT_i}$

If M_A is the molar mass of air,

mass of air inside the balloon, *i.e*,

$$M_i = n_iM_A = \left(\frac{P_iV}{RT_i}\right)M_A = \frac{M_AV}{R}\left(\frac{P_i}{T_i}\right)$$

Mass of outside air (of volume V) displaced by the balloon, *i.e.*,

$$M_0 = \frac{M_AV}{R}\left(\frac{P_0}{T_0}\right)$$

If W is load that the balloon can lift, then from figure,

$W + M_i g = M_0 g$

or $W = (M_0 - M_i)g = \dfrac{M_AV}{R}\left(\dfrac{P_0}{T_0} - \dfrac{P_i}{T_i}\right)g$ ... (i)

Further, pressure inside the balloon due to membrane tension $(S) = \dfrac{2S}{r}$

$$= \frac{2\times 5\ \text{N m}^{-1}}{8\ \text{m}} = 1.25\ \text{N m}^{-2}$$

This can be neglected as compared to 1 atm

$(= 1.013 \times 10^5\ \text{N m}^{-2})$

We know that

$T_0 = 20 + 273 = 293$ K,

$T_i = 60 + 273 = 333$ K

$r = 8$ m, $V = \dfrac{4\pi}{3}r^3 = 2.144\times 10^3\ \text{m}^3$

$P_0 = P_i = 1.013 \times 10^5\ \text{N m}^{-2}$

$M_A = 21\%$ of $O_2 + 79\%$ of N_2

$= 0.21 \times 32\ \text{g} + 0.79 \times 28\ \text{g}$

$= 28.84\ \text{g mol}^{-1}$

$= 28.84 \times 10^{-3}\ \text{kg mol}^{-1}$

From eqn. (i),

$$W = \left[\frac{(28.84\times 10^{-3}\text{kg mol}^{-1})(2.144\times 10^3\text{m}^3)}{8.314\ \text{J mol K}^{-1}}\right] \times \left[\frac{1.013\times 10^5\ \text{N m}^{-2}}{293\ \text{K}} - \frac{1.013\times 10^5\ \text{N m}^{-2}}{333\ \text{K}}\right] \times (9.8\ \text{m s}^{-2})$$

$= 7.44 \times (1.013 \times 10^5)\ (4.1 \times 10^{-4})\ (9.8)$ N

$= 3028$ N

OR

(a) Consider a horizontal layer of air with cross-section A and height dh.

P = Pressure at the top of the layer

$P + dP$ = Pressure at the bottom of the layer

The layer of air is in equilibrium

$\therefore$ Net upward force = net downward force

$\Rightarrow$ $(P + dP)\,A - PA = -\rho g\,Adh$

$\Rightarrow$ $dP = -\rho gdh$

(b) $P \propto \rho$

$$\therefore \quad \frac{\text{Pressure at some height } (P)}{\text{Pressure at the surface of Earth}(P_0)} = \frac{\rho}{\rho_0}$$

$$\rho = \frac{\rho_0 P}{P_0} \qquad \text{...(i)}$$

$$\because \quad dP = -\rho gdh = -\frac{\rho_0}{P_0}Pgdh \qquad \text{[Using equation (i)]}$$

$$\Rightarrow \quad \frac{dP}{P} = -\frac{\rho_0 g}{P_0}dh$$

$$\int_{P_0}^{P}\frac{dP}{P} = -\frac{\rho_0 g}{P_0}\int_0^h dh$$

$$\Rightarrow \quad [\ln P]_{P_0}^{P} = -\frac{\rho_0 g}{P_0}[h]_0^h$$

$$\Rightarrow \quad \ln\frac{P}{P_0} = -\frac{\rho_0 g}{P_0}h \qquad \text{...(ii)}$$

$$\therefore \quad P = P_0\exp\left(\frac{-\rho_0 gh}{P_0}\right)$$

(c) $P_0 = 1.013 \times 10^5\ \text{N m}^{-2}$

$\rho_0 = 1.29\ \text{kg m}^{-3}$, $g = 9.8\ \text{m s}^{-1}$, $P = \dfrac{P_0}{10}$, $h = ?$

Using these values in eqn (ii)

$$\ln\frac{1}{10} = -\frac{1.29\times 9.8}{1.013\times 10^5}h$$

$$\Rightarrow \quad -2.30 = -\frac{12.642}{1.013\times 10^5}h$$

$$\Rightarrow \quad h = \frac{2.3\times 1.013\times 10^5}{12.642} = 0.1843 \times 10^5$$

$\therefore$ $h = 18.43$ km

MPP-5 CLASS XI ANSWER KEY

1.	(a)	**2.**	(a)	**3.**	(b)	**4.**	(c)	**5.**	(b)
6.	(d)	**7.**	(b)	**8.**	(c)	**9.**	(b)	**10.**	(c)
11.	(a)	**12.**	(c)	**13.**	(a)	**14.**	(d)	**15.**	(c)
16.	(b)	**17.**	(a)	**18.**	(d)	**19.**	(d)	**20.**	(c,d)
21.	(b,d)	**22.**	(a,c,d)	**23.**	(b,c)	**24.**	(3)	**25.**	(6)
26.	(5)	**27.**	(b)	**28.**	(d)	**29.**	(a)	**30.**	(a)

(d) The assumption, $P \propto \rho$ is valid only if the temperature is uniform in the air. And temperature is same only over a small distance.

26. (a) Radius of the ball, $r = 0.5$ m

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}, $T = 10^6$ K

Surface area of nuclear weapon,

$A = 4\pi r^2 = 4 \times 3.14 \times (0.5)^2 = 3.14$ m^2

$\therefore$ Power radiated, $P = (\sigma T^4)A$

$= 5.67 \times 10^{-8} \times (10^6)^4 \times 3.14$

$= 1.8 \times 10^{17}$ W

(b) Energy radiated, $E = P \times t$

$= 1.8 \times 10^{17}$ W $\times$ 1 s

$= 1.8 \times 10^{17}$ J

$Q = 10\%$ of $E = 1.8 \times 10^{16}$ J

Also, $Q = mc_w \Delta T + mL_v = m(c_w \Delta T + L_v)$

Here, $c_w = 4186$ J kg^{-1} K^{-1}

$L_v = 22.6 \times 10^5$ J kg^{-1}

$\Delta T = 100 - 30 = 70$ °C $= 343$ K

$$\therefore \quad m = \frac{Q}{(c_w \Delta T + L_v)} = \frac{1.8 \times 10^{16}}{4186 \times 343 + 22.6 \times 10^5}$$

$$= \frac{1.8 \times 10^{16}}{36.96 \times 10^5} = 4.87 \times 10^9 \text{ kg}$$

(c) $\because \quad p = \dfrac{U}{c}$

The radiation spread in an area of $4\pi r^2$

Here, $r = 1$ km $= 10^3$ m

Momentum imparted per unit time on a unit area at a distance r,

$$= \frac{(U/c)}{4\pi r^2 t} = \frac{U}{4\pi c r^2 t} = \frac{p}{4\pi c r^2}$$

$$= \frac{1.8 \times 10^{17}}{4 \times 3.14 \times 3 \times 10^8 \times 10^6} = 47.7 \text{ N m}^{-2}$$

OR

Here, $\gamma_B = 6 \times 10^{-5}$ K^{-1}, $\gamma_I = 3.55 \times 10^{-5}$ K^{-1}

Volume of vessel,

$V_0 = 100$ cm^3 $= 10^{-4}$ m^3 = constant

To make a vessel whose volume does not change, we should have an iron vessel with a brass rod inside as shown in figure.

According to question

Volume of iron vessel (V_I)

– Volume of brass rod (V_B) $= 10^{-4}$ m^3

$\Rightarrow \quad V_I - V_B = 10^{-4}$ m^3 ...(i)

Volume remain constant if, $\gamma_I V_I \Delta T = \gamma_B V_B \Delta T$

$$\therefore \quad V_I = \left(\frac{\gamma_B}{\gamma_I}\right) V_B = \left(\frac{6 \times 10^{-5}}{3.55 \times 10^{-5}}\right) V_B = 1.69\, V_B$$

From equation (i)

$1.69\, V_B - V_B = 10^{-4}$

$$\Rightarrow V_B = \frac{10^{-4}}{0.69} = 1.449 \times 10^{-4} \text{ m}^3$$

$\Rightarrow \quad V_B = 144.9$ cm^3

$\therefore \quad V_I = 1.69\, V_B = 1.69 \times 144.9 = 244.9$ cm^3

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JEE WORK GUTS

ONE OR MORE OPTIONS CORRECT TYPE QUESTIONS **Class-XI**

1. The potential energy of gravitational interaction of a point mass m and a thin uniform rod of mass M and length l, if they are located along a straight line at distance a from each other is

(a) $U = \frac{GMm}{l}\ln\left(\frac{a+l}{a}\right)$ (b) $U = GMm\left(\frac{1}{a} - \frac{1}{a+l}\right)$

(c) $U = -\frac{GMm}{l}\ln\left(\frac{a+l}{a}\right)$ (d) $U = -\frac{GMm}{a}$

2. The rate of flow of glycerine of density 1.25×10^3 kg m^{-3} through the conical section of a pipe, if the radii of its ends are 0.1 m and 0.04 m and the pressure drop across its length is 10 N m^{-2} is

(a) 5.28×10^{-4} m^3 s^{-1} (b) 6.28×10^{-4} m^3 s^{-1}

(c) 7.28×10^{-4} m^3 s^{-1} (d) 8.28×10^{-4} m^3 s^{-1}

3. A train starts from a station with a constant acceleration of 0.40 m s^{-2}. A passenger arrives at a station 6 s after the end of the train left the very same point. What is the least constant speed at which the passenger can run and catch the train?

(a) 0.48 m s^{-1} (b) 48 m s^{-1}

(c) 4.8 m s^{-1} (d) 480 m s^{-1}

4. A box weighing 100 N is at rest on a horizontal floor. The coefficient of static friction between the box and the floor is 0.4. What is the smallest force F exerted eastward and upward at an angle of 30° with the horizontal that can start the box in motion?

(a) 27.5 N (b) 37.5 N

(c) 14.2 N (d) 45.4 N

5. The rope shown at an instant is carrying a wave travelling towards right, created by a source vibrating at a frequency υ. Which of the following statements is correct?

(a) The speed of the wave is $4\upsilon \times ab$.

(b) The phase difference between b and e is $\frac{3\pi}{2}$.

(c) Both (a) and (b) are correct.

(d) Both (a) and (b) are wrong.

6. A spherical soap bubble of radius 1 cm is formed inside another bubble of radius 3 cm. The radius of a single soap bubble which maintains the same pressure difference as inside the smaller and outside the larger soap bubble is

(a) 0.75 cm (b) 0.75 m

(c) 7.5 cm (d) 7.5 m

7. A horizontal stretched string, fixed at two ends, is vibrating in its fifth harmonic according to the equation,

$y(x, t) = (0.01 \text{ m}) \sin[(62.8 \text{ m}^{-1})x] \cos[(628 \text{ s}^{-1})t]$.

Assuming $\pi = 3.14$, the correct statement(s) is (are)

(a) The number of nodes is 5.

(b) The length of the string is 0.25 m.

(c) The maximum displacement of the midpoint of the string, from its equilibrium position is 0.01 m.

(d) The fundamental frequency is 100 Hz.

8. A block of mass m is attached to a massless spring of force constant k, the other end of which is fixed from the wall of a truck as shown in figure. The block is placed over a smooth surface and initially the spring is unstretched. Suddenly the truck starts moving towards right with a constant acceleration a_0. As seen from the truck

(a) the particle will execute SHM

(b) the time period of oscillations will be $2\pi\sqrt{\frac{m}{k}}$

(c) the amplitude of oscillations will be $\frac{ma_0}{k}$

(d) the energy of oscillations will be $\frac{m^2a_0^2}{k}$.

9. Six moles of an ideal gas performs a cycle shown in figure. If $T_A = 600$ K, $T_B = 800$ K, $T_C = 2200$ K and T_D = 1200 K, the work done per cycle is approximately

(a) 20 kJ (b) 30 kJ (c) 40 kJ (d) 60 kJ

10. The length of a sonometer wire AB is 110 cm. Where should the two bridges be placed from A to divide the wire in 3 segments whose fundamental frequencies are in the ratio of 1 : 2 : 3?

(a) 30 cm and 90 cm (b) 40 cm and 80 cm
(c) 60 cm and 90 cm (d) 30 cm and 60 cm

11. Two blocks A and B each of mass m are connected by a massless spring of natural length L and spring constant k. The blocks are initially resting on a smooth horizontal floor with the spring at its natural length as shown in figure. A third identical block C, moving on the floor with a speed v along the line joining A and B, collides with A. Then

(a) The maximum compression of the spring is $v\sqrt{m/k}$

(b) The maximum compression of the spring is $v\sqrt{m/2k}$

(c) The K.E. of A-B system at maximum compression of the spring is zero.

(d) The K.E. of A-B system at maximum compression of the spring is $mv^2/4$.

12. A point P moves in counter-clockwise direction on a circular path as shown in the figure. The movement of P is such that it sweeps out a length $s = t^3 + 5$; where s is in metres and t is in seconds.

The radius of the path is 20 m. The acceleration of P when t = 2 s is nearly

(a) 12 m s^{-2} (b) 7.2 m s^{-2}
(c) 14 m s^{-2} (d) 13 m s^{-2}

13. A solid sphere of radius R and density ρ is attached to one end of a massless spring of force constant k. The other end of the spring is connected to another solid sphere of radius R and density 3ρ. The complete arrangement is placed in a liquid of density 2ρ and is allowed to reach equilibrium. The correct statement(s) is (are)

(a) the net elongation of the spring is $\frac{4\pi R^3\rho g}{3k}$.

(b) the net elongation of the spring is $\frac{8\pi R^3\rho g}{3k}$.

(c) the light sphere is partially submerged.

(d) the light sphere is completely submerged.

14. The potential energy of a particle of mass 0.1 kg moving along the x-axis is given by $U = 5x(x - 4)$ J where x is in metres. Which of the following is/are correct statement(s)?

(a) The particle is acted upon by a constant force.
(b) The particle executes SHM.
(c) The speed of the particle is maximum at x = 2 m.
(d) The period of oscillation of particle is $\pi/5$ s.

15. Four rods, A, B, C and D of the same length and material but of different radii r, $r\sqrt{2}$, $r\sqrt{3}$ and $2r$ respectively are held between two rigid walls. The temperature of all rods is increased through the same range. If the rods do not bend, then

(a) the stress in the rods A, B, C and D are in the ratio 1 : 2 : 3 : 4
(b) the forces on them exerted by the wall are in the ratio 1 : 2 : 3 : 4
(c) the energy stored in the rods due to elasticity are in the ratio 1 : 2 : 3 : 4
(d) the strains produced in the rods are in the ratio 1 : 2 : 3 : 4

SOLUTIONS

1. (c) :

Mass per unit length of rod $= \frac{M}{l}$

Mass of element of length dx, $dm = \frac{M}{l}dx$

The gravitational potential energy between this element and point mass is

$$dU = -\frac{Gmdm}{x} = -\frac{Gm\left(\frac{M}{l}dx\right)}{x}$$

$$\therefore \quad U = -\frac{GmM}{l}\int_a^{a+l}\frac{dx}{x}$$

$$\text{or} \quad U = -\frac{GmM}{l}\ln\left(\frac{a+l}{a}\right)$$

2. (b) : According to continuity equation,

$$\frac{v_2}{v_1} = \frac{A_1}{A_2} = \frac{\pi\times(0.1)^2}{\pi\times(0.04)^2} = \frac{25}{4} \quad \text{...(i)}$$

According to Bernoulli's equation for horizontal tube,

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

$$i.e.,\ v_2^2 - v_1^2 = \frac{2(P_1 - P_2)}{\rho}$$

$$i.e.,\ v_2^2 - v_1^2 = \frac{(2\times 10)}{(1.25\times 10^3)} = 16\times 10^{-3} \quad ...(ii)$$

Substituting the value of v_2 from equation (i) in (ii)

$(6.25v_1)^2 - v_1^2 = 16 \times 10^{-3}$, *i.e.*, $v_1 = 0.02\ \text{m s}^{-1}$

So rate of flow through the tube

$= A_1v_1\ (= A_2v_2) = \pi \times (0.1)^2 \times 0.02$

$= 6.28 \times 10^{-4}\ \text{m}^3\ \text{s}^{-1}$

3. **(c) :** Assume the train is at $x = 0$ at $t = 0$, the equation for train is

$$x_T = \frac{1}{2}a_T t^2 = \frac{1}{2}(0.40)t^2$$

The passenger reached $x = 0$ at $t = t_0 = 6$ s, so his coordinate at time t is $x_P = v_P(t - t_0)$.

For the passenger to catch the train, $x_T = x_P$.

$$\frac{1}{2}a_T t^2 = v_P(t - t_0) \quad \text{or} \quad a_T t^2 - 2v_P t + 2v_P t_0 = 0$$

$$\text{or}\quad t = \frac{v_P \pm \sqrt{v_P^2 - 2a_T v_P t_0}}{a_T}$$

The roots are real if $v_P^2 - 2a_T v_P t_0 \geq 0$

$$\therefore\ v_P \geq 2a_T t_0 = 2\times 0.40\times 6 = 4.8\ \text{m s}^{-1}$$

4. **(b) :**

Consider the forces in the x-direction and apply the conditions for equilibrium, noting f equals its maximum value to start motion.

$\Sigma F_x = 0, \Rightarrow F\cos\theta - f = 0$

$F\cos\theta = f$

$F\cos 30° = f = \mu_s N = 0.4N \quad ...(i)$

Now apply the conditions for equilibrium to the forces in y-direction,

$\Sigma F_y = 0 \Rightarrow N + F\sin\theta - W = 0$

$N + F\sin 30° - 100 = 0$

$N = 100 - F\sin 30° \quad ...(ii)$

From equations (i) and (ii),

$F\cos 30° = 0.4(100 - F\sin 30°)$

or $0.866F + 0.2F = 40$

$\therefore\ F = 37.5$ N

5. **(c) :** Speed of the wave $= \upsilon\lambda = \upsilon(4ab)\ \left(\because\ ab = \frac{\lambda}{4}\right)$

$= 4\upsilon \times ab$

Path difference between b and e is $\frac{3\lambda}{4}$.

$$\therefore\ \text{Phase difference} = \frac{2\pi}{\lambda}\times \text{Path difference}$$

$$= \frac{2\pi}{\lambda}\frac{3\lambda}{4} = \frac{3\pi}{2}$$

6. **(a) :** Pressure outside the bigger drop $= P_1$

Pressure inside the bigger drop $= P_2$

Radius of bigger drop, $r_1 = 3$ cm

$$\text{Excess pressure} = P_2 - P_1 = \frac{4S}{r_1} = \frac{4S}{3}$$

Pressure inside small drop $= P_3$

$$\text{Excess pressure} = P_3 - P_2 = \frac{4S}{r_2} = \frac{4S}{1}$$

Pressure difference between inner side of small drop and outer side of bigger drop

$$= P_3 - P_1 = \frac{4S}{3} + \frac{4S}{1} = \frac{16S}{3}$$

This pressure difference should exist in a single drop of radius r.

$$\therefore\ \frac{4S}{r} = \frac{16S}{3} \quad \text{or}\quad r = \frac{3}{4}\ \text{cm} = 0.75\ \text{cm}$$

7. **(b, c) :** The fifth harmonic of vibrations of a stretched string fixed at both ends is as shown in the figure.

Total number of nodes = 6

The given equation of a wave is

$y = 0.01\sin(62.8x)\cos(628t)$

Comparing it with standard equation, we get

$y = 2A\sin kx\cos\omega t$

We get,

$2A = 0.01$ m, $k = 62.8\ \text{m}^{-1}$, $\omega = 628\ \text{s}^{-1}$

$$\text{As}\quad \lambda = \frac{2\pi}{k} = \frac{2\pi}{62.8\ \text{m}^{-1}} = \frac{2\times 3.14}{62.8\ \text{m}^{-1}} = 0.1\ \text{m}$$

As the distance between two consecutive nodes is $\frac{\lambda}{2}$.

$\therefore\ \frac{5}{2}\lambda = L$, where L is the length of the string.

$$L = \frac{5}{2}\times 0.1 = 0.25\ \text{m}$$

As the midpoint is an antinode.

Its maximum displacement is $2A = 0.01$ m

$$\text{Fundamental frequency, } \upsilon = \frac{v}{2L}$$

where v is the velocity of the wave.

$$\text{Here, } v = \frac{\omega}{k} = \frac{628\ \text{s}^{-1}}{62.8\ \text{m}^{-1}} = 10\ \text{m s}^{-1}$$

$$\therefore\ \upsilon = \frac{10\ \text{m s}^{-1}}{2\times 0.25\ \text{m}} = 20\ \text{Hz}$$

8. **(a, b, c)**

9. **(c) :**

Processes A to B and C to D are parts of straight line graphs passing through origin $P \propto T$.
So, volume remains constant for the graph AB and CD.
So, no work is done during processes for A to B and C to D.
i.e., $W_{AB} = W_{CD} = 0$
and $W_{BC} = P_2(V_C - V_B) = nR(T_C - T_B)$
$= 6R(2200 - 800) = 6R \times 1400$ J
Also, $W_{DA} = P_1(V_A - V_D) = nR(T_A - T_D)$
$= 6R(600 - 1200) = -6R \times 600$ J
Hence, work done in complete cycle

$$W = W_{AB} + W_{BC} + W_{CD} + W_{DA}$$
$$= 0 + 6R \times 1400 + 0 - 6R \times 600$$
$$= 6R \times 800 = 6 \times 8.3 \times 800 = 40 \text{ kJ}$$

10. (c) : Fundamental frequency

$$\upsilon \propto \frac{1}{l}$$

Given $\upsilon_1 : \upsilon_2 : \upsilon_3 = 1 : 2 : 3$

$$\therefore \quad \frac{1}{l_1} : \frac{1}{l_2} : \frac{1}{l_3} = 1 : 2 : 3$$

or $\quad l_1 : l_2 : l_3 = \frac{1}{1} : \frac{1}{2} : \frac{1}{3} \quad$ or $\quad l_1 : l_2 : l_3 = 6 : 3 : 2$

$$l_1 = \frac{6}{11} \times 110 = 60 \text{ cm}, \quad l_2 = \frac{3}{11} \times 110 = 30 \text{ cm}$$

and $\quad l_3 = \frac{2}{11} \times 110 = 20$ cm

11. (b, d) : After collision of C with A, let velocity acquired by A and B be v' and spring gets compressed by length x. Using law of conservation of linear momentum, we have

$$mv = mv' + mv' \text{ or } v' = v/2$$

Using law of conservation of mechanical energy, we have

$$\frac{1}{2}mv^2 = \frac{1}{2}mv'^2 + \frac{1}{2}mv'^2 + \frac{1}{2}kx^2$$

or $\quad mv^2 = m\left(\frac{v}{2}\right)^2 + m\left(\frac{v}{2}\right)^2 + kx^2$

or $\quad \frac{mv^2}{2} = kx^2 \quad$ or $\quad x = v\left(\frac{m}{2k}\right)^{1/2}$

At maximum compression of the spring, the K.E. of A-B system will be

$$= \frac{1}{2}mv'^2 + \frac{1}{2}mv'^2 = mv'^2 = m\left(\frac{v}{2}\right)^2 = \frac{mv^2}{4}$$

12. (c) :

Here, $s = t^3 + 5$; $r = 20$ m

Velocity, $v = \frac{ds}{dt} = 3t^2$

When, $t = 2$ s,

$$v = 3 \times 2^2 = 12 \text{ m s}^{-1}$$

Tangential acceleration, $a_t = \frac{dv}{dt} = 6t$

When, $t = 2$ s, $a_t = 6 \times 2 = 12$ m s^{-2}
Centripetal acceleration,

$$a_c = \frac{v^2}{r} = \frac{12^2}{20} = 7.2 \text{ m s}^{-2}$$

Effective acceleration,

$$a = \sqrt{a_t^2 + a_c^2} = \sqrt{12^2 + 7.2^2} = 14 \text{ m s}^{-2}$$

13. (a, d) : The situation is as shown in adjacent figure.

At equilibrium, for upper sphere

$$W + F_S = F_B$$

$$\frac{4}{3}\pi R^3 \rho g + kx = \frac{4}{3}\pi R^3 (2\rho) g$$

$$kx = \frac{4}{3}\pi R^3 2\rho g - \frac{4}{3}\pi R^3 \rho g$$

$$kx = \frac{4\pi R^3 \rho g}{3} \quad \text{or} \quad x = \frac{4\pi R^3 \rho g}{3k}$$

14. (b, c, d) : Here, $U = 5x(x - 4)$ J $= (5x^2 - 20x)$ J

$$\therefore \quad F = -\frac{dU}{dx} = -(10x - 20) = (-10x + 20) \text{ N} \quad \text{... (i)}$$

As F changes with x, so F is not constant.
Since $F \propto x$ and it is directed towards mean position, hence the particle executes SHM.
In SHM, the speed is maximum at mean position where force is zero.

$\therefore \quad 0 = -10x + 20$ or $x = 2$ m

Here, $m\omega^2 = 10$

or $\quad \omega^2 = \frac{10}{m} = \frac{10}{0.1} = 100 \quad$ or $\quad \omega = 10$ rad s^{-1}

$$\therefore \quad T = \frac{2\pi}{\omega} = \frac{2\pi}{10} = \frac{\pi}{5} \text{ s}$$

15. (b, c) : Thermal force $= YA\alpha\, d\theta = Y\pi r^2 \alpha\, d\theta$

$r_1 = r$, $r_2 = r\sqrt{2}$, $r_3 = r\sqrt{3}$, $r_4 = 2r$,

The ratio of forces on them exerted by the wall,
$F_1 : F_2 : F_3 : F_4 = 1 : 2 : 3 : 4$
Thermal stress $= Y\alpha\, d\theta$
As Y and α are same for all the rods, hence stress developed in each rod will be same.
As strain $= \alpha\, d\theta$, so strain will also be same.

Energy stored $= \frac{1}{2} \times Y \times (\text{strain})^2 \times A \times L$

$$\therefore \quad E_1 : E_2 : E_3 : E_4 = 1 : 2 : 3 : 4$$

MPP-5 MONTHLY Practice Problems

Class XI

This specially designed column enables students to self analyse their extent of understanding of specified chapters. Give yourself four marks for correct answer and deduct one mark for wrong answer. Self check table given at the end will help you to check your readiness.

Mechanical Properties of Solids and Fluids

Total Marks : 120 **Time Taken : 60 min**

NEET / AIIMS / PMTs

Only One Option Correct Type

1. Two wires of same material and length but diameter in the ratio 1 : 2 are stretched by the same force. The potential energy per unit volume for the two wires when stretched will be in the ratio
(a) 16 : 1 (b) 4 : 1 (c) 2 : 1 (d) 1 : 1

2. A thick rope of rubber of density 1.5×10^3 kg m^{-3}, Young's modulus 5×10^6 N m^{-2} and length 8 m is hung from the ceiling of a room. The increase in its length due to its own weight is (Take $g = 10$ m s^{-2})
(a) 9.6×10^{-2} m (b) 9.6×10^{-5} m
(c) 9.6×10^{-7} m (d) 9.6 m

3. A bimetallic strip consists of metals X and Y. It is mounted rigidly at the base as shown in figure. The metal X has a higher coefficient of expansion compared to that for metal Y. When bimetallic strip is placed in a cold bath

(a) it will bend towards the right
(b) it will bend towards the left
(c) it will not bend but shrink
(d) it will neither bend nor shrink.

4. Two glass plates are separated by water. If surface tension of water is 75 dyne cm^{-1} and area of each plate wetted by water is 8 cm^2 and the distance between the plates is 0.12 mm, then the force applied to separate the two plates is
(a) 10^2 dyne (b) 10^4 dyne
(c) 10^5 dyne (d) 10^6 dyne

5. The rate of flow of glycerine of density 1.25×10^3 kg m^{-3} through the conical section of a pipe, if the radii of its ends are 0.1 m and 0.04 m and the pressure drop across its length is 10 N m^{-2} is
(a) 5.28×10^{-4} m^3 s^{-1} (b) 6.28×10^{-4} m^3 s^{-1}
(c) 7.28×10^{-4} m^3 s^{-1} (d) 8.28×10^{-4} m^3 s^{-1}

6. Water rises in a capillary tube to a height h. Choose the false statement regarding a capillary rise from the following.
(a) On the surface of the Jupiter, height is less than h.
(b) In a lift, moving up with constant acceleration, height is less than h.
(c) On the surface of the moon, the height is more than h.
(d) In a lift moving down with constant acceleration, height is less than h.

7. A candle of diameter d is floating on a liquid in a cylindrical container of diameter D ($D >> d$) as shown in figure. If it is burning at the rate of 2 cm h^{-1}, then the top of the candle will

(a) remain at the same height
(b) fall at the rate of 1 cm h^{-1}
(c) fall at the rate of 2 cm h^{-1}
(d) go up at the rate of 1 cm h^{-1}.

8. A frame made of metallic wire enclosing a surface area A is covered with a soap film. If the area of the frame of metallic wire is reduced by 50%, the energy of the soap film will be changed by
(a) 100% (b) 75%
(c) 50% (d) 25%

9. A water drop is divided into 8 equal droplets. The pressure difference between the inner and outer side of the big drop will be
(a) same as for smaller droplet
(b) $\frac{1}{2}$ of that for smaller droplet
(c) $\frac{1}{4}$ of that for smaller droplet
(d) twice that for smaller droplet.

10. If the terminal speed of a sphere of gold (density = 19.5 kg m^{-3}) is 0.2 m s^{-1} in a viscous liquid (density = 1.5 kg m^{-3}). Then, the terminal speed of sphere of silver (density = 10.5 kg m^{-3}) of the same size in the same liquid is
(a) 0.4 m s^{-1} (b) 0.133 m s^{-1}
(c) 0.1 m s^{-1} (d) 0.2 m s^{-1}

11. A cylindrical tank has a hole of 1 cm^2 in its bottom. If the water is allowed to flow into the tank from a tube above it at the rate of 70 cm^3 s^{-1} then the maximum height upto which water can rise in the tank is
(a) 2.5 cm (b) 5 cm
(c) 10 cm (d) 0.25 cm

12. A uniform plank of Young's modulus Y is moved over a smooth horizontal surface by a constant horizontal force F_0. The area of cross-section of the plank is A. The compressive strain on the plank in the direction of the force is
(a) $\frac{F_0}{AY}$ (b) $\frac{2F_0}{AY}$ (c) $\frac{F_0}{2AY}$ (d) $\frac{3F_0}{2AY}$

Assertion & Reason Type

Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as :
(a) If both assertion and reason are true and reason is the correct explanation of assertion
(b) If both assertion and reason are true but reason is not the correct explanation of assertion
(c) If assertion is true but reason is false
(d) If both assertion and reason are false.

13. **Assertion :** A piece of ice, with a stone frozen inside it, floats on water in a beaker. When the ice melts, the level of water in the beaker decreases.
Reason : Density of stone is more than that of water.

14. **Assertion :** Surface energy of an oil drop is same whether placed on glass or water surface.
Reason : Surface energy is dependent only on the properties of oil.

15. **Assertion :** A needle placed carefully on surface of water may float whereas a ball of the same material will always sink.
Reason : The buoyancy of an object depends both on the material and the shape of the object.

JEE MAIN / JEE ADVANCED / PETs

Only One Option Correct Type

16. The pressure that has to be applied to the ends of a steel wire of length 10 cm to keep its length constant when its temperature is raised by 100 °C is (for steel Young's modulus is 2×10^{11} N m^{-2} and coefficient of thermal expansion is 1.1×10^{-5} K^{-1})
(a) 2.2×10^6 Pa (b) 2.2×10^8 Pa
(c) 2.2×10^9 Pa (d) 2.2×10^7 Pa

17. Assume that a drop of liquid evaporates by decrease in its surface energy, so that its temperature remains unchanged. What should be the minimum radius of the drop for this to be possible? The surface tension is T, density of liquid is ρ and L is its latent heat of vaporization.
(a) $\frac{2T}{\rho L}$ (b) $\frac{\rho L}{T}$
(c) $\sqrt{\frac{T}{\rho L}}$ (d) $\frac{T}{\rho L}$

18. Water is flowing continuously from a tap having an internal diameter 8×10^{-3} m. The water velocity as it leaves the tap is 0.4 m s^{-1}. The diameter of the water stream at a distance 2×10^{-1} m below the tap is close to
(a) 5.0×10^{-3} m (b) 7.5×10^{-3} m
(c) 9.6×10^{-3} m (d) 3.6×10^{-3} m

19. Work done in increasing the size of a soap bubble from a radius of 3 cm to 5 cm is nearly (surface tension of soap solution = 0.03 N m^{-1})
(a) 4π mJ (b) 0.2π mJ
(c) 2π mJ (d) 0.4π mJ

More than One Option Correct Type

20. When a capillary tube is dipped in a liquid, the liquid rises to a height h in the tube. The free liquid surface inside the tube is hemispherical in shape. The tube is now pushed down so that the height of the tube outside the liquid is less than h.

(a) The liquid will ooze out of the tube slowly.
(b) The liquid will come out of the tube like in a small fountain.
(c) The free liquid surface inside the tube will not be hemispherical.
(d) The liquid will fill the tube but not come out of its upper end.

21. If W_0 represents true weight of solid body, B the force of buoyancy on the body when immersed in a liquid, W_1 an apparent weight of the body and W_2 the weight of twice the volume of the liquid displaced by the solid body, then which of the following relations is/are valid?

(a) $W_0 = B - W_1$
(b) $W_0 - B = W_1$
(c) $W_0 = B + W_1 - W_2$
(d) $W_0 - W_1 = W_2 - B$

22. A metal wire of length L is suspended vertically from a rigid support. When a body of mass M is attached to the lower end of wire, the elongation of the wire is l.

(a) The loss in gravitational potential energy of mass M is Mgl.
(b) The elastic potential energy stored in the wire is Mgl.
(c) The elastic potential energy stored in the wire is $\frac{1}{2}Mgl$.
(d) Heat produced is $\frac{1}{2}Mgl$.

23. When an air bubble rises from the bottom of a deep lake to a point just below the water surface, the pressure of air inside the bubble

(a) is less than the pressure outside it
(b) is greater than the pressure outside it
(c) decreases as the bubble moves up
(d) increases as the bubble moves up.

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Integer Answer Type

24. Two bodies are in equilibrium when suspended in water from the arms of a balance. The mass of one body is 36 g and its density is 9 g cm^{-3}. If the mass of the other is 48 g, its density in g cm^{-3} is

25. Two soap bubbles A and B are kept in a closed chamber when the air is maintained at pressure of 8 N m^{-2}. The radii of bubbles A and B are 2 cm and 4 cm respectively. Surface tension of soap water used to make bubbles is 0.04 N m^{-1}. Find the ratio n_B/n_A, where n_A and n_B are the number of moles of air in bubbles A and B respectively. Neglect effect of gravity.

26. Two bodies of masses 1 kg and 2 kg are connected by a metal wire shown in figure. A force of 12 N is applied on the body of mass 2 kg. The breaking stress of the wire is 2×10^9 N m^{-2}. If the wire is not to break, the diameter of the wire is $n \times 10^{-5}$ m. The value of n is nearly

Comprehension Type

A cylindrical tank having a cross-sectional area A is resting on a smooth horizontal plane. It is filled with two immiscible, non-viscous and incompressible liquids of density ρ and 2ρ each of height $H/2$ as shown in figure. The liquid of density ρ is open to the atmosphere having pressure P_0. A tiny hole of area of cross-section $a(< A)$ is made in right vertical side of the wall of the tank at a height h ($< H/2$).

27. The maximum horizontal distance R_{max} travelled by liquid will be

(a) $\frac{3H}{8}$ (b) $\frac{3H}{4}$ (c) $\frac{3H}{2}$ (d) $3H$

28. Maximum value of F to keep the cylinder in static equilibrium is (if the coefficient of friction between the cylinder and plane is μ)

(a) $(a\rho v^2 + \mu AH\rho g)$
(b) $(a\rho v^2 + 2\mu AH\rho g)$
(c) $(2\, a\rho v^2 + 3\, \mu AHrg)$
(d) $\left(2a\rho v^2 + \frac{3}{2}\mu AH\rho g\right)$

Matrix Match Type

29. Match the entries in Column I with those given in Column II.

Column I	Column II
(A) Stress on a body depends on	(P) Length of the body
(B) Strain in a body depends on	(Q) Area of cross-section of body
(C) Modulus of elasticity of a body depends on	(R) Nature of material of body
(D) Poisson's ratio of the body depends on	(S) Force applied on the body

	A	B	C	D
(a)	Q, R, S	P, Q, R, S	R	R
(b)	Q, S	P	R	S
(c)	Q, R	P, S	R	R
(d)	Q, S	P	P, Q, S	R

30. Match the entries in Column I with those given in Column II.

Column I	Column II
(A) Yl^3	(P) N m^{-1}
(B) $YA/\Delta L$	(Q) J m^{-3}
(C) Stress × strain	(R) m
(D) FL/AY	(S) J

	A	B	C	D
(a)	S	P	Q	R
(b)	P	S	Q	R
(c)	P	Q	R	S
(d)	R	P	Q	S

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NEET | JEE ESSENTIALS

Class XII

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Unit 5 OPTICS

Reflection of Light

- If the incident light after interacting with a boundary separating the two media comes back in the same medium, the phenomenon is called reflection and the boundary is known as reflector.
- The angle which the incident ray and the reflected ray make with the normal to the surface are termed as the angle of incidence (i) and reflection (r) respectively.

- Laws of reflection
  - The angle of incidence i equals the angle of reflection r.
  - Incident ray, the normal and the reflected ray lie in the same plane.
- The laws of reflection are valid both in case of plane and curved reflecting surfaces.
- For normal incidence *i.e.*, $\angle i = 0$, $\angle r = 0$. Hence a ray of light falling normally on a mirror retraces its path on reflection.

Reflection from Plane Surface

- The image formed by a plane mirror is at the same distance behind the mirror as the object is in front of it.
- The image formed by a plane mirror is laterally inverted. The lateral inversion means that the right side of the object appears as the left side of the image and vice-versa.
- The image formed by a plane mirror is virtual, erect w.r.t. object and of the same size as the object.
- If keeping the incident ray fixed, the plane mirror is rotated through an angle θ, the reflected ray turns through double the angle *i.e.*, 2θ in that very direction.
- If the object is fixed and the mirror moves relative to the object with a speed v, the image moves with a speed $2v$ relative to the object.
- If the mirror is fixed and the object moves relative to the mirror with a speed v, the image also moves with the same speed v relative to the mirror.
- Deviation suffered by a light ray incident at an angle i is given by

  $$\delta = (180° - 2i)$$

Number of Images Formed by Two Inclined Mirrors

- For two inclined plane mirrors M_1, M_2

  I_1 = Image of O by M_1;

  I_2 = Image of O by M_2

  I_{21} = Image of I_2 by M_1;

  I_{12} = Image of I_1 by M_2 and so on.

- Total number of images is given by

  $\frac{360°}{\theta} = N$ with some special cases; $\theta = \alpha + \beta$

  - If $\frac{360°}{\theta}$ = even number; number of images $= \frac{360°}{\theta} - 1$.
  - If $\frac{360°}{\theta}$ = odd number; number of images $= \frac{360°}{\theta} - 1$ if the object is placed on the angle bisector.
  - If $\frac{360°}{\theta}$ = odd number; number of images $= \frac{360°}{\theta}$, if the object is not placed on the angle bisector.
  - If $\frac{360°}{\theta} \neq$ integer, then count the number of images as explained.

☞ Spherical Mirrors

- Spherical mirror is formed by polishing one surface of a part of sphere. Depending upon which part is shining the spherical mirror is classified as

  - Concave mirror, if the side towards center of curvature is shining.
  - Convex mirror, if the side away from the center of curvature is shining.
- Important terms for spherical mirrors
  - Pole (P) is the mid point of reflecting surface.
  - Centre of curvature (C) is the centre of the sphere of which the mirror is a part.
  - Radius of curvature is the radius of the sphere of which the mirror is a part. Distance between P and C.
  - Principal axis is the straight line connecting pole P and centre of curvature C.
  - A narrow beam of rays, parallel and near to principal axis, is reflected from a mirror so that all the rays converge or appear to converge at a point on the principle axis, this point is called principle focus of mirror.
  - Focal length (f) is distance from pole to focus.
  - Aperture the diameter of the mirror is called aperture of the mirror.
  - Plane perpendicular to principal axis and passing through focus is known as focal plane.

- **Sign convention :** We follow cartesian co-ordinate system conventions according to which
  - The pole of mirror is the origin.
  - The distance measured in the direction of the incident rays is considered as positive x-axis.
  - The heights measured in the vertically up direction are positive y-axis.

- Mirror Formula

  $$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

  u = distance of object, v = image distance, f = focal length and $f = R/2$; R = radius of curvature.

☞ Ray Tracing

Following facts are useful in ray tracing.

- If the incident ray is parallel to the principal axis, the reflected ray passes through the focus.
- If the incident ray passes through the focus, then the reflected ray is parallel to the principal axis.
- Incident ray passing through centre of curvature will be reflected back through the centre of curvature (because it is normal to the plane.

- It is easy to make the ray tracing of a ray incident at the pole as shown below.

Magnification

- Linear magnification : $m = \frac{h_2}{h_1} = -\frac{v}{u}$

  h_1 = height of the object, h_2 = height of the image. (h_1 and h_2 both are perpendicular to the principal axis of mirror)
- If the image is upright or erect with respect to the object then m is positive. And m is negative if the image is inverted with respect to the object.
- Longitudinal magnification, $m_l = \frac{v_2 - v_1}{u_2 - u_1}$
  - For very small object

$$m_l = \frac{dv}{du} = -\frac{v^2}{u^2} = -(m_t)^2$$

Refraction of Light

- When light passes obliquely from one transparent medium to another, the direction of its path may change at the interface of the two media. This phenomenon is known as refraction of light.
- If a ray of light passes from an optically rarer medium to a denser medium, it bends towards the normal.
- If a ray of light passes from an optically denser medium to a rarer medium, it bends away from the normal.
- A ray of light travelling along the normal passes undeflected, the incident ray and refracted ray make angle zero with normal.
- Laws of refraction
  - The incident ray, the normal to the interface at the point of incidence and the refracted ray all lie in the same plane.
  - The ratio of the sine of the angle of incidence to the sine of the angle of refraction is always a constant (a different constant for a different set of media).

    i.e., $\frac{\sin i}{\sin r} = \text{constant} = {}^1\mu_2$
  - This constant (${}^1\mu_2$) is called refractive index of medium 2 (in which refracted ray travels) with respect to medium 1 (in which incident ray travels). It is known as Snell's law and holds good for all angles of incidence.

Refractive Index and its Effect on Refraction

- The refractive index of a medium for a light of given wavelength may be defined as the ratio of the speed of light in vacuum to its speed in that medium.

$$\mu = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in medium}} = \frac{c}{v}$$

- Refractive index of a medium with respect to vacuum is also called absolute refractive index.
- When a light ray travels from one medium to another, its frequency remains constant but its wavelength as well as velocity changes.
- The deviation of the incident ray when it is refracted is given by an angle $\delta = |i - r|$.
- If a light ray passes through a number of parallel media and if the first and the last medium are same, the emergent ray is parallel to the incident ray as shown in figure below.

$${}^1\mu_2 = \frac{\sin i_1}{\sin r_1},\ {}^2\mu_3 = \frac{\sin r_1}{\sin r_2} \text{ and } {}^3\mu_1 = \frac{\sin r_2}{\sin i_1}$$

Hence, ${}^1\mu_2 \times {}^2\mu_3 \times {}^3\mu_1 = \frac{\sin i_1}{\sin r_1} \times \frac{\sin r_1}{\sin r_2} \times \frac{\sin r_2}{\sin i_1} = 1$

- For principle of reversibility, ${}^1\mu_2 = \frac{1}{{}^2\mu_1}$
- **Lateral shift due to glass slab :** When the medium is same on both sides of a glass slab, then the deviation of the emergent ray is zero. That is the emergent ray is parallel to the incident ray but it does suffer lateral displacement/shift with respect to the incident ray and is given by

Lateral shift, $h = t\,\frac{\sin(i - r)}{\cos r}$

where t is the thickness of the slab.

- **Apparent depth :** An object placed in a denser medium (*e.g.* water). when viewed from a rarer medium (*e.g.* air) appears to be at a lesser depth than its real depth. This is on account of refraction of light.

  $$\text{Apparent depth} = \frac{\text{Real depth}}{\text{Refractive index}}$$

  - As the refractive index of any medium (other than vacuum) is greater than unity, so the apparent depth is less than the real depth.
  - The height through which an object appears to be raised in a denser medium is called normal shift or apparent shift.

    Normal shift = real depth – apparent depth

    $$d = t - \frac{t}{\mu} = t\left(1 - \frac{1}{\mu}\right)$$

    Here, t is the real depth of water and μ is its refractive index.

☞ Total Internal Reflection

- The total internal reflection is the phenomenon in which a ray of light travelling from an optically denser into an optically rarer medium at an angle of incidence greater than the critical angle for the two media is totally reflected back into the same medium.
- Necessary conditions for total internal reflection.
  - Light is travelling from optically denser to optically rarer medium.
  - The angle of incidence at the surface is greater than the critical angle for the pair of media.
- The critical angle for the two media is the angle of incidence in the optically denser medium for which the angle of refraction is 90°. It is given by

  $$\sin i_C = \frac{1}{\mu}$$

- Let i = angle of incidence. Consider the following cases :
  - If $i < i_C$, then refraction takes place.
  - If $i = i_C$, then grazing emergence takes place.
  - If $i > i_C$, then total internal reflection takes place.
- A fish in water at a depth d sees the world outside through a horizontal circle of radius

  $$r = d \tan i_C = \frac{d}{\sqrt{\mu^2 - 1}}$$

- Applications of total internal reflection
  - Brilliance of diamonds
  - Mirage
  - Totally reflecting glass prisms
  - Optical fibres

☞ Refraction through a Prism

- A prism is a homogeneous, transparent medium bounded by two plane surfaces inclined at an angle A with each other. These surfaces are called the refracting surfaces and angle between them is called the refracting angle or the angle of prism A.
- The angle between the incident ray and the emergent ray is called the angle of deviation.

  For refraction through a prism it is found that

  $\delta = i + e - A$ where $A = r_1 + r_2$

  When A and i are small

  $\therefore \quad \delta = (\mu - 1)\, A$

  - In a position of minimum deviation $\delta = \delta_m$, $i = e$, and $r_1 = r_2 = r$

  $$\therefore \quad i = \left(\frac{A + \delta_m}{2}\right) \text{ and } r = \frac{A}{2}$$

- The refractive index of the material of the prism is

  $$\mu = \frac{\sin\left[\frac{(A + \delta_m)}{2}\right]}{\sin\left(\frac{A}{2}\right)}$$

  This is called prism formula.

Dispersion of Light

- It is the phenomenon of splitting of white light into its constituent colours on passing through a prism. This is because different colours have different wavelengths ($\lambda_R > \lambda_V$). According to Cauchy's formula

$$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

where A, B, C are arbitrary constants. Therefore, μ of material of prism for different colours is different ($\mu_V > \mu_R$). As $\delta = (\mu - 1)A$, therefore different colours turn through different angles on passing through the prism. This is the cause of dispersion.

- Angular dispersion, $\theta = \delta_V - \delta_R = (\mu_V - \mu_R)A$ where μ_V and μ_R are the refractive indices for violet and red light respectively.
- Dispersive power, $\omega = \dfrac{\text{angular dispersion}}{\text{mean deviation}}$

$$\omega = \frac{\mu_V - \mu_R}{(\mu - 1)}$$

where $\mu = \dfrac{\mu_V + \mu_R}{2}$ = mean refractive index

  - It depends on the material of the prism.
  - It is a unit less and dimensionless quantity.
  - Dispersive power of a flint glass prism is more than that of a crown glass prism.
- When two prisms are combined together, we can get deviation without dispersion or vice versa.
- Condition for deviation without dispersion is

$$\theta + \theta' = 0$$

$$(\mu_V - \mu_R)A + (\mu'_V - \mu'_R)A' = 0$$

or $$A' = -\frac{(\mu_V - \mu_R)A}{(\mu'_V - \mu'_R)}$$

where A and A' are refracting angles of two prisms respectively and μ_V, μ_R and μ'_V, μ'_R be the refractive indices of the violet and red light of the corresponding prisms.

Negative sign shows that the refracting angles of the two prisms are in opposite direction.

Under this condition, net deviation produced by the combination is

$$= \delta + \delta' = (\mu - 1)A + (\mu' - 1)A'$$

The prism which produces deviation without dispersion is called achromatic prism.

- Condition for dispersion without deviation is

$$\delta + \delta' = 0$$

$$(\mu - 1)A + (\mu' - 1)A' = 0$$

or $$A' = -\frac{(\mu - 1)A}{(\mu' - 1)}$$

where μ and μ' be the refractive indices of the material of two prisms respectively.

Negative sign shows that the refracting angles of two prisms are in opposite direction.

Under this condition, net angular dispersion produced by the combination is

$$= (\delta_V - \delta_R) + (\delta'_V - \delta'_R)$$

$$= (\mu_V - \mu_R)A + (\mu'_V - \mu'_R)A'$$

The prism which produces dispersion without deviation is called direct vision prism.

Scattering of Light

- As sunlight travels through the earth's atmosphere, it gets scattered (changes its direction) by the atmospheric particles. Light of shorter wavelengths is scattered much more than the light of longer wavelengths. The amount of scattering is inversely proportional to the fourth power of the wavelength. This is called Rayleigh scattering.
- Illustrations of scattering of light
  - Blue colour of sky
  - White colour clouds
  - The sun looks reddish at the time of sun rise and sun set

Refraction at Spherical Surfaces

- A refractive surface which forms a part of a sphere of transparent medium is called a spherical refracting surface. Spherical refracting surfaces are of two types
  - Convex spherical refracting surface
  - Concave spherical refracting surface
- For both surfaces refracting formula is given by

$$\frac{{}^1\mu_2}{v} - \frac{1}{u} = \frac{{}^1\mu_2 - 1}{R}$$

where ${}^1\mu_2$ is refractive index of second medium with respect to first and u, v, R are the object distance, image distance and radius of curvature of the spherical surface respectively.

  - If μ_1 and μ_2 are refractive indices of first and second medium with respect to air, then

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

☞ Lenses

- A lens is a transparent medium bounded by two refracting surfaces such that at least one of the refracting surfaces is curved.
- If the thickness of the lens is negligibly small in comparison to the object distance or the image distance, the lens is called thin.
- Broadly, lenses are of the following types :

- The focal length (f) of a lens depends upon the refractive indices of the material of the lens and the medium in which the lens is present and the radii of curvature of both sides. The following relation giving focal length (f) is called as lens maker's formula.

$$\frac{1}{f} = \left(\frac{\mu}{\mu_0} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

where μ = refractive index of the material of the lens, μ_0 = refractive index of the medium.

- Lens formula

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

- The ratio of the size of the image formed by a lens to the size of the object is called linear magnification produced by the lens. It is denoted by m.

If h_1 and h_2 are the sizes of the object and image respectively, then

$$m = \frac{h_2}{h_1} = \frac{v}{u}.$$

- The power of a lens is defined as the reciprocal of the focal length in metre.

$$P = \frac{1}{f(\text{in m})}$$

  - The SI unit of power of lens is diopter (D).
  - For a convex lens, P is positive.
  - For a concave lens, P is negative.
  - When focal length (f) of lens is in cm, then

$$P = \frac{100}{f\ (\text{in cm})} \text{ dioptre.}$$

- When a number of thin lenses of focal length f_1, f_2, ... etc. are placed in contact coaxially, the equivalent focal length F of the combination is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \ldots.$$

  - The total power of the combination is given by $P = P_1 + P_2 + P_3 + \ldots$
  - The total magnification of the combination is given by $m = m_1 \times m_2 \times m_3 \ldots.$

- When two thin lenses of focal lengths f_1 and f_2 are placed coaxially and separated by a distance d, the focal length of combination is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}.$$

  - In terms of power, $P = P_1 + P_2 - dP_1P_2$.

- **Silvering of a lens :** Let a planoconvex lens is having a curved surface of radius of curvature R and has refractive index μ.
  - If its plane surface is silvered, it behaves as a concave mirror of focal length

$$f = -\frac{R}{2(\mu - 1)}$$

  - If the curved surface of planoconvex lens is silvered then it behaves as a concave mirror of focal length

$$f = -\frac{R}{2\mu}$$

- Displacement method is used to determine focal length of convex lens in laboratory.

BRAIN MAP

CLASS XI

WORK, ENERGY AND POWER

WORK

Work is said to be done whenever a force acts on a body and the body moves through some distance.

$W = \vec{F}\cdot\vec{S} = FS\cos\theta$ (where θ is the angle between force applied $\vec{F}$ and displacement vector $\vec{S}$.)

The SI unit of work is joule (J).

Nature of Work Done

If $\theta = 0°$, $W = FS$ *i.e.*, work done is maximum.

If $\theta = 90°$, $W = 0$ *i.e.*, work done is zero.

Work Done by a Variable Force

The work done by a variable force in changing the displacement from S_1 to S_2 is $W = \int_{S_1}^{S_2} \vec{F}\cdot d\vec{S}$ = Area under the force-displacement graph

ENERGY

It is defined as the ability of a body to do work. It is measured by the amount of work that a body can do. The unit of energy used at the atomic level is electron volt (eV) and SI unit is J.

Kinetic Energy

It is the energy possessed by a body by virtue of its motion. The K.E. of a body of mass m moving with speed v is

$$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

Potential Energy

It is the energy possessed by a body by virtue of its position (in a field) or configuration (shape or size). For a conservative force in one dimension, the potential energy function $U(x)$ may be defined as

$$F(x) = -\frac{dU(x)}{dx} \text{ or } \Delta U = U_f - U_i = -\int_{x_i}^{x_f} F(x)dx$$

Power

The rate of doing work is called power.

Average Power:

It is defined as the ratio of the small amount of work done W to the time taken t to perform the work.

$$P = \frac{W}{t}$$

The SI unit of power is watt (W).

Work Energy Theorem

The work done by the net force acting on a body is equal to the change in kinetic energy of the body.

W = Change in kinetic energy

$$= \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \Rightarrow W = \Delta K.E.$$

The work energy theorem may be regarded as the scalar form of Newton's second law of motion.

Potential Energy of a Spring

According to Hooke's law, when a spring is stretched through a distance x, the restoring force F is such that

$F \propto x$ (where k is the spring constant or $F = -kx$ and its unit is N m^{-1}.)

The work done is stored as potential energy U of the spring.

$$W = \int_0^x kx\,dx = \frac{1}{2}kx^2 \Rightarrow U = \frac{1}{2}kx^2$$

COLLISION

A collision between two bodies is said to occur if either they physically collide against each other or the path of the motion of one body is influenced by the other.

Types of Collision

Elastic collision : Both the momentum and kinetic energy of the system remain conserved.

Inelastic collision : Only the momentum of the system is conserved but kinetic energy is not conserved.

Head-on Collision or One-Dimensional Collision

It is a collision in which the colliding bodies move along the same straight line path before and after the collision.

Velocity of approach = Velocity of separation

or $u_1 - u_2 = v_2 - v_1$

Also, $v_1 = \frac{m_1 - m_2}{m_1 + m_2}\cdot u_1 + \frac{2m_2}{m_1 + m_2}\cdot u_2$ and

$$v_2 = \frac{2m_1}{m_1 + m_2}\cdot u_1 + \frac{m_2 - m_1}{m_1 + m_2}\cdot u_2$$

Oblique Collision

If the two bodies do not move along the same straight line path before and after the collision, the collision is said to be oblique collision.

BRAIN MAP

CLASS XII

MAGNETISM AND MATTER

THE BAR MAGNET

Bar Magnet as an Equivalent Solenoid

For solenoid of length $2l$ and radius a consisting n turns per unit length, the magnetic field is given by

$$B = \frac{\mu_0 2m}{4\pi r^3}$$ (where m = magnetic moment of solenoid $= n(2l)I(\pi a^2)$)

Magnetic Dipole in Magnetic Field

Torque on magnetic dipole,

$\tau = MB\sin\theta$

Torque on coil or loop,

$\vec{\tau} = \vec{M}\times\vec{B}$, here $\vec{M} = NI\vec{A}$,

$\vec{\tau} = NI(\vec{A}\times\vec{B})$, $\tau = BINA\sin\theta$

$\theta = 90°$ $\Rightarrow \tau_{max} = BINA$

$\theta = 0°$ or $180°$ $\Rightarrow \tau_{min} = 0$

Potential energy of magnetic dipole,

$U = -MB\cos\theta = -\vec{M}\cdot\vec{B}$

Magnetisation and Magnetic Intensity

Relation between B, χ_m and H

$\vec{B} = \vec{B}_0 + \mu_0\vec{M}$

$\vec{B} = \mu_0(\vec{H} + \vec{M})$ $(\because \vec{B}_0 = \mu_0\vec{H})$

$\vec{B} = \mu_0(1 + \chi_m)\vec{H} = \mu\vec{H}$ $(\because \vec{M} = \chi_m\vec{H})$

$\mu = \mu_0\mu_r = \mu_0(1 + \chi_m) \Rightarrow \mu_r = 1 + \chi_m$

THE EARTH'S MAGNETISM

Cause of Earth's Magnetism

The magnetic field of earth arises due to electrical current produced by convective motion of metallic fluids in the outer core of the earth. This is known as the dynamo effect.

The Earth's Magnetism

Magnetic declination (α): The angle between the geographic meridian and magnetic meridian.

Magnetic dip (δ): The angle made by the earth's magnetic field with the horizontal in the magnetic meridian.

Relation between angle of dip(δ) and components of earth's magnetic field.

$$\tan\delta = \frac{B_V}{B_H},\ B = \sqrt{B_H^2 + B_V^2}$$

CLASSIFICATION OF MAGNETIC MATERIALS

Diamagnetic

Poor magnetisation in opposite direction.

Here $B_m < B_0$

$\chi_m \rightarrow$ Small, negative and temperature independent

$\chi_m \propto T_0$

Paramagnetic

Poor magnetisation in same direction.

Here $B_m > B_0$

$\chi_m \rightarrow$ Small, positive and varies inversely with temperature

$\chi_m \propto \frac{1}{T}$ (Curie's law)

Ferromagnetic

Strong magnetisation in same direction. Here $B_m >>> B_0$

$\chi_m \rightarrow$ Very large, positive and temperature dependent

$\chi_m \propto \frac{1}{T - T_C}$ (Curie-Weiss law)

(for $T > T_C$)

- For a convex lens, the minimum distance between the object and its real image is $4f$. If a convex lens is placed between an object and a screen fixed at a distance D such that $D \geq 4f$, there are two positions of the lens which give a sharp image on the screen.
- The focal length of the lens is given by

$$f = \frac{D^2 - d^2}{4D}$$

where D = distance between the screen and the object, d = distance between the two positions of the lens.

- If I_1, I_2 are the two sizes of image of the object of size O, then $O = \sqrt{I_1 I_2}$.

Simple Microscope

- It is also called magnifying glass or simple magnifier. It consists of a converging lens of small focal length.
- Magnifying power of a simple microscope
  - when the image is formed at infinity (far point),

$$M = \frac{D}{f}$$

where f is the focal length of convex lens.

  - When the image is formed at the least distance of distinct vision D (near point),

$$M = 1 + \frac{D}{f}$$

- A magnification of about 10 is the best, after this lens aberrations begin to distort the image.

Compound Microscope

- It consists of two convergent lenses of short focal lengths and apertures arranged coaxially. Lens facing the object is called objective or field lens while the lens facing the eye, is called eye-piece or ocular. The objective has a smaller aperture and smaller focal length than eye-piece.
- Magnifying power of a compound microscope
  - When the final image is formed at infinity (normal adjustment),

$$M = -\frac{v_o}{u_o}\left(\frac{D}{f_e}\right)$$

Length of tube, $L = v_o + f_e$

  - When the final image is formed at least distance of distinct vision,

$$M = -\frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$$

where u_o and v_o represent the distance of object and intermediate image from the objective lens, f_e is the focal length of an eye lens.

Length of the tube, $L = v_o + \left(\frac{f_e D}{f_e + D}\right)$

Astronomical Telescope (Refracting Type)

- It consists of two converging lenses. The one facing the object is called objective or field lens and has large focal length and aperture while the other facing the eye is called eye-piece or ocular has small focal length and aperture.
- Magnifying power of an astronomical telescope
  - When the final image is formed at infinity (normal adjustment),

$$M = -\frac{f_o}{f_e}$$

Length of tube, $L = f_o + f_e$

  - When the final image is formed at least distance of distinct vision,

$$M = -\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Length of tube, $L = f_o + \frac{f_e D}{f_e + D}$

Terrestrial Telescope

- It is used for observing far off objects on the ground. The essential requirement of such a telescope is that final image must be erect w.r.t. the object. To achieve it, an inverting convex lens (of focal length f) is used in between the objective and eye piece of astronomical telescope. This lens is known as erecting lens.
- In normal adjustment,

Magnifying power, $M = \frac{f_o}{f_e}$

- Length of the tube, $L = f_o + 4f + f_e$

Galileo's Terrestrial Telescope

- It consists of an objective which is a convex lens of large focal length and an eye-piece which is a concave lens of short focal length ($f_o > f_e$).
- In the normal adjustment,

Magnifying power, $M = \frac{f_o}{f_e}$

Length of the tube, $L = f_o - f_e$

☞ Wavefront

- A wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase of any instant.
- The geometrical shape of a wavefront depends on the source of disturbance. Some of the common shapes of wavefronts are
  - **Spherical wavefront :** In the case of waves travelling in all directions from a point source, the wavefronts are spherical in shape.
  - **Cylindrical wavefront :** If the source of light is linear in shape such as a fine rectangular slit, the wavefront is cylindrical in shape.
  - **Plane wavefront :** As a spherical or cylindrical wavefront advances, its curvature decreases progressively and this wavefront behaves as a plane wavefront at infinity.

☞ Huygen's Principle

- According to Huygen's principle, each point on a wavefront is a source of secondary waves, which add up to give a wavefront at any later time.
- Assumptions in Huygen's principle
  - The secondary wavelets spread out in all directions with the speed of light in the given medium.
  - The new wavefront at any later time is given by the forward envelope (tangential surface) in the forward direction of the secondary wavelets at that time.
  - Each point on a wavefront acts as fresh source of new disturbance called secondary waves or wavelets.

☞ Coherent Sources

- Two sources of light which continuously emit light waves of same frequency (or wavelength) with a zero or constant phase difference between them, are called coherent sources.
- Conditions for obtaining two coherent sources of light.
  - The two sources of light must be obtained from a single source by some method.
  - The two sources must give monochromatic light.
  - The path difference between the waves arriving on the screen from the two sources must not be large.
- If two light waves of the same frequency and having zero or constant phase difference travelling in the same direction super position gets redistributed becoming maximum at some points and minimum at others. This phenomenon is called interference of light.
- **Addition of coherent waves :** If A_1, A_2 are the amplitudes of interfering waves due to two coherent sources and ϕ is constant phase difference between the two waves at any point P, then
  The resultant amplitude at P will be

$$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2 \cos\phi}$$

  Resultant intensity at P is

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos\phi$$

  - When $\phi = 2n\pi$, where $n = 0, 1, 2, ...$
    then, $A = A_{max} = (A_1 + A_2)$

$$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

  - When $\phi = (2n - 1)\pi$, where $n = 1, 2, 3, ...$
    then, $A = A_{min} = (A_1 - A_2)$

$$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$$

$$\frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1} + \sqrt{I_2}\right)^2}{\left(\sqrt{I_1} - \sqrt{I_2}\right)^2} = \frac{(A_1 + A_2)^2}{(A_1 - A_2)^2}$$

  - If the amplitudes of the two waves are equal $A_1 = A_2 = A_0$, then resultant amplitude

$$A = \sqrt{2A_0^2 + 2A_0^2 \cos\phi} = 2A_0 \cos\left(\frac{\phi}{2}\right)$$

  Resultant intensity, $I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$

  In this case, $A_{max} = 2A_0$, $I_{max} = 4I_0$
  $A_{min} = 0$, $I_{min} = 0$

Note : If the sources are incoherent, $I = I_1 + I_2$.

☞ Young's Double Slit Experiment

- The phenomenon of interference of light was first observed by a British Physicist Thomas Young. Using two slits illuminated by a monochromatic light source, he obtained alternately bright and dark band on the screen. These bands are called interference fringes or interference bands.

- Constructive interference (*i.e.* formation of bright fringes)
  - For n^{th} bright fringe,

    Path difference = $n\lambda$ or $d\sin\theta = \frac{dx}{D} = n\lambda$

    where $n = 0$ for central bright fringe
    $n = 1$ for first bright fringe,
    $n = 2$ for second bright fringe and so on
    d = distance between the two slits
    D = distance of slits from the screen
  - The position of nth bright fringe from the centre of the screen is given by

    $$x_n = n\lambda\frac{D}{d}$$
- Destructive interference (*i.e.*, formation of dark fringes)
  - For n^{th} dark fringe,

    path difference = $(2n-1)\frac{\lambda}{2}$

    where, $n = 1$ for first dark fringe,
    $n = 2$ for second dark fringe and so on.
  - The position of nth dark fringe from the centre of the screen is given by

    $$x_n = (2n-1)\frac{\lambda}{2}\frac{D}{d}$$
- The distance between any two consecutive bright or dark fringes is called fringe width.

  Fringe width, $\beta = \frac{\lambda D}{d}$
  - Angular fringe width, $\theta = \frac{\beta}{D} = \frac{\lambda}{d}$
- If W_1, W_2 are widths of two slits, I_1, I_2 are intensities of light coming from these two slits; A_1, A_2 are the amplitudes of light from these slits, then

  $$\frac{W_1}{W_2} = \frac{I_1}{I_2} = \frac{A_1^2}{A_2^2}$$
- Fringe visibility, $V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$
- When entire apparatus of Young's double slit experiment is immersed in a medium of refractive index μ, then fringe width becomes

  $$\beta' = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$$
- When a thin transparent plate of thickness t and refractive index μ is placed in the path of one of the interfering waves, fringe width remains unaffected but the entire pattern shifts by

  $$\Delta x = (\mu - 1)\,t\,\frac{D}{d} = (\mu - 1)\,t\,\frac{\beta}{\lambda}$$

  This shifting is towards the side in which transparent plate is introduced.
  - Number of shifted fringes,

    $$N = \frac{\Delta x}{\beta} = \frac{(\mu - 1)t}{\lambda}$$

☞ Interference in Thin Films

- A thin film of liquid (*e.g.* soap film or a layer of oil over water) appears bright or dark when viewed in monochromatic light. This effect is caused due to the interference of light reflected from the top and bottom faces of the film.
- Interference in reflected light (reflected system of light)
  - For a bright fringe,

    $2\mu t\cos r = (2n+1)\frac{\lambda}{2}$; where, n = 0, 1, 2, 3, …
  - For a dark fringe

    $2\mu t\cos r = n\lambda$; where, n = 0, 1, 2, 3 …
- Interference in transmitted light (transmitted system of light)
  - For a bright-fringe,

    $2\mu t\cos r = n\lambda$; where n = 0, 1, 2, 3, …
  - For a dark fringe,

    $2\mu t\cos r = (2n+1)\frac{\lambda}{2}$; where n = 0, 1, 2, 3, …
- The conditions for maxima and minima in the reflected system are just opposite to those for the transmitted system. Thus the reflected and transmitted systems are complimentary *i.e*, a film which appears bright by reflected light will appear dark by transmitted light and vice-versa.

☞ Diffraction of Light

- The phenomenon of bending of light around the corners of an obstacle or aperture is called diffraction of light.
- Diffraction of light is not easily noticed because the obstacles and apertures of size of wavelength of light 10^{-6} m are hardly available.
- In ray optics, we ignore diffraction and assume that light travels in straight lines. This assumption is reasonable because under ordinary conditions, diffraction (bending) of light is negligible.

- The smaller the size of the obstacle or aperture, the greater is the bending (or diffraction) of light around the corners of the obstacle or aperture and vice-versa.
- The diffraction phenomenon is generally divided into the following two classes :
  - **Fresnel diffraction :** In this case, either the source or the screen or both are at finite distances from the aperture or obstacle causing diffraction.
  - **Fraunhofer diffraction :** In this case, the source and the screen on which the pattern is observed are at infinite distances from the aperture or the obstacle causing diffraction.

☞ Diffraction due to a Single Slit

- The diffraction pattern produced by a single slit of width a consists of a central maximum bright band with alternating bright and dark bands of decreasing intensity on both sides of the central maximum.
- Condition for n^{th} secondary maximum is,

  Path difference $= a\sin\theta_n = (2n+1)\dfrac{\lambda}{2}$
  where $n = 1, 2, 3, ...$
- Condition for n^{th} secondary minimum is,
  Path difference $= a\sin\theta_n = n\lambda$
  where $n = 1, 2, 3,.....$
- Width of secondary maxima or minima

  $\beta = \dfrac{\lambda D}{a} = \dfrac{\lambda f}{a}$

  where
  a = width of slit
  D = distance of screen from the slit
  f = focal length of lens for diffracted light
- Width of central maximum $= \dfrac{2\lambda D}{a} = \dfrac{2f\lambda}{a}$

  The width of central maxima is also called primary fringe width.
- Angular fringe width of central maximum $= \dfrac{2\lambda}{a}$.
- Angular fringe width of secondary maxima or minima $= \dfrac{\lambda}{a}$

☞ Resolving Power of Optical Instruments

- Resolving power is the ability of the instrument to resolve or to see as separate, the images of two close objects.
- Resolving power $(R) = \dfrac{1}{\text{Resolving limit}}$
  - Resolving power of microscope, $R = \dfrac{1}{\Delta d} = \dfrac{2\mu\sin\theta}{\lambda}$

    $\mu \rightarrow$ Refractive index of the medium between the object and objective lens of the microscope
    $\lambda \rightarrow$ wavelength of light
    $\theta \rightarrow$ angle subtended by radius of objective lens on the object.
  - Resolving power of telescope, $R = \dfrac{1}{\Delta\theta} = \dfrac{a}{1.22\lambda}$

    a = diameter of objective lens of the telescope.

☞ Polarisation of Light

- The phenomenon of restricting the vibrations of light (electric vector) in a particular direction, perpendicular to direction of wave motion is called polarisation of light.
- Polarisation of light confirms the transverse nature of light. The plane in which vibrations of polarised light are confined is called plane of vibration. A plane which is perpendicular to the plane of vibration is called plane of polarisation.
- Plane polarised light can be produced by the following methods
  - By reflection
  - By scattering
  - By refraction
  - By dichroism
  - By double refraction
- **Polarising sheets (Polaroid) :** Unpolarised light is linearly polarised and reduced in intensity by half after passing through a single polarising sheet. The parallel lines, which are not actually visible on the sheet, suggest its polarisation direction.

- **Malus's Law :** Intensity of transmitted light by analyser depends on the angle between the polariser and analyser.

$I_\theta \propto \cos^2\theta \Rightarrow I_\theta = I\cos^2\theta$

I = intensity of polarised light passing through the polariser.

- **Polarisation by reflection (Brewster's law)**
  - When unpolarised light is reflected from a plane boundary between two transparent media, the reflected light is partially polarised. The degree of polarisation depends on the angle of incidence and the ratio of wave speeds in the two media.
  - At polarising angle (Brewster's angle), the reflected and refracted beams are mutually perpendicular to each other.

$\sin i_B = \mu\sin(r)$

$\sin i_B = \mu\sin(90 - i_B)$

$\Rightarrow \mu = \tan i_B$

This is the Brewster's law.

SPEED PRACTICE

1. When a light of wavelength 4000 Å in vacuum travels through the same thickness in diamond and water separately, the difference in the number of waves is 200. Find the thickness, if refractive indices of diamond and water are $\frac{5}{2}$ and $\frac{4}{3}$ respectively.

(a) 0.685 mm (b) 0.0685 mm
(c) 68.5 mm (d) 6.85 mm

2. A beam of natural light falls on a system of 5 polaroids, which are arranged in succession such that the pass axis of each polaroid is turned through 60° with respect to the preceding one. The fraction of the incident light intensity that passes through the system is

(a) $\frac{1}{64}$ (b) $\frac{1}{32}$ (c) $\frac{1}{256}$ (d) $\frac{1}{512}$

3. Two plane mirrors are arranged at right angles to each other as shown in figure. A ray of light is incident on the horizontal mirror at an angle θ.

For what value of θ, the ray emerges parallel to the incoming ray after reflection from the vertical mirror?

(a) 60° (b) 30°
(c) 45° (d) All of these

4. In a single slit diffraction pattern, the distance between the first minimum on the left and the first minimum on the right is 5 mm. The screen on which the diffraction pattern is displayed is at a distance of 80 cm from the slit. The wavelength is 6000 Å. The slit width (in mm) is about

(a) 0.576 (b) 0.348 (c) 0.192 (d) 0.096

5. A slab of a material of refractive index 2 shown in figure. has a curved surface *APB* of radius of curvature 10 cm and a plane surface *CD*. On the left

of APB is air and on the right of CD is water with refractive indices as given in the figure. An object O is placed at a distance of 15 cm from the pole P as shown. The distance of the final image of O from P, as viewed from the left is

(a) 10 cm (b) 20 cm
(c) –30 cm (d) –20 cm

6. In Young's double slit experiment, the 10th maximum of wavelength λ_1 is at a distance of y_1 from the central maximum. When the wavelength of the source is changed to λ_2, 5th maximum is at a distance of y_2 from its central maximum. The ratio $\left(\frac{y_1}{y_2}\right)$ is

(a) $\frac{2\lambda_1}{\lambda_2}$ (b) $\frac{2\lambda_2}{\lambda_1}$ (c) $\frac{\lambda_1}{2\lambda_2}$ (d) $\frac{\lambda_2}{2\lambda_1}$

7. A point luminous object (O) is at a distance h from front face of a glass slab of width d and of refractive index μ. On the back face of slab is a reflecting plane mirror.

An observer sees the image of object in mirror as shown in figure. Distance of image from front face as seen by observer will be

(a) $h+\frac{2d}{\mu}$ (b) $2h + 2d$ (c) $h + d$ (d) $h+\frac{d}{\mu}$

8. A compound microscope has an eye piece of focal length 10 cm and an objective of focal length 4 cm. Calculate the magnification, if an object is kept at a distance of 5 cm from the objective, so that the final image is formed at the least distance of distinct vision 25 cm.

(a) 12 (b) 11 (c) 13 (d) 14

9. A beaker contains water up to a height h_1 and kerosene of height h_2 above water so that the total height of (water + kerosene) is $(h_1 + h_2)$. Refractive index of water is μ_1 and that of kerosene is μ_2. The apparent shift in the position of the bottom of the beaker when viewed from above is

(a) $\left(1-\frac{1}{\mu_1}\right)h_2+\left(1-\frac{1}{\mu_2}\right)h_1$

(b) $\left(1+\frac{1}{\mu_1}\right)h_1-\left(1+\frac{1}{\mu_2}\right)h_2$

(c) $\left(1-\frac{1}{\mu_1}\right)h_1+\left(1-\frac{1}{\mu_2}\right)h_2$

(d) $\left(1+\frac{1}{\mu_1}\right)h_2-\left(1+\frac{1}{\mu_2}\right)h_1$

10. The focal length of the lenses of an astronomical telescope are 50 cm and 5 cm. The length of the telescope when the image is formed at the least distance of distinct vision is

(a) 45 cm (b) 55 cm
(c) $\frac{275}{6}$ cm (d) $\frac{325}{6}$ cm

11. In Young's double slit experiment, first slit has width four times the width of the second slit. The ratio of the maximum intensity to the minimum intensity in the interference fringe system is

(a) 2 : 1 (b) 4 : 1 (c) 9 : 1 (d) 8 : 1

12. In a compound microscope, the focal lengths of two lenses are 1.5 cm and 6.25 cm. If an object is placed at 2 cm from objective and the final image is formed at 25 cm from eye lens, the distance between the two lenses is

(a) 6.00 cm (b) 7.75 cm
(c) 9.25 cm (d) 11.0 cm

13. Two identical glass (μ_g = 3/2) equiconvex lenses of focal length f each are kept in contact. The space between the two lenses is filled with water (μ_w = 4/3). The focal length of the combination is

(a) $f/3$ (b) f (c) $4f/3$ (d) $3f/4$

[NEET Phase II 2016]

14. In a diffraction pattern due to a single slit of width a, the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. The first secondary maximum is observed at an angle of

(a) $\sin^{-1}\left(\frac{1}{2}\right)$ (b) $\sin^{-1}\left(\frac{3}{4}\right)$
(c) $\sin^{-1}\left(\frac{1}{4}\right)$ (d) $\sin^{-1}\left(\frac{2}{3}\right)$

[NEET Phase I 2016]

15. The intensity at the maximum in a Young's double slit experiment is I_0. Distance between two slits is $d = 5\lambda$, where λ is the wavelength of light used in the experiment. What will be the intensity in front of one of the slits on the screen placed at a distance $D = 10d$?

(a) $\frac{3}{4}I_0$ (b) $\frac{I_0}{2}$ (c) I_0 (d) $\frac{I_0}{4}$

[NEET Phase I 2016]

16. An astronomical telescope has objective and eyepiece of focal lengths 40 cm and 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance

(a) 50.0 cm (b) 54.0 cm (c) 37.3 cm (d) 46.0 cm

[NEET Phase I 2016]

17. The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If the ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are

(a) $45°; \sqrt{2}$ (b) $30°; \frac{1}{\sqrt{2}}$

(c) $45°; \frac{1}{\sqrt{2}}$ (d) $30°; \sqrt{2}$

[NEET Phase I 2016]

18. The box of a pin hole camera, of length L, has a hole of radius a. It is assumed that when the hole is illuminated by a parallel beam of light of wavelength λ, the spread of the spot (obtained on the opposite wall of the camera) is the sum of its geometrical spread and the spread due to diffraction. The spot would then have its minimum size (say b_{min}) when

(a) $a = \frac{\lambda^2}{L}$ and $b_{min} = \left(\frac{2\lambda^2}{L}\right)$

(b) $a = \sqrt{\lambda L}$ and $b_{min} = \left(\frac{2\lambda^2}{L}\right)$

(c) $a = \sqrt{\lambda L}$ and $b_{min} = \sqrt{4\lambda L}$

(d) $a = \frac{\lambda^2}{L}$ and $b_{min} = \sqrt{4\lambda L}$

[JEE Main Offline 2016]

19. In Young's double slit experiment, the distance between slits and the screen is 1.0 m and monochromatic light of 600 nm is being used. A person standing near the slits is looking at the fringe pattern. When the separation between the slits is varied, the interference pattern disappears for a particular distance d_0 between the slits. If the angular resolution of the eye is $\frac{1°}{60}$, the value of d_0 is close to

(a) 1 mm (b) 3 mm (c) 2 mm (d) 4 mm

[JEE Main Online 2016]

20. On a hot summer night, the refractive index of air is smallest near the ground and increases with height from the ground. When a light beam is directed horizontally, the Huygen's principle leads us to conclude that as it travels, the light beam

(a) bends downwards
(b) bends upwards
(c) becomes narrower
(d) goes horizontally without any deflection.

[JEE Main Offline 2015]

SOLUTIONS

1. **(b):** Here, $\mu_{diamond} = \frac{5}{2}$, $\mu_{water} = \frac{4}{3}$

$\lambda_{vacuum} = 4000$ Å $= 4000 \times 10^{-10}$ m

Refractive index of diamond

$$\mu_{diamond} = \frac{\text{Wavelength of light in vacuum}}{\text{Wavelength of light in diamond}} = \frac{\lambda_{vacuum}}{\lambda_{diamond}}$$

$$\lambda_{diamond} = \frac{4000 \text{ Å}}{(5/2)} = 1600 \text{ Å}$$

Refractive index of water

$$\mu_{water} = \frac{\text{Wavelength of light in vacuum}}{\text{Wavelength of light in water}} = \frac{\lambda_{vacuum}}{\lambda_{water}}$$

$$\lambda_{water} = \frac{4000 \text{ Å}}{(4/3)} = 3000 \text{ Å}$$

Number of waves in thickness t of diamond,

$$n_{diamond} = \frac{t}{\lambda_{diamond}}$$

Number of waves in same thickness t of water,

$$n_{water} = \frac{t}{\lambda_{water}}$$

According to question,

$n_{diamond} - n_{water} = 200$

$$\frac{t}{\lambda_{diamond}} - \frac{t}{\lambda_{water}} = 200$$

$$t\left(\frac{\lambda_{water} - \lambda_{diamond}}{\lambda_{diamond}\,\lambda_{water}}\right) = 200$$

$$t\left(\frac{3000\ \text{Å} - 1600\ \text{Å}}{(1600\ \text{Å})(3000\ \text{Å})}\right) = 200$$

On solving, we get

$$t = 6.85 \times 10^{-5}\ \text{m} = 0.0685\ \text{mm}$$

2. **(d):** Let I_0 be the intensity of incident light. Then the intensity of light from the 1st polaroid is

$$I_1 = \frac{I_0}{2}$$

Intensity of light from the 2nd polaroid is

$$I_2 = I_1 \cos^2 60° = \frac{I_0}{2}\left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$$

Intensity of light from the 3rd polaroid is

$$I_3 = I_2 \cos^2 60° = \frac{I_0}{8}\left(\frac{1}{2}\right)^2 = \frac{I_0}{32}$$

Intensity of light from the 4th polaroid is

$$I_4 = I_3 \cos^2 60° = \frac{I_0}{32}\left(\frac{1}{2}\right)^2 = \frac{I_0}{128}$$

Intensity of light from 5th polaroid is

$$I_5 = I_4 \cos^2 60° = \frac{I_0}{128}\left(\frac{1}{2}\right)^2 = \frac{I_0}{512}$$

Therefore, the fraction of the incident light that passes through the system is

$$\frac{I_5}{I_0} = \frac{1}{512}$$

3. **(d):**

The incident and the second reflected ray make the same angle θ with vertical. Therefore, they are parallel for any value of θ.

4. **(c) :** Distance between the first minimum on the left and the first minimum on the right is also the width of central maximum.

Width of central maximum, $W = \dfrac{2\lambda D}{a}$

where, λ = Wavelength of light

a = Width of the slit

D = Distance of the screen from the slit

$$\therefore \quad a = \frac{2\lambda D}{W}$$

Here, $\lambda = 6000\ \text{Å} = 6000 \times 10^{-10}$ m,

$D = 80$ cm $= 80 \times 10^{-2}$ m

$W = 5$ mm $= 5 \times 10^{-3}$ m

$$\therefore \quad a = \frac{2 \times 6000 \times 10^{-10}\,\text{m} \times 80 \times 10^{-2}\ \text{m}}{5 \times 10^{-3}\,\text{m}}$$

$$= 19.2 \times 10^{-5}\,\text{m} = 0.192 \times 10^{-3}\,\text{m} = 0.192\,\text{mm}$$

5. **(c) :** When light travels from medium of refractive index μ_2 to medium of refractive index μ_1 at a single spherical surface, the formula used is

$$\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}$$

Direction of light is in positive direction.

$$\therefore \quad \frac{1.0}{v} - \frac{2.0}{-15} = \frac{1.0 - 2.0}{-10}$$

F is centre of curvature of APB.

$$\text{or} \quad \frac{1}{v} = \frac{1}{10} - \frac{2}{15} = \frac{3-4}{30} = \frac{-1}{30} \quad \text{or } v = -30\ \text{cm}$$

∴ The distance of the final image of O from P, as viewed from the left, is 30 cm to right of P. The image formed will be virtual at E.

6. **(a) :** The distance of 10th maximum of wavelength λ_1 from the central maximum is

$$y_1 = 10\lambda_1 \frac{D}{d}$$

where D is the distance of the slits from the screen and d is the distance between the slits.

The distance of 5th maximum of wavelength λ_2 from the central maximum is

$$y_2 = 5\lambda_2 \frac{D}{d} \qquad \therefore \quad \frac{y_1}{y_2} = \frac{2\lambda_1}{\lambda_2}$$

7. **(a) :** As shown in figure, glass slab will form the image of bottom *i.e.*, mirror MM' at a depth $\left(\dfrac{d}{\mu}\right)$ from its front face.

So the distance of object O from virtual mirror mm' will be $h + \left(\dfrac{d}{\mu}\right)$.

Now as a plane mirror forms image behind the mirror at the same distance as the object is in front of it, the distance of image I from mm' will be $h+\left(\frac{d}{\mu}\right)$ and as the distance of virtual mirror from the front face of slab is $\left(\frac{d}{\mu}\right)$, the distance of image I from front face as seen by observer will be

$$=\left[h+\frac{d}{\mu}\right]+\frac{d}{\mu}=h+\frac{2d}{\mu}$$

8. (d): Here, f_o = 4 cm, f_e = 10 cm, u_o = –5 cm

For objective

$$\frac{1}{v_o}-\frac{1}{-5}=\frac{1}{4},\quad \frac{1}{v_o}=\frac{1}{4}-\frac{1}{5}=\frac{1}{20}\quad \text{or}\quad v_o=20\text{ cm}$$

Magnification when the final image is formed at the least distance of distinct vision D (= 25 cm) is

$$M=\frac{v_o}{|u_o|}\left(1+\frac{D}{f_e}\right)=\frac{20}{5}\left(1+\frac{25}{10}\right)=14$$

9. (c) : Apparent shift of bottom position of beaker in water is

$$x_1=h_1-\frac{h_1}{\mu_1}=h_1\left(1-\frac{1}{\mu_1}\right)$$

Apparent shift of bottom position in kerosene is

$$x_2=h_2-\frac{h_2}{\mu_2}=h_2\left(1-\frac{1}{\mu_2}\right)$$

$$\text{Total shift}=x_1+x_2=h_1\left(1-\frac{1}{\mu_1}\right)+h_2\left(1-\frac{1}{\mu_2}\right)$$

10. (d): Here, f_o = 50 cm, f_e = 5 cm, D = 25 cm

The length of the telescope when the image is formed at the least distance of distinct vision is

$$L=f_o+\frac{f_eD}{f_e+D}=50+\frac{5\times25}{5+25}=50+\frac{25}{6}=\frac{325}{6}\text{ cm}$$

11. (c) : If W_1 and W_2 are widths of two slits, then

$$\frac{I_1}{I_2}=\frac{W_1}{W_2}=4$$

Also, $\frac{I_1}{I_2}=\frac{A_1^2}{A_2^2}\quad\therefore\quad \frac{A_1^2}{A_2^2}=4$ or $\frac{A_1}{A_2}=2$

$$\frac{I_{max}}{I_{min}}=\left(\frac{A_1+A_2}{A_1-A_2}\right)^2=\frac{\left(\frac{A_1}{A_2}+1\right)^2}{\left(\frac{A_1}{A_2}-1\right)^2}=\frac{(2+1)^2}{(2-1)^2}=\frac{9}{1}$$

12. (d): Here, f_o = 1.5 cm, f_e = 6.25 cm, u_o = –2 cm, v_e = –25 cm

For objective,

$$\frac{1}{v_o}-\frac{1}{u_o}=\frac{1}{f_o}\qquad\therefore\quad \frac{1}{v_o}-\frac{1}{-2}=\frac{1}{1.5}$$

$$\frac{1}{v_o}=\frac{1}{1.5}-\frac{1}{2}\quad\text{or}\quad v_o=6\text{ cm}$$

For eye piece,

$$\frac{1}{v_e}-\frac{1}{u_e}=\frac{1}{f_e}$$

$$\frac{1}{-25}-\frac{1}{u_e}=\frac{1}{6.25}$$

$$-\frac{1}{u_e}=\frac{1}{6.25}+\frac{1}{25}\quad\text{or}\quad u_e=-5\text{ cm}$$

Distance between two lenses = $|v_o|+|u_e|$

= 6 cm + 5 cm = 11 cm

13. (d): Let R be the radius of curvature of each surface.

$$\frac{1}{f}=(1.5-1)\left(\frac{1}{R}+\frac{1}{R}\right)\qquad\therefore\quad R=f$$

For the water lens, $\frac{1}{f'}=\left(\frac{4}{3}-1\right)\left(-\frac{1}{R}-\frac{1}{R}\right)$

$$=\frac{1}{3}\left(-\frac{2}{f}\right)$$

or $\frac{1}{f'}=-\frac{2}{3f}$

Using, $\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3}$

$$\frac{1}{F}=\frac{1}{f}+\frac{1}{f}+\frac{1}{f'}=\frac{2}{f}-\frac{2}{3f}=\frac{4}{3f}$$

$$\therefore\quad F=\frac{3f}{4}$$

14. (b): For first minimum,

the path difference between extreme waves,

$a\sin\theta=\lambda$

Here $\theta=30°\Rightarrow\sin30°=\frac{1}{2}$

$\therefore\quad a=2\lambda$ ...(i)

For first secondary maximum, the path difference between extreme waves

$a\sin\theta'=\frac{3}{2}\lambda$ or $(2\lambda)\sin\theta'=\frac{3}{2}\lambda$ [Using eqn (i)]

or $\sin\theta'=\frac{3}{4}\quad\therefore\quad\theta'=\sin^{-1}\left(\frac{3}{4}\right)$

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15. (b): Here, $d = 5\lambda$, $D = 10d$, $y = \frac{d}{2}$.

Resultant Intensity at $y = \frac{d}{2}, I_y = ?$

The path difference between two waves at $y = \frac{d}{2}$

$$\Delta x = d\tan\theta = d \times \frac{y}{D} = \frac{d \times \frac{d}{2}}{10d} = \frac{d}{20} = \frac{5\lambda}{20} = \frac{\lambda}{4}$$

Corresponding phase difference, $\phi = \frac{2\pi}{\lambda}\Delta x = \frac{\pi}{2}$.

Now, maximum intensity in Young's double slit experiment,

$$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$$

$$I_0 = 4I \Rightarrow \quad I = \frac{I_0}{4}. \qquad (\because \ I_1 = I_2 = I)$$

Required intensity $I_y = I_1 + I_2 + 2I_1 I_2 \cos\frac{\pi}{2}$

$$= 2I = \frac{I_0}{2}$$

16. (b): Here $f_o = 40$ cm, $f_e = 4$ cm

Tube length(l) = Distance between lenses = $v_o + f_e$

For objective lens,

$u_o = -200$ cm, $v_o = ?$

$$\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o} \text{ or } \frac{1}{v_o} - \frac{1}{-200} = \frac{1}{40}$$

$$\text{or } \frac{1}{v_o} = \frac{1}{40} - \frac{1}{200} = \frac{4}{200} \qquad \therefore \ v_o = 50 \text{ cm}$$

$\therefore \quad l = 50 + 4 = 54$ cm

17. (d): Given, $i = 45°$, $A = 60°$

Since the ray undergoes minimum deviation, therefore, angle of emergence from second face, $e = i = 45°$

$\therefore \quad \delta_m = i + e - A = 45° + 45° - 60° = 30°$

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60°+30°}{2}\right)}{\sin\left(\frac{60°}{2}\right)}$$

$$= \frac{\sin 45°}{\sin 30°} = \frac{1}{\sqrt{2}} \times \frac{2}{1} = \sqrt{2}$$

18. (c): Size of spot, b = Geometrical spread + diffraction spread

$$\therefore \quad b = a + L\frac{\lambda}{a}$$

Now, value of b would be minimum if $\frac{db}{da} = 0$

$$1 + L\left(\frac{-\lambda}{a^2}\right) = 0 \Rightarrow a^2 = \lambda L \Rightarrow a = \sqrt{\lambda L}$$

$$\therefore \quad b_{min} = \sqrt{\lambda L} + \frac{\lambda L}{\sqrt{\lambda L}} = 2\sqrt{\lambda L} = \sqrt{4\lambda L}$$

19. (c): For a particular distance d_0 between the slits, the eye is not able to resolve two consecutive bright fringes.

Now, $\theta = \frac{\beta}{D}$ but $\beta = \frac{\lambda D}{d_0}$

$$\therefore \quad \theta = \frac{\lambda}{d_0}$$

$$\text{or } \quad d_0 = \frac{\lambda}{\theta} = \frac{600 \times 10^{-9} \text{ m}}{\frac{1}{60} \times \frac{\pi}{180} \text{ rad}} = 2.06 \times 10^{-3} \text{ m} \approx 2 \text{ mm}$$

20. (b): Consider a plane wavefront travelling horizontally.

As refractive index of air increases with height, so speed of wavefront decreases with height. Hence, the light beam bends upwards.

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CLASS XII Series 6

ACE YOUR WAY CBSE

Dual Nature of Matter and Radiation
Atoms and Nuclei

Time Allowed : 3 hours
Maximum Marks : 70

GENERAL INSTRUCTIONS

(i) All questions are compulsory.
(ii) Q. no. 1 to 5 are very short answer questions and carry 1 mark each.
(iii) Q. no. 6 to 10 are short answer questions and carry 2 marks each.
(iv) Q. no. 11 to 22 are also short answer questions and carry 3 marks each.
(v) Q. no. 23 is a value based question and carries 4 marks.
(vi) Q. no. 24 to 26 are long answer questions and carry 5 marks each.
(vii) Use log tables if necessary, use of calculators is not allowed.

Previous Years Analysis

	2016		2015		2014	
	Delhi	AI	Delhi	AI	Delhi	AI
VSA	–	–	–	–	–	2
SA-I	2	2	2	2	2	1
SA-II	2	2	2	2	2	1
VBQ	–	–	–	–	–	1
LA	–	–	–	–	–	–

SECTION-A

1. Does each incident photon essentially eject a photoelectron from the material?

2. A proton and an electron have same velocity. Which one has greater de Broglie wavelength?

3. The radius of the innermost electron orbit of a hydrogen atom is 5.3×10^{-11} m. What are the radii of the $n = 2$ and $n = 3$ orbits?

4. How many electrons, protons and neutrons are there in a nucleus of atomic number 11 and mass number 24?

5. Two nuclei have mass numbers in the ratio 1 : 2. What is the ratio of their nuclear densities?

SECTION-B

6. The sequence of decay of radioactive nucleus is

$$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta} D_2 \xrightarrow{\alpha} D_3 \xrightarrow{\alpha} D_4$$

If mass number and atomic number of D_2 are 176 and 71 respectively, what are their values for D and D_4?

7. Draw a graph showing the variation of stopping potential with frequency of incident radiation. What does the slope of the line with frequency axis indicate?

8. There are two sources of light, each emitting with a power of 100 W. One emits X-rays of wavelength 1 nm and the other visible light at 500 nm. Find the ratio of number of photons of X-rays to the photons of visible light of the given wavelength.

9. (a) The energy levels of an atom are shown in figure. Which of them will result in the transition of a photon of wavelength 275 nm? (b)Which transition corresponds to emission of radiation of maximum wavelength?

OR

The threshold frequency of metal is υ_0. When the light of frequency $2\upsilon_0$ is incident on the metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\upsilon_0$, the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2.

10. Two nuclei P and Q have equal number of atoms at $t = 0$. Their half lives are 3 hours and 9 hours respectively. Compare their rates of disintegration after 18 hours from the start.

SECTION-C

11. The given graphs show the variation of the stopping potential V_0 with the frequency (υ) of the incident radiations for two different photosensitive materials M_1 and M_2.

(a) What are the values of work functions for M_1 and M_2?

(b) The values of the stopping potential for M_1 and M_2 for a frequency υ_3 ($> \upsilon_{02}$) of the incident radiations are V_1 and V_2 respectively. Show that the slope of the lines equals $\dfrac{V_1 - V_2}{\upsilon_{02} - \upsilon_{01}}$.

12. Monochromatic radiation of wavelength 640.2 nm from a neon lamp irradiates photosensitive material made of cesium. The stopping voltage is measured to be 0.54 V. The source is replaced by another source of wavelength 427.2 nm which irradiates the same photocell. Find the new stopping voltage.

13. The ground state energy of hydrogen atom is –13.6 eV. The photon emitted during the transition of electron from $n = 3$ to $n = 1$ state, is incident on a photosensitive material of unknown work function. The photoelectrons are emitted from the materials with a maximum kinetic energy of 9 eV. Calculate the threshold wavelength of the material used.

14. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect, which can be explained on the basis of the above equation.

15. Calculate the de-Broglie wavelength associated with an electron of energy 200 eV. What will be the change in this wavelength if the accelerating potential is increased to four times its earlier value?

16. X-rays of wavelength λ fall on a photosensitive surface, emitting electrons. Assuming that the work function of the surface can be neglected, prove that the de-Broglie wavelength of electrons emitted will be $\sqrt{\dfrac{h\lambda}{2mc}}$.

17. A nucleus of mass M initially at rest splits into two fragments of masses $M'/3$ and $2M'/3$ ($M > M'$). Find the ratio of de-Broglie wavelengths of the two fragments.

18. Using Rutherford's model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron?

19. The energy of the electron, in the hydrogen atom, is known to be expressible in the form

$$E_n = \frac{-13.6}{n^2}\ \text{eV} \qquad [n = 1, 2, 3 \ldots]$$

Use this expression to show that the

(a) electron in the hydrogen atom cannot have an energy of – 6.8 eV.

(b) Spacing between the lines (consecutive energy level) within the given set of the observed hydrogen spectrum decreases as n increases.

20. A 12.5 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?
Calculate the wavelengths of the first member of Lyman and first member of Balmer series.

21. A nucleus ${}_{10}Ne^{23}$ undergoes β-decay and becomes ${}_{11}Na^{23}$. Calculate the maximum kinetic energy of electrons emitted. Assuming that the daughter nucleus and antineutrino carry negligible kinetic energy.

Give : mass of ${}_{10}Ne^{23}$ = 22.994466 u

mass of ${}_{11}Na^{23}$ = 22.989770 u

1u = 931.5 MeVc^{-2}

OR

Complete the following decay process for β-decay of phosphorous 32 :

$$_{15}P^{32} \rightarrow S + ...$$

The graph shows how the activity of radioactive nucleus changes with time. Using the graph, determine

(a) half life of the nucleus and

(b) its decay constant.

22. The half life of a radioactive sample against β-decay is 5500 years. Its initial activity is found to be 15 decays per minute per gram. In how much time would its activity reduce to 10 decays per minute per gram?

[Given : $\log_e 3 = 1.0986$ and $\log_e 2 = 0.693$]

SECTION-D

23. Some scientists have predicted that a global nuclear war on earth would be followed by a severe nuclear winter with a devastating effect on life on earth.

Answer the following questions based on above prediction:

(a) What is the possible basis of this fear and prediction?

(b) Which human values are violated in the event of a nuclear war?

(c) Which values need to be promoted in humans so that such a situation of global nuclear war does not arise?

(d) Suggest two methods to promote such values.

SECTION-E

24. What do you mean by binding energy? Draw the graph to show variation of binding energy per nucleon with mass number. Explain this graph.

OR

State and explain the laws of radioactive disintegration. Define disintegration constant and half life period. Establish relation between them.

25. What is photoelectric effect? Explain experimentally the variation of photoelectric current with (a) the intensity of the incident light (b) the potential difference between the plates and (c) the frequency of the incident light and hence state the laws of photoelectric emission.

OR

State the basic postulates of Bohr's theory of atomic spectra. Hence obtain an expression for radius of orbit and the energy of orbital electron in hydrogen atom.

26. In Rutherford's scattering experiment, mention two important conclusions which can be drawn by studying the scattering of α-particles by an atom. Draw a schematic arrangement of Geiger and Marsden experiment showing the scattering of α–particles by a thin foil of gold. How does one get information regarding the size of the nucleus in this experiment?

OR

Describe Davisson and Germer's experiment to demonstrate the wave nature of electrons. Draw a labelled diagram of apparatus used.

SOLUTIONS

1. No, it may be absorbed in some other way. If the frequency of the incident photon is less than the threshold frequency, there will be no emission of photoelectrons at all.

2. de-Broglie wavelength, $\lambda = \dfrac{h}{mv}$

or $\lambda \propto \dfrac{1}{m}$ $\quad \therefore \quad \dfrac{\lambda_p}{\lambda_e} = \dfrac{m_e}{m_p} < 1$ or $\lambda_p < \lambda_e$

i.e., de-Broglie wavelength of electron is more than that of proton.

3. Radius of nth orbit of electron,

$$r = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2}$$

For $n = 1$, $r_1 = \dfrac{h^2 \varepsilon_0}{\pi m e^2} = 5.3 \times 10^{-11}$ m

For $n = 2$, $r_2 = (2)^2 r_1 = 2.12 \times 10^{-10}$ m

For $n = 3$, $r_3 = (3)^2 r_1 = 4.77 \times 10^{-10}$ m

4. Mass number, $A = 24$;

Atomic number, Z = Number of protons = 11

$\therefore$ Number of neutrons, $N = A - Z = 24 - 11 = 13$

A nucleus contains no electrons. Therefore, number of electrons, protons and neutrons in this nucleus is zero, 11 and 13 respectively.

5. The ratio of nuclear densities is 1 : 1. This is because nuclear density does not depend upon mass number.

6. As mass number of each α particle is 4 units and its charge number is 2 units, therefore, for D_4

$A = 176 - 8 = 168$

$Z = 71 - 4 = 67$

Now, charge number of β is –1 and its mass number is zero, therefore, for D

$A = 176 + 0 + 4 = 180$

$Z = 71 - 1 + 2 = 72$

7. The V_0 - υ graph is a straight line as shown in the figure.

$eV_0 = h\upsilon - h\upsilon_0$

$$V_0 = \frac{h}{e}(\upsilon - \upsilon_0)$$

Comparing the above relation with the equation of straight line, $y = mx + c$

$\therefore$ The slope of $V_0 - \upsilon$ graph is $\frac{h}{e}$.

8. Here, $P = 100$ W, $\lambda_1 = 1$ nm, $\lambda_2 = 500$ nm

Let n_1, n_2 = Number of photons of X-rays and visible light emitted from the two sources in time t.

$$\therefore \quad P = n_1 \frac{hc}{\lambda_1 t} = n_2 \frac{hc}{\lambda_2 t} \quad \text{or} \quad \frac{n_1}{\lambda_1} = \frac{n_2}{\lambda_2}$$

[$\because$ $P = 100$ W for both sources of light]

$$\text{or} \quad \frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2} = \frac{1}{500}$$

9. (a) Given, $\lambda = 275$ nm $= 275 \times 10^{-9}$ m

$$E = h\upsilon = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{275 \times 10^{-9}} \text{ J}$$

$$= \frac{19.8 \times 10^{-17}}{275 \times 1.6 \times 10^{-19}} \text{ eV} = 4.5 \text{ eV}$$

$\therefore$ Transition B will result in the emission of photon of wavelength, $\lambda = 275$ nm

(b) Maximum wavelength has minimum energy. Transition A provides energy of 2 eV, which is minimum.

OR

As υ_0 is the threshold frequency, so

Work function, $W = h\upsilon_0$

Using Einstein's photoelectric equation, we get

$$\frac{1}{2}mv_1^2 = h \times 2\upsilon_0 - W = 2h\upsilon_0 - h\upsilon_0 = h\upsilon_0 \quad \text{...(i)}$$

$$\text{And} \quad \frac{1}{2}mv_2^2 = h \times 5\upsilon_0 - h\upsilon_0 = 5h\upsilon_0 - h\upsilon_0 = 4h\upsilon_0 \quad \text{...(ii)}$$

Divide (i) by (ii), we get

$$\frac{\frac{1}{2}mv_1^2}{\frac{1}{2}mv_2^2} = \frac{h\upsilon_0}{4h\upsilon_0} \quad \text{or} \quad \frac{v_1}{v_2} = \frac{1}{2} = 1:2$$

10. Number of half lives of P in 18 hours $= \frac{18}{3} = 6$

Number of half lives of Q in 18 hours $= \frac{18}{9} = 2$

Both P and Q nuclei have equal number of atoms at $t = 0$.

Therefore, number of nuclei left undecayed,

$$N_1 = N_0\left(\frac{1}{2}\right)^6 = \frac{N_0}{64}$$

$$N_2 = N_0\left(\frac{1}{2}\right)^2 = \frac{N_0}{4}$$

The ratio of their rates of disintegration is

$$\frac{R_1}{R_2} = \frac{\lambda_1 N_1}{\lambda_2 N_2} = \frac{T_2}{T_1}\left(\frac{N_1}{N_2}\right) = \frac{9}{3} \times \frac{(N_0/64)}{(N_0/4)}$$

$$= \frac{3}{16} = 3:16$$

11. (a) Work function for M_1 is $W_{01} = h\upsilon_{01}$ and for M_2 is $W_{02} = h\upsilon_{02}$

(b) For metal M_1, $eV_1 = h\upsilon_3 - h\upsilon_{01}$

or $eV_1 + h\upsilon_{01} = h\upsilon_3$ ...(i)

For metal M_2, $eV_2 = h\upsilon_3 - h\upsilon_{02}$

or $eV_2 + h\upsilon_{02} = h\upsilon_3$ ... (ii)

By equations (i) and (ii)

$eV_1 + h\upsilon_{01} = eV_2 + h\upsilon_{02}$

or $e(V_1 - V_2) = h(\upsilon_{02} - \upsilon_{01})$

$$\text{or} \quad \frac{h}{e} = \frac{(V_1 - V_2)}{(\upsilon_{02} - \upsilon_{01})} \quad \text{or} \quad \text{Slope} = \frac{V_1 - V_2}{\upsilon_{02} - \upsilon_{01}}$$

12. $$\frac{1}{2}mv_{max}^2 = eV_0 = \frac{hc}{\lambda} - W_0$$

$$\text{or} \quad W_0 = \frac{hc}{\lambda} - eV_0$$

$$\therefore \quad \frac{hc}{\lambda_1} - eV_1 = \frac{hc}{\lambda_2} - eV_2$$

or $$V_2 = \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) + V_1$$

or $$V_2 = \frac{6.6\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times10^{-9}}\left[\frac{1}{427.2} - \frac{1}{640.2}\right] + 0.54$$

or $$V_2 = 12.375\times10^{2}\left[\frac{640.2-427.2}{427.2\times640.2}\right] + 0.54$$

or $$V_2 = 12.375\times10^{2}\times\frac{213}{427.2\times640.2} + 0.54$$

or $$V_2 = 1.5 \text{ volts}$$

13. Maximum kinetic energy $= \frac{1}{2}mv_{max}^2 = 9$ eV

Energy of photon emitted during transition of electron in an atom is

$$h\upsilon = E_i - E_f = -\frac{13.6}{n_i^2} - \left(-\frac{13.6}{n_f^2}\right)$$

$$= \frac{-13.6}{3^2} + \frac{13.6}{1^2} = -1.51 + 13.6$$

or $$h\upsilon = 12.09 \text{ eV} \qquad \text{....(i)}$$

By Einstein's photoelectric equation

$$\frac{1}{2}mv_{max}^2 = h\upsilon - W_0$$

or $$W_0 = h\upsilon - \frac{1}{2}mv_{max}^2 = 12.09 - 9$$

or $$\frac{hc}{\lambda_0} = 3.09 \text{ eV} = 3.09\times1.6\times10^{-19} \text{ J}$$

or $$\lambda_0 = \frac{hc}{3.09\times1.6\times10^{-19}}$$

or $$\lambda_0 = 4\times10^{-7} \text{ m} = 4000 \text{ Å}$$

14. Einstein's photoelectric equation is given below

$$h\upsilon = \frac{1}{2}mv_{max}^2 + W_0$$

or $$K_{max} = \frac{1}{2}mv_{max}^2 = h\upsilon - W_0$$

At threshold frequency υ_0, no kinetic energy is given to the electron. So, $h\upsilon_0 = W_0$

Hence $K_{max} = h\upsilon - W_0 = h(\upsilon - \upsilon_0)$

where υ = Frequency of incident radiation

υ_0 = Threshold frequency

W_0 = Work function of the target metal

Three salient features observed are

(a) Below threshold frequency υ_0 corresponding to W_0, no emission of photoelectron takes place.

(b) As energy of a photon depends on the frequency of light, so the maximum kinetic energy with which photoelectron is emitted depends only on the energy of photon or on the frequency of incident radiation.

(c) As the number of photons in light depend on its intensity, and one photon liberates one photoelectron, so number of photoelectrons emitted depend only on the intensity of incident light.

15. Here, kinetic energy $K = 200$ eV

de-Broglie wavelength of an electron is

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$$

$$\lambda = \frac{6.6\times10^{-34}\times10^{10} \text{ Å}}{\sqrt{2\times9.1\times10^{-31}\times200\times1.6\times10^{-19}}}$$

$\lambda = 0.87$ Å

As $\lambda = \frac{12.27 \text{ Å}}{\sqrt{V}}$, so if accelerating potential V is increased to four times, wavelength will become half of its initial value.

16. When X-rays fall on photosensitive surface

$$\frac{1}{2}mv^2 = h\upsilon - W_0$$

Since, $W_0 \approx 0$

$$\frac{1}{2}mv^2 = h\upsilon = \frac{hc}{\lambda}$$

or $$v^2 = \frac{2hc}{\lambda m} \quad \text{or} \quad v = \sqrt{\frac{2hc}{\lambda m}}$$

de-Broglie wavelength of electron is

$$\lambda' = \frac{h}{mv} = \frac{h}{m}\sqrt{\frac{\lambda m}{2hc}}$$

or $$\lambda' = \sqrt{\frac{h^2}{m^2}\frac{\lambda m}{2hc}} = \sqrt{\frac{h\lambda}{2mc}}$$

17. By principle of conservation of momentum

$$M\times0 = \frac{M'}{3}v_1 + \frac{2M'}{3}v_2$$

or $$\frac{M'}{3}v_1 = \frac{2M'}{3}v_2 \qquad \text{[Magnitude only]}$$

$$\Rightarrow \quad m_1v_1 = m_2v_2$$

Ratio of de-Broglie wavelengths is then given by

$$\frac{\lambda_1}{\lambda_2} = \frac{h/m_1v_1}{h/m_2v_2} = \frac{m_2v_2}{m_1v_1}$$

or $\frac{\lambda_1}{\lambda_2} = 1$

18. Energy of electron in n^{th} orbit of hydrogen atom:
An electron revolving in an orbit of H-atom, has both kinetic energy and electrostatic potential energy.
Kinetic energy of the electron revolving in a circular orbit of radius r is $E_K = \frac{1}{2}mv^2$

Since, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

$$\therefore \quad E_K = \frac{1}{2} \times \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \quad \text{or} \quad E_K = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r}$$

Electrostatic potential energy of electron of charge $-e$ revolving around the nucleus of charge $+e$ in an orbit of radius r is

$$E_P = \frac{1}{4\pi\varepsilon_0}\frac{(+e)\times(-e)}{r} \quad \text{or} \quad E_P = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

So, total energy of electron in orbit of radius r is

$$E = E_K + E_P \quad \text{or} \quad E = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\text{or} \quad E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2r}$$

Putting $r = \frac{n^2h^2\varepsilon_0}{\pi me^2}$, we get

$$E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2\left(\frac{n^2h^2\varepsilon_0}{\pi me^2}\right)} \quad \text{or} \quad E = -\frac{me^4}{8\varepsilon_0^2n^2h^2}$$

$$\text{or} \quad E_n = -\frac{13.6}{n^2}\text{ eV}$$

The negative sign of the energy of electron indicates that the electron and nucleus together form a bound system *i.e.*, electron is bound to the nucleus.

19. (a) $E_n = -\frac{13.6}{n^2}$ eV

$$\text{or} \quad -6.8\text{ eV} = -\frac{13.6}{n^2}\text{ eV}$$

$$\text{or} \quad n^2 = \frac{13.6}{6.8} = 2$$

$$\text{or} \quad n = \sqrt{2} = 1.414$$

Since, the value of n is not an integer, so electron in the hydrogen atom cannot have an energy of –6.8 eV.

(b) For transition of electron from one energy level to the other in hydrogen atom, the wavelength of radiation emitted, called spectral line is

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

In Lyman series, $n_f = 1$

For transition from $n_i = 2$ to $n_f = 1$

$$\frac{1}{\lambda_1} = R_H\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = R_H\left(1 - \frac{1}{4}\right) = \frac{3}{4}R_H$$

$$\text{or} \quad \lambda_1 = \frac{4}{3R_H} = \frac{4}{3\times1.1\times10^7} = 1212\text{ Å}$$

For transition from $n_i = 3$ to $n_f = 1$

$$\frac{1}{\lambda_2} = R_H\left(\frac{1}{1^2} - \frac{1}{3^2}\right) = R_H\left(1 - \frac{1}{9}\right) = \frac{8}{9}R_H$$

$$\text{or} \quad \lambda_2 = \frac{9}{8R_H} = \frac{9}{8\times1.1\times10^7} = 1023\text{ Å}$$

For transition from $n_i = 4$ to $n_f = 1$

$$\frac{1}{\lambda_3} = R_H\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = R_H\left(1 - \frac{1}{16}\right) = \frac{15}{16}R_H$$

$$\text{or} \quad \lambda_3 = \frac{16}{15R_H} = \frac{16}{15\times1.1\times10^7} = 970\text{ Å}$$

Spacing between λ_1 and λ_2 is 1212 – 1023 = 189 Å and spacing between λ_2 and λ_3 is 1023 – 970 = 53 Å
So, spacing between the lines within the given set of the observed hydrogen spectrum decreases as n increases.

20. Here, $\Delta E = 12.5$ eV
Energy of an electron in n^{th} orbit of hydrogen atom is,

$$E_n = -\frac{13.6}{n^2}\text{ eV}$$

In ground state, $n = 1$
$E_1 = -13.6$ eV
Energy of an electron in the excited state after absorbing a photon of 12.5 eV energy will be
$E_n = -13.6 + 12.5 = -1.1$ eV

$$\therefore \quad n^2 = \frac{-13.6}{E_n} = \frac{-13.6}{-1.1} = 12.36 \Rightarrow n = 3.5$$

Here, state of electron cannot be fraction,
So, $n = 3$

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The wavelength λ of the first member of Lyman series is given by

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{2^2}\right] = \frac{3}{4}R$$

$$\Rightarrow \quad \lambda = \frac{4}{3R} = \frac{4}{3 \times 1.1 \times 10^7} = 1.212 \times 10^{-7} \text{ m}$$

$$= 121 \times 10^{-9} \text{ m} \Rightarrow \lambda = 121 \text{ nm}$$

The wavelength λ' of the first member of the Balmer series is given by

$$\frac{1}{\lambda'} = R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = \frac{5}{36}R$$

$$\Rightarrow \quad \lambda' = \frac{36}{5R} = \frac{36}{5 \times (1.1 \times 10^7)}$$

$$= 6.55 \times 10^{-7} \text{ m} = 655 \times 10^{-9} \text{ m} = 655 \text{ nm}$$

21. ${}_{10}Ne^{23} \rightarrow {}_{11}Na^{23} + {}_{-1}e^0 + \bar{\nu}$

Mass lost during the β-decay is

$$\Delta m = m\left({}_{10}Ne^{23}\right) - m\left({}_{11}Na^{23}\right) - m\left({}_{-1}e^0\right) - m(\bar{\nu})$$

As $m({}_{-1}e^0)$ and $m(\bar{\nu})$ are negligible, so

$\Delta m \approx m\,({}_{10}Ne^{23}) - m({}_{11}Na^{23})$

$= 22.994466 - 22.989770$

$\Delta m = 0.004696$ u

So, energy released during β-decay is

$E = \Delta m \times 931.5$ MeV $= 0.004696 \times 931.5$ MeV

or $\quad E = 4.374$ MeV

As daughter nucleus ${}_{11}Na^{23}$ and antineutrino share negligible kinetic energy, so maximum kinetic energy of electrons emitted is 4.374 MeV.

OR

${}_{15}P^{32} \rightarrow {}_{16}S^{32} + {}_{-1}e^0 + \bar{\nu}$

(a) From the graph, $\frac{40}{80} = \left(\frac{1}{2}\right)^n$ or $\frac{1}{2} = \left(\frac{1}{2}\right)^n$

So $n = 1$

As $t = nT_{1/2}$ or $T_{1/2} = \frac{t}{1} = \frac{50}{1}$ or $T_{1/2} = 50$ s

(b) $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{50} = 0.014$ dps

22. $T_{1/2} = 5500$ years, $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{5500}$ years^{-1}

$R_0 = 15$ decays min^{-1} g^{-1}, $R = 10$ decays min^{-1} g^{-1}

$$R = \frac{dN}{dt} = \frac{d}{dt}\left[N_0 e^{-\lambda t}\right] = -\lambda N_0 e^{-\lambda t}$$

or $\quad R = -R_0\, e^{-\lambda t}$

Where negative sign shows, that R decreases with time.

$|R| = R_0\, e^{-\lambda t}$ or $10 = 15\, e^{-\lambda t}$

or $\quad \frac{10}{15} = e^{-\lambda t}$ or $\frac{2}{3} = e^{-\lambda t}$

or $\quad \log_e\left(\frac{2}{3}\right) = \log_e e^{-\lambda t}$

or $\quad \log_e 2 - \log_e 3 = -\lambda t$

or $\quad t = \frac{0.4056 \times 5500}{0.693} = 3219$ years

23. (a) The clouds produced by nuclear war would perhaps cover substantial parts of the sky preventing solar light from reaching many parts of the globe. This would cause a winter.

(b) Humanity, non-violence, understanding between nations, brotherhood.

(c) Restraint on misuse of nuclear weapons, respect for sovereignity of every country, emotional balance.

(d) (i) Vigorous campaign for spreading awareness.

(ii) Highlighting these issues and concerns in curricula in all stages.

24. **Refer to point 8.3 (12, 13, 15) page no. 534 (MTG Excel in Physics)**

OR

Refer to point 8.4 (11, 13) page no. 537 (MTG Excel in Physics)

25. **Refer to point 7.2 page no. 489 (MTG Excel in Physics)**

OR

Refer to point 8.1 (4) page no. 526 and point 8.2 (1, 4) page no. 527 (MTG Excel in Physics)

26. **Refer to point 8.1 (2, 3) page no. 525 (MTG Excel in Physics)**

OR

Refer to point 7.4 (6) page no. 493 (MTG Excel in Physics)

JEE WORK GUTS

INTEGER TYPE QUESTIONS Class-XII

1. A silver ball of radius 4.8 cm is suspended by a thread in a vacuum chamber. Ultraviolet light of wavelength 200 nm is incident on the ball for sometime during which a total light energy of 1.0×10^{-7} J falls on the surface. Assuming that on the average, one photon out of ten thousand photons is able to eject a photoelectron, find the electric potential (in 10^{-1} V) at the surface of the ball assuming zero potential at infinity.

2. A convex lens of focal length 1.5 m is placed in a system of coordinate axis such that its optical centre is at origin and principal axis coinciding with the x-axis. An object and a plane mirror are arranged on the principal axis as shown in figure. Find the value of d (in m) so that y-coordinate of image (after refraction and reflection) is 0.3 m.
(Take tan θ = 0.3)

3. Find recoil speed (approximately in m s^{-1}) when a hydrogen atom emits a photon during the transition from $n = 5$ to $n = 1$.

4. Three capacitors of 2 μF, 3 μF and 6 μF are joined in series and the combination is charged by means of 24 V battery. Find the potential difference in volt between the plates of 6 μF capacitor.

5. In the circuit as shown in figure the resistor (in ohm) in which maximum heat will be produced is :

6. When two identical batteries of internal resistance 1 Ω each are connected in series across a resistor R, the rate of heat produced in R is J_1. When the same batteries are connected in parallel across R, the rate is J_2. If $J_1 = 2.25J_2$ then find the value of R in Ω.

7. Water (with refractive index = 4/3) in a tank is 18 cm deep. Oil of refractive index 7/4 lies on water making a convex surface of radius of curvature R = 6 cm as shown. Consider oil to act as a thin lens. An object S is placed 24 cm above water surface. The location of its image is at x cm above the bottom of the tank. Then find the value of x.

8. A circular loop of radius 0.3 cm lies parallel to a much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then what is the flux (in 10^{-11} Wb) linked with bigger loop?

9. A radioactive sample decays with an average-life of 20 ms. A capacitor of capacitance 100 μF is charged to some potential and then the plates are connected through a resistance R. What should be the value of R (in 10^2 Ω) so that the ratio of the charge on the capacitor to the activity of the radioactive sample remains constant in time?

10. A long coaxial cable consists of two thin-walled conducting cylinders with inner radius 2 cm and outer radius 8 cm. The inner cylinder carries a steady current 0.1 A, and the outer cylinder provides the return path for that current. The current produces a magnetic field between the two cylinders. Find the energy stored in the magnetic field for length 5 m of the cable. Express answer in nJ (use ln 2 = 0.7).

11. Some magnetic flux is changed from a coil of resistance 10 Ω. As a result, an induced current is developed in it, which varies with time as shown in Figure. Find the magnitude of the change in flux through the coil in weber.

12. A ball of mass 2 g having charge 1 μC suspended by a string of length 0.8 m. Another identical ball having the same charge is kept at the point of suspension. Find the minimum horizontal velocity which should be imparted to the lower ball so that it can make complete revolution.

13. A magnetic field $\vec{B} = -B_0\hat{i}$ exists within a sphere of radius $R = v_0 T\sqrt{3}$ where T is the time period of one revolution of a charged particle starting its motion from origin and moving with a velocity $\vec{v}_0 = \frac{v_0}{2}\sqrt{3}\,\hat{i} - \frac{v_0}{2}\hat{j}$. Find the number of turns that the particle will take to come out of the magnetic field.

14. In the circuit shown, the cell is ideal, with emf = 10 V. Each resistance is of 2 Ω. Find the potential difference across the capacitor.

15. A 100 turns coil of area of cross section 200 cm^2 having 2 Ω resistance is held perpendicular to a magnetic field of 0.1 T. If it is removed from the magnetic field in ten seconds, calculate the induced charge produced in it.

SOLUTIONS

1. **(3):** Given, λ = 200 nm = 2 × 10^{-7} m

Energy of one photon is

$$\frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{2\times10^{-7}} = 9.945\times10^{-19}$$

Number of photons is

$$\frac{1\times10^{-7}}{9.945\times10^{-19}} = 1\times10^{11}$$

Hence, number of photoelectrons emitted is

$$\frac{1\times10^{11}}{10^{4}} = 1\times10^{7}$$

Net amount of positive charge 'q' developed due to the outgoing electrons = 1 × 10^7 × 1.6 × 10^{-19} = 1.6 × 10^{-12} C.

Now potential developed at the centre as well as at the surface due to these charges is

$$\frac{Kq}{r} = \frac{9\times10^{9}\times1.6\times10^{-12}}{4.8\times10^{-2}} = 3\times10^{-1}\text{ V} = 0.3\text{ V}$$

2. **(5):** $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$\frac{1}{v} - \frac{1}{-2} = \frac{1}{1.5}$;

$v = 6$ m

$m = \frac{v}{u} = -3$

$x = 6 - d$ and $\tan\theta = \frac{0.3}{x}$ so $d = 5$ m

3. **(4):** Energy of photon

$$E = E_5 - E_1 = -13.6\left[\frac{1}{5^2} - \frac{1}{1^2}\right]\text{ eV} = 2.09\times10^{-18}\text{ J}$$

According to momentum conservation,

Momentum of recoil hydrogen atom = Momentum of photon

$\therefore \quad mv = \frac{E}{c}$

$$\Rightarrow \quad v = \frac{E}{mc} = \frac{2.09\times10^{-18}}{(1.67\times10^{-27})(3\times10^{8})} = 4.17\text{ m s}^{-1}$$

4. **(4):** Here, C_1 = 2 μF, C_2 = 3 μF, C_3 = 6 μF

V = 24 volt, V_3 = ?

As the capacitors are joined in series,

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3+2+1}{6} = 1$$

C_s = 1 μF; $\because$ $q = C_s \times V \Rightarrow 1 \times 24 = 24$ μC

$$V_3 = \frac{q}{C_3} = \frac{24}{6} = 4\text{ volt}$$

5. **(4):** In a given circuit, 3 Ω, 6 Ω and 2 Ω resistances are in parallel, their effective resistance R_1 is

$$\frac{1}{R_1}=\frac{1}{3}+\frac{1}{6}+\frac{1}{2}=\frac{6}{6}=1 \text{ or } R_1 = 1\ \Omega$$

The potential drop across each of them will be equal (= V_1 say).

Of these three resistances maximum heat will be generated across 2 Ω resistance. ($\therefore P = V^2/R$)

Similarly, 5 Ω and 4 Ω resistances are also placed in parallel. Their effective resistance,

$$R_2=\frac{4\times 5}{4+5}=\frac{20}{9}\ \Omega$$

The potential drop across each of them is V_2 (say.)

So more heat will be generated across 4 Ω resistance.

Current in circuit, $I=\dfrac{V}{1+\dfrac{20}{9}}=\dfrac{9V}{29}$

6. (4) : In series

Rate of heat produced in R is $J_1=\left(\dfrac{2\varepsilon}{R+2}\right)^2 R$

In parallel

Rate of heat produced in R is

$$J_2=\left(\frac{\varepsilon}{R+\frac{1}{2}}\right)^2 R=\left(\frac{2\varepsilon}{2R+1}\right)^2 R$$

$$\therefore\ \frac{J_1}{J_2}=\left(\frac{2\varepsilon}{R+2}\right)^2\times\left(\frac{2R+1}{2\varepsilon}\right)^2=\left(\frac{2R+1}{R+2}\right)^2$$

According to given problem

$J_1 = 2.25J_2$

$$\therefore\ 2.25=\left(\frac{2R+1}{R+2}\right)^2 \quad\text{or}\quad 1.5=\frac{2R+1}{R+2}$$

or $1.5R + 3 = 2R + 1$

$0.5R = 2$

$$R=\frac{2}{0.5}=4\ \Omega$$

7. (2): For refraction at air-oil interface, we have

$u = -24$ cm, $\mu_1 = 1, \mu_2 = \dfrac{7}{4}$

$R = +6$ cm, $v = v_1$

As $\dfrac{\mu_2}{v}-\dfrac{\mu_1}{u}=\dfrac{\mu_2-\mu_1}{R}$

$$\therefore\ \frac{(7/4)}{v_1}-\frac{1}{-24}=\frac{(7/4)-1}{6}=\frac{3}{24}$$

or $\dfrac{7}{4v_1}=\dfrac{3}{24}-\dfrac{1}{24}=\dfrac{2}{24}=\dfrac{1}{12}$ or $v_1=\dfrac{12\times 7}{4}=21$ cm

This image will act as object for oil-water interface. For refraction at oil-water interface, we have

$u = +21$ cm, $v = v_2$, $\mu_1=\dfrac{7}{4}, \mu_2=\dfrac{4}{3}, R=\infty$

As $\dfrac{\mu_2}{v}-\dfrac{\mu_1}{u}=\dfrac{\mu_2-\mu_1}{R}$

$$\therefore\ \frac{(4/3)}{v_2}-\frac{(7/4)}{21}=\frac{(4/3)-(7/4)}{\infty}=0 \text{ or } v_2 = 16 \text{ cm}$$

Hence, $x = 18 - 16 = 2$ cm

8. (9):

As field due to current loop 1 at an axial point

$$\therefore\ B_1=\frac{\mu_0 I_1 R^2}{2(d^2+R^2)^{3/2}}$$

Flux linked with smaller loop 2 due to B_1 is

$$\phi_2=B_1A_2=\frac{\mu_0 I_1 R^2}{2(d^2+R^2)^{3/2}}\pi r^2$$

The coefficient of mutual inductance between the loops is

$$M=\frac{\phi_2}{I_1}=\frac{\mu_0 R^2\pi r^2}{2(d^2+R^2)^{3/2}}$$

Flux linked with bigger loop 1 is

$$\phi_1=MI_2=\frac{\mu_0 R^2\pi r^2 I_2}{2(d^2+R^2)^{3/2}}$$

Substituting the given values, we get

$$\phi_1=\frac{4\pi\times 10^{-7}\times(20\times 10^{-2})^2\times\pi\times(0.3\times 10^{-2})^2\times 2}{2[(15\times 10^{-2})^2+(20\times 10^{-2})^2]^{3/2}}$$

$\phi_1 = 9.1 \times 10^{-11}$ weber

9. (2): The activity of the sample at time t is given by $A = A_0e^{-\lambda t}$. Where λ is the decay constant, A_0 is the activity at time $t = 0$ when the capacitor plates are connected. The charge on the capacitor at time t is given by $Q = Q_0e^{-t/CR}$

Where Q_0 is the charge at $t = 0$ and $C = 100$ μF

Thus, $\dfrac{Q}{A}=\dfrac{Q_0}{A_0}\dfrac{e^{-t/CR}}{e^{-\lambda t}}$

It is independent of t if $\lambda=\dfrac{1}{CR}$

$$\text{or } R=\frac{1}{\lambda C}=\frac{t_{av}}{C}=\frac{20\times 10^{-3}\text{s}}{100\times 10^{-6}\text{F}}=200\ \Omega$$

10. (7): The magnetic field inside is only due to the current of the inner cylinder.

$$B = \frac{\mu_0 i}{2\pi r}$$

Magnetic field energy density is not uniform in the space between the cylinders. At a distance r from the centre,

$$u_B = \frac{B^2}{2\mu_0} = \frac{\mu_0 i^2}{8\pi^2 r^2}$$

Energy in volume of element (length l)

$$dU_B = u_B dV = \frac{\mu_0 i^2}{8\pi^2 r^2}(2\pi r l)dr = \frac{\mu_0 i^2 l}{4\pi}\frac{dr}{r}$$

$$U_B = \frac{\mu_0 i^2 l}{4\pi}\int_a^b \frac{dr}{r} = \frac{\mu_0 i^2 l}{4\pi}\ln\frac{b}{a}$$

Using values, we get $U = 7$ nJ

11. (2): $\Delta\phi = R(\Delta q) = R\int I dt$

$= R$ [area under I-t graph]

$= \frac{1}{2}(4)(0.1)(10) = 2$ weber

12. (6): If the ball has to just complete the circle then the tension must vanish at the topmost point *i.e.*, $T_2 = 0$.

From Newton's second law,

$$T_2 + mg - \frac{q^2}{4\pi\varepsilon_0 l^2} = \frac{mv^2}{l} \quad \ldots(i)$$

At the topmost point, $T_2 = 0$

$$\therefore \quad mg - \frac{q^2}{4\pi\varepsilon_0 l^2} = \frac{mv^2}{l} \quad \ldots(ii)$$

From principle of energy conservation,

Energy at the lowest point

= Energy at topmost point

$$\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + mg(2l) \text{ or } v^2 = u^2 - 4gl \quad \ldots(iii)$$

From eqn. (ii),

$$v^2 = gl - \frac{q^2}{4\pi\varepsilon_0 ml} \quad \ldots(iv)$$

From equations (iii) and (iv), using ($m = 2 \times 10^{-3}$ kg)

we get, $u = \sqrt{5gl - \frac{q^2}{4\pi\varepsilon_0 ml}} = \sqrt{\frac{275}{8}}$

$= 5.86 \text{ m s}^{-1} \simeq 6 \text{ m s}^{-1}$

13. (2): $v_\perp = -\frac{v_0}{2}$ will contribute to circular motion.

$v_{\|} = \frac{v_0\sqrt{3}}{2}$ will contribute to helical path. $T = 2\pi\frac{m}{B_0 q}$

Pitch, $P = v_{\|}T = \frac{v_0\sqrt{3}}{2}T$ $\quad (\because R = v_0 T\sqrt{3})$

$\therefore$ Number of turns $= \frac{R}{P} = \frac{v_0 T\sqrt{3}(2)}{v_0\sqrt{3}T} = 2$

14. (8): A fully charged capacitor draws no current. Therefore, no current flows in arm GHF. So the resistance, R of arm HF is ineffective.

The equivalent resistance of the resistors in circuit is

$$R_{eq} = \frac{(R+R)\times R}{(R+R)+R} + R = \frac{(2+2)\times 2}{(2+2)+2} + 2 = \frac{10}{3}\,\Omega$$

Total current, $I = \frac{V}{R_{eq}} = \frac{10 \text{ V}}{(10/3)\,\Omega} = 3$ A

In parallel circuit, the current divides in the inverse ratio of resistance, so current in arm $ABGD = 1$ A and current in arm $AD = 2$ A.

Potential difference between G and D

$= V_G - V_D = 1 \text{ A} \times 2\,\Omega = 2$ V

Potential difference between D and F

$= V_D - V_F = 3 \text{ A} \times 2\,\Omega = 6$ V

$\therefore \quad V_G - V_F = (V_G - V_D) + (V_D - V_F) = 2 + 6 = 8$ V

15. (c): Here, area of cross-section

$A = 200 \text{ cm}^2 = 200 \times 10^{-4} \text{ m}^2$

Number of turn $= N = 100$

Resistance, $R = 2\,\Omega$

Initial magnetic flux linked with the coil is

$\phi_i = BA\cos\theta = 0.1 \times 200 \times 10^{-4} \times \cos 0°$

$= 2 \times 10^{-3}$ Wb

Final magnetic flux linked with the coil is

$\phi_f = 0 \quad (\because B = 0)$

$\therefore$ Induced emf in the coil is, $\varepsilon = -\frac{N\Delta\phi}{\Delta t}$

$= \frac{-N(\phi_f - \phi_i)}{\Delta t}$

$= \frac{-100(0 - 2\times 10^{-3})}{1} = 2 \times 10^{-1}$ V $= 0.2$ V

Induced current in the coil is,

$I = \frac{\varepsilon}{R} = \frac{0.2 \text{ V}}{2\,\Omega} = 0.1$ A

Induced charge in coil, $q = It = 0.1 \times 10 = 1$ C

EXAM PREP 2017

CHAPTERWISE MCQs FOR PRACTICE

Useful for All National and State Level Medical/Engg. Entrance Exams

SEMICONDUCTOR ELECTRONICS : MATERIALS, DEVICES AND SIMPLE CIRCUITS

1. A semiconductor diode and resistor of constant resistance are connected in some way inside a box having two external terminals. When a potential difference of 1 V is applied, $I = 25$ mA. If potential difference is reversed, $I = 50$ mA. Forward resistance and diode resistance respectively are

(a) 40 Ω, 20 Ω (b) 40 Ω and 40 Ω
(c) 0 Ω, ∞ (d) 40 Ω, 12 Ω

2. A transistor is used in a common-emitter mode in an amplifier circuit. When a signal of 20 mV is added to base-emitter voltage, the base current changes by 20 μA and collector current by 2 mA. The load resistance is 5 kΩ. What is the resistance gain?
(a) 10 (b) 100
(c) 5 (d) 10^6

3. The part of transistor which is most heavily doped to produce large number of majority carriers is
(a) emitter (b) base
(c) collector (d) none of these

4. The transistor is connected in common base configuration. What would be the change in collector current when base current changes by 4 mA? [$\alpha = 0.9$]
(a) 1.2 mA (b) 12 mA
(c) 24 mA (d) 36 mA

5. Select the output Y of the combination of gates shown in figure for inputs $A = 1, B = 0$; $A = 1, B = 1$ and $A = 0, B = 0$ respectively.

(a) (0, 1, 1) (b) (1, 0, 1)
(c) (1, 1, 1) (d) (1, 0, 0)

6. Which of the following gates has the truth table?
(a) NAND
(b) NOR
(c) XOR
(d) AND

A	B	X
0	0	1
1	0	1
0	1	1
1	1	0

7. Which of the junction diodes shown below is forward biased?

8. In a common emitter amplifier, using output resistance of 5000 Ω and input resistance of 2000 Ω, if the peak value of input signal voltage is 10 mV and $\beta = 50$, then peak value of output voltage is
(a) 5×10^{-6} V (b) 12.5×10^{-4} V
(c) 1.25 V (d) 125 V

9. A *n-p-n* transistor conducts when
(a) both collector and emitter are positive with respect to the base
(b) collector is positive and emitter is negative with respect to the base
(c) collector is positive and emitter is at same potential as the base
(d) both collector and emitter are negative with respect to the base.

10. The following figure shows a logic gate circuit with two inputs *A* and *B* and the output *C*.

The voltage waveforms of *A*, *B* and *C* are as shown below.

The logic circuit gate is
(a) OR gate (b) AND gate
(c) NAND gate (d) NOR gate

11. Two amplifiers are connected one after the other in series (cascaded). The first amplifier has a voltage gain of 10 and the second has a voltage gain of 20. If the input signal is 0.01 V, the output ac signal is
(a) 1 V (b) 2 V
(c) 3 V (d) 4 V

12. With an ac input from 50 Hz power line, the ripple frequency is
(a) 50 Hz in the dc output of half wave as well as full wave rectifier
(b) 100 Hz in the dc output of half wave as well as full wave rectifier
(c) 50 Hz in the dc output of half wave and 100 Hz in dc output of full wave rectifier
(d) 100 Hz in the dc output of half wave and 50 Hz in the dc output of full wave rectifier.

13. If α and β are the current gain in the *CB* and *CE* configurations respectively of the transistor circuit, then $\frac{\beta-\alpha}{\alpha\beta}=$
(a) zero (b) 1 (c) 2 (d) 0.5

14. The circuit shown in the figure contains two diodes each with a forward resistance of 30 Ω and with infinite backward resistance. If the battery is 3 V, the current through the 50 Ω resistance (in ampere) is

(a) zero (b) 0.01 (c) 0.02 (d) 0.03

15. Figure shows the transfer characteristics of a base biased CE transistor. Which of the following statements is false?

(a) At $V_i = 0.4$ V, transistor is in active state.
(b) At $V_i = 1$ V , it can be used as an amplifier.
(c) At $V_i = 0.5$ V, it can be used as a switch turned off.
(d) At $V_i = 2.5$ V, it can be used as a switch turned on.

COMMUNICATION SYSTEMS

16. In frequency modulated wave,
(a) frequency varies with time
(b) amplitude varies with time
(c) both frequency and amplitude vary with time
(d) both frequency and amplitude are constant.

17. The waves used by artificial satellites for communication purposes are
(a) microwaves (b) AM radiowaves
(c) FM radiowaves (d) X-rays

18. In satellite communication,
1. the frequency used lies between 5 MHz and 10 MHz
2. the uplink and downlink frequencies are different
3. the orbit of the geostationary satellite lies in the equatorial plane at an inclination of 0°

In the above statements
(a) only 2 and 3 are true
(b) all are true
(c) only 2 is true
(d) only 1 and 3 are true

19. For skywave propagation of a 10 MHz signal, what should be the minimum electron density in ionosphere?
(a) $\approx 1.2 \times 10^{12}\ m^{-3}$ (b) $\approx 10^{6}\ m^{-3}$
(c) $\approx 10^{14}\ m^{-3}$ (d) $\approx 10^{22}\ m^{-3}$

20. The maximum distance upto which TV transmission from a TV tower of height h can be received is proportional to
(a) $h^{1/2}$ (b) h (c) $h^{3/2}$ (d) h^2

21. In frequency modulation,
(a) the amplitude of the modulated wave varies as frequency of the carrier wave
(b) the frequency of the modulated wave varies as amplitude of modulating wave
(c) the amplitude of modulated wave varies as amplitude of carrier wave
(d) the frequency of modulated wave varies as frequency of modulated wave.

22. When a low lying aeroplane passes overhead, we sometimes notice a slight shaking of the picture on our TV screen. This is due to
(a) diffraction of the signal received from the antenna
(b) interference of the direct signal received by the antenna with the weak signal reflected by the passing aircraft
(c) change of magnetic flux occurring due to the passage of aircraft
(d) vibrations created by the passage of aircraft.

23. Modulation is a process of superposing
(a) low frequency audio signal on high frequency radiowaes
(b) low frequency radio signal on low frequency audiowaves
(c) high frequency radio signal on low frequency audio signal
(d) high frequency audio signal on low frequency radiowaves

24. A radio station has two channels. One is AM at 1020 kHz and the other FM at 89.5 MHz. For good results you will use
(a) longer antenna for the AM channel and shorter for the FM
(b) shorter antenna for the AM channel and longer for the FM
(c) same length antenna will work for both
(d) information given is not enough to say which one to use for which

25. Which of the following statements is wrong?
(a) Ground wave propagation can be sustained at frequencies 500 kHz to 1500 kHz.
(b) Satellite communication is useful for the frequencies above 30 MHz.
(c) Space wave propagation takes place through tropospheric space.
(d) Sky wave propagation is useful in the range of 30 to 40 MHz.

26. Figure shows a communication system. What is the output power when input signal is of 1.01 mW ? (gain in dB = $10 \log_{10} (P_o/P_i)$).

(a) 50 mW (b) 200 mW
(c) 101 mW (d) 99 mW

27. A TV transmission tower antenna is at a height of 20 m. How much service area can it cover if the receiving antenna is at a height of 25 m?
(a) 3608 km^2 (b) 2596 km^2
(c) 804 km^2 (d) 5390 km^2

28. For an amplitude modulated wave, the maximum amplitude is found to be 10 V while the minimum amplitude is found to be 2 V. Determine the modulation index, μ.
(a) 1.00 (b) 0.67 (c) 0.53 (d) 0.42

29. A sinusoidal carrier wave : 80 sin $2\pi(10^5\ t)$ V is modulated by an audio frequency signal :
20 sin $2\pi\ (2 \times 10^3\ t)$ V. Determine percentage modulation.
(a) 20% (b) 35% (c) 40% (d) 25%

30. What will be the required height of a TV tower which can cover a population 60.3 lakhs if the average population density around the tower is 1000 per km^2 ?
(a) 150 m (b) 200 m
(c) 250 m (d) 100 m

SOLUTIONS

1. **(b) :** When a diode is reverse-biased, the diode does not conduct. So, if resistor and diode are in series, then the current should be zero in one of the two given cases. But this is not the case. So, clearly, the two are connected in parallel. Clearly, I = 25 mA corresponds to resverse-biasing.

Now $R = \dfrac{1\ V}{25 \times 10^{-3}\ A} = \dfrac{1000}{25}\Omega = 40\ \Omega$

Again, I = 50 mA

Now, current shall flow through the diode also because diode is forward-biased.

If R_p is combined resistance of diode and resistor, then

$$R_p = \frac{1}{50\times10^{-3}}\,\Omega = \frac{1000}{50}\,\Omega = 20\,\Omega$$

Clearly, it is a parallel combination of 40 Ω and 40 Ω.

2. **(c) :** Current gain, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2\text{ mA}}{20\ \mu\text{A}} = \frac{2\times10^{-3}}{20\times10^{-6}} = 100$

$$\text{Voltage gain} = \frac{2\text{mA}\times5\text{k}\Omega}{20\text{mV}} = \frac{1\times5\times10^3}{10} = 500$$

$$\text{Resistance gain} = \frac{\text{Voltage gain}}{\text{Current gain}} = \frac{500}{100} = 5$$

3. **(a) :** Emitter is heavily doped.

4. **(d):** For a transistor $\Delta I_E = \Delta I_B + \Delta I_C$

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$\therefore\ \alpha = \frac{\Delta I_C}{\Delta I_B + \Delta I_C}$$

Substituting the values we get

$$0.9 = \frac{\Delta I_C}{4+\Delta I_C} \quad \text{or} \quad \Delta I_C = 36\text{ mA}$$

5. **(d) :**

6. **(a) :** The given truth table represents the NAND gate. The Boolean expression for NAND is

$$X = \overline{A\cdot B}$$

7. **(a) :** The *pn* junction diode is forward biased when *p* is at high potential w.r.t to *n*. Hence option (a) is correct.

8. **(c) :** Voltage gain,

$$A_v = \frac{V_o}{V_i} = \beta\frac{R_o}{R_i} \quad \text{or} \quad V_o = V_i \times \beta\frac{R_o}{R_i}$$

Substituting the values we get,

$$\therefore\ V_o = 10\times10^{-3}\times50\times\frac{5000}{2000} = 1250\ \text{mV} = 1.25\text{ V}$$

9. **(b) :** A *n-p-n* transistor conducts when emitter-base junction is forward biased while collector-base junction is reverse biased.

10. **(b) :** The truth table corresponding to the given waveforms is given by

A	*B*	*C*
1	1	1
0	1	0
1	0	0
0	0	0

∴ The given logic circuit gate is AND gate.

11. **(b) :** Total voltage gain, $A_V = \frac{V_o}{V_i} = A_{V_1}\times A_{V_2}$

or $V_o = V_i \times A_{V_1}\times A_{V_2} = 0.01\times10\times20 = 2\text{ V}$

12. **(c)**

13. **(b) :** Since $\beta = \frac{\alpha}{1-\alpha}$

$$\therefore\ \alpha\beta = \frac{\alpha^2}{1-\alpha} \qquad \text{... (i)}$$

$$\beta-\alpha = \frac{\alpha}{1-\alpha} - \alpha \quad \text{or} \quad \beta-\alpha = \frac{\alpha^2}{1-\alpha} \qquad \text{... (ii)}$$

$$\therefore\ \frac{\beta-\alpha}{\alpha\beta} = \left(\frac{\alpha^2}{1-\alpha}\right)\left(\frac{1-\alpha}{\alpha^2}\right) = 1$$

14. **(c) :** In the circuit, the upper diode D_1 is reverse biased and the lower diode D_2 is forward biased. Thus there will be no current across upper diode junction. The effective circuit will be as shown in figure.

Total resistance of circuit

$R = 50 + 70 + 30 = 150\ \Omega$

$$\text{Current in circuit, } I = \frac{V}{R} = \frac{3\text{ V}}{150\ \Omega} = 0.02\text{ A}$$

15. (a): At V_i = 1 V, (which is between 0.6 and 2 V), transistor is in active region, it can be used as an amplifier.
At V_i = 0.5 V, it can be used as switch turned off because of cut off region.
At V_i = 2.5 V, the collector current becomes maximum and transistor is in saturation state and can be used as switch turned on.

16. (a): In frequency modulated wave, frequency of the carrier wave varies in accordance with the modulating signal.

17. (a): Microwaves are used in artificial satellites for communication purposes.

18. (a): Microwaves have frequency range 10^9 Hz to 10^{12} Hz. So statement 1 is wrong. But statements 2 and 3 are correct.

19. (a): $\upsilon_c = 9(N_{max})^{1/2}$

$\therefore \quad 10 \times 10^6 = 9(N_{max})^{1/2}$

or $\quad N_{max} = \left(\frac{10^7}{9}\right)^2 \approx 1.2 \times 10^{12}\ m^{-3}$.

20. (a): $d = \sqrt{2\,Rh}$

$\therefore \quad d \propto h^{1/2}$

21. (b): The frequency of the modulated wave varies as the amplitude of the modulating wave.

22. (b): Slight shaking of the picture of the TV screen is due to interference of the direct signal received by the antenna with the weak signal reflected by the passing aircraft.

23. (a): Modulation is the superposition of low frequency audio signal on a high frequency radiowave.

24. (b): For AM channel of 1020 kHz, ground wave propagation is used for which antenna need not be very tall.
For high frequency FM 89.5 MHz, space wave communication is used for which very tall antenna is needed.

25. (d): Sky wave propagation is useful for radiowaves of frequencies 2-30 MHz. Higher frequencies cannot be reflected by the ionosphere.

26. (c):

Path length = 5 km, Loss rate = 2 dB km^{-1}
Loss suffered in path = 5 × 2 = 10 dB.
Total gain of both amplifier = 10 + 20 = 30 dB
Overall gain = 30 – 10 = 20 dB.

Gain in dB = $10\log_{10}\frac{P_0}{P_i}$ or $20 = 10\log_{10}\left(\frac{P_0}{P_i}\right)$

$P_0 = 10^2\,(1.01) = 101$ mW.

27. (a): Now, h_R = 25 m
h_T = 20 m

So, $d_m = \sqrt{2Rh_T} + \sqrt{2h_R R}$

$= \sqrt{2\times20\times(6.4\times10^6)} + \sqrt{2\times25\times6.4\times10^6}$

= 33.9 km

Area covered $= \pi d_m^2$

$= 3.14 \times (33.9)^2 = 3608.52\ km^2$

28. (b): Modulation index, $\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$

or $\quad \mu = \frac{10-2}{10+2} = \frac{8}{12} = \frac{2}{3} = 0.67$

29. (d): Percentage modulation,

$\mu \times 100 = \frac{A_m}{A_c} \times 100 = \frac{20V}{80V} \times 100 = 25\%$

30. (a): Let h_T be the height of the transmission tower. If d_T is the radio horizon of this tower, then $d_T = \sqrt{2Rh_T}$ and area covered by the telecast = rd_T^2 = $2\pi Rh_T$
Since area covered by the telecast × population density = population covered,
$(2\pi Rh_T)(1000/km^2) = 60.3 \times 10^5$

or $\quad h_T = \frac{60.3\times10^5}{2\times3.14\,(6.37\times10^3\ km)(1000/km^2)}$

(as $R = 6.37 \times 10^3$ km)

or $\quad h_T = 1.5 \times 10^{-1}$ km = 150 m.

MPP-5 CLASS XII ANSWER KEY

1.	(c)	**2.**	(c)	**3.**	(c)	**4.**	(a)	**5.**	(c)
6.	(d)	**7.**	(c)	**8.**	(b)	**9.**	(d)	**10.**	(a)
11.	(a)	**12.**	(d)	**13.**	(c)	**14.**	(a)	**15.**	(a)
16.	(a)	**17.**	(d)	**18.**	(b)	**19.**	(a)	**20.**	(a,c)
21.	(a,c)	**22.**	(a, d)	**23.**	(a, d)	**24.**	(7)	**25.**	(5)
26.	(2)	**27.**	(d)	**28.**	(a)	**29.**	(b)	**30.**	(c)

MPP-5 MONTHLY Practice Problems

Class XII

This specially designed column enables students to self analyse their extent of understanding of specified chapters. Give yourself four marks for correct answer and deduct one mark for wrong answer. Self check table given at the end will help you to check your readiness.

Electromagnetic Induction, Alternating Current and Electromagnetic Waves

Total Marks : 120 **Time Taken : 60 min**

NEET / AIIMS / PMTs

Only One Option Correct Type

1. Magnetic flux through a stationary loop with a resistance R varies during the time interval τ as $\phi = at(\tau - t)$ where a is a constant. The amount of heat generated in the loop during the time interval τ is

(a) $\frac{a^2\tau^3}{6R}$ (b) $\frac{a^2\tau^3}{4R}$ (c) $\frac{a^2\tau^3}{3R}$ (d) $\frac{a^2\tau^3}{2R}$

2. An alternating current is given by $I = I_0(\sin\omega t + \cos\omega t)$. The rms current is

(a) $\sqrt{2}I_0$ (b) $\frac{I_0}{\sqrt{2}}$ (c) I_0 (d) $2I_0$

3. A series LCR circuit is connected to an ac source of frequency υ and a voltage V. At this frequency, reactance of the capacitor is 350 Ω while the resistance of the circuit is 180 Ω. Current in the circuit leads the voltage by 54° and power dissipated in the circuit is 140 W. Then the voltage V is

(a) 250 V (b) 260 V (c) 270 V (d) 280 V

4. Some magnetic flux is changed from a coil of resistance 10 Ω. As a result, an induced current is developed in it, which varies with time as shown in figure.

The magnitude of change in magnetic flux through the coil in weber is

(a) 2 (b) 4 (c) 6 (d) 8

5. In a series LCR circuit, R = 200 Ω and the voltage and the frequency of the main supply is 220 V and 50 Hz respectively. On taking out the capacitance from the circuit, the current lags behind the voltage by 30°. On taking out the inductor from the circuit, the current leads the voltage by 30°. The power dissipated in the LCR circuit is

(a) zero (b) 210 W (c) 242 W (d) 305 W

6. A 16 μF capacitor is charged to 20 V. The battery is then disconnected and pure 40 mH coil is connected across the capacitor so that LC oscillations are set up. The maximum current in the coil is

(a) 0.2 A (b) 40 mA (c) 2 A (d) 0.4 A

7. Figure shows a circuit that contains three identical resistors with resistance R = 9 Ω, two identical inductors with inductance L = 2 mH, and an ideal battery with emf ε = 18 V.

The current in the circuit long after the switch S is closed is

(a) 2 A (b) 4 A (c) 6 A (d) 8 A

8. Figure shows a conducting loop consisting of a half-circle of radius r = 0.2 m and three straight sections. The half-circle lies in a uniform magnetic field $\vec{B}$ that is directed out of the page, the field magnitude is given by $B = (4t^2 + 2t + 3)$ T, where t is in seconds.

An ideal battery with emf ε = 2 V is connected to the loop. The resistance of the loop is 2 Ω. The current in the loop at t = 10 s will be close to

(a) 3.6 A (b) 1.6 A (c) 6.2 A (d) 4.2 A

9. The electric field of an electromagnetic wave in free space is given by $\vec{E} = 10\cos(10^7 t + kx)\hat{j}$ V m^{-1} where t and x are in seconds and metres, respectively. It can be inferred that

(i) the wavelength λ is 188.4 m.
(ii) the wave number k is 0.33 rad m^{-1}.
(iii) the wave amplitude is 10 V m^{-1}
(iv) the wave is propagating along $+x$ direction.

Which one of the following pairs of statements is correct?

(a) (iii) and (iv) (b) (i) and (ii)
(c) (ii) and (iii) (d) (i) and (iii)

10. As shown in the figure, a metal rod makes contact with a partial circuit and completes the circuit. The circuit area is perpendicular to a magnetic field with B = 0.15 T. If the resistance of the total circuit is 3 Ω, the force needed to move the rod as indicated with a constant speed of 2 m s^{-1} will be

(a) 3.75×10^{-3} N (b) 2.75×10^{-3} N
(c) 6.57×10^{-4} N (d) 4.36×10^{-4} N

11. A transformer with efficiency 80% works at 4 kW and 100 V. If the secondary voltage is 200 V, then the primary and secondary currents are respectively

(a) 40 A, 16 A (b) 16 A, 40 A
(c) 20 A, 40 A (d) 40 A, 20 A

12. A coaxial cable consists of two thin cylindrical conducting shells of radii a and b ($a < b$). The inductance per unit length of the cable is

(a) $\frac{\mu_0}{2\pi}\frac{(a+b)}{a}$ (b) $\frac{\mu_0}{4\pi}\ln\left(\frac{a}{b}\right)$

(c) $\frac{\mu_0}{4\pi}\ln\left(\frac{b}{a}\right)$ (d) $\frac{\mu_0}{2\pi}\ln\left(\frac{b}{a}\right)$

Assertion & Reason Type

Directions : In the following questions, a statement of assertion is followed by a statement of reason. Mark the correct choice as :

(a) If both assertion and reason are true and reason is the correct explanation of assertion.
(b) If both assertion and reason are true but reason is not the correct explanation of assertion.
(c) If assertion is true but reason is false.
(d) If both assertion and reason are false.

13. **Assertion :** No power loss is associated with a pure capacitor in an ac circuit.
Reason : No current is flowing in this circuit.

14. **Assertion :** In series LCR circuit, the resonance occurs at one frequency only.
Reason : At resonance, the inductive reactance is equal and opposite to the capacitive reactance.

15. **Assertion :** Dipole oscillations produce electromagnetic waves.
Reason : Accelerated charge produces electromagnetic waves.

JEE MAIN / JEE ADVANCED / PETs

Only One Option Correct Type

16. A magnetic field directed along z axis varies as $B = B_0 x/a$, where a is a positive constant. A square loop of side l and made of copper is placed with its edges parallel to x and y axes. If the loop is made to move with a constant velocity v_0 directed along x axis, the emf induced is

(a) $\frac{B_0 v_0 l^2}{a}$ (b) $B_0 v_0 l$ (c) $\frac{B_0 v_0 l^2}{2a}$ (d) $\frac{B_0 v_0 l^3}{a^2}$

17. In a series LCR circuit, impedance Z is the same at two frequencies υ_1 and υ_2. Then, the resonant frequency of the circuit is

(a) $\frac{\upsilon_1 + \upsilon_2}{2}$ (b) $\frac{2\upsilon_1\upsilon_2}{\upsilon_1 + \upsilon_2}$

(c) $\frac{\sqrt{\upsilon_1^2 + \upsilon_2^2}}{2}$ (d) $\sqrt{\upsilon_1\upsilon_2}$

18. A spatially uniform magnetic field $\vec{B}$ exists in the circular region S and this field is decreasing in magnitude with time at a constant rate (see figure). The wooden ring C_1 and the conducting ring C_2 are concentric with a magnetic field. The magnetic field is perpendicular to the plane of the figure. Then,

(a) there is no induced electric field in C_1.
(b) there is an induced electric field in C_1 and its magnitude is greater than the magnitude of the induced electric field in C_2.
(c) there is an induced electric field in C_2 and its magnitude is greater than induced electric field in C_1.
(d) there is no induced electric field in C_2.

19. In the series *LCR* circuit, the voltmeter and ammeter readings are

(a) $V = 100$ V, $I = 2$ A (b) $V = 100$ V, $I = 5$ A
(c) $V = 800$ V, $I = 2$ A (d) $V = 300$ V, $I = 1$ A

More than One Options Correct Type

20. In the given circuit, the ac source has $\omega = 100$ rad s^{-1}. Considering the inductor and capacitor to be ideal, the correct choices are

(a) The current through the circuit I is 0.3 A.
(b) The current through the circuit I is $0.3\sqrt{2}$ A.
(c) The voltage across 100 Ω resistor is $10\sqrt{2}$ V.
(d) The voltage across 50 Ω resistor is 10 V.

21. A current carrying infinitely long wire is kept along the diameter of a circular wire loop, without touching it. The correct statements are
(a) The emf induced in the loop is zero if the current is constant.
(b) The emf induced in the loop is finite if the current is constant.
(c) The emf induced in the loop is zero if the current decreases at a steady rate.
(d) The emf induced in the loop is finite if the current decreases at a steady rate.

22. As the frequency of an ac circuit increases, the current first increases and then decreases. What combination of circuit elements is most likely to comprise the circuit?
(a) Inductor and capacitor
(b) Resistor and inductor
(c) Resistor and capacitor
(d) Resistor, inductor and capacitor

23. The mutual inductance M_{12} of coil 1 with respect to coil 2
(a) increases when they are brought nearer.
(b) depends on the current passing through the coils.
(c) increases when one of them is rotated about an axis.
(d) is the same as M_{12} of coil 2 with respect to coil 1.

Integer Answer Type

24. A circular wire loop of radius R is placed in the x - y plane centered at the origin O. A square loop of side a ($a << R$) having two turns is placed with its center at $z = \sqrt{3}R$ along the axis of the circular wire loop as shown in figure. The plane of the square loop makes an angle of 45° with respect to the z-axis. If the mutual inductance between the loops is given by $\dfrac{\mu_0 a^2}{2^{p/2} R}$, then the value of p is

25. A step down transformer transforms a supply line voltage of 2200 V into 220 V. The primary coil has 5000 turns. The efficiency and power transmitted by the transformer are 90% and 8 kW respectively. If the number of turns in secondary coil is $k \times 10^2$, then the value of k is

26. At time $t = 0$, a battery of 10 V is connected across points A and B in the circuit shown in figure. If the capacitors have no charge initially, at what time (in seconds) does the voltage across them becomes 4 V?

(Take ln 5 = 1.6, ln 3 = 1.1)

Comprehension Type

A solenoid of resistance R and inductance L has a piece of soft iron inside it. A battery of emf ε and of negligible internal resistance is connected across the solenoid as shown in figure. At any instant, the piece of soft iron is pulled out suddenly so that inductance of the solenoid decreases to ηL ($\eta < 1$) with battery remaining connected.

27. The work done to pull out the soft iron piece is

(a) $\dfrac{\eta L\varepsilon^2}{2R^2}$ (b) $\dfrac{(1-\eta)L\varepsilon^2}{2R^2}$

(c) $\dfrac{(1-\eta)L\varepsilon^2}{\eta R^2}$ (d) $\dfrac{(1-\eta)L\varepsilon^2}{2\eta R^2}$

28. Assume $t = 0$ is the instant when iron piece has been pulled out, the current as a function of time after this is

(a) $I = \dfrac{\varepsilon}{R}\left[1-\left(1-\dfrac{1}{\eta}\right)e^{-\frac{tR}{\eta L}}\right]$

(b) $I = \dfrac{\varepsilon}{R}\left[1+\left(1+\dfrac{1}{\eta}\right)e^{-\frac{tR}{\eta L}}\right]$

(c) $I = \dfrac{\varepsilon}{R}\left[1-\left(1+\dfrac{1}{\eta}\right)e^{-\frac{tR}{\eta L}}\right]$

(d) $I = \dfrac{\varepsilon}{R}\left[1+\left(1-\dfrac{1}{\eta}\right)e^{-\frac{tR}{\eta L}}\right]$

Matrix Match Type

29. You are given many resistors, capacitors and inductors. These are connected to variable dc voltage source (the first two circuits) or ac voltage source of 50 Hz frequency (the next two circuits) in different ways as shown in column II. When a current I (steady state for dc or rms for ac) flows through the circuit, the corresponding voltage V_1 and V_2 (indicated in circuits) are related as shown in column I. Match the entries of column I with those given in column II.

Column I

(A) $I \neq 0$, V_1 is proportional to I

(B) $I \neq 0$, $V_2 > V_1$

(C) $V_1 = 0$, $V_2 = V$

(D) $I \neq 0$, V_2 is proportional to I

Column II

(P)

(Q)

(R)

(S)

	A	B	C	D
(a)	P, Q, R	Q, R, S	Q, S	R, S
(b)	R, S	Q, R, S	P, Q	Q, R, S
(c)	P, Q, R	R, S	Q, R, S	P, S
(d)	R, S	P, Q, S	P, S	Q, R, S

30. A frame $ABCD$ is rotating with an angular velocity ω about an axis passing through point O perpendicular to the plane of paper as shown in the figure. A uniform magnetic field $\vec{B}$ is applied into the plane of the paper in the region as in the figure. Match the entries of column I with those given in column II.

Column I

(A) Potential difference between A and O is

(B) Potential difference between O and D is

(C) Potential difference between C and D is

(D) Potential difference between A and D is

Column II

(P) zero

(Q) $\dfrac{B\omega L^2}{2}$

(R) $B\omega L^2$

(S) constant

	A	B	C	D
(a)	P, Q	Q, R	Q, S	R, S
(b)	Q, S	P, S	R, S	R, S
(c)	R, S	R, S	Q, S	P, S
(d)	P, S	Q, S	R, S	R, S

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No. of questions correct .....

Marks scored in percentage .....

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In every issue of Physics For You, 10 challenging problems are proposed in various topics of JEE (Main and Advanced) / various PMTs. The detailed solutions of these problems will be published in next issue of Physics For You.

The readers who have solved five or more problems may send their detailed solutions with their names and complete address. The names of those who send atleast five correct solutions will be published in the next issue.

We hope that our readers will enrich their problem solving skills through "Physics Musing" and stand in better stead while facing the competitive exams.

PROBLEM Set 40

SINGLE OPTION CORRECT TYPE

1. A thin uniform annular disc (see figure) of mass M has outer radius $4R$ and inner radius $3R$. The work required to take a unit mass from point P on its axis to infinity is

(a) $\frac{2GM}{7R}(4\sqrt{2}-5)$ (b) $-\frac{2GM}{7R}(4\sqrt{2}-5)$

(c) $\frac{GM}{4R}$ (d) $\frac{2GM}{5R}(\sqrt{2}-1)$

2. A tiny spherical oil drop carrying a net charge q is balanced in still air with a vertical uniform electric field of strength $\frac{81\pi}{7}\times 10^5$ V m^{-1}. When the field is switched off, the drop is observed to fall with terminal velocity 2×10^{-3} m s^{-1}. The magnitude of q is (Given g = 9.8 m s^{-2}, viscosity of the air $= 1.8\times 10^{-5}$ N s m^{-2} and the density of oil = 900 kg m^{-3})

(a) 1.6×10^{-19} C (b) 3.2×10^{-19} C

(c) 4.8×10^{-19} C (d) 8.0×10^{-19} C

3. A ball suspended by a thread swings in a vertical plane so that its acceleration values at the extreme and the mean position are equal. Find the thread's deflection angle at the extreme position.

(a) 2 tan^{-1} (2) (b) 2 tan^{-1} (1/2)

(c) tan^{-1} (2) (d) tan^{-1} (1/2)

4. A block of mass 200 kg is being pulled up by men at point A on an inclined plane at angle of 45° as shown. The coefficient of static friction is 0.5. Each man can only apply a maximum force of 500 N. Find the number of men required for the block to just start moving up the plane.

(a) 10 (b) 15 (c) 5 (d) 3

5. From an atom of mass number 220, initially at rest, α-decay takes place. If the Q value of the reaction is 5.5 MeV, the most probable kinetic energy of α-particle is

(a) 4.4 eV (b) 5.4 eV

(c) 5.6 eV (d) 6.5 eV

6. A solid ball of radius 0.2 m and mass 1 kg lying at rest on a smooth horizontal surface is given an instantaneous impulse of 50 N s at point P as shown. The number of rotations made by the ball about its diameter before hitting the ground is

(a) $\frac{625\sqrt{3}}{2\pi}$ (b) $\frac{2500\sqrt{3}}{2\pi}$

(c) $\frac{3125\sqrt{3}}{2\pi}$ (d) $\frac{1250\sqrt{3}}{2\pi}$

Contd. on page no. 84

By Akhil Tewari, Author Foundation of Physics for JEE Main & Advanced, Professor, IITians PACE, Mumbai.

YOU ASK WE ANSWER

Do you have a question that you just can't get answered?

Use the vast expertise of our mtg team to get to the bottom of the question. From the serious to the silly, the controversial to the trivial, the team will tackle the questions, easy and tough.

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Q1. Why there is no magnetic field outside of the solenoid?

– Saikat Karmakar

Ans. Magnetic field is not always zero outside the solenoid. Taking the external field to be zero is an assumption for real solenoid if its length is much greater than its diameter.

At point P, outside the solenoid, the field set up by the upper part of the solenoid turns (marked ⊙), points to the left and tends to cancel the field set up by the lower part of the turns (marked ⊗), which points to the right. Similarly at other points outside the solenoid, magnetic field from upper and lower part cancel each other. As the solenoid approaches the configuration of an infinitely long cylindrical sheet, the magnetic field outside solenoid approaches to zero.

Q2. When we cut a magnet into two equal parts then its magnetic moment becomes half but magnetic strength remains same?

– Basavraj S. Watiger, Hubballi

Ans. A bar magnet consists of two equal and opposite magnetic poles, separated by a distance; hence a magnet is also called a magnetic dipole.

If m is the pole strength and '$2l$' is the separation between the poles, the magnetic moment $\vec{M} = m\,2\vec{l}$

$\therefore$ If we cut the magnet into two halves, the magnetic moment becomes half of the previous value whereas the pole strength is independent of the length of bar magnet.

Q3. What happens to the magnetic field of the magnet when it is placed in water?

– Basavraj S. Watiger, Hubballi

Ans. Magnetisation of water is too small to make significant change in the magnetic field produced by a magnet which is placed in water. In other word we say water is non-magnetic.

Q4. Is there any harmful effects of LED bulb?

– Arman Ameen

Ans. No, as such there is no harmful effects of LED bulb. But, the accidental exposure to very intense light of LED can harm retina of your eyes.

Q5. When a normal person wears spectacles with certain power used by another person (mostly myopic) he feels uncomfortable and his eye lens can't adjust. Why?

– Shubhakant, Odisha

Ans. In myopia, the person can see nearby objects clearly but cannot see the distant object clearly beyond a certain point. This is because the light coming from infinity converge before retina. To correct such defect, we use concave lens of appropriate power (according to far point of defected eye.)

If a normal person wears spectacles then the image from infinity tends to form beyond the retina and eye puts more stress on ciliary muscles to adjust the focal length so that the person is able to see the object clearly. For normal eye, the power of accommodation is about 4 D. Consequently, the eyes of the normal person wearing concave lens become red or watery.

Hence, the person feels uncomfortable.

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–Albert Einstein

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PHYSICS MUSING

SOLUTION SET-39

1. (c) : Let v_c = recoil velocity of the cannon

Since $F_x = 0$ on a system of masses $(M + m)$, $p_x = 0$

or, $m\vec{v}_{s_x} + M\vec{v}_C = 0$ ...(i)

Now, where $\vec{v}_{s_x} = \vec{v}_{sc_x} + \vec{v}_{c_x} = u\cos\theta\,\hat{i} - v_c\,\hat{i}$

or, $\vec{v}_{s_x} = (u\cos\theta - v_c)\hat{i}$ ...(ii)

Using equations (i) and (ii), we have

$$v_c = \frac{mu\cos\theta}{M+m}$$

2. (c) : If initial elongation in the spring is x_0 then using torque about bottom point, $mg\sin\theta = kx_0$

From work energy theorem

$W_{\text{Total}} = \Delta KE = 0$

$$W_{M_0} = M_0\theta = M_0\frac{x}{R}, W_g = (mg\sin\theta)x = kx\,x_0$$

$$W_{\text{friction}} = 0, W_{\text{spring}} = \frac{-1}{2}k(x+x_0)^2 + \frac{1}{2}kx_0^2$$

$$= \frac{-1}{2}k(x^2 + 2x\,x_0)$$

Now $W_{\text{spring}} + W_{M_0} + W_g + W_{\text{friction}} = 0$

$$\Rightarrow \quad -\frac{1}{2}k(x^2 + 2xx_0) + \frac{M_0x}{R} + kx_0x + 0 = 0$$

On solving, $x = \dfrac{2M_0}{Rk}$

3. (d) : From $v = \upsilon\lambda \Rightarrow 340 = 340 \times \lambda \Rightarrow \lambda = 1$ m

For 1st resonance, $l_1 = \dfrac{\lambda}{4}$

$\Rightarrow l_1 = 25$ cm, so length of water column is 95 cm.

For 2nd resonance, $l_2 = \dfrac{3\lambda}{4} = 75\,\text{cm}$, so length of water column is (120–75) cm = 45 cm

3rd resonance will not be established, as for that the required length of air column is, $l = \dfrac{5\lambda}{4} = 125\,\text{cm} >$ length of tube.

Separation between consecutive nodes is, $\dfrac{\lambda}{2} = 50\,\text{cm}$.

4. (d) : As per question, $T = \dfrac{T_0}{2} + 2t = \pi\sqrt{\dfrac{l}{g}} + 2t$ ...(i)

$t \rightarrow$ time to travel from 0 to β and $\beta = \alpha\sin\omega t$ ...(ii)

$$t = \frac{1}{\omega}\sin^{-1}\left(\frac{\beta}{\alpha}\right) \Rightarrow t = \frac{T_0}{2\pi}\sin^{-1}\left(\frac{\beta}{\alpha}\right)$$

Putting value of t in equation (i)

$$T = 2\sqrt{\frac{l}{g}}\left[\frac{\pi}{2} + \sin^{-1}\left(\frac{\beta}{\alpha}\right)\right] = 2\sqrt{\frac{l}{g}}\left[\cos^{-1}\left(-\frac{\beta}{\alpha}\right)\right]$$

5. (c) : Work done by the gas,

$\Delta W = \int PdV$ = area under P–V curve

$$= P_i(V_f - V_i) + \frac{1}{2}(P_f - P_i)\times(V_f - V_i)$$

$$= \frac{1}{2}(V_f - V_i)(P_f + P_i)$$

$$= \frac{1}{2}(0.5 - 0.2)(8+4)\times 10^5$$

$$= 1.8\times 10^5\ \text{J}$$

6. (a) : Change in internal energy of a gas is given by

$$\Delta U = nC_V\Delta T = \frac{nR\Delta T}{\gamma - 1} = \frac{P_fV_f - P_iV_i}{\gamma - 1}$$

SOLUTION OF OCTOBER 2016 CROSSWORD

	1E	C	H	E	L	O	N	G	R	A	T	I	N	G		2R	3A	M	J	E	T
4R		5S		6D		7C	R	Y	O	M	E	T	8E	R			D				
E		I		Y									L				H		9T		
T		E		N			10D	E	C	O	U	P	L	I	N	G	E		E		
I		V		A						11R	A	D	I	O	L	Y	S	I	S		
C		E		M		12H							P				I		L		
L		R		I		A					13A		S			14K	O	V	A	R	
15E	U	T	E	C	T	I	16C				C		O				N		C		
				S		L	O				T		M			17R		18H	O	L	E
	19G		20M	21P	H	O	N	O	N		I		E			E			I		22H
	R		Y				S				V		T			S			L		A
	A		O				O				I		E			I					L
	V		23P	Y	R	A	N	O	24M	E	T	E	R			L					A
	I		I				A		E		Y				25N	I	T				T
	T		A				N		G							E					I
	O				26N		C		G			27G	R	O	U	N	D	I	N	G	O
28A	N	T	I	N	O	D	E		E							C					N
					D				R			29N	U	C	L	E	O	N	I	C	S
	30A	E	T	H	E	R				31C	O	N	T	A	I	N	M	E	N	T	

Winner (October 2016)

- Priyambada Tiwari, Lucknow

Solution Senders (September 2016)

- Rajat Malik, Delhi
- Abhimanyu Singh, Kanpur

Solution Senders of Physics Musing

SET-39

1. Prashant Shankar, Chennai (Tamil Nadu)
2. Ajoy Ghatak, Huggli (W.B.)
3. Roshan Chandra, Madhepura (Bihar)

As the gas is monoatomic, $\gamma = 5/3$

So $\Delta U = \dfrac{10^5(8\times0.5-4\times0.2)}{\left[\frac{5}{3}-1\right]} = \dfrac{3}{2}\times10^5(4-0.8)$

$\Rightarrow \Delta U = 4.8\times10^5$ J

7. (c) : From first law of thermodynamics

$\Delta Q = \Delta U + \Delta W$

$= (4.8 + 1.8)\times10^5 = 6.6\times10^5$ J

8. (b) : Molar heat capacity,

$$C = \frac{\Delta Q}{n\Delta T} = \frac{\Delta Q\times R}{P_fV_f - P_iV_i} = \frac{6.6\times10^5\times8.31}{10^5(8\times0.5-4\times0.2)}$$

$$C = \frac{54.846}{3.2} = 17.14 \text{ J mol}^{-1}\text{ k}^{-1}$$

9. If at a distance r from the centre of the earth the body has velocity v, by conservation of mechanical energy,

$$\frac{1}{2}mv^2 + \left(-\frac{GMm}{r}\right) = \frac{1}{2}mv_e^2 + \left(-\frac{GMm}{R}\right)$$

or $v^2 = v_e^2 + \dfrac{2GM}{R}\left[\dfrac{R}{r}-1\right]$

But as $v_e = \sqrt{2gR}$ and $g = \left(GM/R^2\right)$

$v^2 = 2gR + 2gR[(R/r) - 1]$

or $v = \sqrt{\dfrac{2gR^2}{r}}$, *i.e.*, $\dfrac{dr}{dt} = R\dfrac{\sqrt{2g}}{\sqrt{r}}$

i.e., $\displaystyle\int_0^t dt = \frac{1}{R\sqrt{2g}}\int_R^{R+h} r^{1/2}dr$

$$\Rightarrow t = \frac{2}{3}\frac{1}{R\sqrt{2g}}\left[(R+h)^{3/2} - R^{3/2}\right]$$

$$\Rightarrow t = \frac{1}{3}\sqrt{\frac{2R}{g}}\left[\left(1+\frac{h}{R}\right)^{3/2} - 1\right]$$

10. The fringes disappear when the maxima of λ_1 fall over the minima of λ_2.

That is $\dfrac{p}{\lambda_1} - \dfrac{p}{\lambda_2} = \dfrac{1}{2}$

Where p is the optical path difference at that point.

or $p = \dfrac{\lambda_1\lambda_2}{2(\lambda_2-\lambda_1)}$

Here, $\lambda_1 = 4000$ Å, $\lambda_2 = 4002$ Å

$\therefore$ $p = 0.04$ cm $= 0.4$ mm

In Young's double slit experiment, $p = \dfrac{xd}{D}$

$\therefore$ $x = \dfrac{D}{d}p = \dfrac{(1000)}{10}(0.4) = 40$ mm

PHYSICS MUSING

Contd. from page no. 80

SUBJECTIVE TYPE

7. Two parallel plate capacitors each of capacitance C are connected in series with a battery of emf ε. Then one of the capacitors is filled with a dielectric constant K. Find the change in electric field in the two capacitors if any, what amount of charge flows through the battery?

8. An ideal gas has specific heat at constant pressure $C_P = \dfrac{5R}{2}$. The gas is kept in a closed vessel of volume 0.0083 m^3, at a temperature of 300 K and a pressure of 1.6×10^6 N m^{-2}. An amount of 2.49×10^4 J of heat energy is supplied to the gas. Calculate the final temperature and pressure of the gas.

9. Figure shows a sphere of mass 500 g moving in a steady flow of air which is in the x-direction. The air stream exerts an essentially constant force of 0.9 N on the sphere in the x-direction. If at $t = 0$ the sphere is moving as shown in figure. Determine the time 't' required for the sphere to cross the y-axis again

10. A mixture of two diatomic gases is obtained by mixing m_1 and m_2 masses of two gases, with velocities of sound in them being v_1 and v_2 respectively. Determine the velocity of sound in the mixture of gases.

CROSS WORD

Readers can send their responses at editor@mtg.in or post us with complete address by 25th of every month to win exciting prizes. Winners' name with their valuable feedback will be published in next issue.

CUT HERE

ACROSS

2. The dissociation of molecules by nuclear radiation. [10]
3. The adiabatic rate at which temperature falls with increasing altitude. [5, 4]
4. The electromagnetic wave produced by klystron valve. [9]
5. The moon of mars that has orbital period of 7.66 hours. [6]
7. An instrument used for measuring the total pressure of fluid stream. [5, 4]
10. A prefix denoting 10^{21}. [5]
11. An instrument uses polarised light for studying the properties of substances. [11]
15. The temperature at which the two forms of liquid helium can exist together. [6, 5]
16. A simple pendulum that demonstrates the earth's rotation. [8, 8]
21. A unit of loudness of sound. [4]
23. The rectangular pattern of image capture and reconstruction in television. [6, 4]
25. A measure of amount of magnetic flux embraced by an electric circuit. [7]
27. A hypothetical elementary particle responsible for the effects of gravitation. [8]
28. An imaginary line connecting places of equal barometric pressure. [6]
29. A high-voltage electric short circuit made through the air between exposed conductors. [9]

DOWN

1. The condition at which entropy of an isolated system is maximum. [4, 5]
2. A temperature scale in which ice point is taken as 0° and the steam point as 80°. [7, 5]
6. A single input-output device which has a gain of one. [6]
8. A resistor inserted into a circuit to compensate for changes arising from temperature fluctuations. [9]
9. High-frequency static disturbance of cosmic origin. [6,5]
12. An effect occurring in transmission lines when the load is suddenly reduced to very small value. [8, 6]
13. The god particle. [5, 5]
14. The process of changing the waveform of transmitted pulses. [5, 7]
17. The condition in which people or objects appear to be weightless. [12]
18. The branch of physics concerned with properties of sound. [9]
19. A device used to measure the thickness of the eye's cornea. [10]
20. A common boundary between two parts, devices or systems. [9]
22. The solid carbon dioxide, used as a refrigerant. [3, 3]
24. An instrument for measuring rate at which water evaporates. [9]
26. The maximum number of digital inputs that a single logic gate can accept. [3, 2]

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