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We understand the pressure of cost on the student-teacher community in general but, we are hoping our readers will understand our problems and that we have no option but to comply with this unavoidable move. We on our part, will keep up our efforts to improve the magazines in all its aspects.

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PHYSICS MUSING

Physics Musing was started in August 2013 issue of Physics For You. The aim of Physics Musing is to augment the chances of bright students preparing for JEE (Main and Advanced) / NEET / AIIMS / JIPMER with additional study material.

In every issue of Physics For You, 10 challenging problems are proposed in various topics of JEE (Main and Advanced) / NEET. 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 at least 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.

---

**SINGLE OPTION CORRECT TYPE**

1. A constant force produces maximum velocity $v$ on the block connected to the spring of force constant $k$ as shown in the figure. When the force constant of spring becomes $4k$, the maximum velocity of the block is:

   (a) $\frac{v}{4}$  
   (b) $2v$  
   (c) $\frac{v}{2}$  
   (d) $v$

   ![Diagram of a block connected to a spring](image)

2. A street car moves rectilinearly from station $A$ (here car stops) to the next station $B$ (here also car stops) with an acceleration varying according to the law $F = a - bx$, where $a$ and $b$ are positive constants and $x$ is the distance from station $A$. The distance between the two stations and the maximum velocity are respectively

   (a) $x = \frac{2a}{b}$; $v_{\text{max}} = \frac{2a}{\sqrt{b}}$  
   (b) $x = \frac{a}{b}$; $v_{\text{max}} = \frac{a}{\sqrt{b}}$  

   ![Diagram of street car](image)

3. A brass bar, having cross-sectional area $10 \text{ cm}^2$ is subjected to axial forces as shown in figure. The total elongation of the bar will be (Take $E = 8 \times 10^5 \text{ t/cm}^2$).

   (a) $0.775 \text{ cm}$  
   (b) $7.75 \text{ cm}$  
   (c) $0.0775 \text{ cm}$  
   (d) $77.5 \text{ cm}$

   ![Diagram of brass bar](image)

---

**SUBJECTIVE TYPE**

4. At a particular instant a source of sound of frequency $100 \text{ Hz}$ is at $(2\text{m}, 1\text{m})$ and an observer is at $(5\text{m}, 5\text{m})$. The velocity of source and observer are $15(2i + j) \text{ m s}^{-1}$ and $5i + 15j \text{ m s}^{-1}$ respectively at this instant. The velocity of sound in air is $330 \text{ m s}^{-1}$. Find the frequency of the sound (in Hz) received by the observer.

5. A drop of water volume $0.05 \text{ cm}^3$ is pressed between two glass-plates, as a consequence of which, it spreads and occupies an area of $40 \text{ cm}^2$. If the surface tension of water is $70 \text{ dyne cm}^{-1}$, find...
the normal force required to separate out the two glass plates in newton.

6. A soap bubble of radius $r$ and surface tension at constant $T$ is given a charge, so that its surface charge density is $\sigma$. Due to charge, the radius of the soap bubble becomes double then find $\sigma$'. (Atmospheric pressure is $P_0$)

7. A chain of mass $m$ forming a circle of radius $R$ is slipped on a smooth round cone with half-angle $\theta$. Find the tension of the chain if it rotates with a constant angular velocity $\omega$ about a vertical axis coinciding with the symmetry axis of the cone.

8. A rod $AB$ is moving on a fixed circle of radius $R$ with constant velocity $v$ as shown in figure. $P$ is the point of intersection of the rod and the circle. At an instant the rod is at a distance $x = \frac{3R}{5}$ from centre of the circle. The velocity of the rod is perpendicular to the rod and the rod is always parallel to the diameter $CD$.

(a) Find the speed of point of intersection $P$.
(b) Find the angular speed of point of intersection $P$ with respect to centre of the circle.

9. Side of a cube is measured with the help of vernier caliper. Main scale reading is 10 mm and vernier scale reading is 1. It is known that 9 M.S.D. = 10 V.S.D. Mass of the cube is 2.735 g. Find density of the cube upto appropriate significant figure.

10. Three identical discs $A$, $B$, and $C$ as shown in figure rest on a smooth horizontal plane. The disc $A$ is set in motion with velocity $v$ after which it experiences an elastic collision simultaneously with discs $B$ and $C$. The distance between the centres of the latter discs prior to the collision is $\eta$ times the diameter of each disc. Find the velocity of the disc. $A$ after the collision. At what value of $\eta$ will the disc $A$ recoil after the collision.

---

**Only 36 foreign students register for JEE Advanced**

Despite holding a good ground in global rankings, IITs have failed to catch the fancy of international aspirants this year. Only 36 candidates have registered for JEE (Advanced)—the entry level test for admission to IITs this year as against 69 last year. Eventually, only 31 this year appeared for the test last year and seven qualified.

Not just the rankings, IITs, on their own, have been taking mindful efforts in the last few years to increase students' diversity on campus. Only last year, the premier institutes decided to reach out to international students in Sri Lanka, Nepal, Singapore, Bangladesh, Ethiopia and the UAE, and have been holding exams at these centres.

"We have been releasing admission details from time to time on our website and are also taking all measures to promote the institutes in these countries. We approach the Indian embassies in the selected countries with all the admission data required to ensure a smooth conduct of the test," said an official from the JEE (advanced) committee.

However, the efforts are not translating into numbers for the country's elite group of institutes.

"Our country has to offer good liveable conditions, safety and security, better social conditions to international students to make it a lucrative destination. Why do our students prefer studying in the western part of Europe and not eastern Europe? Why do we prefer going to Northern America instead of south, it is the same case here. People look at options to study abroad also for a prospective career destination. Holding exams in select countries may not yield desirable results," said a professor.
1. A minute spherical air bubble is rising slowly through a column of mercury contained in a deep jar. If the radius of the bubble at a depth of 100 cm is 0.1 cm, calculate its depth where its radius is 0.126 cm, given that the surface tension of mercury is 567 dyn cm\(^{-1}\). Assume that the atmospheric pressure is 76 cm of mercury.
(a) 948 cm  
(b) 94.8 cm  
(c) 9.48 cm  
(d) 0.948 cm

2. The mass of a hydrogen molecule is 3.32 \times 10^{-27} \text{ kg}. If 10^{23} molecules are colliding per second on a stationary wall of area 2 \text{ cm}^2 at an angle of 45^\circ to the normal to the wall and reflected elastically with a speed 10^3 \text{ m s}^{-1}. Find the pressure exerted on the wall (in N m\(^{-2}\)).
(a) 3.32 \times 10^{-24}  
(b) 2.347 \times 10^{-24}  
(c) 2.347 \times 10^{3}  
(d) 3.32 \times 10^{3}

3. 2 m\(^3\) volume of a gas at a pressure of 4 \times 10^5 \text{ N m}^{-2} is compressed adiabatically so that its volume becomes 0.5 m\(^3\). Calculate work done in this process.
(a) 1.1 \times 10^6 \text{ J}  
(b) 2.8 \times 10^6 \text{ J}  
(c) 1.6 \times 10^5 \text{ J}  
(d) 1.48 \times 10^6 \text{ J}

4. Choose the correct statement(s).
Statement-1: If \(x\) and \(y\) are the distances along \(x\) and \(y\) axes respectively then the dimensions of \(\frac{d^2 y}{dx^2}\) is M\(^0\) L\(^{-2}\) T\(^{-4}\).
Statement-2: Dimensions of \(\int_a^b y \, dx\) is M\(^0\) L\(^2\) T\(^{-1}\).
(a) Both statement 1 and statement 2 are true and statement 2 is the correct explanation of statement 1.
(b) Both statement 1 and statement 2 are true but statement 2 is not the correct explanation of statement 1.
(c) Statement 1 is true but statement 2 is false.
(d) Statement 1 is false but statement 2 is true.

5. An aircraft loops the loop of radius \(R = 500 \text{ m}\) with a constant velocity \(v = 360 \text{ km h}^{-1}\). The weight of the flyer of mass \(m = 70 \text{ kg}\) in the lower, upper and middle points of the loop will respectively be
(a) 210 N, 700 N, 1400 N  
(b) 1400 N, 700 N, 2100 N  
(c) 700 N, 1400 N, 2100 N  
(d) 2100 N, 700 N, 1400 N

6. A uniform rod is made to lean between a rough vertical wall and the ground. If \(\mu_1\) is the coefficient of friction between rod and wall, \(\mu_2\) is the coefficient of frictions between rod and ground, then the least angle \(\theta\) at which the rod can be leaned without slipping is
(a) \(\tan^{-1}\left[\frac{\mu_1}{2\mu_2}\right]\)  
(b) \(\tan^{-1}\left[\frac{1+\mu_1\mu_2}{2\mu_2}\right]\)  
(c) \(\tan^{-1}\left[\frac{\mu_1}{2\mu_2}\right]\)  
(d) \(\tan^{-1}\left[\frac{1-\mu_1\mu_2}{2\mu_2}\right]\)
7. A bob of simple pendulum is suspended by a metallic wire. If \( \alpha \) is the coefficient of linear expansion and \( d\theta \) is the change in temperature then percentage change in time period is
   (a) \( 50\alpha c^2 d\theta \) (b) \( 50\alpha c\theta \) (c) \( 20c^2 d\theta \) (d) \( 20c\alpha d\theta \)

8. A steel wire of length 1 m and mass 0.1 kg and having a uniform cross-sectional area of \( 10^{-6} \text{ m}^2 \) is rigidly fixed at both ends. The temperature of the wire is lowered by 20°C. If the wire is vibrating in fundamental mode, find the frequency (in Hz) \( (\gamma_{\text{steel}} = 2 \times 10^{11} \text{ N m}^{-2}, \alpha_{\text{steel}} = 1.21 \times 10^{-5} \text{ / } ^\circ \text{C}) \)
   (a) 11 (b) 20 (c) 15 (d) 10

9. A ball rolls off top of a stair way with a horizontal velocity \( u \text{ m s}^{-1} \). If the steps are \( h \text{ m} \) high and \( b \text{ m} \) wide, the ball will just hit the edge of \( n^\text{th} \) step if \( n \) equals to
   (a) \( \frac{hu^2}{gb^2} \) (b) \( \frac{u^2g}{hb^2} \) (c) \( \frac{2hu^2}{gb^2} \) (d) \( \frac{2u^2g}{hb^2} \)

10. If a body travels half its total path in the best last second of its fall from rest. The time and height of its fall, will respectively be \( (g = 9.8 \text{ m s}^{-2}) \)
    (a) 0.59 s, 57 m (b) 3.41 s, 57 m (c) 5.9 s, 5.7 m (d) 5.9 s, 34.1 m

11. A car accelerates from rest at a constant rate \( \alpha \) for sometime after which it decelerates at constant rate \( \beta \) to come to rest. If the total time elapsed is \( t \) sec. The maximum velocity of car will be
    (a) \( \frac{\alpha t}{\beta} \) (b) \( \frac{\alpha + \beta}{\beta} \) (c) \( \frac{\alpha t}{\alpha + \beta} \) (d) \( \frac{\alpha \beta}{\alpha + \beta} \)

12. A uniform rod \( AB \) of mass \( m \) and length \( 5a \) is free to rotate on a smooth horizontal table about a pivot through \( P \), a point on \( AB \) such that \( AP = a \). A particle of mass \( 2m \) moving on the table strikes \( AB \) perpendicularly at the point \( 2a \) from \( P \) with speed \( v \), the rod being at rest. If the coefficient of restitution between them is \( \frac{1}{4} \), find their speeds immediately after impact.
    (a) \( \frac{15v}{37} \) and \( \frac{83v}{148} \) (b) \( \frac{83v}{37} \) and \( \frac{15v}{148} \) (c) \( \frac{83v}{148} \) and \( \frac{30v}{37} \) (d) \( \frac{83v}{37} \) and \( \frac{30v}{148} \)

13. The blades of a windmill sweep out a circle of area \( A \). The wind flows at a velocity perpendicular to the circle. Assume that the windmill converts 25% of the wind's energy into electrical energy, if \( A = 30 \text{ m}^2 \), \( v = 36 \text{ km h}^{-1} \) and the density of air is \( 1.2 \text{ g m}^{-3} \). What is the electrical power produced?
   (a) 2.3 kW (b) 4.5 kW (c) 6.7 kW (d) 8 kW

14. The Poisson's ratio for a material is 0.1. If the longitudinal strain of a rod of this material is \( 1 \times 10^{-3} \), find the percentage change in the volume of the rod.
   (a) 1.12 % (b) 11.2 % (c) 112 % (d) 0.12 %

15. Two point masses \( m_1 \) and \( m_2 \) are initially at rest and at infinite distance apart. They start moving towards one another under their mutual gravitational field. Their relative speed when they are at a distance \( d \) apart is
    (a) \( \sqrt{\frac{2G(m_1 + m_2)}{d}} \) (b) \( \sqrt{\frac{G(m_1 + m_2)}{d}} \) (c) \( \sqrt{\frac{2G(m_1 + m_2)}{d}} \) (d) \( \sqrt{\frac{2Gd}{m_1 + m_2}} \)

**SOLUTIONS**

1. (c): The total pressure inside the bubble at depth \( h_1 \) is
   \[ (P \text{ atmospheric pressure}) = (P + h_1 \rho g) + \frac{2T}{r_1} = P_1 \]
   and the total pressure inside the bubble at depth \( h_2 \) is \( (P + h_2 \rho g) + \frac{2T}{r_2} = P_2 \)

   Now, according to Boyle's law,
   \[ P_1 V_1 = P_2 V_2, \]
   where \( V_1 = \frac{4}{3} \pi r_1^3 \) and \( V_2 = \frac{4}{3} \pi r_2^3 \)

   Hence, we get
   \[ \left( P + h_1 \rho g \right) + \frac{2T}{r_1} \frac{4}{3} \pi r_1^3 = \left( P + h_2 \rho g \right) + \frac{2T}{r_2} \frac{4}{3} \pi r_2^3 \]

2. (c): As the impact is elastic
   \[ |\vec{p}_1| = |\vec{p}_2| = p = mv = 3.32 \times 10^{-24} \text{ kg m s}^{-1} \]

   The change in momentum along the normal
   \[ \Delta p = |\vec{p}_2 - \vec{p}_1| = 2p \cos 45^\circ = \sqrt{2} p \]

   If \( v \) is the collision frequency then the force applied on the wall \( F = \frac{\Delta p}{\Delta t} = \Delta v \times v = \sqrt{2} pv \)
3. (d) 4. (b) 5. (d): Here \( v = 360 \text{ km h}^{-1} = 100 \text{ m s}^{-1} \)

At lower point, \( N - mg = \frac{mv^2}{R} \), (where \( N \) = weight of the flyer)

\[ N = mg + \frac{mv^2}{R} \]

\[ N = 70 \times 10^3 + \frac{70 \times (10000)}{500} = 2100 \text{ N} \]

At upper point, \( N + mg = \frac{mv^2}{R} \)

\[ N = \frac{mv^2}{R} - mg = 1400 - 700 = 700 \text{ N} \]

At middle point, \( N = \frac{mv^2}{R} = 1400 \text{ N} \)

6. (d): For equilibrium of rod

\[ \sum F_x = 0 \Rightarrow R_1 = R_1 \mu_1 \ldots (i) \]

\[ \sum F_y = 0 \Rightarrow \mu_1 R_1 + R_2 = W \ldots (ii) \]

From eqn (i) and (ii)

\[ (\mu_1 \mu_2 + 1) R_2 = W \ldots (iii) \]

Taking torque about point A,

\[ W \left( \frac{l}{2} \cos \theta \right) + \mu_1 R_1 \left( l \sin \theta \right) = R_2 \left( l \cos \theta \right) \]

\[ \Rightarrow W = 2R_2 \left( 1 - \mu_2 \tan \theta \right) \] (Using (iii))

\[ \Rightarrow \tan \theta = \frac{2R_2}{1 - \mu_2 \tan \theta} \]

7. (b): With change in temperature \( \alpha \theta \), the effective length of wire becomes \( l' = l (1 + \alpha \theta) \)

\[ T' = 2\pi \frac{l'}{\sqrt{g}} \text{ and } T = 2\pi \frac{l}{\sqrt{g}} \]

\[ \frac{T'}{T} = \sqrt{\frac{l}{l}} = (1 + \alpha \theta)^{1/2} = 1 + \frac{1}{2} \alpha \theta \]

\[ \Rightarrow \text{Percentage increase in time period} = \left( \frac{T' - T}{T} \right) \times 100 = \left( \frac{T}{T - 1} \right) \times 100 \]

\[ = \left( 1 + \frac{\alpha \theta}{2} - 1 \right) \times 100 = 50 \alpha \theta \]

8. (a): \( \Delta l = \alpha l \Delta \theta \) and \( Y = \frac{T}{A} \Rightarrow T = YA \frac{\Delta l}{l} \)

\[ T = \alpha Y A \Delta \theta = 48.4 \text{ N} \]

\[ v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{48.4}{0.1}} = 22 \text{ m s}^{-1} \]

\[ \Rightarrow \text{For fundamental note } l = \frac{\lambda}{2} \Rightarrow \lambda = 2 \text{ m} \]

\[ \Rightarrow \text{Frequency, } \nu = \frac{v}{\lambda} = \frac{22}{2} = 11 \text{ Hz} \]

9. (c): If the ball hits the \( n^{th} \) step, the horizontal and vertical distances traversed are \( nb \) and \( nh \) respectively. Let \( t \) be the time taken by the ball for these horizontal and vertical displacement. Then velocity along horizontal direction remains constant = \( u \) and initial vertical velocity is zero.

\[ \Rightarrow nb = ut \Rightarrow t = \frac{nb}{u} \ldots (i) \]

\[ nh = 0 + (1/2)gt^2 \]

From (i) and (ii) we get, \[ nh = (1/2)g \left( \frac{nb}{u} \right)^2 \ldots (ii) \]

\[ \Rightarrow n = \frac{2hu^2}{g t^2} \]

10. (b): If the body falls a height \( h \) in time \( t \), from 2nd equation of motion, we have

\[ h = \frac{1}{2} gt^2 \ldots (i) \]

\( u = 0 \) as body starts from rest

Now the distance fallen in \( t - 1 \) seconds is \( h' = \frac{1}{2} g (t - 1)^2 \ldots (ii) \)

So from eq. (i) and (ii), distance fallen in the last second is

\[ h - h' = \frac{(1/2)g t^2}{2} - \frac{(1/2)g (t - 1)^2}{2} \]

But according to given problem as \( (h - h') = h/2 \). i.e., \( (1/2)h = (1/2)g (2t - 1) \) or \( (1/2)gt^2 = g(2t - 1) \)

(Using eqn. (i))

or \( t^2 - 4t + 2 = 0 \) or \( t = \frac{4 \pm \sqrt{(4^2 - 4 \times 2)}}{2} \)

or \( t = 2 \pm \sqrt{2} \) or \( t = 0.59 \) or 3.41 s

5.9 s is physically unacceptable as it gives the total time \( t \) taken by the body to reach ground is lesser than one sec. while according to the given problem time of motion must be greater than 1 s.

So \( t = 3.41 \) s and \( h = (1/2) \times (9.8) \times (3.41)^2 = 57 \text{ m} \)

11. (c): If the car accelerates for time \( t_1 \) and decelerates for time \( t_2 \), then according to given problems \( t = t_1 + t_2 \)

If \( V_{max} \) is the maximum velocity of the car, then from \( v/t \) curve, we have

\[ \alpha = \frac{V_{max}}{t_1}, \beta = \frac{V_{max}}{t_2} \]
12. (c): Let the point of impact be Q so that \( PQ = 2a \).
Let P be the point of pivot that \( AP = a \).
Let the velocities of point Q and the particle after impact be \( v_q \) and \( v_p \) respectively then from momentum conservation about point P,
\[
I_{e} = I_{f} = 2a(2mv) = I_P \omega + (2a)(2mv_p) \\
I_p = \frac{1}{3} m \left( \frac{5a^2}{2} + m \frac{3a^2}{2} \right)^2 \quad \text{(using parallel axis theorem)} \\
I_q = \frac{13ma^2}{3} \quad \text{...(ii)}
\]
from (i) and (ii) equation
\[
4ma(v - v_p) = \frac{13ma^2}{3} \omega \quad \text{...(iii)}
\]
coefficient of restitution, \( e = \frac{1}{4} \frac{v_q - v_p}{v} \) velocity of seperation velocity of approach
\[
\frac{1}{4} = \frac{v_q - v_p}{v} \Rightarrow v_q - v_p = \frac{v}{4} \quad \text{...(iv)}
\]
\[
v_q = 2a \omega \quad \text{...(v)}
\]
Put value of \( \omega \) from eq. (iii) to equation (v)
\[
\frac{24}{13} (v - v_p) - v_p = \frac{v}{4} \Rightarrow v_p = \frac{83v}{148}
\]
So in this way we get, \( v_q = \frac{30v}{37} \).

13. (b): Volume of wind flowing per second = \( Av \)
Mass of wind flowing per second = \( AvP \)
Mass of air passing in \( t \) second = \( AvPt \)
kinetic energy of air
\[
= \frac{1}{2} mv^2 = \frac{1}{2} (AvP) v^2 = \frac{1}{2} Av^3 Pt
\]
Electrical energy produced = \( \frac{25}{100} \times \frac{1}{2} Av^3 Pt = \frac{Av^3 Pt}{8} \)
Electrical power = \( \frac{Av^3 P}{8t} \)
Now, \( A = 30 \) m², \( v = 10 \) m s⁻¹, \( p = 1.2 \) kg m s⁻¹
\( \therefore \) Electrical power = 4500 W = 4.5 kW

14. (d): Here, \( \sigma = 0.1 \); Longitudinal strain, \( \alpha = 10^{-3} \)
Poisson ratio, \( \sigma = \frac{\text{longitudinal strain}}{\text{lateral strain}} \)
\[
\beta = 0.1 \times 10^{-3} = 10^{-4}
\]
\[
\alpha = \frac{l_i - l_f}{l_i} - 1 \quad \text{or} \quad l_s = 1 + \alpha = 1 + 10^{-3} = 1.001
\]
and \( \beta = \frac{r_s - r_i}{r_i} = \frac{r_s}{r_i} - 1 \)
or \( \frac{r_s}{r_i} = 1 + \beta = 1 + 10^{-4} = 1.0001
\]
percentage increase in volume
\[
\frac{V_s - V_i}{V_i} = 100 = \frac{(\frac{r_s}{r_i})^3 - 1}{1} \times 100 = (1.0001)^3 - 1 \times 100 = 0.12 \%
\]

15. (b): We choose reference point, infinity, where total energy of the system is zero.
So, initial energy of the system = 0.
Final energy = \( \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 \)
\[
\frac{Gm_1m_2}{d}
\]
From conservation of energy,
Initial energy = Final energy
\[
0 = \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 - \frac{Gm_1m_2}{d}
\]
or \( \frac{1}{2} m_1v_1^2 + \frac{1}{2} m_2v_2^2 = \frac{Gm_1m_2}{d} \quad \text{...(i)}
\]
By conservation of linear momentum,
\[
m_1v_1 + m_2v_2 = 0 \quad \text{or} \quad v_1 = -\frac{m_2}{m_1} \Rightarrow v_2 = -\frac{m_1}{m_2}v_1
\]
Putting value of \( v_2 \) in equation (i), we get
\[
m_1v_1^2 + m_2 \left( -\frac{m_1v_1}{m_2} \right) = \frac{2Gm_1m_2}{d}
\]
\[
\Rightarrow v_1 = m_2 \sqrt{\frac{2G}{d(m_1 + m_2)}}
\]
Similarly \( v_2 = -m_1 \sqrt{\frac{2G}{d(m_1 + m_2)}} \);
\[
\therefore \text{Relative speed} \ v = v_2 - (-v_1) = v_2 + v_1
\]
\[
= \sqrt{\frac{2G}{d \left( \frac{m_1 + m_2}{m_1 + m_2} \right)}} = \sqrt{\frac{2G(m_1 + m_2)}{d}}
\]
5 MIND BLOWING FACTS

1. Black holes aren't black
They're very dark, sure, but they aren't black. They glow, slightly, giving off light across the whole spectrum, including visible light. This radiation is called “Hawking radiation”, as Stephen Hawking, who first proposed its existence. Because they are constantly giving this off, and therefore losing mass, black holes will eventually evaporate altogether if they don't have another source of mass to sustain them; for example interstellar gas or light.

2. Air current and birds
The speed of wind near the surface of ocean is much lower than what is observed in the higher altitudes. The reason can be attributed to the friction it receives from the water surface. It is due to this reason that most birds fly at a higher altitude. They manipulate the wind power in order to use least amount of energy on flying.

3. Expanding Universe
It is proved by scientific theories that the universe is constantly expanding. It is expanding at a decent pace and it is believed that galaxies will evaporate in the coming $10^{19}$ to $10^{20}$ years. It has been learnt from a number of theories by different Physicists worldwide that only White Dwarfs (a type of star) would be able to survive as their lifetime is more than $10^{32}$ years.

4. Anti-gravity movement
Water can easily run against the gravitational pull when moving up narrow pipes. The process is described as ‘Capillary Action’. Water moves up in the narrow spaces without any assistance and against the gravitational force. This ability of the liquid proves that gravitational force can’t control the movement of every matter present on earth. At times, other forces (Surface tension, in this case) can defeat it.

5. Hydrogen energy
It is estimated that Sun burns around 620 million metric tons of hydrogen per second into 616 million metric tons of helium. The sun releases energy at a mass–energy conversion rate of 4.26 million metric tons per second, which produces the equivalent of 38,460 septillion watts (3.846x1026 W) per second. To put that in perspective, this is the equivalent of about 9.192x1010 megatons of TNT per second, or 1,820,000,000 Tsar Bombas, the most powerful thermonuclear bomb ever built! Out of this total volume, around 4 million tons of mass enters the solar system.
1. A rod of mass \( m \) and resistance \( r \) is placed on fixed, resistanceless, smooth conducting rails (closed by a resistance \( R \)) and it is projected with an initial velocity \( u \). Find its velocity as a function of time.
   (a) \( v = ut \)
   (b) \( v = ue^{kt} \)
   (c) \( v = ue^{-kt} \)
   (d) \( v = ue^{-kt} \)

2. The plates of a capacitor are charged to a potential difference of 320 V and are then connected across a resistor. The potential difference across the capacitor decays exponentially with time. After 1 second, the potential difference between the plates of the capacitor is 240 V and then after 2 and 3 seconds, the potential difference between the plates will be
   (a) 200 V and 180 V
   (b) 180 V and 135 V
   (c) 160 V and 80 V
   (d) 140 V and 20 V

3. An AC source of angular frequency \( \omega \) is fed across a resistor \( R \) and a capacitor \( C \) in series. The current registered is \( i \). If now the frequency of the source to \( \omega/3 \) (but maintaining the same voltage), the current in the circuit is found to be halved. The ratio of reactance to resistance at the original frequency is \( \sqrt{x \times 10^{-1}} \). Find the value of \( x \).

4. A parallel plate capacitor made of circular plates each of radius \( R = 6.0 \) cm has a capacitance \( C = 100 \) pF. The capacitor is connected to a 230 V a.c. supply with an angular frequency of 300 rad s\(^{-1}\).
   Determine the magnitude of \( B \) at a point 3.0 cm from the axis between the plates.
   (a) \( 6.9 \times 10^{-11} \) T
   (b) \( 7.5 \times 10^{-11} \) T
   (c) \( 2.6 \times 10^{-11} \) T
   (d) \( 1.63 \times 10^{-11} \) T

5. Find the position of the final image after three successive reflections taking first reflection on \( m_1 \).

6. In a YDSE with \( D = 1 \) m, \( d = 1 \) mm, light of wavelength 500 nm is incident at an angle of 0.57\(^\circ\) w.r.t. the axis of symmetry of the experimental setup.
If centre of symmetry of screen is O as shown. Find the position of central maxima and number of maxima lying between O and the central maxima.
(a) $y = 1$ cm and 19th maxima
(b) $y = 2$ cm and 20th maxima
(c) $y = -1$ cm and 19th maxima
(d) $y = -2$ cm and 20th maxima

7. A carrier signal of 100 kHz is to be detected in a diode AM detector. Its output circuit consists of $R$ and $C$. What value of $R$ and $C$ would you suggest for a satisfactory arrangement?
(a) $R = 10$ p$\Omega$; $C = 1$ k$\mu$F
(b) $R = 1$ k$\Omega$; $C = 10$ p$\mu$F
(c) $R = 1$ k$\Omega$; $C = 1$ $\mu$F
(d) None of these

8. Find the current produced at a room temperature in a pure germanium plate of area $2 \times 10^{-4}$ m$^2$ and of thickness $1.2 \times 10^{-3}$ m when a potential of 5V is applied across the faces. Concentration of carriers in germanium at room temperature is $1.6 \times 10^{19}$/m$^3$. The mobilities of electron and holes are 0.4 m$^2$/V$s$ and 0.2 m$^2$/V$s$, respectively. How much heat is generated in the plate in 100 seconds?
(a) $1.28 \times 10^{-13}$ J
(b) $6.4 \times 10^{-11}$ J
(c) $8.3 \times 10^{-9}$ J
(d) $2.8 \times 10^{-6}$ J

9. A radioactive sample decays with an average-life of 20 ms. A capacitor of capacitance 100 $\mu$F is charged to some potential and then the plates are connected through a resistance $R$. What should be the value of $R$ so that the ratio of the charge on the capacitor to the activity of the radioactive sample remains constant in time?
(a) 50 $\Omega$
(b) 100 $\Omega$
(c) 200 $\Omega$
(d) 250 $\Omega$

10. A He$^+$ ions is at rest and is in ground state. A neutron with initial kinetic energy $K$ collides head on with the He$^+$ ion. Find minimum value of $K$ so that there can be an inelastic collision between these two particles.
(a) 40 eV
(b) 48 eV
(c) 51 eV
(d) 54 eV

11. Find the wavelength of Ha line ($3 \rightarrow 2$ transition) of positronium.
(a) 1986 $\AA$
(b) 2431 $\AA$
(c) 2052 $\AA$
(d) 1313 $\AA$

12. In given situation, radius of disc is $\sqrt{3}b$ and distance of point charge from the disc is $b$.

Ratio of electric flux not going through the disc and electric flux of charge through the disc is $k$. Then, find value of $k$ which will be an integer from 1 to 10.
(a) 1
(b) 2
(c) 3
(d) 4

13. A cylindrical conductor carries a current such that current density varies with radial distance $r$ or $j = ar^2$, with $a = 2$ constant. The current through the outer portion of the wire between radial distances $\frac{R}{2}$ and $R$ is proportional to $R^k$, where $R$ is radius of wire. Find the value of $k$.
(a) $\frac{1}{2}$
(b) 2
(c) $\frac{1}{4}$
(d) 4

14. A non-conducting sphere has mass of 100 g and radius 20 cm. A flat compact coil of wire with 5 turns is wrapped tightly around it with each turns concentric with the sphere. This sphere is placed on an inclined plane such that plane of coil is parallel to the inclined lane.
A uniform magnetic field of 0.5 T exists in the region in vertically upwards direction. If a current of $\frac{k}{\pi}\text{A}$ is required to rest the sphere in equilibrium, then find the value of $k$.
(a) 1
(b) 2
(c) 3
(d) 4

15. Let a wire is placed in a magnetic field that varies with distance from origin as $B = B_0 \left(1 + \frac{X}{a}\right)\hat{k}$.

Ends of wire are at $(a, 0)$ and $(2a, 0)$ and it carries a current $i$. If force on wire is $F = B_0 i \left(\frac{ka}{2}\right)(-\hat{j})$.

Then, find the value of $k$.
(a) 5
(b) 7
(c) 9
(d) 11
1. (c): Let at an instant the velocity of the rod be \( v \). The emf induced in the rod will be \( Blv \). The electrically equivalent circuit is shown in the following diagram.

\[ i = \frac{Blv}{R + r} \] ...(i)

At a later time \( t \) after projection
Magnetic force acting on the rod is \( F = iIB \), opposite to the motion of the rod.

\[ iIB = -m \frac{dv}{dt} \]

Now solving equations (i) and (ii),

\[ B^2 l^2 \frac{dv}{R + r} = \frac{dv}{dt} \]

\[ \Rightarrow \frac{B^2 l^2}{R + r} m = \frac{dv}{dt} \]

Let \( \frac{B^2 l^2}{R + r} m = K \)

\[ \Rightarrow \frac{dv}{dt} = \frac{K}{m} \]

\[ \Rightarrow t \frac{dv}{dt} = \int K \ dt \Rightarrow \ln \left( \frac{v}{u} \right) = -Kt \Rightarrow v = ue^{-Kt} \]

2. (b): During discharging, the potential difference across the capacitor falls exponentially as

\[ V = V_0 e^{-\lambda t} \] (Here, \( \lambda = \frac{1}{RC} \))

where \( V \) is instantaneous P.D. and \( V_0 \) = maximum P.D. across capacitor.

After 1 second, \( V_1 = 320 \ (e^{-\lambda}) \)

\[ \Rightarrow 240 = 320 \ (e^{-\lambda}) \quad \Rightarrow \quad e^{-\lambda} = \frac{3}{4} \]

After 2 seconds, \( V_2 = 320 \ (e^{-\lambda})^2 \)

\[ \Rightarrow 320 \times \left( \frac{3}{4} \right)^2 = 180 \text{ V} \]

After 3 seconds,

\( V_3 = 320 (e^{-\lambda})^3 = 320 \times \left( \frac{3}{4} \right)^3 = 135 \text{ V} \)

3. (a): At angular frequency \( \omega \), the current in RC circuit is given by

\[ \begin{align*}
\text{rms} & = \frac{E}{\sqrt{R^2 + \left( \frac{1}{\omega^2 C^2} \right)}} \\
\text{rms} & = \frac{E}{\sqrt{R^2 + \left( \frac{1}{(\omega/3)^2 C^2} \right)}}
\end{align*} \] ...(i)

When the frequency is changed to \( \frac{\omega}{3} \), the current is halved.
Thus,

\[ \begin{align*}
\frac{1}{2} i_{\text{rms}} & = \frac{E}{\sqrt{R^2 + \left( \frac{1}{\omega^2 C^2} \right)}} \\
\frac{1}{2} i_{\text{rms}} & = \frac{E}{\sqrt{R^2 + \left( \frac{9}{\omega^2 C^2} \right)}}
\end{align*} \] ...(ii)

From equations (i) and (ii), we have

\[ \begin{align*}
\frac{1}{R^2 + \left( \frac{1}{\omega^2 C^2} \right)} & = \frac{1}{R^2 + \left( \frac{9}{\omega^2 C^2} \right)}
\end{align*} \]

Solving this equation, we get

\[ 3R^2 = \frac{5}{\omega^2 C^2} \]

Hence, the ratio of reactance to resistance is

\[ \left( \frac{1}{60C} \right) = \frac{3}{5} \Rightarrow x = 6 \quad \Rightarrow \quad \left( \frac{1}{60C} \right) = \left( \frac{x}{x^2 - 1} \right) \]

4. (d): Here, \( R = 6.0 \text{ cm}, C = 100 \text{ pF} = 100 \times 10^{-12} \text{ F}, \omega = 300 \text{ rad s}^{-1}, E_{\text{rms}} = 230 \text{ V} \)

\[ i_{\text{rms}} = \frac{E_{\text{rms}}}{X_C} = \frac{E_{\text{rms}}}{1/60C} = E_{\text{rms}} \times 60C \quad \Rightarrow \quad i_{\text{rms}} = 230 \times 300 \times 100 \times 10^{-12} \]

\[ = 6.9 \times 10^{-6} \text{ A} = 6.9 \mu\text{A} \]

Now \( I_D = \frac{d(\phi_E)}{dt} = \frac{dE}{dt} (\text{EA}) \quad (\because \phi_E = EA) \)

or \( I_D = \frac{A dE}{dt} = \frac{A dQ}{\varepsilon_0 A} = \frac{Q}{\varepsilon_0} \)

\( I = I_D \), whether \( I \) is a steady d.c. or a.c.

We know, \( B = \frac{\mu_0 I_0}{2\pi R^2} \)

The formula is valid even if \( I_D \) is oscillating.

As \( I_D = I \), therefore \( B = \frac{\mu_0 I_0}{2\pi R^2} \)

If \( I \) is the maximum value of current, then

Amplitude of \( B \) = maximum value of

\[ \begin{align*}
B & = \frac{\mu_0 I_0}{2\pi R^2} \\
& = \frac{\mu_0 \sqrt{2} I_{\text{rms}}}{2\pi R^2} \quad (\because I_0 = \sqrt{2} I_{\text{rms}}) \\
& = \frac{4 \pi \times 10^{-7} \times 0.03 \times \sqrt{2} \times 6.9 \times 10^{-6}}{2 \times 3.14 \times (0.06)^2} = 1.63 \times 10^{-11} \text{ T}
\end{align*} \]

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5. (b):  

First reflection at mirror $m_1$:

$u = -15 \text{ cm}, \quad f = -10 \text{ cm}$

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

$\therefore v = \frac{uf}{u-f} = \frac{(-15) \times (-10)}{(-15) + 10} = 150 \text{ cm} = -30 \text{ cm}$

Thus, image is formed at a point 5 cm right of $m_2$ which will act as an object for the reflection at $m_2$.

For second reflection at $m_2$:

$u = 5 \text{ cm}, \quad f = 10 \text{ cm}$

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

$\therefore v = \frac{uf}{u-f} = \frac{5 \times 10 \times 50}{5 - 10} = -10 \text{ cm}$

Third reflection at $m_1$ again:

$u = -15 \text{ cm}, \quad f = -10 \text{ cm}$

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

$\therefore v = \frac{uf}{u-f} = \frac{-15 \times (-10)}{(-15) + 10} = -30 \text{ cm}$

6. (c) $\theta = \theta_0 = 0.57$

$\Rightarrow y = -D \tan \theta = -D \theta = -1 \text{ m} \times 10^{-2} \text{ rad}$

$\Rightarrow y = -1 \text{ cm}$

For point $O$, $\theta = 0$

Hence, $\Delta \theta = d \sin \theta_0 = d \theta_0 = 1 \text{ mm} \times (10^{-2} \text{ rad}) = 10,000 \text{ nm} = 20 \times (500 \text{ nm})$

$\Rightarrow \Delta \theta = 20 \lambda$

Hence, point $O$ corresponds to 20th maxima

$\Rightarrow$ Intensity at $O = I_0$

The 19th maxima lies between central maxima and $O$, excluding maxima at $O$ and central maxima.

7. (c) Here, $R = 1 \text{ k}\Omega = 10^3 \Omega$

$C = 10 \text{ pF} = 10 \times 10^{-12} \text{ F} = 10^{-11} \text{ F}$

$R = 10 \text{ pF} = 10 \times 10^{-12} \Omega = 10^{-11} \Omega$

$C = 1 \text{ k}\Omega = 10^3 \text{ F}$

$\therefore \frac{1}{RC} = \frac{1}{10^5 \times 10^{-11}} \text{ s} = 10^{-8} \text{ s}$

and $\frac{1}{f_c} = \frac{1}{100 \times 10^{-3}} \text{ s} = 10^{-5} \text{ s}$

We find that $\frac{1}{f_c}$ is not less than $RC$ as is required for demodulation. Therefore, the arrangement is not good.

For a satisfactory arrangement, let us try $C = 1 \text{ m}\Omega = 10^{-6} \text{ F}$

$\therefore RC = 10^5 \times 10^{-6} \text{ s} = 10^{-3} \text{ s}$

Now, $\frac{1}{f_c} = 10^{-5} \text{ s} < < RC = 10^{-3} \text{ s}$

$\therefore$ The condition is satisfied. This is good enough for demodulation.

8. (b): Electrical field

$E = \frac{V}{d} = \frac{5}{1.2 \times 10^{-3}} = \frac{5}{12} \times 10^4 \text{ V/m}$

$\mu = \frac{v_d}{E} = \frac{v_d}{\mu E}$

Thus, electric current across the plate

$i = neAE\mu = neAE(\mu_e + \mu_h)$

$= 1.6 \times 10^6 \times 1.6 \times 10^{-19} \times 2 \times 10^{-4} \times \frac{5}{12} \times 10^4 \times (0.4 + 0.2) = 1.28 \times 10^{-13} \text{ A}$

Heat produced in the plate in 100 seconds

$H = Vit = 5 \times 1.28 \times 10^{-13} \times 100 = 6.4 \times 10^{-11} \text{ J}$

9. (c): The activity of the sample of time $t$ is given by $A = A_0 e^{-\lambda t}$

where $\lambda$ is the decay constant and $A_0$ is the activity at time $t = 0$ when the capacitor plates are connected. The charge on the capacitor at time $t$ is given by

$Q = Q_0 e^{-\lambda t}$

where $Q_0$ is the charge at $t = 0$ and $C = 100 \text{ } \mu\text{F}$ is the capacitance. Thus

$\frac{Q}{A} = \frac{Q_0}{A_0} e^{-\lambda t}$

It is independent of $t$ if $\lambda = \frac{1}{CR}$

or $R = \frac{1}{\lambda C} = \frac{e^{t/v}}{C} = \frac{20 \times 10^{-3} \text{ s}}{100 \times 10^{-6} \text{ F}} = 200 \text{ } \Omega$

10. (c): Here the loss during the collision can only be used to excite the atoms or electrons.

So, according to quantum mechanics loss $\Rightarrow [0, 40.8 \text{ eV}, 48.3 \text{ eV}, ..., 54 \text{ eV}]$

$E_n = -13.6 \frac{Z^2}{n^2} \text{ eV}$

Now according to Newtonian mechanics

Minimum loss $= 0$

Maximum loss will be for perfectly inelastic collision.

Let $v_0$ be the initial speed of neutron and $v_f$ be the final common speed.

So, by momentum conservation $mv_0 = mv_f + 4mv_f$

$v_f = \frac{v_0}{5}$; where $m$ is the mass of Neutron.

$\therefore$ Mass of $\text{He}^+$ ion $= 4m$
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So, final kinetic energy of system

\[
K.E. = \frac{1}{2}(m + 4m)v_f^2 = \frac{1}{2}(5m)v_0^2 = 5\left(\frac{1}{2}mv_0^2\right) = \frac{K}{5}
\]

Maximum loss = \(K - \frac{4K}{5}\)

So, loss will be [0, \frac{4K}{5}]

For inelastic collision, there should be at least one common value other than zero is set (1) and (2)

\[
\therefore \frac{4K}{5} > 40.8 \text{ eV}
\]

\[
K > 51 \text{ eV}
\]

Minimum value of \(K = 51 \text{ eV}\)

11. (d): In positronium, the electron and the positron revolve around their centre of mass, i.e.,

\[
\frac{1}{4\varepsilon_0}r^2 = \frac{me^2}{\hbar} \quad \text{(i)} \quad \frac{e^2}{2\pi} = 2mvr \frac{r}{2} \quad \text{(ii)}
\]

From (i) and (ii),

\[
\nu = \frac{1}{2} \cdot \frac{e^2}{4\varepsilon_0} \cdot \frac{\hbar}{2\pi} = \frac{e^2}{4\varepsilon_0 \hbar}
\]

\[
TE = -\frac{1}{2}mv^2 < 2 = -m \cdot \frac{e^4}{16\varepsilon_0^2 \hbar^2} = -6.8 \cdot \frac{1}{n^2} \text{ eV}
\]

\[
E_1 = -6.8 \text{ eV}
\]

\[
E_2 = -6.8 \times \frac{1}{2^2} \text{ eV} = -1.70 \text{ eV}
\]

\[
E_3 = -6.8 \times \frac{1}{3^2} \text{ eV} = -0.76 \text{ eV}
\]

\[
\Delta E (3 \rightarrow 2) = E_3 - E_2 = -0.76 - (-1.70) \text{ eV} = 0.94 \text{ eV}
\]

The corresponding wavelength

\[
\lambda = \frac{1.24 \times 10^{-4}}{0.94} = 1313 \text{ Å}
\]

12. (c): Flux through an area with half angle \(\theta\) as shown is

\[
\Phi_E = \frac{Q}{2\varepsilon_0} (1 - \cos \theta)
\]

Here, \(\cos \theta = \frac{1}{\sqrt{1 + \tan^2 \theta}} = \frac{1}{\sqrt{1 + b^2}} = \frac{1}{2}
\]

\[
\therefore \text{ Flux through disc, } \Phi = \frac{Q}{4\varepsilon_0}
\]

So, flux which is not passing through the disc

\[
\Phi_2 = \frac{Q}{4\varepsilon_0} - \frac{Q}{4\varepsilon_0} = \frac{3Q}{4\varepsilon_0}
\]

Hence, ratio is \(\frac{\Phi_1}{\Phi_2} = \frac{\frac{4\varepsilon_0}{Q}}{\frac{3Q}{4\varepsilon_0}} = 3\)

13. (d): Current through outer portion is

\[
i = \int R \frac{j \cdot dA}{R/2} (\text{As, } j ||dA) = \int R \frac{ar^2 \pi r \cdot dr}{R/2} \quad (\therefore dA = 2\pi rdr)
\]

\[
= 2\pi a \int R/2 r^3 dr = 2\pi a \left(\frac{r^4}{4}\right)_{R/2} = \frac{15 \pi aR^4}{32}
\]

So, \(i \approx R^3\); As \(i \approx \frac{R^4}{a^3}\)

Comparing both, we get \(k = 4\).

14. (b): Sphere is in translational equilibrium.

\[
\mu g - m \sin \theta = 0 \quad \text{(i)}
\]

The sphere is also in rotational equilibrium.

\[
\therefore \mu R - \mu B \sin \theta = 0 \quad \text{(ii)}
\]

From eqns. (i) and (ii), we get

\[
\mu B = mgR
\]

\[
\mu = N\frac{\pi R^2}{2}
\]

So,

\[
I = \frac{mg}{N\pi R^2} = \frac{0.1 \times 0.1}{\pi \times 5 \times 0.5 \times 0.2} = \frac{2}{\pi}
\]

and \(i = \frac{k}{\pi} \); so comparing both, we get \(k = 2\).

15. (a): Force on a small element of wire is

\[
dF = idx \times B = \left[iB_0 \left(1 + \frac{x}{a}\right) dx \right] \hat{k} \cdot \left[i \hat{x} \times \hat{k}\right]
\]

\[
= iB_0 \left(1 + \frac{x}{a}\right) dx
\]

So, magnitude of total force on wire will be

\[
F = \int_{x=a}^{x=2a} iB_0 \left(1 + \frac{x}{a}\right) dx
\]

\[
= iB_0 \left(x + \frac{x^2}{2a}\right)_{x=a}^{x=2a} = iB_0 \left(\frac{5a}{2}\right)
\]

in negative Y-axis

If force on the wire is

\[
F = B_0 \left[\frac{ka}{2}\right]
\]

On comparing both, we get \(k = 5\)
Here, the references of few are given:

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and more such questions .......

1. An electromagnetic wave is propagating in a medium with a velocity \( \vec{v} = v \hat{v} \). The instantaneous oscillating electric field of this wave is along +y axis. Then the direction of oscillating magnetic field of the em wave will be along
   (a) -z direction   (b) +z direction
   (c) -y direction   (d) -x direction

2. The refractive index of the material of a prism is \( \sqrt{2} \) and the angle of the prism is 30°. One of the two refracting surfaces of the prism is made a mirror inwards, by silver coating. A beam of monochromatic light entering the prism from the other face will retrace its path (after reflection from the silvered surface) if its angle of incidence on the prism is
   (a) 60°  (b) 45°
   (c) 30°  (d) zero

3. The magnetic potential energy stored in a certain inductor is 25 mJ, when the current in the inductor is 60 mA. This inductor is of inductance
   (a) 0.138 H   (b) 138.88 H
   (c) 1.389 H   (d) 13.89 H

4. An object is placed at a distance of 40 cm from a concave mirror of focal length 15 cm. If the object is displaced through a distance of 20 cm towards the mirror, the displacement of the image will be
   (a) 30 cm away from the mirror
   (b) 36 cm away from the mirror
   (c) 30 cm towards the mirror
   (d) 36 cm towards the mirror

5. In the combination of the following gates the output \( Y \) can be written in terms of inputs \( A \) and \( B \) as

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6. In the circuit shown in the figure, the input voltage $V_i$ is 20 V, $V_{BE} = 0$ and $V_{CE} = 0$. The values of $I_B$, $I_C$ and $\beta$ are given by

(a) $I_B = 40 \mu A$, $I_C = 10 mA$, $\beta = 250$
(b) $I_B = 25 \mu A$, $I_C = 5 mA$, $\beta = 200$
(c) $I_B = 20 \mu A$, $I_C = 5 mA$, $\beta = 250$
(d) $I_B = 40 \mu A$, $I_C = 5 mA$, $\beta = 125$

7. In a $p$-$n$ junction diode, change in temperature due to heating
(a) affects only reverse resistance
(b) affects only forward resistance
(c) does not affect resistance of $p$-$n$ junction
(d) affects the overall $V$ - $I$ characteristics of $p$-$n$ junction

8. A small sphere of radius 'r' falls from rest in a viscous liquid. As a result, heat is produced due to viscous force. The rate of production of heat when the sphere attains its terminal velocity, is proportional to
(a) $r^3$ (b) $r^2$ (c) $r^5$ (d) $r^4$

9. A sample of 0.1 g of water at 100°C and normal pressure $(1.013 \times 10^5 N \text{ m}^{-2})$ requires 54 cal of heat energy to convert to steam at 100°C. If the volume of the steam produced is 167.1 cc, the change in internal energy of the sample, is
(a) 104.3 J (b) 208.7 J (c) 42.2 J (d) 84.5 J

10. Two wires are made of the same material and have the same volume. The first wire has cross-sectional area $A$ and the second wire has cross-sectional area $3A$. If the length of the first wire is increased by $\Delta l$ on applying a force $F$, how much force is needed to stretch the second wire by the same amount?

(a) $9F$ (b) $6F$ (c) $4F$ (d) $F$

11. The power radiated by a black body is $P$ and it radiates maximum energy at wavelength, $\lambda_0$. If the temperature of the black body is now changed so that it radiates maximum energy at wavelength $\frac{3}{4} \lambda_0$, the power radiated by it becomes $nP$. The value of $n$ is
(a) $\frac{3}{4}$ (b) $\frac{4}{3}$ (c) $\frac{256}{81}$ (d) $\frac{81}{256}$

12. A set of $n$ equal resistors, of value $R$ each, are connected in series to a battery of emf $E$ and internal resistance $R$. The current drawn is $I$. Now, the $n$ resistors are connected in parallel to the same battery. Then the current drawn from battery becomes $10I$. The value of $n$ is
(a) 10 (b) 11 (c) 20 (d) 9

13. A battery consists of a variable number $n$ of identical cells (having internal resistance $r$ each) which are connected in series. The terminals of the battery are short-circuited and the current $I$ is measured. Which of the graphs shows the correct relationship between $I$ and $n$?

(a) \[ \text{Graph A} \] (b) \[ \text{Graph B} \]
(c) \[ \text{Graph C} \] (d) \[ \text{Graph D} \]

14. A carbon resistor of $(47 \pm 4.7)$ k$\Omega$ is to be marked with rings of different colours for its identification. The colour code sequence will be
(a) Violet – Yellow – Orange – Silver
(b) Yellow – Violet – Orange – Silver
(c) Yellow – Green – Violet – Gold
(d) Green – Orange – Violet – Gold

15. Which one of the following statements is incorrect?
(a) Rolling friction is smaller than sliding friction.
(b) Limiting value of static friction is directly proportional to normal reaction.
(c) Frictional force opposes the relative motion.
(d) Coefficient of sliding friction has dimensions of length.
16. A moving block having mass \( m \), collides with another stationary block having mass \( 4m \). The lighter block comes to rest after collision. When the initial velocity of the lighter block is \( v \), then the value of coefficient of restitution \( (e) \) will be
(a) 0.5  
(b) 0.25  
(c) 0.8  
(d) 0.4

17. A body initially at rest and sliding along a frictionless track from a height \( h \) (as shown in the figure) just completes a vertical circle of diameter \( AB = D \). The height \( h \) is equal to

![Diagram](image)

(a) \( \frac{3}{2} D \)  
(b) \( D \)  
(c) \( \frac{7}{5} D \)  
(d) \( \frac{5}{4} D \)

18. Three objects, \( A \) : (a solid sphere), \( B \) : (a thin circular disk) and \( C \) : (a circular ring), each have the same mass \( M \) and radius \( R \). They all spin with the same angular speed \( \omega \) about their own symmetry axes. The amounts of work \( (W) \) required to bring them to rest, would satisfy the relation
(a) \( W_C > W_B > W_A \)  
(b) \( W_A > W_B > W_C \)  
(c) \( W_B > W_A > W_C \)  
(d) \( W_A > W_C > W_B \)

19. A tuning fork is used to produce resonance in a glass tube. The length of the air column in this tube can be adjusted by a variable piston. At room temperature of \( 27^\circ \text{C} \), two successive resonances are produced at 20 cm and 73 cm of column length. If the frequency of the tuning fork is 320 Hz, the velocity of sound in air at \( 27^\circ \text{C} \) is
(a) \( 330 \text{ m s}^{-1} \)  
(b) \( 339 \text{ m s}^{-1} \)  
(c) \( 350 \text{ m s}^{-1} \)  
(d) \( 300 \text{ m s}^{-1} \)

20. An electron falls from rest through a vertical distance \( h \) in a uniform and vertically upward directed electric field \( E \). The direction of electric field is now reversed, keeping its magnitude the same. A proton is allowed to fall from rest in it through the same vertical distance \( h \). The time of fall of the electron, in comparison to the time of fall of the proton is
(a) smaller  
(b) 5 times greater  
(c) 10 times greater  
(d) equal

21. A pendulum is hung from the roof of a sufficiently high building and is moving freely to and fro like a simple harmonic oscillator. The acceleration of the bob of the pendulum is 20 m s\(^{-2}\) at a distance of 5 m from the mean position. The time period of oscillation is
(a) \( 2\pi \text{ s} \)  
(b) \( \pi \text{ s} \)  
(c) \( 2 \text{ s} \)  
(d) \( 1 \text{ s} \)

22. The electrostatic force between the metal plates of an isolated parallel plate capacitor \( C \) having a charge \( Q \) and area \( A \), is
(a) Independent of the distance between the plates  
(b) Linearly proportional to the distance between the plates  
(c) Proportional to the square root of the distance between the plates  
(d) Inversely proportional to the distance between the plates

23. An electron of mass \( m \) with an initial velocity \( \vec{v} = v_0 \hat{i} \) \( (v_0 > 0) \) enters an electric field \( \vec{E} = -E_0 \hat{j} \) \( (E_0 \text{ constant} > 0) \) at \( t = 0 \). If \( \lambda_0 \) is its de-Broglie wavelength initially, then its de-Broglie wavelength at time \( t \) is
(a) \( \frac{\lambda_0}{1 + \frac{eE_0}{mv_0} t} \)  
(b) \( \lambda_0 \left(1 + \frac{eE_0}{mv_0} t\right) \)  
(c) \( \lambda_0 t \)  
(d) \( \lambda_0 \)

24. For a radioactive material, half-life is 10 minutes. If initially there are 600 number of nuclei, the time taken (in minutes) for the disintegration of 450 nuclei is
(a) 20  
(b) 10  
(c) 30  
(d) 15

25. When the light of frequency \( 2v_0 \) (where \( v_0 \) is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is \( v_1 \). When the frequency of the incident radiation is increased to \( 5v_0 \), the maximum velocity of electrons emitted from the same plate is \( v_2 \). The ratio of \( v_1 \) to \( v_2 \) is
(a) 1 : 2  
(b) 1 : 4  
(c) 4 : 1  
(d) 2 : 1

26. The ratio of kinetic energy to the total energy of an electron in a Bohr orbit of the hydrogen atom, is
(a) 1 : 1  
(b) 1 : -1  
(c) 2 : -1  
(d) 1 : -2

27. The moment of the force, \( \vec{F} = 4\hat{i} + 5\hat{j} - 6\hat{k} \) at \( (2, 0, -3) \), about the point \( (2, -2, -2) \), is given by
(a) \( -8\hat{i} - 4\hat{j} - 7\hat{k} \)  
(b) \( -4\hat{i} - 7\hat{j} - 8\hat{k} \)  
(c) \( -7\hat{i} - 8\hat{j} - 4\hat{k} \)  
(d) \( -7\hat{i} - 4\hat{j} - 8\hat{k} \)
28. A block of mass $m$ is placed on a smooth inclined wedge $ABC$ of inclination $\theta$ as shown in the figure. The wedge is given an acceleration $a$ towards the right. The relation between $a$ and $\theta$ for the block to remain stationary on the wedge is

(a) $a = \frac{g}{\cos \theta}$  
(b) $a = \frac{g}{\sin \theta}$  
(c) $a = g \cos \theta$  
(d) $a = g \tan \theta$

29. A toy car with charge $q$ moves on a frictionless horizontal plane surface under the influence of a uniform electric field $\vec{E}$. Due to the force $q \vec{E}$, its velocity increases from 0 to 6 m s$^{-1}$ in one second duration. At that instant the direction of the field is reversed. The car continues to move for two more seconds under the influence of this field. The average velocity and the average speed of the toy car between 0 to 3 seconds are respectively

(a) 2 ms$^{-1}$, 4 ms$^{-1}$  
(b) 1 ms$^{-1}$, 3 ms$^{-1}$  
(c) 1 ms$^{-1}$, 3.5 ms$^{-1}$  
(d) 1.5 ms$^{-1}$, 3 ms$^{-1}$

30. A student measured the diameter of a small steel ball using a screw gauge of least count 0.001 cm. The main scale reading is 5 mm and zero of circular scale division coincides with 25 divisions above the reference level. If screw gauge has a zero error of -0.004 cm, the correct diameter of the ball is

(a) 0.521 cm  
(b) 0.525 cm  
(c) 0.503 cm  
(d) 0.529 cm

31. Unpolarised light is incident from air on a plane surface of a material of refractive index $\mu$. At a particular angle of incidence $i$, it is found that the reflected and refracted rays are perpendicular to each other. Which of the following options is correct for this situation?

(a) Reflected light is polarised with its electric vector parallel to the plane of incidence  
(b) Reflected light is polarised with its electric vector perpendicular to the plane of incidence  
(c) $i = \sin^{-1} \left( \frac{1}{\mu} \right)$  
(d) $i = \tan^{-1} \left( \frac{1}{\mu} \right)$

32. In Young’s double slit experiment the separation $d$ between the slits is 2 mm, the wavelength $\lambda$ of the light used is 5896 Å and distance $D$ between the screen and slits is 100 cm. It is found that the angular width of the fringes is 0.20°. To increase the fringe angular width to 0.21° (with same $\lambda$ and $D$) the separation between the slits needs to be changed to

(a) 1.8 mm  
(b) 1.9 mm  
(c) 2.1 mm  
(d) 1.7 mm

33. An astronomical refracting telescope will have large angular magnification and high angular resolution, when it has an objective lens of

(a) small focal length and large diameter  
(b) large focal length and small diameter  
(c) large focal length and large diameter  
(d) small focal length and small diameter

34. The volume ($V$) of a monatomic gas varies with its temperature ($T$), as shown in the graph. The ratio of work done by the gas, to the heat absorbed by it, when it undergoes a change from state $A$ to state $B$, is

(a) $\frac{2}{5}$  
(b) $\frac{2}{3}$  
(c) $\frac{1}{3}$  
(d) $\frac{2}{7}$

35. The fundamental frequency in an open organ pipe is equal to the third harmonic of a closed organ pipe. If the length of the closed organ pipe is 20 cm, the length of the open organ pipe is

(a) 13.2 cm  
(b) 8 cm  
(c) 12.5 cm  
(d) 16 cm

36. The efficiency of an ideal heat engine working between the freezing point and boiling point of water, is

(a) 26.8%  
(b) 20%  
(c) 6.25%  
(d) 12.5%

37. At what temperature will the rms speed of oxygen molecules become just sufficient for escaping from the Earth’s atmosphere? (Given : Mass of oxygen molecule $(m) = 2.76 \times 10^{-26}$ kg, Boltzmann’s constant $k_B = 1.38 \times 10^{-23}$ J K$^{-1}$)

(a) $2.508 \times 10^4$ K  
(b) $8.360 \times 10^4$ K  
(c) $5.016 \times 10^4$ K  
(d) $1.254 \times 10^5$ K

38. A metallic rod of mass per unit length 0.5 kg m$^{-1}$ is lying horizontally on a smooth inclined plane which makes an angle of 30° with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25 T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is

(a) 7.14 A  
(b) 5.98 A  
(c) 14.76 A  
(d) 11.32 A

39. An inductor 20 mH, a capacitor 100 µF and a resistor 50 Ω are connected in series across a source of emf,
40. A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from
(a) The current source
(b) The magnetic field
(c) The lattice structure of the material of the rod
(d) The induced electric field due to the changing magnetic field

41. Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is
(a) 40 Ω (b) 25 Ω (c) 250 Ω (d) 500 Ω

42. If the mass of the Sun were ten times smaller and the universal gravitational constant were ten times larger in magnitude, which of the following is not correct?
(a) Raindrops will fall faster.
(b) Walking on the ground would become more difficult.
(c) Time period of a simple pendulum on the Earth would decrease.
(d) $g$ on the Earth will not change.

43. A solid sphere is in rolling motion. In rolling motion a body possesses translational kinetic energy ($K_t$) as well as rotational kinetic energy ($K_r$) simultaneously. The ratio $K_i : (K_t + K_r)$ for the sphere is
(a) 7 : 10 (b) 5 : 7 (c) 10 : 7 (d) 2 : 5

44. The kinetic energies of a planet in an elliptical orbit about the Sun, at positions $A$, $B$ and $C$ are $K_A$, $K_B$ and $K_C$ respectively. $AC$ is the major axis and SB is perpendicular to $AC$ at the position of the Sun $S$ as shown in the figure. Then
(a) $K_A < K_B < K_C$ (b) $K_A > K_B > K_C$
(c) $K_B < K_A < K_C$ (d) $K_B > K_A > K_C$

45. A solid sphere is rotating freely about its symmetry axis in free space. The radius of the sphere is increased keeping its mass same. Which of the following physical quantities would remain constant for the sphere?
(a) Angular velocity
(b) Moment of inertia
(c) Rotational kinetic energy
(d) Angular momentum

**SOLUTIONS**

1. (b) : Velocity of em wave in a medium is given by $\vec{v} = \vec{E} \times \vec{B}$
   $\therefore \quad \vec{v}i = (Ej) \times (Bk)$
   $\therefore \quad \vec{E} = Ej \text{ (Given)}$
   As $\hat{i} \times \hat{j} = \hat{k}$, so $\vec{B} = \hat{B}k$
   Direction of oscillating magnetic field of the em wave will be along +z direction.

2. (b) : For retracing the path shown in figure, light ray should be incident normally on the silvered face.
   Applying Snell's law at point $M$,
   $\frac{\sin i}{\sin 30°} = \frac{\sqrt{2}}{\frac{1}{2}} \Rightarrow \sin i = \sqrt{2} \times \frac{1}{2}$
   $\sin i = \frac{1}{\sqrt{2}} \Rightarrow i = 45°$.

3. (d) : Magnetic potential energy stored in an inductor is given by
   $U = \frac{1}{2} LI^2 \Rightarrow 25 \times 10^{-3} = \frac{1}{2} \times L \times (60 \times 10^{-3})^2$
   $L = \frac{25 \times 2 \times 10^6 \times 10^{-3}}{3600} = \frac{500}{36} = 13.89 \text{ H}$

4. (b) : Using mirror formula,
   $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
   $\frac{1}{15} = \frac{1}{-15} + \frac{1}{40} \Rightarrow \frac{1}{v} = \frac{1}{-15} + \frac{1}{40}$
   $v = -24 \text{ cm}$
   When object is displaced by 20 cm towards mirror.
   Now, $u_2 = -20 \text{ cm}$
   $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
   $\frac{1}{15} = \frac{1}{-15} + \frac{1}{20} \Rightarrow \frac{1}{v} = \frac{1}{20} - \frac{1}{15}$
   $v_2 = -60 \text{ cm}$
   So, the image will be shift away from mirror by $(60 - 24) \text{ cm} = 36 \text{ cm}$.
5. (b): $Y = (A \cdot \vec{B} + \vec{A} \cdot B)$

6. (d): Given $V_{RE} = 0$, $V_{CE} = 0$

7. (d): Due to heating, number of electron-hole pairs will increase, so overall resistance of diode will change. Due to which forward biasing and reversed biasing both are changed.

8. (c): The viscous drag force, $F = 6\pi \eta rv$; where $v$ = terminal velocity

9. (b): Using first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$

10. (a): Young’s modulus, $Y = \frac{FL}{A\Delta l}$

Since initial volume of wires are same

\[\because\] Their areas of cross sections are $A$ and $3A$ and lengths are $3l$ and $l$ respectively.

For wire 1,

\[\Delta l = \frac{F}{AY} 3l \quad \ldots(i)\]

For wire 2, let $F'$ force is applied

\[\frac{F'}{3A} = Y \frac{\Delta l}{l} \Rightarrow \Delta l = \frac{F'}{3AY} l \quad \ldots(ii)\]

From equations (i) and (ii)

\[\left(\frac{F}{AY}\right) 3l = \left(\frac{F'}{3AY}\right) l \Rightarrow F' = 9F\]

11. (c): From Wien’s law, $\lambda_{max}T = \text{constant}$

So, $\lambda_{max}, T_1 = \lambda_{max}, T_2$

\[\Rightarrow \lambda_{eq}T = \frac{3\lambda_{max}}{4} \Rightarrow T' = \frac{4}{3} \quad \ldots(i)\]

According to Stefan-Boltzmann law, energy emitted unit time by a black body is $\alpha e\sigma T^4$, i.e., power radiated.

\[P \propto T^4\]

So,

\[\frac{P_1}{P_2} = \left(\frac{T'}{T}\right)^4 \Rightarrow n = \left(\frac{4}{3}\right)^4 = \frac{256}{81}\]

12. (a): Current drawn from a battery when $n$ resistors are connected in series is

\[I = \frac{E}{nR + R} \quad \ldots(i)\]

Current drawn from same battery when $n$ resistors are connected in parallel is

\[10I = \frac{E}{R + nR} \quad \ldots(ii)\]

On dividing eqn. (ii) by (i), $10 = \frac{(n+1)R}{n(1+R)}$

After solving the equation, $n = 10$.

13. (a): Current drawn from the cell is

\[I = \frac{nI}{nR} \quad \because\] $I$ is independent of $n$ and $I$ is constant.

14. (b): $\{47 \pm 4.7\} k\Omega = 47 \times 10^3 \pm 10\% \Omega$

\[\because\] Yellow – Violet – Orange – Silver

15. (d): Coefficient of sliding friction has no dimension.

\[f = \mu_sN \Rightarrow \mu_s = \frac{f}{N}\]
16. (b): Let final velocity of the block of mass $4 \text{ m} = v'$
Initial velocity of block of mass $4 \text{ m} = 0$
Final velocity of block of mass $m = 0$
According to law of conservation of linear momentum,
\[ mv' + 4m \times 0 = 4mv' + 0 \]
\[ v' = \frac{v}{4} \]

Coefficient of restitution,
\[ e = \frac{\text{Relative velocity of separation}}{\text{Relative velocity of approach}} = \frac{v/4}{v} = 0.25 \]

17. (d):

As body is at rest initially, i.e., speed = 0.
At point A, speed = v.
As track is frictionless, so total mechanical energy will remain constant.
\[ \text{(T.M.E)}_{i} = \text{(T.M.E)}_{f} \]
\[ 0 + mgh = \frac{1}{2}mv^2 + 0 \quad \text{or} \quad h = \frac{v^2}{2g} \]
For completing the vertical circle, \( v \geq \sqrt{5gR} \)
\[ h = \frac{5gR}{2} \quad \text{or} \quad R = \frac{5}{4}D \]

18. (a): Work done required to bring a object to rest \( \Delta W = \Delta KE \)
\[ \Delta W = \frac{1}{2}I\omega^2 \quad \text{where} \quad I = \text{moment of inertia} \]
For same \( \omega \), \( \Delta W \propto I \)
For a solid sphere, \( I_A = \frac{2}{5}MR^2 \)
For a thin circular disk, \( I_B = \frac{1}{2}MR^2 \)
For a circular ring, \( I_C = MR^2 \)
\[ \therefore I_C > I_B > I_A \]
\[ \therefore W_C > W_B > W_A \]

19. (b): The velocity of sound in air at 27°C is \( v = 2\sqrt{u} [L_2 - L_1] \); where \( u \) = frequency of tuning fork and \( L_1, L_2 \) are the successive column length.
\[ v = 2 \times 320[73 - 20] \times 10^{-2} \]
\[ = 339.2 \text{ m s}^{-1} = 339 \text{ m s}^{-1}. \]

20. (a): Force experienced by a charged particle in an electric field, \( F = qE \)
As \( F = ma \)
\[ ma = qE \Rightarrow a = \frac{qE}{m} \]

As electron and proton both fall from same height at rest. Then initial velocity = 0
From \( s = ut + \frac{1}{2}at^2 \)
\[ \therefore \quad h = \frac{1}{2}at^2 \quad \Rightarrow \quad h = \frac{1}{2} \frac{qE}{m} t^2 \quad \text{[Using (i)]} \]
\[ \therefore \quad t = \sqrt{\frac{2hm}{qE}} \quad \Rightarrow \quad t \propto \sqrt{m} \quad \text{as ‘q’ is same for electron and proton.} \]
\( \therefore \quad \text{Electron has smaller mass so it will take smaller time.} \)

21. (b): Magnitude of acceleration of a particle moving in a SHM is
\[ |a| = \omega^2 y; \text{where} \quad y \text{ is amplitude.} \]
\[ \Rightarrow \quad 20 = \omega^2(5) \quad \Rightarrow \quad \omega = 2 \text{ rad s}^{-1} \]
\[ \therefore \quad \text{Time period of oscillation} \quad T = \frac{2\pi}{\omega} = \frac{2\pi}{2} = \pi \text{ s} \]

22. (a): For isolated capacitor, charge \( Q \) = constant.
\[ \therefore \quad \text{Electrostatic force,} \quad F_{\text{plate}} = \frac{Q^2}{2\varepsilon_0} \]
\( F \) is independent of the distance between plates.

23. (a): Here, \( \vec{E} = -E_0 \hat{i} \); initial velocity \( \vec{v} = v_0 \hat{i} \)
Force action on electron due to electric field
\[ \vec{F} = -e(-E_0 \hat{i}) = eE_0 \hat{i} \]
Acceleration produced in the electron, \( \vec{a} = \frac{eE_0}{m} \hat{i} \)
Now, velocity of electron after time \( t \),
\[ \vec{v}_t = \vec{v} + \vec{a} \cdot t = \left(v_0 + \frac{eE_0 t}{m} \hat{i}\right) \quad \text{or} \quad |\vec{v}_t| = v_0 + \frac{eE_0 t}{m} \]
Now, \( \lambda_t = \frac{h}{mv_t} = \frac{h}{m \left(v_0 + \frac{eE_0 t}{m} \right)} = \frac{h}{mv_0 \left(1 + \frac{eE_0 t}{mv_0} \right)} \quad \text{[\( \lambda_0 = \frac{h}{mv_0} \)]} \]

24. (a): Number of nuclei remaining
\[ N = 600 - 450 = 150 \]
According to the law of radioactive decay,
\[ \frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} \quad \text{where} \quad N_0 \text{ is the number of nuclei initially.} \]
\[ \therefore \quad \frac{150}{600} = \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} \quad \text{where} \quad T_{1/2} = \text{half life.} \]

or \( \left(\frac{1}{2}\right)^2 = \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} \quad \Rightarrow \quad t = 2T_{1/2} = 2 \times 10 \text{ minutes} = 20 \text{ minutes} \)
25. (a): According to the Einstein’s photoelectric equation,  
\[ E = W_0 + \frac{1}{2}mv^2 \]
When frequency of incident light is \(2\nu_0\),
\[ h(2\nu_0) = h\nu_0 + \frac{1}{2}mv_1^2 \quad \Rightarrow \quad h\nu_0 = \frac{1}{2}mv_1^2 \quad \text{(i)} \]
When frequency of incident light is \(5\nu_0\),
\[ h(5\nu_0) = h\nu_0 + \frac{1}{2}mv_2^2 \quad \Rightarrow \quad 4h\nu_0 = \frac{1}{2}mv_2^2 \quad \text{(ii)} \]
Dividing (i) by (ii),
\[ \frac{1}{4} = \frac{v_2^2}{v_1^2} \quad \text{or} \quad \frac{v_1}{v_2} = \frac{1}{2} \]

26. (b): In a Bohr orbit of the hydrogen atom,  
Kinetic energy = -(Total energy)  
So, Kinetic energy : Total energy = 1 : -1  

27. (d):  
Moment of the force is,  
\[ \vec{r} = (\vec{r} - \vec{r}_0) \times \vec{F} \]
Here, \(\vec{r}_0 = 2\hat{i} - 2\hat{j} - 2\hat{k} \) and \(\vec{r} = 2\hat{i} + 0\hat{j} - 3\hat{k} \)
\[ \Rightarrow \vec{r} - \vec{r}_0 = (2\hat{i} + 0\hat{j} - 3\hat{k}) - (2\hat{i} - 2\hat{j} - 2\hat{k}) = 0\hat{i} + 2\hat{j} - \hat{k} \]
\[ \therefore \vec{r} = 0 \quad \begin{array}{ccc} 2 & -1 & -3 \\ 4 & 5 & -6 \end{array} \]
\[ \Rightarrow \vec{a} = -7\hat{i} - 4\hat{j} - 8\hat{k} \]

28. (d): In non-inertial frame,  
\[ N \sin\theta = ma \quad \text{(i)} \]
\[ N \cos\theta = mg \quad \text{(ii)} \]
From (i) and (ii),
\[ \tan\theta = \frac{a}{g} \]
\[ a = g \tan\theta. \]

29. (b):  
\[ t = 0 \quad \begin{array}{c} \rightarrow \end{array} \quad t = 1 \quad \begin{array}{c} \rightarrow \end{array} \quad t = 2 \quad \begin{array}{c} \rightarrow \end{array} \]
\[ v = 0 \quad \begin{array}{c} \rightarrow \end{array} \quad v = \frac{5}{2} \quad \begin{array}{c} \rightarrow \end{array} \quad v = 0 \]
\[ C = 3 \quad \begin{array}{c} \rightarrow \end{array} \quad v = -6 \quad \begin{array}{c} \rightarrow \end{array} \quad v = 0 \]

Acceleration \(a = \frac{6 - 0}{1} = 6 \text{ m/s}^2 \)
For \(t = 0\) to \(t = 1\) s,
\[ s_1 = \frac{1}{2} \times 6(1)^2 = 3 \text{ m} \quad \text{(i)} \]
For \(t = 1\) s to \(t = 2\) s,
\[ s_2 = 6 \times 1 - \frac{1}{2} \times 6(1)^2 = 3 \text{ m} \quad \text{(ii)} \]
For \(t = 2\) s to \(t = 3\) s,
\[ s_3 = 0 - \frac{1}{2} \times 6(1)^2 = -3 \text{ m} \quad \text{(iii)} \]
Total displacement \(s = s_1 + s_2 + s_3 = 3 \text{ m} \)
Average velocity = \(\frac{s}{3} = 1 \text{ m/s} \)
Total distance travelled = 9 m
Average speed = \(\frac{9}{3} = 3 \text{ m/s} \)

30. (d): Diameter of the ball
\[ = \text{MSR} + \text{CSR} \times (\text{Least count}) - \text{Zero error} \]
\[ = 5 \text{ mm} + 25 \times 0.001 \text{ cm} - (-0.004) \text{ cm} \]
\[ = 0.5 \text{ cm} + 25 \times 0.001 \text{ cm} - (-0.004) \text{ cm} = 0.529 \text{ cm}. \]

31. (b): When reflected light and refracted light are perpendicular, reflected light is polarised with electric field vector perpendicular to the plane of incidence.
Also, \(\tan i = \mu\) (Brewster angle)

32. (b): Angular width \(\frac{\lambda}{d} \quad \text{(i)} \)
\[ 0.20^\circ = \frac{\lambda}{2 \text{ mm}} \quad \text{(i)} \]
\[ 0.21^\circ = \frac{\lambda}{d} \quad \text{(ii)} \]
Dividing we get, \[ \frac{0.20}{0.21} = \frac{d}{2 \text{ mm}} \]
\[ \therefore d = 1.9 \text{ mm}. \]

33. (c): For telescope, angular magnification \[ \frac{f_o}{f_e} \]
Angular resolution \[ = \frac{D}{1.22 \lambda} \]
should be large.
So, objective lens should have large focal length \(f_o\) and large diameter \(D\) for large angular magnification and high angular resolution.

34. (a): Given process is isobaric.
\[ dQ = nC_pdT \]
where \(C_p\) is specific heat at constant pressure.
\[ \text{or} \quad dQ = n\left(\frac{5}{2}R\right)dT \]
Also, \[ dW = PdV = nRdT \quad (\therefore PV = nRT) \]
Required ratio \[ \frac{dW}{dQ} = \frac{nRdT}{n\left(\frac{5}{2}R\right)dT} = \frac{2}{5} \]

35. (a): For closed organ pipe, third harmonic is \[ \frac{3\nu}{4l} \]
For open organ pipe, fundamental frequency is \[ \frac{\nu}{2l} \]
Given, third harmonic for closed organ pipe
\[ = \text{fundamental frequency for open organ pipe.} \]
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\[ \frac{3v}{4l} = \frac{v}{2l'} \Rightarrow l' = \frac{4l}{3 \times 2} = \frac{2l}{3} \]

where \( l \) and \( l' \) are the lengths of closed and open organ pipes respectively.

\[ l' = \frac{2 \times 20}{3} = 13.33 \text{ cm} \]

36. (a): Efficiency of an ideal heat engine,
\[ \eta = \left( 1 - \frac{T_2}{T_1} \right) \]
Freezing point of water = 0°C = 273 K
Boiling point of water = 100°C = (100 + 273)K = 373 K
\( T_2 \): Sink temperature = 273 K
\( T_1 \): Source temperature = 373 K
\[ \% \eta = \left( 1 - \frac{T_2}{T_1} \right) \times 100 = \left( 1 - \frac{273}{373} \right) \times 100 \]
\[ = \left( \frac{100}{373} \right) \times 100 = 26.8\% \]

37. (b): Escape velocity from the Earth’s surface is \( v_{\text{escape}} = 11200 \text{ m s}^{-1} \)
Say at temperature \( T \), oxygen molecule attains escape velocity.
So, \[ v_{\text{escape}} = \frac{3k_B T}{m_{\text{O}_2}} \Rightarrow 11200 = \frac{3 \times 1.38 \times 10^{-23} \times T}{2.76 \times 10^{-26}} \]
On solving, \( T = 8.360 \times 10^4 \) K.

38. (d): Mass per unit length of a metallic rod is
\[ \frac{m}{l} = 0.5 \text{ kg m}^{-1} \]
Let \( I \) be the current flowing.
For equilibrium,
\[ mg \sin 30^\circ = IIB \cos 30^\circ \]
\[ I = \frac{mg \tan 30^\circ}{I B} = \frac{0.5 \times 9.8}{0.25 \times \sqrt{3}} = 11.32 \text{ A} \]

39. (a): Impedance \( Z \) in an ac circuit is
\[ Z = \sqrt{R^2 + (X_C - X_L)^2} \text{ where } X_C = \text{capacitive reactance and } X_L = \text{inductive reactance.} \]
Also \( X_C = \frac{1}{\omega C} \) and \( X_L = \omega L \)
\[ \therefore Z = \sqrt{(50)^2 + \left( \frac{1}{314 \times 100 \times 10^{-6}} - 314 \times 20 \times 10^{-3} \right)^2} \]
or \[ Z = 56 \Omega \]
The power loss in the circuit is \[ P_{av} = \left( \frac{V_{rms}}{Z} \right)^2 R \]

40. (a): Energy of current source will be converted into gravitational potential energy of the rod.

41. (c): Let \( N \) = number of turns in galvanometer
\( A = \text{Area, } B = \text{magnetic field} \)
\( k = \text{the restoring torque per unit twist.} \)
Current sensitivity, \( I_S = \frac{NB A}{k} \)
Voltage sensitivity, \( V_S = \frac{NB A}{kR_G} \)
So, resistance of galvanometer
\[ R_G = \frac{I_S}{V_S} = \frac{5 \times 1}{20 \times 10^{-3}} = \frac{5000}{20} = 250 \Omega \]

42. (d): If universal Gravitational constant becomes ten times, then \( G' = 10G \).
So, acceleration due to gravity increases.
\( i.e., \) (d) is wrong option.

43. (b): Translational kinetic energy, \( K_t = \frac{1}{2} m v^2 \)
Rotational kinetic energy \( K_r = \frac{1}{2} I \omega^2 \)
\[ \therefore K_t + K_r = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2 = \frac{1}{2} m v^2 + \frac{1}{2} \left( \frac{2}{5} m r^2 \right) \left( \frac{v}{r} \right)^2 \]
\[ \therefore K_t + K_r = \frac{7}{10} m v^2 \text{ [\( \therefore I = \frac{2}{5} m r^2 \text{ (for sphere)} \) ]} \]

44. (b): Point A is perihelion and C is aphelion.
So, \( v_A > v_B > v_C \)
As kinetic energy \( k = 1/2 m v^2 \) or \( k \propto v^2 \)
So, \( K_A > K_B > K_C \).

45. (d): As there is no external torque acting on a sphere, \( i.e., \) \( \tau_{ex} = 0 \)
So, \( \frac{dL}{dt} = \tau_{ex} = 0 \)
\( i.e., \) \( L = \text{constant} \)
So angular momentum remains constant.
1. In a screw gauge, 5 complete rotations of the screw cause it to move a linear distance of 0.25 cm. There are 100 circular scale divisions. The thickness of a wire measured by this screw gauge gives a reading of 4 main scale divisions and 30 circular scale divisions. Assuming negligible zero error, the thickness of the wire is
   (a) 0.3150 cm  (b) 0.2150 cm  (c) 0.4300 cm  (d) 0.0430 cm

2. A body of mass $m$ is moving in a circular orbit of radius $R$ about a planet of mass $M$. At some instant, it splits into two equal masses. The first mass moves in a circular orbit of radius $\frac{R}{2}$, and the other mass, in a circular orbit of radius $\frac{3R}{2}$. The difference between the final and initial total energies is
   (a) $+\frac{GMm}{6R}$  (b) $\frac{GMm}{2R}$  (c) $-\frac{GMm}{2R}$  (d) $-\frac{GMm}{6R}$

3. In a meter bridge, as shown in the figure, it is given that resistance $Y = 12.5 \ \Omega$ and that the balance is obtained at a distance $39.5 \ \text{cm}$ from end $A$ (by jockey $J$). After interchanging the resistances $X$ and $Y$, a new balance point is found at a distance $l_2$ from end $A$. What are the values of $X$ and $l_2$?
   (a) 19.15 $\Omega$ and 60.5 cm  (b) 8.16 $\Omega$ and 60.5 cm  (c) 8.16 $\Omega$ and 39.5 cm  (d) 19.15 $\Omega$ and 39.5 cm

4. The number of amplitude modulated broadcast stations that can be accommodated in a 300 kHz band width for the highest modulating frequency 15 kHz will be
   (a) 20  (b) 10  (c) 8  (d) 15

5. A force of 40 N acts on a point $B$ at the end of an $L$-shaped object, as shown in the figure. The angle $\theta$ that will produce maximum moment of the force about point $A$ is given by
   (a) $\tan \theta = \frac{1}{2}$  (b) $\tan \theta = 4$  (c) $\tan \theta = 2$  (d) $\tan \theta = \frac{1}{4}$

6. The velocity-time graphs of a car and a scooter are shown in the figure. (i) The difference between the distance travelled by the car and the scooter in 15 s and (ii) the time at which the car will catch up with the scooter are, respectively.
7. A body of mass \( M \) and charge \( q \) is connected to a spring of spring constant \( k \). It is oscillating along the \( x \)-direction about its equilibrium position, taken to be at \( x = 0 \), with an amplitude \( A \). An electric field \( E \) is applied along the \( x \)-direction. Which of the following statements is correct?
   (a) The total energy of the system is
   \[
   \frac{1}{2} m_0 \omega^2 A^2 + \frac{1}{2} \frac{q^2 E^2}{k}
   \]
   (b) The new equilibrium position is at a distance \( \frac{2qE}{k} \) from \( x = 0 \).
   (c) The new equilibrium position is at a distance \( \frac{qE}{2k} \) from \( x = 0 \).
   (d) The total energy of the system is
   \[
   \frac{1}{2} m_0 \omega^2 A^2 + \frac{1}{2} \frac{q^2 E^2}{2k}
   \]

8. An automobile, travelling at 40 km h\(^{-1} \), can be stopped at a distance of 40 m by applying brakes. If the same automobile is travelling at 80 km h\(^{-1} \), the minimum stopping distance, in metres, is (assume no skidding)
   (a) 100 m  (b) 75 m  (c) 160 m  (d) 150 m

9. A charge \( Q \) is placed at a distance \( a/2 \) above the centre of the square surface of edge \( a \) as shown in the figure. The electric flux through the square surface is
   (a) \( \frac{Q}{3 \varepsilon_0} \)  (b) \( \frac{Q}{6 \varepsilon_0} \)  (c) \( \frac{Q}{2 \varepsilon_0} \)  (d) \( \frac{Q}{2 \varepsilon_0} \)

10. A uniform rod \( AB \) is of variable distance \( x \) from \( A \), as shown. To make the rod horizontal, a mass \( m \) is suspended from its end \( A \). A set of \( (m, x) \) values is recorded. The appropriate variables that give a straight line, when plotted, are
   (a) \( m, \frac{1}{x^2} \)  (b) \( m, x^2 \)  (c) \( m, x \)  (d) \( m, \frac{1}{x} \)

11. In the given circuit all resistances are of value \( R \) ohm each. The equivalent resistance between \( A \) and \( B \) is
   (a) \( 2R \)  (b) \( \frac{5R}{2} \)  (c) \( 3R \)  (d) \( \frac{5R}{3} \)

12. A solution containing active cobalt \( ^{60}\text{Co} \) having activity of 0.8 \( \mu \text{Ci} \) and decay constant \( \lambda \) is injected in an animal's body. If 1 cm\(^3 \) of blood is drawn from the animal's body after 10 hrs of injection, the activity found was 300 decays per minute. What is the volume of blood that is flowing in the body?

   \( \text{(1 Ci} = 3.7 \times 10^{10} \text{ decays per second and at} \ t = 10 \text{ hrs} \ e^{-\lambda t} = 0.84) \)
   (a) 4 litres  (b) 7 litres  (c) 5 litres  (d) 6 litres

13. One mole of an ideal monoatomic gas is compressed isothermally in a rigid vessel to double its pressure at room temperature, 27°C. The work done on the gas will be
   (a) 300 \( R \)  (b) 300 \( R \ln 2 \)  (c) 300 \( R \ln 6 \)  (d) 300 \( R \ln 7 \)

14. A monochromatic beam of light has a frequency \( \nu = \frac{3}{2\pi} \times 10^{12} \text{ Hz} \) and is propagating along the direction \( \hat{i} + \hat{j} \). It is polarized along the \( \hat{k} \) direction.

   The acceptable form for the magnetic field is
   (a) \( \frac{E_0}{C} \left( \hat{i} + \hat{j} + \hat{k} \right) \cos \left[ 10^4 \left( \frac{\hat{i} + \hat{j}}{\sqrt{2}} \right) \cdot \tau + (3 \times 10^{12}) \tau \right] \)
   (b) \( \frac{E_0}{C} \left( \hat{i} - \hat{j} \right) \cos \left[ 10^4 \left( \frac{\hat{i} + \hat{j}}{\sqrt{2}} \right) \cdot \tau - (3 \times 10^{12}) \tau \right] \)
   (c) \( \frac{E_0}{C} \left( \hat{i} - \hat{j} \right) \cos \left[ 10^4 \left( \frac{\hat{i} - \hat{j}}{\sqrt{2}} \right) \cdot \tau - (3 \times 10^{12}) \tau \right] \)
   (d) \( \frac{E_0}{C} \cos \left[ 10^4 \left( \frac{\hat{i} + \hat{j}}{\sqrt{2}} \right) \cdot \tau + (3 \times 10^{14}) \tau \right] \)
15. Take the mean distance of the moon and the sun from the earth to be \(0.4 \times 10^8\) km and \(150 \times 10^9\) km respectively. Their masses are \(8 \times 10^{22}\) kg and \(2 \times 10^{30}\) kg respectively. The radius of the earth is 6400 km. Let \(\Delta F_1\) be the difference in the forces exerted by the moon at the nearest and farthest points on the earth and \(\Delta F_2\) be the difference in the force exerted by the sun at the nearest and farthest points on the earth. Then, the number closest to \(\frac{\Delta F_1}{\Delta F_2}\) is
(a) 2  (b) 0.6  (c) 6  (d) \(10^{-2}\)

16. The energy required to remove the electron from a singly ionized Helium atom is 2.2 times the energy required to remove an electron from Helium atom. The total energy required to ionize the Helium atom completely is
(a) 34 eV  (b) 79 eV  (c) 20 eV  (d) 109 eV

17. An ideal capacitor of capacitance 0.2 \(\mu F\) is charged to a potential difference of 10 V. The charging battery is then disconnected. The capacitor is then connected to an ideal inductor of self inductance 0.5 mH. The current at a time when the potential difference across the capacitor is 5 V, is
(a) 0.34 A  (b) 0.17 A  (c) 0.25 A  (d) 0.15 A

18. A Carnot's engine works as a refrigerator between 250 K and 300 K. It receives 500 cal heat from the reservoir at the lower temperature. The amount of work done in each cycle to operate the refrigerator is
(a) 2520 J  (b) 772 J  (c) 2100 J  (d) 420 J

19. A particle is oscillating on the x-axis with an amplitude 2 cm about the point \(x_0 = 10\) cm, with a frequency \(\omega\). A concave mirror of focal length 5 cm is placed at the origin (see figure). Identify the correct statements.

![Oscillation Diagram]

(1) The image executes periodic motion.
(2) The image executes non-periodic motion.
(3) The turning points of the image are asymmetric w.r.t. the image of the point at \(x = 10\) cm.
(4) The distance between the turning points of the oscillation of the image is \(\frac{100}{21}\) cm
(a) 2, 4  (b) 2, 3  (c) 1, 3, 4  (d) 1, 4

20. The equivalent capacitance between \(A\) and \(B\) in the circuit given below, is

![Circuit Diagram]

(a) 5.4 \(\mu F\)  (b) 4.9 \(\mu F\)  (c) 3.6 \(\mu F\)  (d) 2.4 \(\mu F\)

21. A Helmholtz coil has a pair of loops, each with \(N\) turns and radius \(R\). They are placed coaxially at distance \(R\) and the same current \(I\) flows through the loops in the same direction. The magnitude of magnetic field at \(P\), midway between the centres \(A\) and \(C\), is given by [Refer to given figure]

![Helmholtz Coil Diagram]

(a) \(\frac{4N\mu_0 I}{5^{3/2}R}\)  (b) \(\frac{4N\mu_0 I}{5^{1/2}R}\)  (c) \(\frac{8N\mu_0 I}{5^{1/2}R}\)  (d) \(\frac{8N\mu_0 I}{5^{3/2}R}\)

22. The relative error in the determination of the surface area of a sphere is \(\alpha\). Then the relative error in the determination of its volume is
(a) \(\frac{3}{2}\alpha\)  (b) \(\alpha\)  (c) \(\frac{5}{2}\alpha\)  (d) \(\frac{2}{3}\alpha\)

23. The \(B-H\) curve for a ferromagnet is shown in the figure. The ferromagnet is placed inside a long solenoid with 1000 turns/cm. The current that should be passed in the solenoid to demagnetise the ferromagnet completely is

![B-H Curve Diagram]

(a) 1 mA  (b) 20 \(\mu A\)  (c) 2 mA  (d) 40 \(\mu A\)

24. Light of wavelength 550 nm falls normally on a slit of width \(2.20 \times 10^{-5}\) cm. The angular position of the second minima from the central maximum will be (in radians)
25. Two electrons are moving with non-relativistic speeds perpendicular to each other. If corresponding de Broglie wavelengths are \( \lambda_1 \) and \( \lambda_2 \), their de Broglie wavelength in the frame of reference attached to their centre of mass is

\[
\lambda_{CM} = \sqrt{\frac{\lambda_1^2 + \lambda_2^2}{2}}
\]

26. A given object takes \( n \) times more time to slide down a 45° rough inclined plane as it takes to slide down a perfectly smooth 45° incline. The coefficient of kinetic friction between the object and the incline is

\[
\frac{1}{\sqrt{1 + \frac{1}{n^2}}} \quad \text{(a)} \quad \frac{1}{1 - \frac{1}{n^2}} \quad \text{(b)} \quad \frac{1}{2 - n^2} \quad \text{(c)} \quad \frac{1}{\sqrt{1 - n^2}} \quad \text{(d)}
\]

27. In a common emitter configuration with suitable bias, it is given that \( R_l \) is the load resistance and \( R_{BE} \) is small signal dynamic resistance (input side). Then, voltage gain, current gain and power gain are given, respectively, by

\[
\beta = \frac{R_l}{R_{BE}}, \quad \beta = \frac{R_{BE}}{R_l}, \quad \beta = \frac{R_l}{R_{BE}}, \quad \beta = \frac{R_{BE}}{R_l}
\]

28. A tuning fork vibrates with frequency 256 Hz and gives one beat per second with the third normal mode of vibration of an open pipe. What is the length of the pipe?

(Speed of sound in air is 340 m s\(^{-1}\))

\[
\begin{align*}
\text{(a)} & \quad 190 \text{ cm} \\
\text{(b)} & \quad 180 \text{ cm} \\
\text{(c)} & \quad 200 \text{ cm} \\
\text{(d)} & \quad 220 \text{ cm}
\end{align*}
\]

29. A thin uniform tube is bent into a circle of radius \( r \) in the vertical plane. Equal volumes of two immiscible liquids, whose densities are \( \rho_1 \) and \( \rho_2 \) (\( \rho_1 > \rho_2 \)), fill half the circle. The angle \( \theta \) between the radius vector passing through the common interface and the vertical is

\[
\theta = \tan^{-1} \left( \frac{\rho_1 + \rho_2}{\rho_1 - \rho_2} \right)
\]

30. A planoconvex lens becomes an optical system of 28 cm focal length when its plane surface is silvered and illuminated from left to right as shown in figure (A). If the same lens is instead silvered on the curved surface and illuminated from other side as shown in figure (B), it acts like an optical system of focal length 10 cm. The refractive index of the material of lens is

SOLUTIONS

1. (b): Least count = \( \frac{0.25}{5 \times 100} \) cm = 5 \times 10^{-4} \text{ cm}

Thickness of wire = 4 \times \frac{0.25}{5} \text{ cm} = 30 \times \text{L.C.}

= 4 \times 0.05 \text{ cm} + 30 \times 5 \times 10^{-4} \text{ cm}

= 0.20 \text{ cm} + 0.0150 \text{ cm} = 0.2150 \text{ cm}

2. (d): Initially, total energy \( E_i = -\frac{GMm}{2R} \)

Final total energy, \( E_f = -\frac{GM(m/2)}{2(R/2)} - \frac{GM(m/2)}{2(3R/2)} \)

\[= -\frac{2GMm}{3R} \]

Required difference in energies,

\[E_F - E_i = -\frac{GMm}{2R} \left( \frac{1}{2} - \frac{1}{2} \right) = \frac{GMm}{6R} \]

3. (b): For a balanced meter bridge

\[Y \times 39.5 = 4 \times (100 - 39.5) \]

\[X = 12.5 \times 39.5 \quad \text{R} = 8.16 \Omega \]

When X and Y are interchanged so \( l_1 \) and \( 100 - l_1 \) will also interchange; and so \( l_2 \) = 60.5 cm.

4. (b): If modulating frequency is 15 kHz then band width of one channel = 30 kHz

Number of channels accommodate = \( \frac{300 \text{ kHz}}{30 \text{ kHz}} = 10 \)
5. (a): Moment of force will be maximum when line of action of force is perpendicular to line AB.
\[ \tan \theta = \frac{2}{4} = \frac{1}{2} \]
Now, \( \hat{k} \times \left( \frac{i - j}{\sqrt{2}} \right) = \frac{j - (-i)}{\sqrt{2}} = \frac{i + j}{\sqrt{2}} \)
Wave propagation vector should be along \( \frac{i + j}{\sqrt{2}} \) and direction of magnetic field is along \( \frac{i - j}{\sqrt{2}} \).

6. (d)

7. (d): Equilibrium position will shift to a point where resultant force is zero.
\[ kx_{eq} = qE \Rightarrow x_{eq} = \frac{qE}{k} \]
Total energy of the system, \( E = \frac{1}{2} m \omega^2 A^2 + \frac{1}{2} q^2 E^2 \)

8. (c)

9. (b): Charged particle can be considered at the centre of a cube of side a, and given surface represents its one side.
So, flux through each face \( \Phi = \frac{Q}{6\varepsilon_0} \)

10. (d): Balancing torque about point of suspension \( X, \)
\( mgx = Mg\left( \frac{1}{2} - x \right) \) or \( m = \left( \frac{M\frac{1}{2}}{x} - M \right) \)
This is equation of straight line with variables \( m \) and \( 1/x \).

11. (a)

12. (c): Let total volume of blood is \( V \).
Initial activity \( A_0 = 0.8 \mu \text{Ci} \)
Its activity at time \( t \), \( A = A_0 e^{-\lambda t} \)
Activity of \( x \) volume, \( A = \left( \frac{A}{V} \right) x = x \left( \frac{A_0}{V} \right) e^{-\lambda t} \)
\( V = (1\text{cm}^3) \left( \frac{8 \times 10^{-7} \times 3.7 \times 10^{10}}{300 \text{ cm}^3/60} \right) \)
\[ = 4.97 \times 10^3 \text{ cm}^3 = 4.97 \text{ litres} = 5 \text{ litres} \]

13. (b): Work done on gas = \( nRT \ln \left( \frac{P_f}{P_i} \right) \)
\[ = R(300) \ln(2) = 300 R \ln 2 \]

14. (b): \( \vec{E} \times \vec{B} \) gives direction of wave propagation.
\[ \Rightarrow \hat{k} \times \vec{B} = \frac{i + j}{\sqrt{2}} \]
16. (b): Energy required to remove an electron from singly ionized helium atom = 54.4 eV.
Energy required to remove the electron form helium atom = x eV
Given 54.4 eV = 2.2x \Rightarrow x = 24.73 eV
Total energy required to ionize helium atom = 54.4 + 24.73 = 79.13 eV

17. (b): Using energy conservation
\[ U_e + 0 = U'_e + U'_B \]
\[ \frac{1}{2} \times 0.2 \times 10^{-6} \times 10^2 + 0 \]
\[ = \frac{1}{2} \times 0.2 \times 10^{-6} \times 5^2 + \frac{1}{2} \times 0.5 \times 10^{-3} I^2 \]
\[ I = \sqrt{3} \times 10^{-1} A = 0.17 A \]

18. (d): For a refrigerator,
\[ 1 - \frac{T_2}{T_1} = -\frac{W}{Q_r + W} \]
\[ \Rightarrow 1 - \frac{250}{300} = -\frac{W}{Q_2 + W} \]
\[ \Rightarrow \frac{Q_2}{50} = 6 \]
\[ W = \frac{500 \times 4.2}{5} = 420 J \]

19. (c): When object is at 8 cm, image distance
\[ v_1 = \frac{f \times u}{u - f} = \frac{(-5)(-8)}{-8 + 5} = -\frac{40}{3} \text{ cm} \]
When object is at 12 cm, image distance
\[ v_2 = -60 \text{ cm} \]
Separation = \[ |v_1 - v_2| = \frac{100}{21} \text{ cm} \]

21. (c): Required magnetic field is given by
\[ B = \frac{\mu_0 NI_R^2}{2 \left( \frac{R^2 + R^2}{4} \right)} = \frac{\mu_0 NI_R^2}{8} = 8 \frac{\mu_0 NI}{R} \]

22. (a): As we know \[ \frac{\Delta S}{S} = 2 \times \frac{\Delta r}{r} \] and
\[ \frac{\Delta V}{V} = 3 \times \frac{\Delta r}{r} \Rightarrow \frac{\Delta V}{V} = \frac{3}{2} \frac{\Delta S}{S} \]

23. (a): Coercivity of ferromagnet \( H = 100 \text{ A m}^{-1} \)
\[ nI = 100 \]
\[ I = \frac{100}{10^2} = 1 mA \]

24. (c): If the angular position of second minima from central maxima is \( \theta \) then
\[ \sin \theta = \frac{2 \lambda}{a} = \frac{2 \times 550 \times 10^{-9}}{22 \times 10^{-7}} = \frac{1}{2} \Rightarrow \theta = \frac{\pi}{6} \text{ rad} \]

25. (a): Momentum of two electrons are \( \frac{h}{\lambda_1} \hat{i} \text{ and } \frac{h}{\lambda_2} \hat{j} \).
Velocity of centre of mass
\[ \vec{V}_{CM} = \frac{h}{2m\lambda_1} \hat{i} + \frac{h}{2m\lambda_2} \hat{j} \]
Velocity of first electron about centre of mass is
\[ \vec{V}_{1CM} = \frac{h}{2m\lambda_1} \hat{i} - \frac{h}{2m\lambda_2} \hat{j} \]
\[ \lambda_{CM} = \sqrt{\frac{h^2}{4\lambda_1^2} + \frac{h^2}{4\lambda_2^2}} = \frac{2\lambda_1\lambda_2}{\lambda_1^2 + \lambda_2^2} \]

26. (b):

27. (b): Current gain \( \beta = \frac{\Delta I_C}{\Delta I_B} \)
Voltage gain \( A_V = \frac{\Delta V_{GE}}{R_{BE}\Delta I_B} = \beta \frac{R_p}{R_{BE}} \)
Power gain \( A_P = \beta^2 \frac{R_p}{R_{BE}} \)

28. (c): Organ pipe will have frequency either 255 or 257 Hz.
For frequency of tuning fork, 255 Hz
\[ 255 = \frac{3v}{2f}, \text{ } l = \frac{3 \times 340}{2 \times 255} \text{ m} \Rightarrow l = 200 \text{ cm} \]
29. (*)

Equating pressure at point A
\[ \rho_1 g (\cos \theta - \sin \theta) = \rho_2 g (\sin \theta + \cos \theta) \]
\[ \frac{\rho_1}{\rho_2} = \frac{\sin \theta + \cos \theta}{\cos \theta - \sin \theta} = \frac{\tan \theta + 1}{1 - \tan \theta} \]
\[ \rho_1 - \rho_1 \tan \theta = \rho_2 + \rho_2 \tan \theta \]
\[ \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \]
\[ \theta = \tan^{-1} \left( \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \right) \]

* None of the given option is correct.

30. (c) : For figure (A)

\[ \frac{1}{f_1} = \left( \frac{\mu - 1}{R} \right) ; \quad f = -28 \text{ cm} \]
\[ P = 2P_1 + P_2 = 2P_1 + 0 \]
\[ \frac{1}{28} = -2 \left( \frac{\mu - 1}{R} \right) \]

For figure (B),

\[ \frac{1}{f_1} = \left( \frac{\mu - 1}{R} \right) \quad f = -10 \text{ cm} \]

\[ P = 2P_1 + P_2 \Rightarrow - \frac{1}{10} = -2 \left( \frac{\mu - 1}{R} \right) - \frac{2}{R} \]
\[ \frac{1}{10} = \frac{2}{R} + \frac{2}{R} \]
\[ \frac{1}{28} = \frac{1}{10} \cdot \frac{1}{28} = \frac{18}{280} ; \quad R = \frac{280}{9} \text{ cm} \]

Substituting \( R \) in eqn. (i)
\[ \frac{1}{28} = 2 \left( \frac{\mu - 1}{280} \right) ; \quad \mu = \frac{5}{9} \]
\[ \mu = 1 + \frac{5}{9} = 1.55 \]
1. Four resistors, 100 Ω, 200 Ω, 300 Ω and 400 Ω are connected to form four sides of a square. The resistors can be connected in any order. What is the maximum possible equivalent resistance across the diagonal of the square?
(a) 210 Ω  (b) 240 Ω  (c) 300 Ω  (d) 250 Ω

2. What will be current through the 200 Ω resistor in the given circuit a long time after the switch 'K' is made on?
(a) Zero  (b) 100 mA  (c) 10 mA  (d) 1 mA

3. A point source is placed at co-ordinates (0, 1) in X-Y plane. A ray of light from the source is reflected on a plane mirror placed along the X-axis and perpendicular to the X-Y plane. The reflected ray passes through the point (3, 3). What is the path length of the ray from (0, 1) to (3, 3)?
(a) 5  (b) \sqrt{13}  (c) 2\sqrt{3}  (d) 1+2\sqrt{3}

4. Two identical equiconvex lenses, each of focal length 'f' are placed side by side in contact with each other with a layer of water in between them as shown in the figure. If refractive index of the material of the lenses is greater than that of water, how the combined focal length 'F' is related to 'f'?

5. There is a small air bubble at the centre of a solid glass sphere of radius 'r' and refractive index 'µ'. What will be the apparent distance of the bubble from the centre of the sphere, when viewed from outside?
(a) \frac{r}{\mu}  (b) \frac{r}{\mu}  (c) \frac{r}{\mu}  (d) zero

6. If Young's double slit experiment is done with white light, which of the following statements will be true?
(a) All the bright fringes will be coloured.
(b) All the bright fringes will be white.
(c) The central fringe will be white.
(d) No stable interference pattern will be visible.

7. How the linear velocity 'v' of an electron in the Bohr orbit is related to its quantum number 'n'?
(a) v \propto \frac{1}{n}  (b) v \propto \frac{1}{n^2}  (c) v \propto \frac{1}{\sqrt{n}}  (d) v \propto n

8. If the half life of a radioactive nucleus is 3 days, nearly what fraction of the initial number of nuclei will decay on the 3rd day?
(Given that \sqrt[3]{0.25} \approx 0.63)
(a) 0.63  (b) 0.5  (c) 0.37  (d) 0.13

9. An electron accelerated through a potential of 10,000 V from rest has a de-Broglie wavelength \lambda. What should be the accelerating potential so that the wave length is doubled?
10. In the circuit shown, inputs A and B are in states ‘1’ and ‘0’ respectively. What is the only possible stable state of the outputs ‘X’ and ‘Y’?

(a) X = ‘1’, Y = ‘1’ 
(b) X = ‘1’, Y = ‘0’ 
(c) X = ‘0’, Y = ‘1’ 
(d) X = ‘0’, Y = ‘0’

11. What will be the current flowing through the 6 kΩ resistor in the circuit shown, where the breakdown voltage of the zener is 6 V?

(a) \(\frac{2}{3}\) mA 
(b) 1 mA 
(c) 10 mA 
(d) \(\frac{3}{2}\) mA

12. In case of a simple harmonic motion, if the velocity is plotted along the X-axis and the displacement (from the equilibrium position) is plotted along the Y-axis, the resultant curve happens to be an ellipse with the ratio major axis (along X) : minor axis (along Y) = 20 : π

What is the frequency of the simple harmonic motion?

(a) 100 Hz 
(b) 20 Hz 
(c) 10 Hz 
(d) \(\frac{1}{10}\) Hz

13. A block of mass \(m_2\) is placed on a horizontal table and another block of mass \(m_1\) is placed on top of it. An increasing horizontal force \(F = at\) is exerted on the upper block but the lower block never moves as a result. If the coefficient of friction between the blocks is \(\mu_1\) and that between the lower block and the table is \(\mu_2\), then what is the maximum possible value of \(\mu_1 / \mu_2\)?

(a) \(\frac{m_2}{m_1}\) 
(b) \(1 + \frac{m_2}{m_1}\) 
(c) \(\frac{m_1}{m_2}\) 
(d) \(1 + \frac{m_1}{m_2}\)

14. In a triangle ABC, the sides \(AB\) and \(AC\) are represented by the vectors \(3\hat{i} + \hat{j} + \hat{k}\) and \(\hat{i} + 2\hat{j} + \hat{k}\) respectively. Calculate the angle \(\angle ABC\).

(a) \(\cos^{-1}\sqrt{\frac{5}{11}}\) 
(b) \(\cos^{-1}\sqrt{\frac{6}{11}}\) 
(c) \(90° - \cos^{-1}\left(\frac{5}{11}\right)\) 
(d) \(180° - \cos^{-1}\left(\frac{5}{11}\right)\)

15. The velocity (v) of a particle (under a force F) depends on its distance (x) from the origin (with \(x > 0\)) as \(v \propto \frac{1}{\sqrt{x}}\). Find how the magnitude of the force (F) on the particle depends on x.

(a) \(F \propto \frac{1}{x^{3/2}}\) 
(b) \(F \propto \frac{1}{x}\) 
(c) \(F \propto \frac{1}{x^2}\) 
(d) \(F \propto x\)

16. The ratio of accelerations due to gravity \(g_1 : g_2\) on the surface of two planets is 5 : 2 and the ratio of their respective average densities \(\rho_1 : \rho_2\) is 2 : 1. What is the ratio of respective escape velocities \(v_1 : v_2\) from the surface of the planets?

(a) 5 : 2 
(b) \(\sqrt{5} : \sqrt{2}\) 
(c) 5 : \(2\sqrt{2}\) 
(d) 25 : 4

17. A spherical liquid drop is placed on a horizontal plane. A small disturbance causes the volume of the drop to oscillate. The time period of oscillation (T) of the liquid drop depends on radius (r) of the drop, density (p) and surface tension (s) of the liquid. Which among the following will be a possible expression for T (where k is a dimensionless constant)?

(a) \(k \sqrt{\frac{rpr}{s}}\) 
(b) \(k \sqrt{\frac{p^2r}{s}}\) 
(c) \(k \sqrt{\frac{pr^3}{s}}\) 
(d) \(k \sqrt{\frac{p^3r}{s}}\)

18. The stress along the length of a rod (with rectangular cross section) is 1% of the Young's modulus of its material. What is the approximate percentage of change of its volume? (Poisson's ratio of the material of the rod is 0.3).

(a) 3% 
(b) 1% 
(c) 0.7% 
(d) 0.4%

19. What will be the approximate terminal velocity of a rain drop of diameter \(1.8 \times 10^{-3}\) m, when density of rain water = \(10^3\) kg m\(^{-3}\) and the co-efficient of viscosity of air = \(1.8 \times 10^{-5}\) N s m\(^{-2}\)? (Neglect buoyancy of air).
(a) 49 m s\(^{-1}\)  (b) 98 m s\(^{-1}\)
(c) 392 m s\(^{-1}\)  (d) 980 m s\(^{-1}\)

20. The water equivalent of a calorimeter is 10 g and it contains 50 g of water at 15°C. Some amount of ice, initially at \(-10^\circ\text{C}\), is dropped in it and half of the ice melts till equilibrium is reached. What was the initial amount of ice that was dropped (when specific heat of ice = 0.5 cal g\(^{-1}\)°C\(^{-1}\), specific heat of water = 1.0 cal g\(^{-1}\)°C\(^{-1}\) and latent heat of melting of ice = 80 cal g\(^{-1}\))?
(a) 10 g  (b) 18 g  (c) 20 g  (d) 30 g

21. One mole of a mono-atomic ideal gas undergoes a quasi-static process, which is depicted by a straight line joining points \((V_0, T_0)\) and \((2V_0, 3T_0)\) in a \(V-T\) diagram. What is the value of the heat capacity of the gas at the point \((V_0, T_0)\)?
(a) \(R\)  (b) \(\frac{3}{2} R\)  (c) \(2R\)  (d) 0

22. For an ideal gas with initial pressure and volume \(P_i\) and \(V_i\), respectively, a reversible isothermal expansion happens, when its volume becomes \(V_2\). Then it is compressed to its original volume \(V_i\) by a reversible adiabatic process. If the final pressure is \(P_f\), then which of the following statements is true?
(a) \(P_f = P_i\)  (b) \(P_f > P_i\)
(c) \(P_f < P_i\)  (d) \(P_f = \frac{P_i}{V_0} V_i\)

23. A point charge \(-q\) is carried from a point \(A\) to another point \(B\) on the axis of a charged ring of radius \(r\) carrying a charge \(+q\). If the point \(A\) is at a distance \(\frac{2}{3} r\) from the centre of the ring and the point \(B\) is \(\frac{3}{4} r\) from the centre but on the opposite side, what is the net work that need to be done for this?
(a) \(-\frac{7}{5} 4\pi \varepsilon_0 q^2 r\)
(b) \(-\frac{1}{5} 4\pi \varepsilon_0 q^2 r\)
(c) \(-\frac{7}{4} 4\pi \varepsilon_0 q^2 r\)
(d) \(-\frac{1}{4} 4\pi \varepsilon_0 q^2 r\)

24. Consider a region in free space bounded by the surface of an imaginary cube having sides of length \(a\) as shown in the diagram. A charge \(+Q\) is placed at the centre \(O\) of the cube. \(P\) is such a point outside the cube that the line \(OP\) perpendicularly intersects the surface \(ABCD\) at \(R\) and also \(OR = RP = a/2\). A charge \(+Q\) is placed at point \(P\) also. What is the total electric flux through the five faces of the cube other than \(ABCD\)?
(a) \(\frac{Q}{\varepsilon_0}\)  (b) \(\frac{5Q}{6\varepsilon_0}\)
(c) \(\frac{10Q}{6\varepsilon_0}\)  (d) zero

25. Four equal charges of value \(+Q\) are placed at any four vertices of a regular hexagon of side ‘a’. By suitably choosing the vertices, what can be the maximum possible magnitude of electric field at the centre of the hexagon?
(a) \(\frac{Q}{4\pi \varepsilon_0 a^2}\)  (b) \(\frac{\sqrt{2}Q}{4\pi \varepsilon_0 a^2}\)
(c) \(\frac{\sqrt{3}Q}{4\pi \varepsilon_0 a^2}\)  (d) \(\frac{2Q}{4\pi \varepsilon_0 a^2}\)

26. A proton of mass ‘\(m\)’ moving with a speed \(v\) \((<< c\), velocity of light in vacuum\) completes a circular orbit in time ‘\(T\)’ in a uniform magnetic field. If the speed of the proton is increased to \(\sqrt{2}v\), what will be time needed to complete the circular orbit?
(a) \(\sqrt{2}T\)  (b) \(T\)  (c) \(\frac{T}{\sqrt{2}}\)  (d) \(\frac{T}{2}\)

27. A uniform current is flowing along the length of an infinite, straight, thin, hollow cylinder of radius ‘\(R\)’. The magnetic field ‘\(B\)’ produced at a perpendicular distance ‘\(d\)’ from the axis of the cylinder is plotted in a graph. Which of the following figures looks like the plot?
(a)  
(b) 
(c) 
(d) 

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28. A circular loop of radius 'r' of conducting wire connected with a voltage source of zero internal resistance produces a magnetic field 'B' at its centre. If instead, a circular loop of radius '2r' made of same material, having the same cross section is connected to the same voltage source what will be the magnetic field at its centre?
   (a) \( \frac{B}{2} \)  \hspace{1cm} (b) \( \frac{B}{4} \)  \hspace{1cm} (c) \( 2B \)  \hspace{1cm} (d) \( B \)

29. An alternating current is flowing through a series LCR circuit. It is found that the current reaches a value of 1 mA at both 200 Hz and 800 Hz frequency. What is the resonance frequency of the circuit?
   (a) 600 Hz  \hspace{1cm} (b) 300 Hz  \hspace{1cm} (c) 500 Hz  \hspace{1cm} (d) 400 Hz

30. An electric bulb, a capacitor, a battery and a switch are all in series in a circuit. How does the intensity of light vary when the switch is turned on?
   (a) Continues to increase gradually
   (b) Gradually increases for some time and then becomes steady
   (c) Sharply rises initially and then gradually decreases
   (d) Gradually increases for some time and then gradually decreases

31. A light charged particle is revolving in a circle of radius 'r' in electrostatic attraction of a static heavy particle with opposite charge. How does the magnetic field 'B' at the centre of the circle due to the moving charge depend on 'r'?
   (a) \( B \propto \frac{1}{r} \)  \hspace{1cm} (b) \( B \propto \frac{1}{r^2} \)
   (c) \( B \propto \frac{1}{3r^2} \)  \hspace{1cm} (d) \( B \propto \frac{1}{5r^2} \)

32. As shown in the figure a rectangular loop of a conducting wire is moving away with a constant velocity 'v' in a perpendicular direction from a very long straight conductor carrying a steady current 'I'. When the breadth of the rectangular loop is very small compared to its distance from the straight conductor, how does the e.m.f. 'E' induced in the loop vary with time 't'?\[ E \propto \frac{1}{t^2} \]

33. A solid spherical ball and a hollow spherical ball of two different materials of densities \( \rho_1 \) and \( \rho_2 \) respectively have same outer radii and same mass. What will be the ratio of moment of inertia (about an axis passing through the centre) of the hollow sphere to that of the solid sphere?
   (a) \( \frac{\rho_2 \left(1 - \frac{\rho_2}{\rho_1}\right)^5}{\rho_1} \)  \hspace{1cm} (b) \( \frac{\rho_2 \left(1 - \frac{\rho_2}{\rho_1}\right)^3}{\rho_1} \)
   (c) \( \frac{\rho_2 \left(1 - \frac{\rho_1}{\rho_2}\right)^5}{\rho_1} \)  \hspace{1cm} (d) \( \frac{\rho_2 \left(1 - \frac{\rho_1}{\rho_2}\right)^3}{\rho_1} \)

34. The insulated plates of a charged parallel plate capacitor (with small separation between the plates) are approaching each other due to electrostatic attraction. Assuming no other force to be operative and no radiation taking place, which of the following graphs approximately shows the variation with time (t) of the potential difference (V) between the plates?
   (a) \[ \begin{array}{c}
   \text{Graph A} \\
   \end{array} \]  \hspace{1cm} (b) \[ \begin{array}{c}
   \text{Graph B} \\
   \end{array} \]
   (c) \[ \begin{array}{c}
   \text{Graph C} \\
   \end{array} \]  \hspace{1cm} (d) \[ \begin{array}{c}
   \text{Graph D} \\
   \end{array} \]

35. The bob of a pendulum of mass 'm' suspended by an inextensible string of length 'L' as shown in the figure carries a small charge 'q'. An infinite horizontal plane conductor with uniform surface charge density '\( \sigma \)' is placed below it. What will be the time period of the pendulum for small amplitude oscillations?

\[ E \propto \frac{1}{t} \]

\[ \text{PHYSICS FOR YOU} \hspace{1cm} \text{JUNE '18} \hspace{1cm} 41 \]
38. The intensity of a sound appears to an observer to be periodic. Which of the following can be the cause of it?
(a) The intensity of the source is periodic
(b) The source is moving towards the observer
(c) The observer is moving away from the source
(d) The source is producing a sound composed of two nearby frequencies

39. Which of the following statement(s) is/are true?
"Internal energy of an ideal gas ___"?
(a) decreases in an isothermal process
(b) remains constant in an isothermal process
(c) increases in an isobaric process
(d) decreases in an isobaric expansion

40. Two positive charges Q and 4Q are placed at points A and B respectively, where B is at a distance ‘d’ units to the right of A. The total electric potential due to these charges is minimum at P on the line through A and B. What is (are) the distance(s) of P from A?
(a) \( \frac{d}{3} \) units to the right of A
(b) \( \frac{d}{3} \) units to the left of A
(c) \( \frac{d}{5} \) units to the right of A
(d) \( d \) units to the left of A

SOLUTIONS

1. (d): In the figure, resistors 2R and 3R are in series.
   ∴ Equivalent resistance,
   \[ R_1 = 2R + 3R = 5R \]
   Also, R and 4R are in series their equivalent resistance will be,
   \[ R_2 = R + 4R = 5R \]
   Now, \( R_1 \) and \( R_2 \) are in parallel.
   Hence, maximum equivalent resistance,
   \[ R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{5 \times 5}{2} = 25 \Omega \]

2. (c): As key is ON for long, the circuit is in steady state. Hence, resistance of each capacitor is infinite. Thus current through resistances 200 \( \Omega \) and 400 \( \Omega \) is same.
   Now, equivalent resistance,
   \[ R_{eq} = 200 \Omega + 400 \Omega \]
   \[ = 600 \Omega \]
   ∴ Current through 200 \( \Omega \) resistance will be
   \[ I_{steady} = \frac{6V}{600\Omega} = 10 \text{ mA} \]
3. (a)

4. (b): As the water is filled in between the two convex lenses, they act as a biconcave lens of focal length \( f_w \).

\[
\frac{1}{f_w} = (\mu_w - 1) \left[ \frac{1}{R_1} - \frac{1}{R_2} \right]
\]

or

\[
\frac{1}{f_w} = (\mu_w - 1) \left[ \frac{1}{R} - \frac{1}{R} \right] = (\mu_w - 1) \left[ \frac{-2}{R} \right] \quad \text{(i)}
\]

Similarly, combined focal length of convex lenses is

\[
\frac{1}{f_1} = (\mu_1 - 1) \frac{2}{R} \quad \text{or} \quad \frac{2}{R} = \frac{1}{f_1(\mu_1 - 1)} \quad \text{(ii)}
\]

From eqn. (i) and (ii),

\[
\frac{1}{f_w} = \frac{1}{f_1} \quad \text{(iii)}
\]

\( \therefore \) Equivalent focal length is

\[
\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_1} \left( \frac{\mu_w - 1}{\mu_1 - 1} \right) \frac{1}{f_1} = \frac{1}{f_1} \left[ 2 - \frac{\mu_w - 1}{\mu_1 - 1} \right] \quad \text{(iv)}
\]

As given, \( \mu_1 > \mu_w \)

or \( \mu_1 - 1 > \mu_w - 1 \) or \( \frac{\mu_w - 1}{\mu_1 - 1} < 1 \) \( \text{(v)} \)

From eqn. (iv) and (v),

Hence, \( \frac{1}{f_1} < F < \frac{1}{f} \)

5. (d): Since, all the incident rays are normal to surface, therefore rays are undeviated and travel along the normal. Hence the apparent distance of the bubble from the centre of the sphere, when viewed from outside will be zero.

6. (c): If Young’s double slit experiment is done with white light, then central fringe will be white. Because central fringe is the place on the screen where path difference or phase difference between any two waves simultaneously emanating from the two slits is zero.

7. (a): The linear velocity of an electron in the Bohr orbit is given by

\[
v = \frac{Ze^2}{2\epsilon_0 m} \quad \text{or} \quad v \propto \frac{1}{n}
\]

8. (d): Let \( N_0 \) be the number of atoms of a radioactive nucleus initially and \( N \) be the number at the end of 3\(^{rd}\) day.

\[
N = \frac{N_0}{2}
\]

No. of nucleus at the 2 day

\[
N_2 = \left( \frac{1}{2} \right)^2 \Rightarrow N_2 = \left( \frac{1}{4} \right) N_0
\]

No. of nucleus at the 3 day

\[
N_3 = \left( \frac{1}{2} \right)^3 N_0
\]

\( \therefore \) on 3\(^{rd}\) day

\[
N' = \frac{N_3 - N_2}{N_0} = 0.13
\]

9. (c): The wavelength associated with the moving electron is given by

\[
\lambda = \frac{12.27}{\sqrt{V}} \quad \text{where} \ V = \text{accelerating potential}
\]

\( \therefore \)

\[
\lambda = \frac{12.27}{\sqrt{V}} \quad \Rightarrow \quad \frac{\lambda}{\lambda'} = \frac{V}{V'} = 2 \lambda = \frac{\sqrt{V'}}{20000} \quad \text{(i)}
\]

\( \Rightarrow \)

\[
V' = 5000
\]

10. (c)

11. (a): As the breakdown voltage of the zener diode

\[
= 6 \text{ V}
\]

So, potential across 4 k\( \Omega \) resistor = 6 V

(\( \therefore \) Potential across 6 k\( \Omega \) resistor = 10 V – 6 V

\[
E = 4 \text{ V}
\]

Hence, the current flowing through the 6 k\( \Omega \) resistor in the circuit

\[
= \frac{4}{6 \text{ k}\Omega} = \frac{4}{6 \times 10^3 \Omega} = \frac{2}{3} \text{ mA}
\]

12. (c): As the resultant curve is ellipse then equation for S.H.M is

\[
\frac{v^2}{(OQ)^2} + \frac{x^2}{(OP)^2} = 1 \quad \text{(i)}
\]

Now, \( OQ = a\omega \)

and \( OP = a \); where \( \omega = \text{angular velocity} \)

From eqn. (i),

\[
\frac{v^2}{a^2} + \frac{x^2}{a^2} = 1
\]

Thus, major axis = \( 2 \times a\omega = 2a\omega \)

minor axis = \( 2a \)

Given that, major axis (along X) = \( 20\pi \)

minor axis (along Y) = \( 2a \)

\( \therefore \)

\[
\frac{2a\omega}{2a} = 20\pi
\]

or \( \omega = 20\pi \Rightarrow 20\pi f = 2\pi (\text{where} \ f \text{ is frequency}) \)

or \( f = 10 \text{ Hz} \)
13. (b) : Let \( f_1 \) be the friction force acting between lower block and the upper block and \( f_2 \) be the friction force acting between lower block and the table. As \( m_3 \) never moves, so friction acting in between the blocks is always less than or equal to friction acting between lower block and the table.
\[
\therefore \quad f_1 \leq f_2
\]
or
\[
\mu_1 m_1 g \leq \mu_2 (m_1 + m_2) g
\]
or
\[
\frac{\mu_1}{\mu_2} \leq \frac{m_1 + m_2}{m_1}
\]
\[
\Rightarrow \quad \frac{\mu_1}{\mu_2} \leq 1 + \frac{m_2}{m_1}
\]
So, maximum possible value of \( \frac{\mu_1}{\mu_2} = 1 + \frac{m_2}{m_1} \).

14. (a) : \[
\overrightarrow{AB} = (3 \hat{i} + \hat{j} + \hat{k})
\]
\[
\overrightarrow{AC} = (\hat{i} + 2\hat{j} + \hat{k})
\]
\[
\overrightarrow{CB} = \overrightarrow{AB} - \overrightarrow{AC} = (3\hat{i} + \hat{j} + \hat{k}) - (\hat{i} + 2\hat{j} + \hat{k}) = 2\hat{i} - \hat{j}
\]
\[
\angle ABC = 0 \text{ is the angle between } \overrightarrow{AB} \text{ and } \overrightarrow{CB}
\]
\[
\overrightarrow{AB} \cdot \overrightarrow{CB} = |\overrightarrow{AB}| \cdot |\overrightarrow{CB}| \cos \theta
\]
\[
= (3\hat{i} + \hat{j} + \hat{k}) \cdot (2\hat{i} - \hat{j})
\]
\[
= (3)(2) + (1)(-1) = 5
\]
\[
\Rightarrow \quad \cos \theta = \frac{5}{\sqrt{11} \cdot \sqrt{5}}
\]
\[
\therefore \quad \theta = \cos^{-1} \left( \frac{5}{\sqrt{11}} \right)
\]

15. (c) : The velocity of a particle under force from the origin is \( v = \frac{1}{\sqrt{x}} \).
Differentiating both sides, with respect to time \( t \), we get
\[
\frac{dv}{dt} = \frac{1}{2x^{3/2}} \cdot \frac{dx}{dt}
\]
or
\[
\frac{dv}{dt} = \frac{1}{2x^{3/2}} \cdot \frac{1}{x^{1/2}} = \frac{1}{2x^{2/2}}
\]
or
\[
\frac{dv}{dt} = \frac{1}{2x^2}
\]
Multiplying both sides by mass \( m \), we get
\[
m \times \frac{dv}{dt} = m \times \frac{1}{2x^2} \quad \text{or} \quad F = \frac{1}{x^2}
\]

16. (c) : Escape velocity of an object from the surface of the planet is given by
\[
\nu_e = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2gR}{R}} = \sqrt{2gR}
\]
where \( g \) is gravity, \( R \) is the radius of the planet, \( G \) is the gravitational constant and \( M \) is the mass of the planet.

As Mass = volume \times density or \( M = \frac{4}{3} \pi R^3 \rho_1 \)
\[
\therefore \quad M_1 = \frac{4}{3} \pi R_1^3 \rho_1 \quad \text{and} \quad M_2 = \frac{4}{3} \pi R_2^3 \rho_2
\]
Let \( M_1 \) and \( M_2 \) be the masses of the planets and \( \rho_1 \) and \( \rho_2 \) be the densities of the planets.
As we know,
\[
g = \frac{GM}{R^2}
\]
\[
\therefore \quad \frac{g_1}{g_2} = \frac{M_1 R_2^3}{M_2 R_1^3} = \frac{\frac{4}{3} \pi R_1^3 \times R_2^3}{\frac{4}{3} \pi R_2^3 \times R_1^3} = \frac{3}{2}
\]
\[
\Rightarrow \quad \frac{g_2}{g_1} = \frac{5}{2} \quad \text{or} \quad \rho_1 = \frac{5}{2} \times \frac{1}{2} = \frac{5}{4}
\]
Now, the ratio of respective escape velocities
\[
\nu_1 : \nu_2 = \sqrt{g_1 R_1} : \sqrt{g_2 R_2} = \frac{5}{2}\sqrt{2}
\]
Using eqn. (i)]

17. (c)

18. (d) : Let volume of the rod be \( V \).
\[
\because \quad V = xyz
\]
Now change in volume is
\[
\frac{dV}{V} = \frac{dx}{x} + \frac{dy}{y} + \frac{dz}{z}
\]
or
\[
\frac{dV}{V} = \frac{dl}{l} - \frac{dl}{l} - \frac{dl}{l} = (1 - 2\mu) \frac{dl}{l}
\]
...(i)
Stress = Young's modulus \((Y) \times \text{strain} \) ...(ii)
As stress = \( 1 \% \) of \( Y = 0.01Y \)
\[
\therefore \quad 0.01Y = Y \times \frac{dl}{l}
\]
...(from (ii))
From eqn. (i),
\[
\frac{dV}{V} = (1 - 2 \times 0.3) \times 0.01 \quad \therefore \mu = 0.3 \text{ and } \frac{dl}{l} = 0.01
\]
\[
\Rightarrow \quad \frac{dV}{V} = 0.01 \times 0.4 = 0.4 \%
\]

19. (b) : Here, Diameter of a rain drop = \( 1.8 \times 10^{-3} \text{ m} \)
\[
\therefore \quad \text{Radius, } r = \frac{1.8 \times 10^{-3}}{2} = 0.9 \times 10^{-3} \text{ m}
\]
Density of rain water, \( \rho = 10^3 \text{ kg m}^{-3} \)
Coefficient of viscosity of air, \( \eta = 1.8 \times 10^{-5} \text{ Ns m}^{-2} \)
When a raindrop falls in air (viscous medium), then it accelerates initially due to gravity.
The viscous drag force,

\[ F = 6 \pi \eta v \]

where \( v \) = terminal velocity

In equilibrium, \( F = mg \)

or \( 6 \pi \eta v = \frac{4}{3} \pi r^3 \rho g \)

or \( v = \frac{2}{9} \pi r^3 \rho g \)

\[
\Rightarrow v = \frac{2 \times 0.9 \times 0.9 \times 10^{-6} \times 10^3 \times 9.8}{9 \times 1.8 \times 10^{-5}} = 98 \text{ m s}^{-2}
\]

20. (c) : Let initial mass of the ice be \( m \).

![Water and Ice Diagram]

Mass of water equivalent of a calorimeter and water contained by it,

\[ m_1 = 10 \text{ g} + 50 \text{ g} = 60 \text{ g} \]

The amount of heat lost by the water, \( Q_1 = m_1 s \Delta T \)

where \( s \) = specific heat of water, \( \Delta T \) = temperature

\[ Q_1 = (60 \times 1 \times 15) \text{ cal} \]

Amount of heat gained by ice is \( Q_2 \)

\[ Q_2 = \frac{m}{2} \times 10 + \frac{m}{2} \times 80 = (45m) \text{ cal} \]

In steady state, heat gained = heat lost

\[ 45m = 60 \times 1 \times 15 \Rightarrow m = 20 \text{ g} \]

21. (c) : Since path is isochoric.

\( \therefore \) Work done, \( dW = PdV \)

Change in internal energy is \( \Delta U = nC_V \Delta T \)

where \( C_V \) = specific heat at constant volume

Heat given in process is \( \Delta Q = nC_V \Delta T \)

where \( n \) = number of moles of a gas, \( C \) = molar heat capacity

According to graph, temperature is increasing with increase in volume.

It means that energy is used both in increasing internal energy and work done

According to 1st law of thermodynamics

\[ PdV + nC_V dT = nC_V dT \]

or \( \frac{P}{n} \frac{dV}{dT} + C_V = C \) \( \ldots (i) \)

At \( (V_0, T_0) \)

\[ \frac{dV}{dT} \bigg|_{T_0} = \frac{V_0}{2T_0} \] \( \ldots (ii) \)

\[ P_0V_0 = nRT_0 \Rightarrow \frac{P_0}{n} = \frac{RT_0}{V_0} \] \( \ldots (iii) \)

From (i), (ii) and (iii),

\[ C = \frac{RT_0}{V_0} \times \frac{3}{2} = \frac{3}{2} \]

\[ \therefore C_V = \frac{3}{2} \]

22. (b) : For isothermal expansion, \( P_iV_i = P_0V_0 \) \( \ldots (i) \)

\( P_0 \) is the pressure of the gas corresponding to volume \( V_0 \).

For adiabatic compression, \( P_iV_i^\gamma = P_fV_f^\gamma \) \( \ldots (ii) \)

or, \( \frac{P_iV_i}{V_i^\gamma} = P_fV_f^\gamma \) or, \( \frac{P_i}{P_f} = \left( \frac{V_f}{V_i} \right)^{\gamma-1} \)

Since, \( V_i < V_f \) so \( P_f > P_i \)

23. (b) : A point charge is placed at the centre of a cube, then net flux through six surfaces = \( \frac{Q}{\varepsilon_0} \)

Since all the surfaces are symmetrical, therefore net flux through one surface due to charge at \( P \),

\[ \phi_1 = 0 \]

\( \therefore \) Net flux due to charge at \( O \) is \( \phi_2 = \frac{5Q}{6\varepsilon_0} \)

\( \therefore \) The total electric flux through 5 faces of the cube other than \( ABCD \) is

\[ \phi = \phi_1 + \phi_2 = 0 + \frac{5Q}{6\varepsilon_0} = \frac{Q}{6\varepsilon_0} \]

25. (c) : To maximize the electric field at the centre both charges should be placed at adjacent vertices.

Net field due to charge at \( A \) and \( D \) is zero here.

\( \therefore \) Total System of electric field due to the charges is

\[ E_{total} = \sqrt{E_F^2 + E_E^2 + 2E_FE_E \cos 60^\circ} \]

\[ = \sqrt{2E^2 + 2E^2 \times \frac{1}{2}} \]

\( \therefore E_F = E_E = E \)

\[ = \sqrt{2E^2 + E^2} = \sqrt{3E^2} \text{ or } E_{total} = \sqrt{3}E \]

So, maximum electric field is

\[ E_{total} = \sqrt{3} \times \frac{1}{4\pi\varepsilon_0} \left( \frac{Q}{a^2} \right) \] \( \text{(using (i))} \)

26. (b) : The time period of the revolving change is

\[ T = \frac{2\pi R}{\sqrt{2}} = \frac{2\pi m}{\sqrt{2}qB} \] or \( T = \frac{2\pi m}{qB} \)

\[ \text{Using } r = \frac{mv}{qB} \]
Here $T$ is independent of $v$.
So there is no change in the time period of proton if speed is increased to $\sqrt{2}v$.

27. (c) : For $d > R$
By symmetry, the amperian loop is a circle.
\[\oint B \cdot dl = \int Bdl \cos \theta \quad \therefore \quad \theta = 0^\circ\]
\[\therefore \mu_0 I = \oint B \cdot dl = \int Bdl = B \int_0^{2\pi r} dl\]
\[= B \cdot 2\pi r \quad (\therefore \quad B = \text{constant})\]
\[\therefore \mu_0 I = \frac{2\pi}{B}\]
\[\therefore \quad B = \frac{\mu_0 I}{2\pi R}\]
For $d < R$ \quad \therefore \quad \theta = 0^\circ
\[B = \mu_0 I \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi R} \quad \therefore \quad B = 0 \quad \therefore \quad I = 0\]

28. (b) : Field due to circular loop of radius $r$ of conducting wire at the centre is
\[B = \frac{\mu_0}{2\pi} \frac{I}{r}\]  
(i)
For same material and having the same cross section. When radius of loop is doubled, the resistance of the circuit is also doubled. Therefore the current in the circuit becomes half.
\[i.e., \quad I' = \frac{I}{2} \quad \text{and} \quad r' = 2r\]
\[\therefore \quad \text{Field due to new circular loop is} \]
\[B' = \frac{\mu_0}{2\pi} \frac{I'}{r'} \quad \text{or} \quad B' = \frac{\mu_0 I}{8r} = \frac{1}{4} B \quad \text{[using (i)]}\]

29. (d) : Since the alternating current is flowing through a series LCR circuit.
For maximum value of current
\[\omega L - \frac{1}{\omega C} = 0 \quad \text{or} \quad \omega L = \frac{1}{\omega C}\]  
(i)
Resonance frequency of series LCR circuit is
\[\omega = \frac{1}{\sqrt{LC}}\]
From (i), $200 L = \frac{1}{800} C$
\[\therefore \quad \text{current reaches a value of 1 mA}\]
or
\[\frac{1}{LC} = 200 \times 800\]
or
\[\frac{1}{LC} = \sqrt{200 \times 800} = 400 \text{ Hz}\]

30. (c) : Time constant of circuit = $CR$
Maximum charge on capacitor = $C \times \varepsilon$
Hence equations of charge and current are as given below.

\[q = \varepsilon C [1 - e^{-\frac{q}{t}}] RC\]
\[i = \frac{dq}{dt} = \frac{e^{-\frac{q}{t}}}{R} RC\]
\[\therefore \quad \text{intensity of light} \approx 1^2 R\]

31. (d) : Electrostatic force of attraction
\[F_e = \frac{ekQ}{r^2}\]
For circular motion of the charged particle,
\[F_e = F_c\]
\[\frac{mv^2}{r} = \frac{ekQ}{r^2} \quad \therefore \quad v = \frac{kQ}{r}\]
Time period, $T = 2\pi r / v \quad \therefore \quad T = \frac{r}{v}
\[T \approx r^{3/2}\]
Current flow, $I = \frac{Q}{T} \quad \therefore \quad I \approx r^{-3/2} \quad \text{(i)}$
Now, magnetic field, $B = \frac{\mu_0 I}{2\pi r}$
\[\therefore \quad B \approx \frac{1}{r} \quad \therefore \quad B \approx r^{-5/2} \quad \text{(using (i))}\]

32. (a) : According to Faraday’s law
\[E = -\frac{d\phi}{dt} \quad \therefore \quad E = -\frac{d}{dt} (BA)\]
\[\therefore \quad E = -A \frac{dB}{dt} = \frac{d}{dt} (\mu_0 I)\]
\[\therefore \quad E = \frac{Ai}{2\pi v} d (r^{-1}) \quad \therefore \quad E = Ai \frac{\mu_0}{2\pi v} \frac{1}{r^2}\]
\[\therefore \quad E \approx \frac{1}{I^2}\]

33. (d) : Given that $\rho_1$ is the density of material of solid sphere and $\rho_2$ is density of material of hollow sphere.
Also, $R_{\text{solid}} = R_{\text{hollow}} = R$ (say)
and $M_{\text{solid}} = M_{\text{hollow}}$
\[\mu = \frac{4}{3} \pi \rho_1 R^3\]
\[\therefore \quad \mu = \frac{4}{3} \pi \rho_2 [R^3 - R_{\text{inner}}^3]\]
\[\therefore \quad R^3 - R_{\text{inner}}^3 = \frac{\rho_1}{\rho_2} R^3 \quad \therefore \quad R_{\text{inner}}^3 = R^3 \left[1 - \frac{\rho_1}{\rho_2}\right]^{1/3}\]
\[\therefore \quad R_{\text{inner}} = \left[1 - \frac{\rho_1}{\rho_2}\right]^{1/3}\]
Now, ratio of their moment of inertia about the central axis will be
34. (a): As separation between the plates are decreasing as they approach each other. Also, electric field remains constant between the plates. So, \( V \propto d \) and \( V = E \cdot d \). Force on each plate = \( ma = \frac{q^2}{2AE_0} \).

\[ \therefore \text{ Acceleration, } a = \frac{qE}{2AE_0} \]

Since \( a = \text{constant} \),

\[ \therefore \] \text{d-t graph will be}

So V-t curve \( \therefore V \propto d \)

35. (d): In the given situation the electrostatic force acting on the bob is \( F_e = qE \).

\[ \text{or acceleration } a = \frac{qE}{m} \]

Now effective value of \( g \) is \( g_{\text{effective}} = g - a = g - \frac{qE}{m} \).

\[ \therefore T = 2\pi \sqrt{\frac{L}{g - \frac{qE}{m}}} \quad (\text{using } E = \frac{\sigma}{\varepsilon_0}) \]

36. (b, c, d): It is a case of balanced Wheatstone bridge.

\[ \therefore \frac{200}{300} = \frac{100}{G} \Rightarrow G = 150 \Omega \]

\[ \frac{500 \times 250}{750} = \frac{500}{3} \text{ \Omega} \]

Now, current through galvanometer

\[ \frac{10}{250} = \frac{1}{25} = 0.04 \text{ A} = 40 \text{ mA} \]

After key is closed Wheatstone bridge condition is applied and since 200 \( \Omega \) and 300 \( \Omega \) are in series, therefore current through both will be the same.

37. (a, c): \[ \sin i = \sqrt{\frac{3}{2}} \sin 15^\circ \]

\[ 1 \sin i = \sqrt{\frac{3}{2}} \sin 15^\circ \]

\[ \sin i = \frac{\sqrt{3} - 1}{2} \]

Ray will undergo total internal reflection at \( P \) only.

If ray emerge from \( R \) (partially) it is possible, then it will become parallel to the incident ray.

38. (a, d)

39. (b): In isothermal process, \( \Delta U = 0 \).

In isobaric expansion \( V \propto T \) so \( \Delta U \) increases.

40. (a): Electric potential is minimum

where \( E_{\text{total}} = 0 \).

At equilibrium

\[ \frac{KQ}{x^2} = \frac{K4Q}{(d-x)^2} \Rightarrow \frac{1}{x} = \frac{2}{d-x} \Rightarrow x = \frac{d}{3} \]

\[ \therefore \text{ Total electric field will be zero at } \frac{d}{3} \text{ units, right of } A. \]
1. The energy equivalent to a substance of mass 1 g is
   (a) \(18 \times 10^{13}\) J  (b) \(9 \times 10^{13}\) J  
   (c) \(18 \times 10^6\) J  (d) \(9 \times 10^6\) J

2. The half-life of tritium is 12.5 years. What mass of tritium of initial mass 64 mg will remain undecayed after 50 years?
   (a) 32 mg  (b) 8 mg  (c) 16 mg  (d) 4 mg

3. In a CE amplifier, the input ac signal to be amplified is applied across
   (a) forward biased emitter-base junction  
   (b) reverse biased collector-base junction  
   (c) reverse biased emitter-base junction  
   (d) forward biased collector-base junction

4. If \(A = 1\) and \(B = 0\), then in terms of Boolean algebra, \(A + \overline{B} = \)
   (a) \(B\)  (b) \(\overline{B}\)  (c) \(A\)  (d) \(\overline{A}\)

5. The density of an electron-hole pair in a pure germanium is \(3 \times 10^{16}\) m\(^{-3}\) at room temperature. On doping with aluminium, the hole density increases to \(4.5 \times 10^{22}\) m\(^{-3}\). Now the electron density (in m\(^{-3}\)) in doped germanium will be
   (a) \(1 \times 10^{10}\)  (b) \(2 \times 10^{10}\)  
   (c) \(0.5 \times 10^{10}\)  (d) \(4 \times 10^{10}\)

6. The dc common emitter current gain of a \(n-p-n\) transistor is 50. The potential difference applied across the collector and emitter of a transistor used in CE configuration is \(V_{CE} = 2\) V. If the collector resistance \(R_C = 4\) k\(\Omega\), the base current \((I_B)\) and the collector current \((I_C)\) are
   (a) \(I_B = 10\) mA, \(I_C = 0.5\) mA
   (b) \(I_B = 0.5\) mA, \(I_C = 10\) mA
   (c) \(I_B = 5\) mA, \(I_C = 1\) mA
   (d) \(I_B = 1\) mA, \(I_C = 0.5\) mA

7. The radius of the Earth is 6400 km. If the height of an antenna is 500 m, then its range is
   (a) 800 km  (b) 100 km  (c) 80 km  (d) 10 km

8. A space station is at a height equal to the radius of the Earth. If \(v_E\) is the escape velocity on the surface of the Earth, the same on the space station is _____ times \(v_E\).
   (a) \(\frac{1}{2}\)  (b) \(\frac{1}{4}\)  (c) \(\frac{1}{\sqrt{2}}\)  (d) \(\frac{1}{\sqrt{3}}\)

9. A particle shows distance-time curve as shown in the figure. The maximum instantaneous velocity of the particle is around the point
   (a) \(P\)  (b) \(S\)  (c) \(R\)  (d) \(Q\)

10. Which of the following graphs correctly represents the variation of \(g\) on the Earth?
    (a)  
    (b)  
    (c)  
    (d)

11. A cup of tea cools from 65.5°C to 62.5°C in 1 minute in a room at 22.5°C. How long will it take to cool from 46.5°C to 40.5°C in the same room?
   (a) 4 minutes  (b) 2 minutes  
   (c) 1 minute  (d) 3 minutes

12. The dimensions of the ratio of magnetic flux (\(\phi\)) and permeability (\(\mu\)) are
   (a) \([M^0L^1T^{-1}A^{-1}]\)  (b) \([M^0L^{-3}T^{-1}A^{-1}]\)
   (c) \([M^0L^1T^1A^{-1}]\)  (d) \([M^0L^2T^0A^{-1}]\)
13. A mass $m$ on the surface of the Earth is shifted to a target equal to the radius of the Earth. If $R$ is the radius and $M$ is the mass of the Earth, then work done in this process is
(a) $\frac{mgR}{2}$  (b) $mgR$  (c) $2mgR$  (d) $\frac{mgR}{4}$

14. First overtone frequency of a closed pipe of length $l_1$ is equal to the 2nd harmonic frequency of an open pipe of length $l_2$. The ratio $\frac{l_1}{l_2} = \frac{3}{4}$
(a) $\frac{3}{4}$  (b) $\frac{4}{3}$  (c) $\frac{3}{2}$  (d) $\frac{2}{3}$

15. The resistance $R = \frac{V}{I}$ where $V = (100 \pm 5)$ V and $I = (10 \pm 0.2)$ A. The percentage error in $R$ is
(a) 5.2%  (b) 4.8%  (c) 7%  (d) 3%

16. A block rests on a rough inclined plane making an angle of 30° with the horizontal. The coefficient of static friction between the block and the plane is 0.8. If the frictional force on the block is 10 N, the mass of the block is (g = 10 m s$^{-2}$)
(a) 1 kg  (b) 2 kg  (c) 3 kg  (d) 4 kg

17. Two particles of masses $m_1$ and $m_2$ have equal kinetic energies. The ratio of their momenta is
(a) $m_1 : m_2$  (b) $m_2 : m_1$  (c) $\sqrt{m_1} : \sqrt{m_2}$  (d) $m_1^2 : m_2^2$

18. The pressure at the bottom of a liquid tank is not proportional to the
(a) acceleration due to gravity  (b) density of the liquid  (c) height of the liquid  (d) area of the liquid surface

19. A Carnot engine takes 300 calories of heat from a source at 500 K and rejects 150 calories of heat to the sink. The temperature of the sink is
(a) 125 K  (b) 250 K  (c) 750 K  (d) 1000 K

20. Pressure of an ideal gas is increased by keeping temperature constant. The kinetic energy of molecules
(a) decreases  (b) increases  (c) remains same  (d) increases or decreases depending on the nature of gas

21. A man weighing 60 kg is in a lift moving down with an acceleration of 1.8 m s$^{-2}$. The force exerted by the floor on him is
(a) 588 N  (b) 480 N  (c) zero  (d) 696 N

22. Moment of inertia of a body about two perpendicular axes X and Y in the plane of lamina are 20 kg m$^2$ and 25 kg m$^2$ respectively. Its moment of inertia about an axis perpendicular to the plane of the lamina and passing through the point of intersection of X and Y axes is
(a) 5 kg m$^2$  (b) 45 kg m$^2$  (c) 12.5 kg m$^2$  (d) 500 kg m$^2$

23. Two wires A and B are stretched by the same load. If the area of cross-section of wire A is double that of B, then the stress on B is
(a) equal to that on A  (b) twice that on A  (c) half that on A  (d) four times that on A

24. The magnitude of point charge due to which the electric field 30 cm away has the magnitude 2 N C$^{-1}$ will be
(a) $2 \times 10^{-11}$ C  (b) $3 \times 10^{-11}$ C  (c) $5 \times 10^{-11}$ C  (d) $9 \times 10^{-11}$ C

25. A mass of 1 kg carrying a charge of 2 C is accelerated through a potential of 1 V. The velocity acquired by it is
(a) $\sqrt{2}$ m s$^{-1}$  (b) 2 m s$^{-1}$  (c) $\frac{1}{\sqrt{2}}$ m s$^{-1}$  (d) $\frac{1}{2}$ m s$^{-1}$

26. The force of repulsion between two identical positive charges when kept with a separation $r$ in air is $F$. Half the gap between the two charges is filled by a dielectric slab of dielectric constant = 4. Then the new force of repulsion between those two charges becomes
(a) $\frac{F}{3}$  (b) $\frac{F}{2}$  (c) $\frac{F}{4}$  (d) $\frac{4F}{9}$

27. For the arrangement of capacitors as shown in the circuit, the effective capacitance between the points A and B is
(capacitance of each capacitor is 4 $\mu$F)

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(a) 4 $\mu$F  (b) 2 $\mu$F  (c) 1 $\mu$F  (d) 8 $\mu$F

28. The work done to move a charge on an equipotential surface is
(a) infinity  (b) less than 1  (c) greater than 1  (d) zero
29. Two capacitors of 3 μF and 6 μF are connected in series and a potential difference of 900 V is applied across the combination. They are then disconnected and reconnected in parallel. The potential difference across the combination is
(a) zero (b) 100 V (c) 200 V (d) 400 V
30. Ohm's law is applicable to
(a) diode (b) transistor (c) electrolyte (d) conductor
31. If the last band on the carbon resistor is absent, then the tolerance is
(a) 5% (b) 20% (c) 10% (d) 15%
32. The effective resistance between P and Q for the following network is
\[ R = \frac{1}{\sum \frac{1}{R}} \]
(a) \( \frac{1}{12} \) Ω (b) 21 Ω (c) 12 Ω (d) \( \frac{1}{21} \) Ω
33. Five identical resistors each of resistance \( R = 1500 \) Ω are connected to a 300 V battery as shown in the circuit. The reading of the ideal ammeter \( A \) is
(a) \( \frac{1}{5} \) A (b) \( \frac{3}{5} \) A (c) \( \frac{2}{5} \) A (d) \( \frac{4}{5} \) A
34. Two cells of internal resistances \( r_1 \) and \( r_2 \) and of same emf are connected in series across a resistor of resistance \( R \). If the terminal potential difference across the cell of internal resistance \( r_1 \) is zero, then the value of \( R \) is
(a) \( R = 2(r_1 + r_2) \) (b) \( R = r_2 - r_1 \) (c) \( R = r_1 - r_2 \) (d) \( R = 2(r_1 - r_2) \)
35. The \( I-V \) graphs for two different electrical appliances \( P \) and \( Q \) are shown in the diagram. If \( R_P \) and \( R_Q \) be the resistances of the devices, then
(a) \( R_P = R_Q \) (b) \( R_P > R_Q \) (c) \( R_P < R_Q \) (d) \( R_P = \frac{R_Q}{2} \)
36. The correct Biot-Savart law in vector form is
(a) \( d\vec{B} = \frac{\mu_0}{4\pi} \frac{I(d\vec{l} \times \vec{r})}{r^2} \)
(b) \( d\vec{B} = \frac{\mu_0}{4\pi} \frac{I(d\vec{l}) \times \vec{r}}{r^2} \)
(c) \( d\vec{B} = \frac{\mu_0}{4\pi} \frac{I(d\vec{l})}{r^2} \)
(d) \( d\vec{B} = \frac{\mu_0}{4\pi} \frac{I(d\vec{l})}{r^3} \)
37. An electron is moving in a circle of radius \( r \) in a uniform magnetic field \( B \). Suddenly the field is reduced to \( \frac{B}{2} \). The radius of the circular path now becomes
(a) \( \frac{r}{2} \) (b) \( 2r \) (c) \( \frac{r}{4} \) (d) \( 4r \)
38. A charge \( q \) is accelerated through a potential difference \( V \). It is then passed normally through a uniform magnetic field, where it moves in a circle of radius \( r \). The potential difference required to move it in a circle of radius \( 2r \) is
(a) \( 2V \) (b) \( 4V \) (c) \( 1V \) (d) \( 3V \)
39. A cyclotron's oscillator frequency is 10 MHz and the operating magnetic field is 0.66 T. If the radius of its dees is 60 cm, then the kinetic energy of the proton beam produced by the accelerator is
(a) 9 MeV (b) 10 MeV (c) 7 MeV (d) 11 MeV
40. Needles \( N_1, N_2 \) and \( N_3 \) are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will
(a) attract all three of them (b) attract \( N_1 \) strongly, \( N_2 \) weakly and repel \( N_3 \) weakly (c) attract \( N_1 \) strongly but repel \( N_2 \) and \( N_3 \) weakly (d) attract \( N_1 \) and \( N_2 \) strongly but repel \( N_3 \)
41. The strength of the Earth's magnetic field is
   (a) constant everywhere
   (b) zero everywhere
   (c) having very high value
   (d) varying from place to place on the Earth's surface

42. A jet plane having a wing-span of 25 m is travelling horizontally towards east with a speed of 3600 km/hour. If the Earth's magnetic field at the location is $4 \times 10^{-4}$ T and the angle of dip is 30°, then the potential difference between the ends of the wing is
   (a) 4 V  (b) 5 V  (c) 2 V  (d) 2.5 V

43. Which of the following represents the variation of inductive reactance ($X_L$) with the frequency of voltage source ($v$)?

44. The magnetic flux linked with a coil varies as $\phi = 3t^2 + 4t + 9$. The magnitude of the emf induced at $t = 2$ seconds is
   (a) 8 V  (b) 16 V  (c) 32 V  (d) 64 V

45. A 100 W bulb is connected to an AC source of 220 V, 50 Hz. Then the current flowing through the bulb is
   (a) $\frac{5}{11}$ A  (b) $\frac{1}{2}$ A  (c) 2 A  (d) $\frac{3}{4}$ A

46. In the series LCR circuit, the power dissipation is through
   (a) $R$  (b) $L$
   (c) $C$  (d) both $L$ and $C$

47. In Karnataka, the normal domestic power supply AC is 220 V, 50 Hz. Here 220 V and 50 Hz refer to
   (a) peak value of voltage and frequency
   (b) rms value of voltage and frequency
   (c) mean value of voltage and frequency
   (d) peak value of voltage and angular frequency

48. A step-up transformer operates on a 230 V line and a load current of 2 A. The ratio of primary and secondary windings is 1 : 25. Then the current in the primary is
   (a) 25 A  (b) 50 A  (c) 15 A  (d) 12.5 A

49. The number of photons falling per second on a completely darkened plate to produce a force of $6.62 \times 10^{-5}$ N is $n$. If the wavelength of the light falling is $5 \times 10^{-7}$ m, then $n = \_ \_ \_ \_ \times 10^{22}$.
   $(h = 6.62 \times 10^{-34}$ J s
   (a) 1  (b) 5  (c) 0.2  (d) 3.3

50. An object is placed at the principal focus of a convex mirror. The image will be at
   (a) centre of curvature
   (b) principal focus
   (c) infinity
   (d) no image will be formed

51. An object is placed at a distance of 20 cm from the pole of a concave mirror of focal length 10 cm. The distance of the image formed is
   (a) +20 cm  (b) +10 cm  (c) −20 cm  (d) −10 cm

52. A candle placed 25 cm from a lens forms an image on a screen placed 75 cm on the other side of the lens. The focal length and type of the lens should be
   (a) +18.75 cm and convex lens
   (b) −18.75 cm and concave lens
   (c) +20.25 cm and convex lens
   (d) −20.25 cm and concave lens

53. A plane wavefront of wavelength $\lambda$ is incident on a single slit of width $a$. The angular width of principal maximum is
   (a) $\frac{\lambda}{a}$  (b) $\frac{2\lambda}{a}$  (c) $\frac{a}{\lambda}$  (d) $\frac{a}{2\lambda}$

54. In a Fraunhoffer diffraction at a single slit, if yellow light illuminating the slit is replaced by blue light, then diffraction bands
   (a) remain unchanged  (b) become wider
   (c) disappear  (d) become narrower

55. In Young's double slit experiment, two wavelengths $\lambda_1 = 780$ nm and $\lambda_2 = 520$ nm are used to obtain interference fringes. If the $n$th bright band due to $\lambda_1$ coincides with $(n + 1)^{th}$ bright band due to $\lambda_2$, then the value of $n$ is
   (a) 4  (b) 3  (c) 2  (d) 6

56. In Young's double slit experiment, slits are separated by 2 mm and the screen is placed at a distance of 1.2 m from the slits. Light consisting of two wavelengths 6500 Å and 5200 Å are used to obtain interference fringes. Then the separation between the fourth bright fringes of two different patterns produced by the two wavelengths is
57. The maximum kinetic energy of emitted photoelectrons depends on
(a) intensity of incident radiation
(b) frequency of incident radiation
(c) speed of incident radiation
(d) number of photons in the incident rotation

58. A proton and an α particle are accelerated through the same potential difference V. The ratio of their de Broglie wavelengths is
(a) \( \sqrt{2} \)  (b) \( 2\sqrt{2} \)  (c) \( \sqrt{3} \)  (d) \( 2\sqrt{3} \)

59. The total energy of an electron revolving in the second orbit of a hydrogen atom is
(a) -13.6 eV  (b) -1.51 eV  (c) -3.4 eV  (d) zero

60. The period of revolution of an electron in the ground state of hydrogen atom is \( T \). The period of revolution of the electron in the first excited state is
(a) 2\( T \)  (b) 4\( T \)  (c) 6\( T \)  (d) 8\( T \)

1. (b): Here, Mass, \( m = 1 \text{ g} = 10^{-3} \text{ kg} \)
   According to Einstein's mass-energy relation, the energy equivalent of mass \( m \) is
   \[ E = mc^2 \text{ (where } c \text{ is the speed of light in vacuum)} \]
   \[ = (10^{-3} \text{ kg})(3 \times 10^8 \text{ m s}^{-1})^2 \]
   \[ = 10^{-3} \times 9 \times 10^{16} \text{ J} = 9 \times 10^{13} \text{ J} \]

2. (d): Here, Half-life of tritium, \( T_{1/2} = 12.5 \text{ years} \)
   Initial mass of tritium, \( m_0 = 64 \text{ mg} \)
   Time, \( t = 50 \text{ years} \)
   Mass of tritium remained undecayed after 50 years is
   \[ m = m_0 \left( \frac{1}{2} \right)^{30 \text{ years/12.5 years}} \]
   \[ = (64 \text{ mg}) \left( \frac{1}{2} \right)^4 = 64 \text{ mg} \left( \frac{1}{16} \right) = 4 \text{ mg} \]

3. (a): In a CE amplifier, the input ac signal to be amplified is applied across forward biased emitter-base junction.

4. (b,c): In terms of Boolean algebra, if \( A = 1 \) and \( B = 0 \),
   \[ A + \bar{B} = 1 + 0 = 1 \]
   \[ A \bar{B} = A \text{ or } \bar{B} \]

5. (b): In pure germanium, \( n_i = n_e = n_h = 3 \times 10^{16} \text{ m}^{-3} \)
   In doped germanium, \( n_i^2 = n_e n_h \)

\[ \therefore \quad n_e \frac{n_i}{n_h} = \left( \frac{3 \times 10^{16} \text{ m}^{-3}}{4.5 \times 10^{22} \text{ m}^{-3}} \right)^2 = 9 \times 10^{32} \]
\[ = 2 \times 10^{10} \text{ m}^{-3} \]
Thus, the electron density in doped germanium will be \( 2 \times 10^{10} \text{ m}^{-3} \).

6. (a): Here,
   dc current gain, \( \beta_{dc} = 50 \)
   Voltage across collector and emitter, \( V_{CE} = 2 \text{ V} \)
   Collector resistance, \( R_C = 4 \text{ k} \Omega = 4 \times 10^3 \text{ } \Omega \)
   As \( V_{CE} = I_C R_C \)
   \[ \therefore \quad I_C = \frac{V_{CE}}{R_C} = \frac{2 \text{ V}}{4 \times 10^3 \text{ } \Omega} = 0.5 \times 10^{-3} \text{ A} \]
   \[ = 0.5 \text{ mA (as } 1 \text{ mA} = 10^{-3} \text{ A)} \]
   and \( \beta_{dc} = \frac{I_C}{I_B} \)
   \[ \therefore \quad I_B = I_C = \frac{0.5 \times 10^{-3} \text{ A}}{50} = 1 \times 10^{-5} \text{ A} \]
   \[ = 10 \times 10^{-6} \text{ A} = 10 \mu\text{A (as } 1 \mu\text{A} = 10^{-6} \text{ A)} \]

7. (c): Here,
   Radius of the Earth, \( R = 6400 \text{ km} = 64 \times 10^5 \text{ m} \)
   Height of the antenna, \( h = 500 \text{ m} \)
   The range \( d \) is
   \[ d = \sqrt{2Rh} \]
   \[ = \sqrt{2(64 \times 10^5 \text{ m})(500 \text{ m})} = \sqrt{64 \times 10^8 \text{ m}^2} \]
   \[ = 8 \times 10^4 \text{ m} = 80 \text{ km} \]

8. (c): The escape velocity on the surface of the Earth is
   \[ v_E = \sqrt{\frac{2GM}{R}} \]
   where \( M \) and \( R \) are the mass and radius of the Earth respectively.
   As the space station is at a height \( h \) from the surface of the earth, its distance from the centre of the earth is \( (R + h) \).
   Thus, the escape velocity on the space station is
   \[ v_s = \sqrt{\frac{2GM}{(R + h)}} = \sqrt{\frac{2GM}{R + h}} = \sqrt{\frac{2GM}{2R}} \quad \text{(as } h = R) \]
   \[ = \frac{1}{\sqrt{2}} \left( \sqrt{\frac{2GM}{R}} \right) = \frac{v_E}{\sqrt{2}} \]

9. (c): The slope of the tangent to the curve at a point gives the instantaneous velocity. Thus, the maximum instantaneous velocity of the particle is around the point \( R \).
10. (b): The variation of \( g \) with distance \( r \) from the centre of the Earth is as follows:

For \( r < R \),
\[
g = \frac{GMr}{R^3} \text{ or } g \propto \frac{1}{r^2}
\]

For \( r \geq R \),
\[
g = \frac{GM}{r^2} \text{ or } g \propto \frac{1}{r^2}
\]

Thus, graph (b) correctly represents the variation of \( g \) on the Earth as shown in the figure above.

11. (a): According to Newton's law of cooling,
\[
\frac{T_1 - T_2}{t} = K \left( \frac{T_1 + T_2}{2} - T_s \right)
\]
where \( T_s \) is the temperature of surroundings.

For the first case,
\[
T_1 = 65.5^\circ C, \quad T_2 = 62.5^\circ C, \quad T_s = 22.5^\circ C, \quad t = 1 \text{ min}
\]
\[
\frac{65.5^\circ C - 62.5^\circ C}{1 \text{ min}} = K \left( \frac{65.5^\circ C + 62.5^\circ C}{2} - 22.5^\circ C \right)
\]
\[
3^\circ C = K(41.5^\circ C)
\]
... (i)

For the second case,
\[
T_1 = 46.5^\circ C, \quad T_2 = 40.5^\circ C, \quad T_s = 22.5^\circ C, \quad t = ?
\]
\[
\frac{46.5^\circ C - 40.5^\circ C}{t} = K \left( \frac{46.5^\circ C + 40.5^\circ C}{2} - 22.5^\circ C \right)
\]
\[
6^\circ C = K(21^\circ C)
\]
... (ii)

Dividing eqn. (i) by eqn. (ii), we get
\[
\frac{\frac{3^\circ C}{1 \text{ min}}}{\frac{6^\circ C}{t}} = \frac{K(41.5^\circ C)}{K(21^\circ C)} \quad \text{or} \quad \frac{t}{2 \text{ min}} = 1.98
\]

or \( t = 3.96 \text{ min} = 4 \text{ min} \)

12. (a): As \( [\phi] = [ML^2T^{-2}A^{-1}] \) and \( [\mu] = [MLT^{-2}A^{-2}] \)
\[
\therefore \frac{[\phi]}{[\mu]} = \frac{[ML^2T^{-2}A^{-1}]}{[MLT^{-2}A^{-2}]} = [M^0L^1T^0A^1]
\]

13. (a): Gravitational potential energy of the mass \( m \) on the surface of the Earth is
\[
U_i = -\frac{GMm}{R}
\]
and that at a target at a height \( h (= R) \) from the surface of the Earth is
\[
U_f = -\frac{GMm}{R + h} = -\frac{GMm}{R + R} = -\frac{GMm}{2R}
\]
\therefore\ Work done in shifting the mass from the surface of the Earth to the target is

\[
W = U_f - U_i = -\frac{GMm}{2R} - \left( -\frac{GMm}{R} \right)
\]
\[
= -\frac{GMm}{2R} + \frac{GMm}{R} = \frac{GMm}{R} \left( 1 - \frac{1}{2} \right)
\]
\[
= \frac{GMm}{2R} \quad \text{(as } g = \frac{GM}{R^2})
\]

14. (a): First overtone frequency (i.e., 3rd harmonic) of the closed pipe of length \( l_1 \) is
\[
v_c = \frac{3v}{4l_1} \quad \text{(where } v \text{ is the speed of sound in air)}
\]
and 2nd harmonic frequency of the open pipe of length \( l_2 \) is
\[
v_o = \frac{2v}{l_2}
\]
As per question \( v_c = v_o \)
\[
\therefore \frac{3v}{4l_1} = \frac{2v}{l_2} \quad \text{or} \quad \frac{l_1}{l_2} = \frac{3}{4}
\]

15. (c): Here, \( V = (100 \pm 5) \text{ V} \) and \( I = (10 \pm 0.2) \text{ A} \)

As \( R = \frac{V}{I} \) \quad \therefore \quad \frac{\Delta R}{R} = \Delta \frac{V}{V} + \Delta \frac{I}{I}

The percentage error in \( R \) is
\[
\frac{\Delta R}{R} \times 100 = \left( \frac{\Delta V}{V} + \frac{\Delta I}{I} \right) \times 100
\]
\[
= \left( \frac{5 \text{ V}}{100 \text{ V}} + \frac{0.2 \text{ A}}{10 \text{ A}} \right) \times 100
\]
\[
= 0.05 + 0.02 \times 100 = 7%\]

16. (b): Here,
Angle of inclination, \( \theta = 30^\circ \)
Coefficient of static friction between block and plane, \( \mu_s = 0.8 \)
Frictional force on the block, \( f = 10 \text{ N} \)
Let the mass of the block be \( m \).
The various forces acting on the block are shown in the figure below.

As the block is resting on the plane,
\[
\therefore \quad f = mg \sin \theta
\]
or \( m = \frac{f}{g \sin \theta} = \frac{10 \text{ N}}{(10 \text{ m/s}^2) \sin 30^\circ} = 2 \text{ kg} \)
17. (c): The kinetic energy $K$ and momentum $p$ of a particle are related by the relation

$$ K = \frac{p^2}{2m} $$

where $m$ is the mass of the particle.

So $K_1 = \frac{p_1^2}{2m_1}$ and $K_2 = \frac{p_2^2}{2m_2}$

But as per question $K_1 = K_2$

$$ \therefore \frac{p_1^2}{2m_1} = \frac{p_2^2}{2m_2} \quad \text{or} \quad \frac{p_1^2}{m_1} = \frac{p_2^2}{m_2} \quad \text{or} \quad \frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}} $$

18. (d): The pressure at the bottom of a liquid tank is $P = P_{\text{atm}} + \rho gh$

where,

$P_{\text{atm}}$ = atmospheric pressure
\[ \rho = \text{density of the liquid} \]
\[ g = \text{acceleration due to gravity} \]
\[ h = \text{height of the liquid} \]

Thus, it is independent of the area of the liquid surface.

19. (b): Here,

Temperature of the source, $T_1 = 500$ K
Heat taken from the source, $Q_1 = 300$ cal
Heat rejected to the sink, $Q_2 = 150$ cal

Temperature of the sink, $T_2 = 250$ K

As $\frac{T_1}{T_2} = \frac{Q_1}{Q_2} \quad \therefore \frac{T_2}{T_1} = \frac{Q_2}{Q_1}$

or $T_2 = \left( \frac{150 \text{ cal}}{300 \text{ cal}} \right) (500 \text{ K}) = 250$ K

20. (c): The kinetic energy of molecules of an ideal gas is

$$ E = \frac{3}{2} Nk_BT $$

where $N$ is the number of molecules, $k_B$ is the Boltzmann constant and $T$ is the temperature of the gas.

From the above expression it is clear that $E$ depends on the temperature but not on the pressure, volume and nature of the gas.

Thus, on increasing the pressure by keeping the temperature constant, the kinetic energy of molecules remains same.

21. (b): Here,

Mass of the man, $m = 60$ kg
Acceleration of the lift, $a = 1.8$ m s$^{-2}$

As the lift moving down with acceleration $a$, the force exerted by the floor on the man is

$$ N = mg - ma = m(g-a) $$

$$ = (60 \text{ kg})(9.8 \text{ m s}^{-2} - 1.8 \text{ m s}^{-2}) $$

$$ = (60 \text{ kg})(8.0 \text{ m s}^{-2}) = 480 \text{ N} $$

22. (b): Here,

Moment of inertia of the body about $X$ axis, $I_X = 20$ kg m$^2$ and about $Y$ axis, $I_Y = 25$ kg m$^2$

By the theorem of perpendicular axes, the moment of inertia of the body about the given axis (i.e., $Z$ axis) is

$$ I_Z = I_X + I_Y = (20 + 25) \text{ kg m}^2 = 45 \text{ kg m}^2 $$

23. (b): As both wires $A$ and $B$ are stretched by the same load (say $W$),

Stress on $A$ is

$$ (\text{stress})_A = \frac{W}{A_A} $$

and that on $B$ is

$$ (\text{stress})_B = \frac{W}{A_B} $$

where $A_A$ and $A_B$ are the areas of cross-section of wires $A$ and $B$ respectively.

Thus, $\frac{(\text{stress})_B}{(\text{stress})_A} = \frac{A_A}{A_B}$

But as per question $A_A = 2A_B$

$$ \therefore (\text{stress})_B = 2(\text{stress})_A $$

24. (a): The magnitude of electric field due to a point charge $q$ at a distance $r$ from the charge is

$$ E = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} $$

Here, $E = 2 \text{ N C}^{-1}$, $r = 30 \text{ cm} = 0.3 \text{ m}$,

$$ \frac{1}{4\pi \varepsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \quad q = ? $$

$$ \therefore 2 \text{ N C}^{-1} = \left( 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \right) q $$

or $q = \left( \frac{2 \text{ N C}^{-1}}{9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}} \right) (0.09 \text{ m}^2) = 2 \times 10^{-11} \text{ C}$

Thus, the magnitude of point charge will be $2 \times 10^{-11} \text{ C}$.

25. (b): Here, $q = 2 \text{ C}$, $m = 1 \text{ kg}$, $V = 1 \text{ V}$

Let the velocity acquired by the mass be $v$. Then

$$ \frac{1}{2} mv^2 = qV $$

or $v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2(2 \text{ C})(1 \text{ V})}{1 \text{ kg}}} = 2 \text{ m s}^{-1}$
26. (d): Let \( q \) be each charge.

According to Coulomb's law, the force of repulsion between the two charges when kept in air is

\[
F = \frac{1}{4\pi\varepsilon_0} \frac{q^2}{r^2}
\]

When half of the gap between the two charges is filled with the dielectric slab of dielectric constant \( K(=4) \), the new force of repulsion between them becomes

\[
F' = \frac{1}{4\pi\varepsilon_0} \frac{q^2}{(r-t) + t\sqrt{K}}
\]

where \( t \) is the thickness of the slab

\[
= \frac{1}{4\pi\varepsilon_0} \frac{q^2}{\left(\frac{r}{2} + \frac{t}{2}\sqrt{4}\right)^2}
\]

\[
= \frac{1}{4\pi\varepsilon_0} \frac{q^2}{\left(\frac{r}{2} + \frac{t}{2}\right)^2}
\]

\[
= \frac{4}{9} \frac{q^2}{4\pi\varepsilon_0 \frac{r}{2}^2} = \frac{4F}{9}
\]

27. (a):

The given circuit can be redrawn as shown in figure (ii).

As \( \frac{4 \, \mu F}{4 \, \mu F} = \frac{4 \, \mu F}{4 \, \mu F} \)

Therefore, the given circuit is a balanced Wheatstone bridge and the capacitance in arm CD is ineffective.

Thus, it reduces to the equivalent circuit as shown in figure (iii).

As \( 4 \, \mu F \) and \( 4 \, \mu F \) are in series in the upper branch, so their equivalent capacitance \( C_1 \) is

\[
C_1 = \frac{(4 \, \mu F)(4 \, \mu F)}{4 \, \mu F + 4 \, \mu F} = 2 \, \mu F
\]

Similarly, \( 4 \, \mu F \) and \( 4 \, \mu F \) are in series in the lower branch, so their equivalent capacitance \( C_2 \) is

\[
C_2 = \frac{(4 \, \mu F)(4 \, \mu F)}{4 \, \mu F + 4 \, \mu F} = 2 \, \mu F
\]

And the corresponding equivalent circuit is shown in figure (iv).

Since \( C_1 \) and \( C_2 \) are in parallel, the effective capacitance between the points \( A \) and \( B \) is

\[
C_{AB} = C_1 + C_2 = 2 \, \mu F + 2 \, \mu F = 4 \, \mu F
\]

28. (d): Potential difference between any two points on an equipotential surface, i.e., \( \Delta V = 0 \).

Thus, the work done to move a charge \( q \) on it is

\[
W = q\Delta V = 0
\]

29. (d): Let \( V_1 \) and \( V_2 \) be the voltages across \( 3 \, \mu F \) and \( 6 \, \mu F \) capacitors respectively as shown in the figure. Then

\[
V_1 + V_2 = 900 \, V
\]

As \( 3 \, \mu F \) and \( 6 \, \mu F \) capacitors are series, charges on each is the same.

\[
\therefore \ C_1V_1 = C_2V_2
\]

or \( \frac{V_1}{C_1} = \frac{V_2}{C_2} = \frac{6 \, \mu F}{3 \, \mu F} = 2 \)

or \( V_1 = 2V_2 \)

Substituting this value of \( V_1 \) in eqn. (i), we get

\[
2V_2 + V_2 = 900 \, V
\]

or \( V_2 = \frac{900 \, V}{3} = 300 \, V
\]

From eqn. (i)

\[
V_1 = 900 \, V - V_2 = 900 \, V - 300 \, V = 600 \, V
\]

Now they are disconnected and reconnected in parallel.

Let the potential difference across the combination be \( V \). Then

\[
V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2} = \frac{(3 \, \mu F)(600 \, V) + (6 \, \mu F)(300 \, V)}{3 \, \mu F + 6 \, \mu F}
\]

\[
= \frac{3600}{9} \, V = 400 \, V
\]

30. (d): Ohm’s law is applicable to conductor because \( V-I \) relationship is linear for conductor.

31. (b): The last band on the carbon resistor stands for tolerance. If it is absent, then the tolerance is 20%.

32. (c): In the given circuit, \( 3 \, \Omega \) and \( 3 \, \Omega \) are in series and this combination is in parallel with \( 6 \, \Omega \). Their equivalent resistance
33. (b): In the given circuit, all the five resistors are connected in parallel to 300 V battery. Therefore, the potential difference across each resistor is

\[ V = 300 \text{ V} \]

and by Ohm's law current through each resistor is

\[ I = \frac{V}{R} = \frac{300 \text{ V}}{1500 \Omega} = \frac{1}{5} \text{ A} \]

Since the three resistors are connected to the right of ammeter, hence the reading of the ideal ammeter A

\[ A = 3I = 3 \left( \frac{1}{5} \right) = \frac{3}{5} \text{ A} \]

34. (c): Let the emf of each cell be \( \varepsilon \).
The cells are connected in series across \( R \) as shown in figure.

Since the cells are in series, so their equivalent emf is

\[ \varepsilon_{\text{eq}} = \varepsilon + \varepsilon = 2\varepsilon \]

and their equivalent internal resistance is

\[ r_{\text{eq}} = r_1 + r_2 \]

The current in the circuit is

\[ I = \frac{\varepsilon_{\text{eq}}}{r_{\text{eq}} + R} = \frac{2\varepsilon}{r_1 + r_2 + R} \]  \( \cdots \)(i)

The terminal potential difference across the cell of internal resistance \( r_1 \) is

\[ V_1 = \varepsilon - Ir_1 \]

But as per question \( V_1 = 0 \)

\[ \therefore 0 = \varepsilon - Ir_1 \quad \text{or} \quad I = \frac{\varepsilon}{r_1} \]  \( \cdots \)(ii)

Equating eqns. (i) and (ii), we get

\[ \frac{2\varepsilon}{r_1 + r_2 + R} = \frac{\varepsilon}{r_1} \quad \text{or} \quad 2r_1 = r_1 + r_2 + R \]

or \( R = 2r_1 - r_1 - r_2 = r_1 - r_2 \)

35. (b): The slope of \( I-V \) graph gives the reciprocal of resistance.

i.e., \( \tan \theta = \frac{1}{R} \)

where \( \theta \) is the angle which the line makes with the \( V \)-axis.

36. (b): The Biot-Savart law in vector form is

\[ d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I(\mathbf{d} \times \mathbf{r})}{r^3} \]

37. (b): As the electron is moving in the circle of radius \( r \) in the uniform magnetic field \( B \),

\[ \therefore \frac{mv^2}{r} = evB \quad \text{or} \quad r = \frac{mv}{eB} \]

where \( m \) and \( v \) is the mass and velocity of the electron respectively.

When the field reduces to \( \frac{B}{2} \), the radius of circular path becomes

\[ r' = \frac{mv}{eB} = 2 \left( \frac{mv}{eB} \right) = 2r \]

38. (b): If \( v \) is the velocity acquired by the charge when accelerated through the potential difference \( V \), then

\[ \frac{1}{2}mv^2 = qV \quad \text{or} \quad v = \sqrt{\frac{2qV}{m}} \]

When it passes normally through a uniform magnetic field \( B \), it moves in the circle of radius \( r \).

\[ \therefore \frac{mv^2}{r} = qB \]

or \( r = \frac{mv}{qB} = qB \sqrt{\frac{2qV}{m}} = \frac{B}{2m} \)

or \( V = \frac{B^2q^2r^2}{2m} \)  \( \cdots \)(i)

Let \( V' \) be the required potential difference in order to move it in the circle of \( 2r \).

From eqn. (i),

\[ V' = \frac{B^2q(2r)^2}{2m} = 4 \left( \frac{B^2q^2r^2}{2m} \right) = 4V \]

39. (c): Here,

Oscillator frequency, \( \nu = 10 \text{ MHz} = 10^6 \text{ Hz} \)

Radius of the dees, \( R = 60 \text{ cm} = 0.6 \text{ m} \)

Magnetic field, \( B = 0.66 \text{ T} \)

Charge on the proton, \( q = 1.6 \times 10^{-19} \text{ C} \)

Mass of the proton, \( m = 1.67 \times 10^{-27} \text{ kg} \)

The kinetic energy of the proton beam produced by the accelerator is
40. (b): A ferromagnetic substance is strongly attracted, a paramagnetic substance is weakly attracted and a diamagnetic substance is weakly repelled by a magnet. Thus, a magnet when brought close to needles $N_1$, $N_2$ and $N_3$ will attract $N_1$ strongly, $N_2$ weakly and repel $N_3$ weakly.

41. (d): The strength of the Earth’s magnetic field varies from place to place on the Earth’s surface.

42. (b): Here,
- Wing-span, $l = 25$ m
- Speed of the plane, $v = 3600$ km h$^{-1}$
  
  \[ v = \frac{3600 \times \frac{5}{18}}{m} \text{ s}^{-1} = 1000 \text{ m s}^{-1} \]
- Earth’s magnetic field, $B = 4 \times 10^{-4}$ T
- Angle of dip, $\delta = 30^\circ$
- As the plane is moving horizontally to the east, it will cut the vertical component of the Earth’s magnetic field which is given by
  
  \[ B_V = B \sin \delta = (4 \times 10^{-4} \text{ T}) \sin 30^\circ = (4 \times 10^{-4} \text{ T}) \times \frac{1}{2} \]
- The potential difference (i.e., induced emf) developed at the ends of the wing is
  
  \[ e = B_V l v = (2 \times 10^{-4} \text{ T})(25 \text{ m})(1000 \text{ m s}^{-1}) = 5 \text{ V} \]

43. (a): The inductive reactance is

\[ X_L = \frac{2\omega L}{\omega} = 2\pi \omega L \text{ (as } \omega = 2\pi \text{)} \]

As $X_L \propto v$, the graph between $X_L$ and $v$ is a straight line.

Thus, option (a) represents the variation of $X_L$ with $v$.

44. (b): The magnitude of induced emf is

\[ |e| = \frac{d\phi}{dt} = \frac{d}{dt} (3t^2 + 4t + 9) = 6t + 4 \]

At $t = 2$ s,

\[ |e| = 6(2) + 4 = 16 \text{ V} \]

45. (a): Here,
- Power of the bulb, $P = 100$ W
- rms value of voltage, $V_{rms} = 220$ Hz
- Frequency of AC source, $v = 50$ Hz
- The current flowing through the bulb is

\[ I_{rms} = \frac{P}{V_{rms}} = \frac{100 \text{ W}}{220 \text{ V}} = \frac{10}{22} \text{ A} \]

46. (a): In the series LCR circuit, the power dissipation is through $R$ only.

47. (b): 220 V and 50 Hz refer to rms value of voltage and frequency.

48. (b): Here, $V_p = 230$ V, $I_s = 2$ A. \[ \frac{N_p}{N_s} = \frac{1}{25} \]

For an ideal transformer, \[ \frac{I_p}{I_s} = \frac{N_s}{N_p} \]

\[ I_p = \left( \frac{N_s}{N_p} \right) I_s = \left( \frac{25}{1} \right) (2 \text{ A}) = 50 \text{ A} \]

Thus, the current in the primary is 50 A.

49. (b): If $\lambda$ is the wavelength of the light falling, then momentum of each photon

\[ = \frac{h}{\lambda} \text{ (where } h \text{ is the Planck's constant)} \]

As $n$ photons falling per second on the plate, the total momentum of all the photons falling per second on the plate

\[ = \frac{nh}{\lambda} \]

Since the plate is completely darkened, all the photons absorbed by it.

\[ \therefore \text{ Rate of change of momentum of photons is} \]

\[ \frac{dp}{dt} = \frac{nh}{\lambda} \]

By Newton’s second law, force on the plate is

\[ F = \frac{dp}{dt} = \frac{nh}{\lambda} \]

or \[ n = \frac{F \lambda}{h} = (6.62 \times 10^{-34} \text{ N})(5 \times 10^{-7} \text{ m}) = 5 \times 10^{22} \]

50. (c, d)

51. (c): Here, as per the Cartesian sign convention, Object distance, $u = -20$ cm
- Focal length of the mirror, $f = -10$ cm

According to mirror formula

\[ \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \]

\[ \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \]

\[ \frac{1}{u} + \frac{1}{v} = -2 + \frac{1}{20} \]

or \[ \frac{1}{v} = -20 \]

or \[ v = -20 \text{ cm} \]

52. (a): Here, as per the Cartesian sign convention, Object distance, $u = -25$ cm
Image distance, \( v = +75 \) cm \( (\text{as image is real}) \)
According to thin lens formula
\[
\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{+75} - \frac{1}{-25} = \frac{1}{75} + \frac{1}{25}
\]
\[
= \frac{1 + 4}{75} = \frac{5}{75} = \frac{1}{15}
\]
\( \text{or } f = -75 \) cm
Since \( f \) is positive, the lens should be convex lens.

53. (b): If \( \beta \) is the half angular width of principal
maximum, then
\[
\beta = \frac{\lambda}{a}
\]
Thus, the angular width of principal maximum
\[
= 2\beta = \frac{2\lambda}{a}
\]

54. (d): Width of diffraction bands is directly
proportional to the wavelength of light used.
Thus, if yellow light is replaced by blue light,
diffraction bands become narrower because
\( \lambda_{\text{blue}} < \lambda_{\text{yellow}} \)

55. (c): As \( n^{th} \) bright band due to \( \lambda_1 \) coincides with \( (n + 1)^{th} \) bright band due to \( \lambda_2 \),
\[
\therefore \quad \frac{n\lambda_1 D}{d} = \frac{(n+1)\lambda_2 D}{d}
\]
or
\[
\frac{n\lambda_1}{n+1} = \frac{\lambda_2}{\lambda_1}
\]
or
\[
\frac{n}{n+1} = \frac{520 \text{ nm}}{780 \text{ nm}} = \frac{2}{3}
\]
or
\( 3n = 2n + 2 \) or \( 3n - 2n = 2 \) or \( n = 2 \)

56. (a): Here,
Distance between the slits, \( d = 2 \) mm \( = 2 \times 10^{-3} \) m
Distance of the screen from the slits, \( D = 1.2 \) m
Wavelengths,
\( \lambda_1 = 6500 \) Å \( = 6500 \times 10^{-10} \) m \( = 6.5 \times 10^{-7} \) m
and \( \lambda_2 = 5200 \) Å \( = 5200 \times 10^{-10} \) m \( = 5.2 \times 10^{-7} \) m
Distance of \( n^{th} \) bright fringe from the centre bright fringe is
\[
x_n = \frac{n\lambda_1 D}{d}
\]
\( \ldots \text{(i)} \)
If \( x_4 \) and \( x'_4 \) be the distances of the fourth bright
fringes of wavelengths \( \lambda_1 \) and \( \lambda_2 \) respectively, then
from eqn. (i)
\[
x_4 = \frac{4\lambda_1 D}{d} \quad \text{and} \quad x'_4 = \frac{4\lambda_2 D}{d}
\]
Thus, the separation between them is
\[
\Delta x = x_4 - x'_4 = \frac{4\lambda_1 D}{d} - \frac{4\lambda_2 D}{d}
\]
\[
= \frac{4(D(\lambda_1 - \lambda_2))}{d}
\]
\[
= \frac{4(1.2 \text{ m})(6.5 \times 10^{-7} \text{ m} - 5.2 \times 10^{-7} \text{ m})}{(2 \times 10^{-3} \text{ m})}
\]
\[= 3.12 \times 10^{-3} \text{ m} = 0.312 \times 10^{-3} \text{ m} = 0.312 \text{ mm} \]

57. (b): According to Einstein’s photoelectric equation,
\( K_{\text{max}} = h\nu - \phi_0 \)
where \( \nu \) is the frequency of incident radiation and \( \phi_0 \) is the work function of a metal.
Thus, the maximum kinetic energy \( (K_{\text{max}}) \) of
emitted photoelectrons depends on frequency of
incident radiation but not on its intensity and speed
and number of photons in the incident radiation.

58. (b): de Broglie wavelength of a particle of mass \( m \) and
charge \( q \) accelerated through a potential difference \( V \) is
\[
\lambda = \frac{h}{\sqrt{2mqV}}
\]
Since potential difference \( V \) is the same for both the
particles,
\[
\lambda = \frac{h}{\sqrt{mq}}
\]
Thus,
\[
\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_{\alpha} \ell_{\alpha}}{m_p \ell_p}} = \sqrt{\frac{4m_p}{m_\alpha \ell_\alpha}} = \frac{\sqrt{8}}{1} = 2\sqrt{2}
\]

59. (c): The total energy of an electron revolving in
the \( n^{th} \) orbit of hydrogen atom is
\[
E_n = -\frac{13.6}{n^2} \text{ eV}
\]
For the second orbit, \( n = 2 \)
\[
\therefore \quad E_2 = -\frac{13.6}{2^2} = -3.4 \text{ eV}
\]

60. (d): The period of revolution of an electron in \( n^{th} \)
orbit of hydrogen atom is
\[
T_n = \frac{2\pi n}{v_n} = \frac{4\pi^2 \hbar^2 n^3}{me^2}
\]
or
\[
T_n \propto n^3 \quad \text{or} \quad \frac{T_n}{T_1} = 8 \quad \text{or} \quad T_2 = 8T_1
\]
For ground state, \( n = 1 \)
and for first excited state, \( n = 2 \)
\[
\therefore \quad \frac{T_2}{T_1} = \frac{8}{1} \quad \text{or} \quad T_2 = 8T_1
\]
But as per question \( T_1 = T \)
\[
\therefore \quad T_2 = 8T
\]
1. Due to atmospheric refraction effects, the day becomes longer by
   (a) 4 minutes    (b) 0 minute
   (c) 2 minutes    (d) 1 minute
2. The molecule of a monatomic gas has
   (a) Only one translational degree of freedom
   (b) Only two translational degrees of freedom
   (c) Only three translational degrees of freedom
   (d) No translational degrees of freedom at all
3. The device or substances which do not obey Ohm’s law are
   (a) Copper     (b) Crystal rectifiers
   (c) Iron       (d) Resistors
4. A cyclist comes to a skidding stop in 10 m. During this process, the force on the cycle due to the road is 200 N and is directly opposed to the motion. How much work does the road do on the cycle?
   (a) 2000 J     (b) −2000 J
   (c) 20 J       (d) −20 J
5. Order of magnitude of a physical quantity is the
   (a) Power of 5 of the number that describes the quantity
   (b) Power of 10 of the number that describes the quantity
   (c) Power of 100 of the number that describes the quantity
   (d) Power of 0.01 of the number that describes the quantity
6. Which of these statements is true regarding photoelectric emission?
   (a) Number of photoelectrons ejected per second is directly proportional to intensity of incident light provided the frequency of incident light is greater than threshold frequency
   (b) Number of photoelectrons ejected per second is inversely proportional to intensity of incident light provided the frequency of incident light is greater than threshold frequency
   (c) Number of photoelectrons ejected per second is directly proportional to intensity of incident light provided the frequency of incident light is smaller than threshold frequency
   (d) Number of photoelectrons ejected per second is inversely proportional to intensity of incident light provided the frequency of incident light is smaller than threshold frequency
7. Which wave, or ray is produced due to decelerating or accelerating charged particles?
   (a) Microwaves     (b) Ultraviolet rays
   (c) Infrared rays   (d) X-rays
8. What is the reason for earth not moving towards the moon, even though moon attracts the earth?
   (a) The mass of the earth is much larger than the mass of the moon, it accelerates at a rate lesser than the acceleration rate of the moon towards the earth
   (b) The mass of the moon is much larger than the mass of the earth, it accelerates at a rate lesser than the acceleration rate of the earth towards the moon
   (c) The mass of the earth is similar to that of the moon, and both accelerate at a same rate
   (d) Both experience unequal gravitational forces from each other
9. Work done in displacing a magnetic dipole of magnetic moment M (bar magnet) in uniform magnetic field B from an angle θ₁ to θ₂ is
   (a) \( W = B (\cos\theta_1 - \cos\theta_2)/M \)
   (b) \( W = M (\cos\theta_1 - \cos\theta_2)/B \)
   (c) \( W = MB (\cos\theta_1 + \cos\theta_2) \)
   (d) \( W = MB (\cos\theta_1 - \cos\theta_2) \)
10. Galvanometer can be converted into ammeter by
   (a) low resistance called shunt resistance in parallel
       to the galvanometer
   (b) very large resistance in parallel to the
       galvanometer
   (c) series connection with a very small resistance
   (d) series connection with a very high resistance

11. For a copper block, find the electric field which can
give an average 1 eV energy to a conduction
electron. (The mean free path of conduction
   electrons in copper is given as \( 4 \times 10^{-8} \) m)
   (a) \( 2.62 \times 10^7 \) V m\(^{-1}\)  (b) \( 2.64 \times 10^7 \) V m\(^{-1}\)
   (c) \( 2.5 \times 10^7 \) V m\(^{-1}\)  (d) \( 2.58 \times 10^7 \) V m\(^{-1}\)

12. When an object is placed between pole and focus
   of a concave mirror, then the images formed are
   (a) real, erect and magnified
   (b) virtual, erect and magnified
   (c) virtual, erect and non-magnified
   (d) virtual, erect and diminished

13. What is the amount of heat needed to raise the
    temperature of the gas in a cylinder of fixed
    capacity (44.8 litres) that contains helium gas at
    standard temperature and pressure, by 15.0\(^\circ\)C?
    (\( R = 8.31 \) J mol\(^{-1}\) K\(^{-1}\))
    (a) 374 J  (b) 37.4 J  (c) 5.42 J  (d) 54.2 J

14. Magnetic energy density in an inductor is given by
    (a) \( U_B = B^2/2\mu_0 \)  (b) \( U_B = B^2 \times 2\mu_0 \)
    (c) \( U_B = 2B^2/\mu_0 \)  (d) \( U_B = B^2 + 2\mu_0 \)

15. What modulation index and side bands are
    produced when a message of frequency 10 KH and
    peak voltage of 10 volts is used to modulate a carrier
    frequency of 1 MHz and peak voltage of 20 volts?
    (a) Modulation index is 1. The side bands are
        1010 – 990 KHz
    (b) Modulation index is 0.5. The side bands are
        1010 – 990 KHz
    (c) Modulation index is 2. The side bands are
        1020 – 980 KHz
    (d) Modulation index is 0.5. The side bands are
        1020 – 980 KHz

16. The net electric charge enclosed by a Gaussian
    surface of dipole is
    (a) 0 C  (b) 1 C  (c) 2 C  (d) 3 C

17. Law that proves that different masses accelerate to
    the earth at the same rate, but with different forces is
    (a) Newton's first law
    (b) Newton's second law
    (c) Newton's third law
    (d) Combination of Newton's first and third law

18. The resistance of a conductor does not depend on
    (a) Length and temperature of the conductor
    (b) Area of cross-section of the conductor
    (c) Material of the conductor
    (d) Weight of the conductor

19. The minimum negative potential given to anode
    plate at which photoelectric current becomes zero
    is called
    (a) Compton effect  (b) Stopping potential
    (c) Moseley's law  (d) Photoelectric effect

20. The property of the substance which shows how
    easily a substance can be magnetized, when placed
    in a magnetic field is called
    (a) Magnetic susceptibility
    (b) Magnetic flux density
    (c) Magnetic permeability
    (d) Magnetic field

21. The resistance of the platinum wire of a platinum
    resistance thermometer at the ice point is 5 \( \Omega \) and
    at steam point is 523 \( \Omega \). When the thermometer
    is inserted in a hot bath, the resistance of the
    platinum wire will be 5.795 \( \Omega \). Calculate the
    temperature of the bath.
    (a) 3.456 \(^\circ\)C  (b) 34.565 \(^\circ\)C
    (c) 345.65 \(^\circ\)C  (d) 45.65 \(^\circ\)C

22. The system that returns to equilibrium as quickly
    as possible without oscillating is
    (a) Over damped  (b) Critically damped
    (c) Under damped  (d) Undamped

23. Which one of the following is not emitted by
    radioactive elements?
    (a) Alpha Rays  (b) Beta Rays
    (c) Delta Rays  (d) Gamma Rays

24. Focal length, radius of curvature and power of a
    plane mirror respectively are
    (a) infinity, infinity and zero
    (b) infinity, infinity and infinity
    (c) zero, zero and finite
    (d) finite, zero, zero

25. Which of the following properties is not true for
    electromagnetic waves?
    (a) The waves are transverse in nature.
    (b) The waves are longitudinal in nature.
    (c) The waves propagate through space with the
        speed of light.
    (d) The energy in electromagnetic wave is divided
        equally between electric fields and magnetic
        field vectors.
26. The "Uplink" satellite communication frequency bands of "C" band are
(a) 5.925 – 6.425 GHz    (b) 3.7 – 4.2 GHz
(c) 5.925 – 6.425 MHz    (d) 3.7 – 4.2 MHz

27. The factor $R/N_A$ in an ideal gas law is
(a) Celsius constant    (b) Kelvin constant
(c) Universal gas constant    (d) Boltzmann's constant

28. An object approaches a convergent lens from the left of the lens with a uniform speed 10 m/s and stops at the focus. The image moves
(a) away from the lens with a uniform speed 10 m s$^{-1}$
(b) away from the lens with a uniform acceleration of 10 m s$^{-2}$
(c) away from the lens with a non-uniform acceleration
(d) towards the lens with a non-uniform acceleration

29. Which is the incorrect statement regarding electric lines of force?
(a) Electric lines of force never intersects with each other.
(b) Electric lines of force are always perpendicular to equipotential surface.
(c) Electric lines of force start from positive charge and terminates on negative charge.
(d) Electric lines of force are always parallel to equipotential surface.

30. A ball is thrown horizontally from a height of 100 m with an initial speed of 15 m s$^{-1}$. How far does it travel horizontally in the first 2 seconds?
(a) 3 m    (b) 7.5 m    (c) 30 m    (d) 0.3 m

31. Nucleons are a collection of
(a) electrons and protons
(b) electron and neutrons
(c) protons and neutrons
(d) protons and positrons

32. The value of magnetic quantum number of the last electron of "Na" is
(a) 3    (b) 2    (c) 1    (d) 0

33. If a point charge $q$ is moving in a circle of radius $r$ with speed $v$, then time period $T$ of the point charge will be
(a) $T = 2\pi r/v$    (b) $T = 2\pi r \times v$
(c) $T = \pi r/2v$    (d) $T = \pi r/v$

34. The force of attraction between two Lead balls, of radius 10 cm and 1 cm that are placed with their centres 1 metre apart is (The density of Lead is $5.51 \times 10^3$ kg m$^{-3}$)
(a) $3.5 \times 10^{-11}$ N    (b) $0.35 \times 10^{-11}$ N
(c) $35 \times 10^{-11}$ N    (d) $350 \times 10^{-11}$ N

35. If the mains voltage is 230 V then the peak voltage approximately is
(a) 230 V    (b) 162 V
(c) 325 V    (d) 330 V

36. Two small charged spheres have charges of $2 \times 10^{-7}$ C and $3 \times 10^{-7}$ C. They are placed 30 cm apart in air. What is the force between them?
(a) $F = 6 \times 10^{-3}$ N    (b) $F = 0.6 \times 10^{-3}$ N
(c) $F = 6.5 \times 10^{-3}$ N    (d) $F = 0.65 \times 10^{-3}$ N

37. The three central concepts in Newtonian mechanics are
(a) mass, motion and gravity
(b) mass, motion and force
(c) weight, speed and gravity
(d) force, mass and acceleration

38. Why there are two propellers in a helicopter?
(a) Due to conservation of linear momentum, the helicopter itself would have turned in the opposite direction, if it had only one propeller.
(b) Due to conservation of angular momentum, the helicopter itself would have turned in the opposite direction, if it had only one propeller.
(c) The helicopter can't rise up with one.
(d) The helicopter would not gain speed with one.

39. A small town is located 10 km away from a power plant. An average of 120 kW of electric power is sent to this town. The transmission lines have a total resistance of 0.40 $\Omega$. Calculate the power loss, if the power is transmitted at 240 V.
(a) 100 W    (b) 10 W
(c) 100 kW    (d) 10 kW

40. In a bar magnet, the ratio of magnetic length to geometrical length is nearly
(a) 0.74    (b) 0.80    (c) 0.84    (d) 0.94

41. If a particle moves in a curved path, it must have a component of acceleration
(a) perpendicular to the mass
(b) perpendicular to the gravity
(c) perpendicular to the velocity
(d) parallel to the velocity

42. In a semiconductor, the concentration of minority carriers depends mainly on
(a) the extent of doping
(b) temperature
(c) the applied bias current
(d) voltage
43. What is the moment of inertia of a ring about a tangent to the circle in the plane of a ring?
   (a) $MR^2$  (b) $2MR^2$
   (c) $(3/2)MR^2$  (d) $(1/2)MR^2$

44. An athlete runs exactly once around a circular track of length 500 m. The runner's displacement in the race is
   (a) 50 m  (b) 5 m  (c) 0.5 m  (d) 0 m

45. Dispersion without deviation is produced by two thin (small angled) prisms which are combined together. One prism has angle $5^\circ$ and refractive index 1.56. If the other prism has refractive index 1.7, what is its angle?
   (a) $3^\circ$  (b) $4^\circ$
   (c) $5^\circ$  (d) $6^\circ$

46. The enthalpy change of a chemical reaction in which 1 mole of a pure substance is formed from the free elements in their most stable states under standard state conditions is called
   (a) Molar enthalpy of vaporization
   (b) Standard enthalpy of fusion
   (c) Standard enthalpy of vaporization
   (d) Standard molar enthalpy of formation

47. A primary coil is connected with an AC source and a bulb is connected with the secondary coil. The voltage across the bulb is 6.0 V and the current through the bulb is 0.4 A. The turns ratio is 5 : 1 ($N_1 : N_2 = 5:1$). Calculate the current in the primary coil.
   (a) 8 A  (b) 0.8 A  (c) 12.5 A  (d) 1.25 A

48. Silicon dioxide layer is found in which of the following devices?
   (a) NPN transistor  (b) Tunnel diode
   (c) JFET  (d) MOSFET

49. The intrinsic carrier concentration of silicon sample at 300 K is $1.5 \times 10^{16}$ m$^{-3}$. What is the density of majority carriers? (after doping, the number of majority carriers is $5 \times 10^{20}$ m$^{-3}$)
   (a) $4.5 \times 10^{11}$ m$^{-3}$  (b) $3.33 \times 10^4$ m$^{-3}$
   (c) $5 \times 10^{20}$ m$^{-3}$  (d) $3 \times 10^{-5}$ m$^{-3}$

50. Considering the fact that the speed of light in glass is not independent of the colour of light, which of the statement is true?
   (a) Violet light travels slower than red light.
   (b) Violet light travels faster than red light.
   (c) Violet light travels same as red light.
   (d) Only white light will be travelling.

51. Naturally oscillating systems undergo
   (a) Simple harmonic motion (SHM)
   (b) 2 Dimensional Circular motion
   (c) Accelerating motion
   (d) Continuous motion

52. The phenomenon that occurs when the frequency of forced vibrations on an object matches the natural frequency of that object, and produces a dramatic increase in amplitude is called
   (a) Resonance  (b) Beats
   (c) Forced vibration  (d) Damping

53. A system has two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C located at points A: (0, 0, -15 cm) and B: (0, 0 + 15 cm), respectively. What is the magnitude and direction of electric dipole moment of the system?
   (a) $7.5 \times 10^{-8}$ cm, from positive to negative charge
   (b) $0.75 \times 10^{-8}$ cm, from negative to positive charge
   (c) $7.5 \times 10^{-8}$ cm, from negative to positive charge
   (d) $0.75 \times 10^{-8}$ cm, from positive to negative charge

54. Gravitational constant ($G$), Planck's constant($h$) and Velocity of light ($c$) are
   (a) Dimensional variables
   (b) Dimensionless variables
   (c) Non-dimensional constants
   (d) Dimensional constants

55. The equation ($\tan \theta = \frac{B_2}{B_1}$), where $B_1$ and $B_2$ are magnetic fields perpendicular to each other represents
   (a) Horizontal component of earth’s magnetic field
   (b) Tangent law
   (c) Dip or inclination  (d) Declination

56. What is lateral shift with respect to optics?
   (a) The parallel distance between the incident ray and the emergent ray.
   (b) The perpendicular distance between the incident ray and the emergent ray.
   (c) The perpendicular distance between the incident ray and the reflected ray.
   (d) The parallel distance between the incident ray and the reflected ray.

57. No work is done on the system, but $q$ amount of heat is taken out from the system and given to the surroundings. Express the change in internal energy ($\Delta U$) of this system and what type of wall does the system have?
(a) $\Delta U = w$, wall is adiabatic
(b) $\Delta U = q - w$, closed system
(c) $\Delta U = -q$, thermally conducting walls
(d) $\Delta U = q$, thermally conducting walls

58. The three types of expansion that takes place in solid are
(a) Linear expansion, superficial expansion and cubical expansion
(b) Volume expansion, real expansion and linear expansion
(c) Apparent expansion, volume expansion and real expansion
(d) Linear expansion, superficial expansion and pressure coefficient expansion

59. My friend has banjo clock. It has a pendulum. For every 1.0 sec the pendulum performs one full swing. If an object at the end of the string weighs 10.0 N, what is the length of the pendulum?
(a) 0.25 m  (b) 2.5 m  
(c) 0.5 m  (d) 0.15 m

60. The work done by a given force on a body depends only on
(a) The force, the displacement, and the angle between them
(b) The force, the velocity and the angle between them
(c) The acceleration, the velocity and the angle between them
(d) The force, the velocity and acceleration between them

SOLUTIONS

1. (a)
2. (c): The molecule of a monatomic gas has three translational degrees of freedom because it can move in space (3-dimensions) freely.
3. (b): Crystal rectifiers are semiconductor devices hence they do not obey ohm's law.
4. (b): Work done by road on a cycle (to stop) = Force by road $\times$ displacement $\times$ $\cos \theta$
   = $200 \times 10 \times \cos 180^\circ = -2000$ J
5. (b): Order of magnitude of a physical quantity is the power of 10 of the number that describes the quantity.
6. (a): In a photoelectric emission, if frequency of incident photon is greater than threshold frequency then number of photoelectrons ejected per second is directly proportional to intensity of incident light.
7. (d)
8. (a): Earth and the moon experience equal magnitude of gravitational force due to each other.
   Acceleration of moon, $a_m = \frac{F}{M_m}$
   Acceleration of earth, $a_e = \frac{F}{M_e}$
   Since $M_e >> M_m$ so $a_e << a_m$
9. (d): Work done = Change in potential energy
   $= U_f - U_i$
   $= -MB \cos \theta_2 - (-MB \cos \theta_1)$
   $= MB(\cos \theta_1 - \cos \theta_2)$
10. (a): Galvanometer can be converted into ammeter by connecting a low resistance in parallel to it.

As $r_s$ is very small so maximum current will pass through it.
11. (c): Energy transfer to conduction electron
   $U = eV = e \times E \times d$
   $\Rightarrow V = E \times \frac{d}{e}$
   $E = \frac{U}{e \times d} = \frac{1eV}{e \times 4 \times 10^{-19}}$
   $= \frac{1.6 \times 10^{-19}}{1.6 \times 10^{-19} \times 4 \times 10^{-19}} = 2.5 \times 10^7$ Vm$^{-1}$
12. (b):

13. (a): At STP, 1 mole of any gas occupies a volume of 22.4 L.

GLIMPSE OF NEXT ISSUE...
Focus: NURTURE (XXI): Units and Measurement
Focus: NEXT (XXII): Electrosatics
Monthly Tune Up (XXI): Units and Measurement
Monthly Tune Up (XXII): Electrosatics
Drive Map: Kinematics
JEE Advanced 2018: Solved Paper
Hence number of moles, \( n = \frac{44.8}{22.4} = 2 \) moles  
\( Q = nC_v \Delta T \)  
\( = 2 \times 1.5R \times 15 \quad \text{\textbullet For monatomic gas } C_v = \frac{3}{2}R \)  
\( = 2 \times 1.5 \times 8.31 \times 15 \)  
\( = 374 \text{ J} \) 

14. (a): Magnetic energy density in the inductor is 
\[ U_B = \frac{B^2}{2\mu_0} \] 

15. (b): Modulation Index = \( \frac{10}{20} = 0.5 \) 
Sides bands are at \((1000 + 10 \text{ kHz}) = 1010 \text{ kHz} \) and \((1000 - 10 \text{ kHz}) = 990 \text{ kHz} \) 

16. (a): The net electric charge enclosed by a Gaussian surface of dipole is zero, as the number of lines coming out cancels with the number of lines going in. 
So, \( \oint \mathbf{E} \cdot d\mathbf{A} = 0 \) 

17. (b): By Newton's universal law of gravitation, 
\[ F = \frac{GMm}{R^2} \]  
where 'M' is the mass of earth and 'm' is the mass of object. 
Also, \( F = ma \)  
Using equation (i) and (ii), 
\[ ma = \frac{GMm}{R^2} \quad \Rightarrow \quad a = \frac{GM}{R^2} \]  
'a' is independent of the mass of the object. 

18. (d): Resistance of a conductor depends upon length, temperature, area of cross-section of the conductor and material of the conductor. 

19. (b)  20. (a) 

21. (c): \( R_0 = 5 \Omega, R_{100} = 5.23 \Omega, R_t = 5.795 \Omega \)  
\[ \alpha = \frac{R_{100} - R_0}{R_0 \times 100} = \frac{R_t - R_0}{R_0 \times t} \] 
Therefore, \( t = \frac{R_t - R_0}{R_{100} - R_0} \times 100 \)  
\( = \frac{(5.795 - 5)}{(5.23 - 5)} \times 100 = 345.65^\circ C \) 

22. (b) 

23. (c): A delta ray is a particle i.e., an electron, ejected from matter by ionizing radiation. 

24. (a) 

25. (b): Electromagnetic waves are transverse in nature. 

26. (a): C band - uplink frequency range is 5.925 GHz to 6.425 GHz. 

27. (d): \( R/N_A \) in an ideal gas law is Boltzmann's constant where \( R \) is ideal gas constant and \( N_A \) is Avogadro's number. 
28. (c): The image velocity depends on the position of the object. So, when the object moves, the velocity of image changes non-uniformly and it moves away from the lens with a non-uniform acceleration. 
29. (d) 
30. (c): \( v_e = 15 \text{ m s}^{-1}, t = 2 \text{ sec} \) 
Horizontal displacement, \( dx = v_e \cdot t = 15 \times 2 = 30 \text{ sec} \) 
31. (c): Nucleons are composite particles made up of protons and neutrons. The protons and neutrons collectively present in the nucleus of an atom. 
32. (d): Electronic configuration of Na is \( 1s^22s^22p^63s^1 \). 
Here the valence electron is in 3 s orbital. The \( l \) value of this orbital is zero. So, the magnetic quantum number of this orbital is zero. 

33. (a): 
\[ T = \frac{2\pi r}{v} \] 

34. (a): Density of balls, \( \rho = 5.51 \times 10^3 \text{ kg m}^{-3} \) 
Radius of first ball, \( r_1 = 10 \text{ cm} \) 
Radius of second ball, \( r_2 = 1 \text{ cm} \) 
\[ F = \frac{Gm_1m_2}{R^2} \]  
Here \( G = 6.67 \times 10^{-11} \text{ N m}^2\text{kg}^{-2}, R = 1 \text{ m (Given)} \) 
\[ m_1 \text{(mass of first ball)} = \frac{4}{3} \pi r_1^3 \times \rho \]  
\[ = \frac{4}{3} \times 3.14 \times 10^{-3} \times 5.51 \times 10^3 = 23 \text{ kg} \]  
\[ m_2 \text{(mass of second ball)} = \frac{4}{3} \pi r_2^3 \times \rho \]  
\[ = \frac{4}{3} \times 3.14 \times 10^{-6} \times 5.51 \times 10^3 = 23 \times 10^{-3} \text{ kg} \]  
\[ F = \frac{6.67 \times 10^{-11} \times 23 \times 23 \times 10^{-3}}{(1)^2} = 3.5 \times 10^{-11} \text{ N} \] 

35. (c): Peak voltage = \( V_{rms} \sqrt{2} = 230 \times \sqrt{2} = 325 \text{ V} \) 

36. (a): \( q_1 = 2 \times 10^{-7} \text{ C} ; q_2 = 3 \times 10^{-7} \text{ C} \) 
\[ r = 30 \text{ cm} = 0.3 \text{ m} ; \quad F = \frac{q_1 q_2}{4\pi \epsilon_0 r^2} \]  
where \( \epsilon_0 = \text{Permittivity of free space} \) 
\[ \frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2} \] 
\[ F = \frac{9 \times 10^9 \times 2 \times 10^{-7} \times 3 \times 10^{-7}}{(0.3)^2} = 6 \times 10^{-3} \text{ N} \] 

37. (b)
38. (b) : If there would be only one propeller, the helicopter start rotating in the direction opposite to the movement of the propeller. The two propeller rotate in the opposite direction as to cancel the torque produced by one propeller.

39. (c) : \[ I = \frac{P}{V} = \frac{120 \times 1000}{240} = 500 \text{ A} \]
Power loss = \((I)^2 \times R = (500)^2 \times 0.40 = 100 \text{ kW} \)

40. (c) : In a bar magnet, magnetic length is slightly less than geometrical length.
Magnetic length = \( \frac{5}{6} \) (Geometric length)

41. (c) : If a particle moves in a curved path, its component of acceleration is perpendicular to the velocity.

42. (b) : The concentration of minority carriers mainly depends on temperature in a semiconductor. If any doped semiconductor is kept at absolute zero temperature then no minority charge will be present there.

43. (c)

44. (d) : Displacement is known as the distance between initial and final position. In a circular track, the initial and final position of the athlete is same, so total displacement is zero.

45. (b) : Dispersion without deviation by combining two prisms of angles \( A_1 \) and \( A_2 \) with refractive indices \( n_1 \) and \( n_2 \) is given by \((n_1 - 1)A_1 = (n_2 - 1)A_2 \) ... (i)
Here \( n_1 = 1.56, A_1 = 5^\circ, n_2 = 1.7 \)
From equation (i),
\[ (1.56 - 1) \times 5 = (1.7 - 1) \times A_2; \quad A_2 = 4^\circ \]

46. (d)

47. (*) : \( N_p : N_n = 5 : 1, I_s = 0.4 \text{ A} \)
\[ \frac{N_S}{N_p} = \frac{I_p}{I_S} \quad \Rightarrow \quad \frac{1}{5} = \frac{I_p}{0.4} \quad \text{or} \quad I_p = \frac{0.4}{5} = 0.08 \text{ A} \]
*None of the given options is correct.

48. (d) : Silicon dioxide layer is found in MOSFET.

49. (a) : \( n_i = 1.5 \times 10^{16} \text{ m}^{-3}; \quad n_o = 5 \times 10^{20} \text{ m}^{-3} \)
\[ \rho_o = \frac{n_i^2}{n_o} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{20}} = 4.5 \times 10^{11} \text{ m}^{-3} \]

50. (a) : As wavelength of violet light is less than red light, so it travels slower than red light.

51. (a)  

52. (a)  

53. (c) : \( q_A = 2.5 \times 10^{-7} \text{ C} \)
\( q_B = -2.5 \times 10^{-7} \text{ C} \)
Total charge of the system, \( q = q_A + q_B = 0 \)
Distance between two charges at points A and B,
\[ d = 15 + 15 = 30 \text{ cm} = 0.3 \text{ m} \]
Electric dipole moment of the system is given by,
\[ p = q_A \times d = q_B \times d = 2.5 \times 10^{-7} \times 0.3 = 7.5 \times 10^{-8} \text{ cm, along positive z-axis} \]

54. (d)  

55. (b)  

56. (b)

57. (c) : \( w = 0 \), the wall is thermally conducting \( \Delta U = -q \) (Exothermic process)

58. (a)

59. (a) : Time = 1.0 sec ; \( g = 9.8 \text{ m s}^{-2} \)
For a simple pendulum, \( T = 2\pi \sqrt{\frac{l}{g}} \)
\[ l = \frac{T^2 \times g}{(2\pi)^2} = \frac{(1)^2 \times 9.8}{(2\pi)^2} = 0.25 \text{ m} \]

60. (a) : \( W = F_s \cos \theta \)
Q1. Why the magnetic North pole is actually a South seeking pole? The Earth’s magnetic poles might flip — Is it a myth or reality? Please explain.

Ans. Every magnet has a North-seeking pole. It is the that end which points due north direction. We all know a fact that opposite poles of two magnets attracts. Therefore, when the compass or a magnet is pointing due north, it is because it is being attracted in that direction by the South end of another magnet, i.e., an imaginary bar magnet inside the earth. So assuming the earth as a big bar magnet, it is the South pole of that magnet that lies in the geographic North pole of the earth.

There is a direction North where the North poles of all magnets line up. The magnetisation of the North pole and North-seeking pole must be opposite to each other because they attract.

It is thought that Earth’s magnetic field is generated by the molten iron core at the centre of the planet. The molten iron has current of its own, like an ocean, and these moving current creates earth’s magnetic field. But currents are not consistent and the Earth's magnetic field moves around with magnetic north pole currently drifting by about 10 miles a year. But this movement of the field is small compared to a complete flip. Scientists have been studying the molten iron “lava” has seeped up from the core and through a ridge on the floor of the Atlantic ocean. It cools and solidifies, it preserves the direction of the Earth’s magnetic field so looking at the rock has formed over times. Here we got some evidences that pole switch ends every half million years or so.

Q2. A large amount of dust is in the interplanetary space in the solar system. Although this dust can theoretically have a variety of sizes, from molecular size upward, very little of it is smaller than about 0.2 μm in our solar system. Why?

Ans. Dust particles in the solar system are subject to two forces, the gravitational force toward the Sun, and the force from radiation pressure, which is away from the Sun. The gravitational force is proportional to the cube of the radius of a spherical dust particle because it is proportional to the mass of the particle. The radiation pressure is proportional to the square of the radius because it depends on the planar cross section of the particle. For large particles, the gravitational force is larger than the force from radiation pressure. For small particles, less than about 0.2 μm, the larger force from radiation pressures sweeps these particles out of the solar system.

Q3. Diving masks often have lenses built into the glass for divers who do not have perfect vision. The lenses in a diving mask faceplate often only have curved surfaces on the inside of the glass. Why is this design desirable?

Ans. The main reason for curving only the inner surface of the lenses in the diving mask faceplate is so that the diver can see clearly when looking at objects straight ahead while underwater and in the air. Consider light rays approaching the mask along a normal to the plane of the faceplate. If curved surfaces were on both the front and the back of the diving lens on the faceplate, refraction would occur at each surface. The lens could be designed so that these two refractions would give clear vision while the diver is in air. When the diver is underwater, however, the refraction between the water and the glass at the first interface is now different because the index of refraction of water is different from that of air. Thus, the vision would not be clear underwater. By making the outer surface of the lens flat, light is not refracted at normal incidence to the faceplate at the outer surface in either air or water— all of the refraction occurs at the inner glass-air surface. Thus, the same refractive correction exists in water and in air, and the diver can see clearly in both environments.
1. One end of a heavy uniform rod $AB$ can slide along a rough horizontal rod $CD$ to which it is attached by a ring. $B$ and $C$ are joined by a string. If $ABC$ is a right angle and $\alpha$ is the angle between $AB$ and vertical when the rod is on the point of sliding, find the coefficient of friction between ring and horizontal rod $CD$ as shown in figure.

(a) $\mu = \frac{\tan \alpha}{2 - \tan^2 \alpha}$  
(b) $\mu = \frac{\sin \alpha}{2 + \tan^2 \alpha}$  
(c) $\mu = \frac{\tan \alpha}{2 + \tan^2 \alpha}$  
(d) $\mu = \frac{\sin \alpha}{2 - \tan^2 \alpha}$

2. Consider a series $L$-$C$-$R$ circuit with switches $S_1$ and $S_2$ which can short circuit inductor and capacitor.

Maximum energy stored in the capacitor when both switches $S_1$ and $S_2$ opened, will be

(a) $\frac{V_{\text{max}}^2 L}{2R^2}$  
(b) $\frac{V_{\text{max}}^2 C}{2R^2}$  
(c) $\frac{V_{\text{max}}^2 L}{2R^2}$  
(d) $\frac{V_{\text{max}}^2 R}{2R^2}$

3. A monochromatic light source emitting photon of energy $2 \times 10^{-19}$ J having a power of 2 W is located at the centre of curvature of a concave metal disc of radius $\left( \frac{1}{\sqrt{\pi}} \right)$ m. Assume that

(i) Each photon gives sufficient energy to a surface electron, so that it leaves the metal surface.
(ii) Electron once leave the metal surface does not come back.
(iii) Work function of metal remains constant.

If area of metal disc is 1.0 m$^2$ and the charge on the disc after 1 s the light source is $q$.

Find value of $10q$.

(a) $-4$  
(b) $10$  
(c) $-10$  
(d) $4$

4. A strip of length $l$ having linear charge density $\lambda$ is placed near a negatively charged particle of mass $m$ and charge $q$ at a distance $l$ from the end $A$ of the strip. Let velocity of particle $p$ when it reaches at a distance $\frac{l}{2}$ from end $A$ is $v$ and, $v^2 = \frac{\mathcal{E}}{2m}$. If proportionality constant is $\log N$, then what is the value of $2N$.

(a) 4  
(b) 17  
(c) 3  
(d) 12

5. In the adjacent diagram, $CP$ represents a wavefront and $AO$ and $BP$, the corresponding two rays. Find the condition of $\theta$ for constructive interference at $P$ between the ray $BP$ and reflected ray $OP$.

(a) $\cos \theta = \frac{3\lambda}{2d}$  
(b) $\cos \theta = \frac{\lambda}{4d}$  
(c) $\sec \theta - \cos \theta = \frac{\lambda}{d}$  
(d) $\sec \theta - \cos \theta = \frac{4\lambda}{d}$

6. A $6 \times 10^{-12}$ F parallel plate capacitor has circular plates of area $10^{-2}$ m$^2$. It is charged with a charge of $42 \times 10^{-11}$ C charge. Now, if plates are connected through a resistor of resistance $2$ $\Omega$, the rate of change of electric field just after connecting with resistor is $395.48 \times 10^2$ V m$^{-1}$ s$^{-1}$. Find the value of $n$.

(a) 13  
(b) 6  
(c) 7.6  
(d) 4

7. An aluminium wire of length $L = 60$ cm and of cross-sectional area $0.01$ cm$^2$ is connected to a steel wire of the same cross-sectional area. The compound wire is loaded with a block of mass $10$ kg as shown in the figure. The distance $L$ from the joint to the supporting pulley is $86.6$ cm. Transverse waves are set up in the composite wire at its lowest frequency, such that the joint in the wire is
a node. What is the total number of nodes observed at this frequency excluding the two at the ends of the wire? Density of aluminium is 2.6 g cm\(^{-3}\) and that of steel is 7.8 g cm\(^{-3}\).

8. A convex lens of focal length 15 cm and a concave mirror of focal length 30 cm are kept with their optic axis PQ and RS parallel but separated in vertical direction by 0.6 cm as shown in the figure. The distance between the lens and mirror is 30 cm. An upright object \(AB\) of height 1.2 cm is placed on the optic axis PQ of the lens at a distance of 20 cm from the lens. If \(A'B'\) is the image after refraction from the lens and the reflection from the mirror, find the distance of \(A'B'\) from the pole of the mirror and obtain its magnification.

9. Consider a crude model for rotating diatomic chlorine molecule. Distance between atomic centres of Cl atoms = \(2 \times 10^{-10}\) m.

   Rotational speed, \(\omega = 2 \times 10^{12}\) radians\(^{-1}\).

   Molar mass of chlorine is 70 g per mole. Temperature is not very high. Find the total energy of 1 molecule of \(\text{Cl}_2\) (on an average) and temperature of \(\text{Cl}_2\).

   (a) \(0.932 \times 10^{-21}\) J, 300 K
   (b) \(5.8 \times 10^{-21}\) J, \(-105^\circ\text{C}\)
   (c) \(1.398 \times 10^{-21}\) J, 105 K
   (d) \(3.8 \times 10^{-21}\) J, 0°C

10. A block is tied to one end of a light string of length \(l\) whose other end is fixed to a rigid support. The block is given a speed of \(\sqrt{\frac{7}{2} gl}\) from the lowermost position. Find the height at which the block leaves the circle.

   (a) 0.5 \(l\) from top
   (b) 2 \(l\) from top
   (c) 1.5 \(l\) from bottom
   (d) 0.75 \(l\) from bottom

**SOLUTIONS**

1. (c): Let \(W\) be the weight of rod \(AB\) acting at its centre of gravity \(G\). Let \(N'\) be the resultant of \(N\) and \(\mu N\), then \(N'\) is inclined to \(N\) at an angle \(\lambda\) given by \(\mu = \tan \lambda\). Three forces, tension \(T\), weight \(W\) of rod and resultant reaction \(N'\) meet at \(O\). Then \(\angle AOG = \lambda\), \(\angle BOG = 90^\circ - \alpha\), and \(\angle BGO = \alpha\). Applying trigonometrical theorem

   \[(m + n)\cot \theta = m\cot \alpha - n\cot \beta.\]

From \(\Delta AOB\), we have

\[\frac{(BG + AG)\cot \alpha = AG \cot \lambda - BG \cot (90^\circ - \alpha)}{2\cot \alpha = \cot \lambda - \tan \alpha} \quad (\because AG = BG)\]

\[\cot \lambda = 2\cot \alpha + \tan \alpha = \frac{2}{\tan \alpha} + \tan \alpha\]

\[\Rightarrow \cot \lambda = \frac{2 + \tan^2 \alpha}{\tan \alpha} \Rightarrow \tan \lambda = \frac{\tan \alpha}{2 + \tan^2 \alpha}\]

\[\Rightarrow \mu = \frac{\tan \alpha}{2 + \tan^2 \alpha} \quad (\because \mu = \tan \lambda)\]

2. (a): During oscillations, maximum energy stored in capacitor is

\[U = \frac{1}{2} C (\Delta V)^2 = \frac{1}{2} CI^2 X_C^2\]
\[ U_{\text{max}} = \frac{1}{2} C l_{\text{max}}^2 X_0^2 \] when \( I \rightarrow I_{\text{max}} \), \( Z \rightarrow R \)

\[ = \frac{1}{2} C \frac{V_{\text{max}}^2}{R^2} \frac{1}{\omega^2 L^2} \]

Note \( I \rightarrow I_{\text{max}} \) at resonance

and \( X_L = X_C \Rightarrow C = \frac{1}{\omega^2 L} \)

\[ \therefore U_{\text{max}} = \frac{V_{\text{max}}^2 L}{2R^2} \]

3. (d): Number of photons emitted by source in 1s which moves in all direction

\[ \text{Power of source} = \frac{2W}{\text{Energy of 1 photon}} = \frac{2 \times 10^{-19}}{J} \]

\[ = 1 \times 10^{19} \text{ per second} \]

This photon flow reaches a sphere of radius, \( R = \frac{1}{\sqrt{\pi}} \)

So, number of photons falling per unit area over this sphere in/s

\[ \text{Total number of photons}/\text{s} = \frac{\text{Area of sphere}}{4\pi (\frac{1}{\sqrt{\pi}})^2} = 1 \times 10^{19} = 2.5 \times 10^{18} \text{ m}^{-2} \text{s}^{-1} \]

As each falling photon over the metal disc can eject an electron, number of electrons ejected in 1s from metal disc

\[ = \text{(Number of photons falling over unit area in unit time) \times (Area of metal disc)} = 2.5 \times 10^{18} \text{ m}^{-2} \text{s}^{-1} \times 1 \text{ m}^2 \]

\[ = 2.5 \times 10^{18} \text{ s}^{-1} \]

Hence, charge acquired by metal disc = \( q = n \times e \times t \)

\[ = 2.5 \times 10^{18} \times 1.6 \times 10^{-19} \times 1 = 0.4C \]. So, 10 q = 4

4. (c): Potential at \( P \) at distance \( d' \) due to strip is

\[ V_p = \frac{\sigma q}{4\pi e_0} \log_e \left(1 + \frac{l}{d} \right) \]

and at point \( Q \) at distance \( d/2 \) due to strip is

\[ V_q = \frac{\sigma q}{4\pi e_0} \log_e \left(1 + \frac{2l}{d} \right) \]

\[ \Rightarrow V_Q - V_P = \frac{\sigma q}{4\pi e_0} \log_e \left( \frac{d + 2l}{d + l} \right) \]

By conservation of energy,

\[ \frac{1}{2} mv^2 = \frac{\sigma q}{4\pi e_0} \log_e \left( \frac{d + 2l}{d + l} \right) \]

\[ \Rightarrow v^2 = \frac{2\sigma q}{4\pi e_0 m} \log_e \left( \frac{3}{2} \right) \text{ as } d = l \]

or \( v^2 \propto \frac{\sigma q}{2\pi e_0 m} \)

Hence, proportionality constant \( \log_e \left( \frac{3}{2} \right) = \log N \)

\[ \Rightarrow 2N = 3 \]

5. (b): \( PR = d \)

\[ \therefore PO = d \sec \theta \text{ and } CO = PO \cos 2\theta = d \sec \theta \cos 2\theta \]

Path difference between two rays is

\[ \Delta x = PO + OC = (d \sec \theta + d \sec \theta \cos 2\theta) \]

Phase difference between two rays is

\[ \Delta \phi = \pi (\text{one is reflected, while another is direct}) \]

Therefore, condition for constructive interference should be

\[ \Delta x = \frac{\lambda}{2} \]

or \( \left( \frac{d \sec \theta}{2 \cos^2 \theta} \right) = \frac{\lambda}{2} \]

or \( \left( \frac{d}{\cos \theta} \right) = \frac{\lambda}{2} \)

6. (b): Here, \( q = q_0 e^{-\frac{t}{RC}} \), \( I = -\frac{dq}{dt} = \frac{q_0}{RC} e^{-\frac{t}{RC}} \)

At \( t = 0 \), \( I_0 = \frac{q_0}{RC} = \frac{42 \times 10^{-11}}{2 \times 6 \times 10^{-12}} = \frac{7}{2} \times 10 = 35A \)

\[ \Rightarrow I = \frac{I_0}{e^{\frac{t}{RC}}} \]

\[ dE = \frac{I_0}{RC} \frac{35}{8.85 \times 10^{-12} \times 10^{-2}} \]

\[ = 395 \times 10^{12} \text{ Vm}^{-1} \text{s}^{-1} \]

\[ \therefore n = 6 \]

7. (a): Velocities on Al and steel wires are different because \( \mu \) is different for both of them. So, \( \lambda \) is also different as \( f \) is same for both.

\( \mu_1 = \mu_{\text{steel}} = \rho_1 \times \text{Area} = 7.8 \times 10^3 \times 10^{-6} \)

\[ = 7.8 \times 10^{-3} \text{ kg m}^{-1} \]

\( \mu_2 = \mu_{\text{Al}} = \rho_2 \times \text{Area} = 2.6 \times 10^3 \times 10^{-6} = 2.6 \times 10^{-3} \text{ kg m}^{-1} \)

\[ f_1 = f_2 \]

\[ \Rightarrow \frac{n_1}{2L_1} \frac{F}{\mu_1} = \frac{n_2}{2L_2} \frac{F}{\mu_2} \]

\[ \Rightarrow \frac{n_1}{n_2} = \frac{5}{2} \]

Therefore, lowest frequency oscillation causes 2 loops in Al and 5 loops in steel. So, total no. of nodes = 8, requires no. of nodes = 6
8. (c): Rays coming from object $AB$ first refract from the lens and then reflect from the mirror.

\[ u = -20 \text{ cm}, f = +15 \text{ cm} \]

Using lens formula \( \frac{1}{v} + \frac{1}{u} = \frac{1}{f} \)

\[ \therefore \quad v = +60 \text{ cm} \]

and linear magnification, \( m_l = \frac{v}{u} = \frac{+60}{-20} = -3 \)

Reflection from mirror image formed by lens \((A_1, B_1)\) will behave like a virtual object for mirror at a distance of 30 cm from it as shown.

So \( u = +30 \text{ cm}, f = -30 \text{ cm} \).

Using mirror formula

\[ \frac{1}{v} + \frac{1}{u} = \frac{1}{f} \]

\[ \therefore \quad v = -15 \text{ cm} \]

and linear magnification

\[ m_s = \frac{v}{u} = \frac{-15}{+30} = -\frac{1}{2} \]

9. (b): Rotational KE \( = \frac{1}{2} I \omega^2 \)

\[ I = 2(mr^2) = 2 \times 35 \times 1.67 \times 10^{-27} \times (10^{-10})^2 \]

\[ = 1.17 \times 10^{-45} \text{ kg m}^2 \]

\[ \therefore \quad K_{\text{rot}} = \frac{1}{2} I \omega^2 = 2.33 \times 10^{-21} \text{ J} \]

Total energy = Rotational energy + Translational energy

\[ = f \left( \frac{1}{2} k_B T \right) \]

As, for a diatomic molecule there are 3 translational and 2 rotational degree of freedom.

\[ \therefore \quad \text{Energy associated with rotation is} \quad \frac{2}{5} \text{ of total energy.} \]

So, total energy of a Cl$_2$ molecule

\[ \leq \frac{5}{2} \times \text{rotational energy} \]

\[ \leq \frac{5}{2} \times 2.33 \times 10^{-21} \text{ J} = 5.8 \times 10^{-21} \text{ J} \]

Also, \( \frac{5}{2} k_B T = 5.8 \times 10^{-21} \text{ J} \)

\[ \Rightarrow \quad T = \frac{2 \times 5.8 \times 10^{-21}}{5 \times 1.38 \times 10^{-23}} \]

\[ = 1.68 \times 10^2 = 168 \text{ K} \]

\[ = 168 - 273 = -105^\circ C \]

10. (c): As velocity of the block \( \sqrt{2gl} < v_b < \sqrt{5gl} \).

The block will leave the circle at some point $P$, where the radius $OP$ makes an angle $\theta$ with the upward vertical.

From $B$ to $P$,

\[ \Delta K + \Delta U = 0 \text{ or } \Delta K = -\Delta U \]

Loss in $KE = \text{Gain in PE}$

\[ \frac{1}{2} mv_b^2 - \frac{1}{2} mv^2 = mg(l + l \cos \theta) \]

(i)

From the force diagram: $T + mg \cos \theta = \frac{mv^2}{l}$

As the block leaves the circle at $P$, $T = 0$

\[ mg \cos \theta = \frac{mv^2}{l} \]

(ii)

Putting the value of $v^2$ from (ii) in (i),

\[ \frac{1}{2} mv_b^2 - \frac{1}{2} m(gl \cos \theta) = mg(l + \cos \theta) \]

\[ \Rightarrow \quad \frac{1}{2} m \left( \frac{7}{2} \frac{gl}{l} \right) = \frac{mg(2 + 3 \cos \theta)}{2} \]

\[ \Rightarrow \quad \cos \theta = \frac{1}{2} \Rightarrow \theta = 60^\circ \]

Hence, the block leaves the circle and string slack at a height $h = l + l \cos 60^\circ = 1.5l$ from the bottom. ✰✰
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Electrostatics

SECTION - A

1. The given graph shows variation of charge \( q \) versus potential difference \( V \) for two capacitors \( C_1 \) and \( C_2 \). Both the capacitors have same plate separation but plate area of \( C_2 \) is greater than that of \( C_1 \). Which line \( (A \) or \( B) \) corresponds to \( C_1 \) and why?

2. A point charge \( +Q \) is kept in the vicinity of an uncharged conducting plate. Sketch the electric field lines between the charge and the plate.

3. A point charge \( +Q \) is placed at point \( O \) as shown in the figure. Is the potential difference \( V_A - V_B \) positive, negative or zero?

4. Calculate the electric field strength required to just support a drop of water of mass \( 10^{-7} \) kg and carrying a charge of \( 1.6 \times 10^{-19} \) C.

SECTION - B

5. Can a metal sphere of radius 1 cm hold a charge of 1 C?

6. Plot a graph showing the variation of coulomb force \( F \) versus \( \left( \frac{1}{r^2} \right) \), where \( r \) is the distance between the two charges of each pair of charges: \( (1 \mu C, 2 \mu C) \) and \( (2 \mu C, -3 \mu C) \), interpret the graphs obtained.

7. Two point charges 2 \( \mu \)C and \(-2 \mu \)C are placed at points \( A \) and \( B \) 6 cm apart.
   (i) Draw equipotential surfaces of the system.
   (ii) Why do the equipotential surfaces get closer to each other near the point charges?

8. Distinguish between polar and non-polar dielectric.

9. Deduce the expression for the electric field \( \vec{E} \) due to a system of two charges \( q_1 \) and \( q_2 \) with position vectors \( \vec{r}_1 \) and \( \vec{r}_2 \) at a point \( \vec{r} \) with respect to the common origin \( O \).
10. An infinite number of charges, each equal to \( q \), are placed along the \( x \)-axis at \( x = 1, x = 2, x = 4, x = 8, \ldots \), and so on. Find the electric field at the point \( x = 0 \) due to this set of charges.

11. A stream of electrons travelling with a speed \( v \) m s\(^{-1}\) at a right angle to a uniform electric field \( E \) is deflected into a circular path of radius \( r \). Prove that

\[
\frac{e}{m} = \frac{v^2}{rE}
\]

12. Assuming that \( 10^{10} \) electrons are transferred from a body per second, find the time required to transfer \( 1 \) C of charge.

### SECTION - C

13. Two point charges \(-\frac{20}{3} \times 10^{-9} \) C and \(+\frac{20}{3} \times 10^{-9} \) C are placed on the \( x \)-axis at \( x = -10 \) cm and \( x = 10 \) cm respectively. Calculate the electric field at the point \( P(0, 10) \) and \( Q(20, 0) \).

14. The electric potential in space is expressed as \( V(x, y, z) = (10 \text{ V m}^{-2})(xy + yz + zx) \). Find the magnitude of the electric field at a point \( P(1 \text{ m}, 1 \text{ m}, 1 \text{ m}) \).

15. A particle of mass \( 40 \) mg and carrying a charge of \( 5 \times 10^{-9} \) C is moving directly towards a fixed positive charge of magnitude \( 10^{-8} \) C. When it is at a distance of \( 0.1 \) m from the fixed positive charge, it has a velocity of \( 0.5 \) m s\(^{-1}\). At what distance from the fixed positive charge will the particle come momentarily to rest? Is the acceleration constant during the motion?

16. Two identical particles of mass \( m \) carry a charge \( Q \) each. Initially, one is at rest on a smooth horizontal plane and the other is projected along the plane directly towards the first particle from a large distance with a speed \( v \). Find the distance of closest approach.

17. A copper ball of density \( 8.6 \text{ g cm}^{-3} \) and diameter \( 1 \) cm is immersed in oil of density \( 0.8 \text{ g cm}^{-2} \). What is the charge on the ball if it remains suspended in oil in an electric field of intensity \( 3600 \text{ V m}^{-1} \) acting in the upward direction?

18. A dielectric completely fills the gap between the plates of a parallel-plate capacitor whose capacitance is equal to \( C_0 \), when the dielectric is absent. Find the mechanical work which must be done against electric forces for extracting the dielectric out of the capacitor if

(i) Voltage \( (V) \) of the capacitor is maintained constant.
(ii) Charge \( (Q) \) of the capacitor is maintained constant.

Neglect the resistance of the circuit (If any)

19. Show that the capacitance of a spherical conductor is \( 4\pi e_0 \) times the radius of the spherical conductor.

20. (a) How is the electric field due to a charged parallel plate capacitor affected when a dielectric slab is inserted between the plates fully occupying the intervening region?
(b) A slab of material of dielectric constant \( K \) has the same area as the plates of a parallel plate capacitor but has thickness \( \frac{1}{2}d \), where \( d \) is the separation between the plates. Find the expression for the capacitance when the slab is inserted between the plates.

21. (i) State Gauss's law.
(ii) A thin straight infinitely long conducting wire of linear charge density \( \lambda \) is enclosed by a cylindrical surface of radius \( r \) and length \( l \). Its axis coinciding with the length of the wire. Obtain the expression for the electric field, indicating its direction, at a point on the surface of the cylinder.

22. A positive point charge \( (+q) \) is kept in the vicinity of an uncharged conducting plate. Sketch electric field lines originating from the point on to the surface of the plate. Derive the expression for the electric field at the surface of a charged conductor.

23. Two identical parallel plate (air) capacitor \( C_1 \) and \( C_2 \) have capacitances \( C \) each. The area between their plates is now filled with dielectrics as shown.

   ![Diagram of capacitors](image)

If the two capacitors still have equal capacitance, obtained the relation between dielectric constants \( K_1, K_2 \) and \( K \).

24. Use Gauss's law to derive the expression for the electric field between two uniformly charged large parallel sheets with surface charge densities \( +\sigma \) and \( -\sigma \) respectively.
25. Apply Gauss's theorem to show that for spherical shell, the electric field inside the shell vanishes, whereas outside it, the field is as if all the charge had been concentrated at the centre.

OR

(a) What are equipotential surfaces? Explain briefly.

(b) Derive an expression for the electric potential at axial point at distance \( x \) from the centre of a dipole. Mention one contrasting feature of electric potential of a dipole at a point as compared to that due to a single charge.

26. (a) Obtain the expression for the energy stored per unit volume in a charged parallel plate capacitor.

(b) What is the area of the plates of 2 F parallel plate capacitor having separation between the plates is 0.5 cm?

OR

(a) Define torque acting on a dipole of dipole moment \( \vec{p} \) placed in a uniform electric field \( \vec{E} \). Express it in the vector form and point out the direction along which it acts.

(b) What happens if the field is non-uniform?

(c) What would happen if the external field \( \vec{E} \) is increasing (i) parallel to \( \vec{p} \) and (ii) anti-parallel to \( \vec{p} \)?

27. (i) Define electric flux. Write its S.I. unit.

(ii) A small metal sphere carrying charge \( +Q \) is located at the centre of a spherical cavity inside a large uncharged metallic spherical shell as shown in the figure. Use Gauss's law to find the expressions for the electric field at points \( P_1 \) and \( P_2 \).

(iii) Draw the pattern of electric field lines in this arrangement.

OR

Two parallel plate capacitors \( A \) and \( B \) have the same separation \( d = 8.85 \times 10^{-4} \) m between the plates. The plate areas of \( A \) and \( B \) are 0.04 m\(^2\) and 0.02 m\(^2\) respectively. A slab of dielectric constant (relative permittivity) \( K = 4 \) has dimensions such that it can exactly fill the space between the plates of capacitor \( B \).

(i) The dielectric slab is placed inside \( A \) as shown in the figure. \( A \) is then charged to potential difference of 110 V. Calculate the capacitance of \( A \) and the energy stored in it.

(ii) The battery is disconnected and then the dielectric slab is removed from \( A \). Find the work done by the external agency in removing the slab from \( A \).

SOLUTIONS

1. The plate area of \( C_2 \) is greater than that of \( C_1 \). Since capacitance of a capacitor is directly proportional to the area of the plates, \( \therefore \ C_2 > C_1 \)

Now, \( C = \frac{q}{V} \)

Therefore, slope of a line (\( =q/V \)) is directly proportional to the capacitance of the capacitor, it represents. Since the slope of line \( A \) is more than that of \( B \), line \( A \) represents \( C_2 \) and the line \( B \) represents \( C_1 \).

3. From the given figure, \( V_A = \frac{1}{4 \pi \epsilon_0} \frac{Q}{r_A} \), \( V_B = \frac{1}{4 \pi \epsilon_0} \frac{Q}{r_B} \)

\( \therefore \ V_A - V_B = \frac{Q}{4 \pi \epsilon_0} \left[ \frac{1}{r_A} - \frac{1}{r_B} \right] \Rightarrow r_B > r_A \Rightarrow \left( \frac{1}{r_A} - \frac{1}{r_B} \right) > 0 \)

Hence, \( (V_A - V_B) > 0 \)

4. Let \( E \) be the electric field strength required to support a drop of water of mass \( m \) and carrying a charge \( q \). The weight of the drop, \( mg \), acts vertically downward. The force acting on the drop due to the electric field, \( qE \), must be equal and opposite to \( mg \).
Thus, \(-qE + mg = 0 \Rightarrow E = \frac{mg}{q}\)

\[
E = \frac{(10^{-7} \text{ kg}) \times (9.8 \text{ m s}^{-2})}{1.6 \times 10^{-19} \text{C}} = 6.125 \times 10^{12} \text{ N C}^{-1}
\]

5. A metal sphere of radius \(r = 1 \text{ cm} = 0.01 \text{ m}\) and carrying a charge \(q = 1 \text{ C}\) will have a potential

\[
V = \frac{1}{4\pi\varepsilon_0} \left(\frac{q}{r}\right) = 9 \times 10^{11} \text{ V}
\]

This potential is far greater than that required to ionize air. (The field required to ionize air is about \(3 \times 10^5 \text{ V m}^{-1}\)). Therefore, the charge will leak to the surrounding air.

6. (i) Pair \((1 \mu\text{C}, 2 \mu\text{C})\): From upper graph it is clear that the force of repulsion increases with the reducing distance between two charges.

(ii) Pair \((2 \mu\text{C}, -3 \mu\text{C})\): From lower graph it is clear that the force of attraction increases as the distance between two charges reduces.

7. (i) Equipotential surface

(ii) Equipotential surfaces get closer to each other near the point charges as strong electric field is produced there.

\[E = -\frac{\Delta V}{\Delta r} \Rightarrow E \propto -\frac{1}{\Delta r}\]

For given equipotential surfaces, small \(\Delta r\) represents strong electric field and vice versa.

8. A dielectric whose molecules possess electric moment even when electric field is not applied is called polar dielectric. On the other hand a dielectric, whose molecules do not possess permanent dipole moment, is called non-polar dielectric.

9. Electric field due to a system of charges:

Consider a system of charges \(q_1\) and \(q_2\) with position vectors \(\hat{r}_1\) and \(\hat{r}_2\) relative to common origin \(O\). Let \(P\) be any point with position vector \(\hat{r}\) at which electric field is to be determined.

Electric field \(E_1\) due to \(q_1\) is given by

\[
E_1 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r_1^2} \hat{r}_1
\]

where \(r_1\) is a unit vector in the direction from \(q_1\) to \(P\) and \(r_1p\) is the distance between \(q_1\) and \(P\).

Similarly, electric field \(E_2\) due to \(q_2\) is

\[
E_2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{r_2^2} \hat{r}_2
\]

where \(r_2\) is a unit vector in the direction from \(q_2\) to \(P\) and \(r_2p\) is the distance between \(q_2\) and \(P\).

By the superposition principle, the electric field \(\vec{E}\) at \(\hat{r}\) due to the system of charges is

\[
\vec{E}(r) = E_1(r) + E_2(r) = \frac{q_1}{4\pi\varepsilon_0 r_1^2} \hat{r}_1 + \frac{q_2}{4\pi\varepsilon_0 r_2^2} \hat{r}_2
\]

10. The electric field at \(x = 0\) is

\[
E = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{\infty} \frac{q_i}{r_i^2} = \frac{1}{4\pi\varepsilon_0} \left(\frac{q}{r^2} + \frac{q}{r^2} + \ldots \right)
\]

\[
\Rightarrow E = \frac{q}{4\pi\varepsilon_0} \left[1 + \left(\frac{1}{4}\right)^n\right] = \frac{q}{4\pi\varepsilon_0} \left(\frac{1}{3/4}\right) = \frac{q}{3\pi\varepsilon_0}
\]

11. To make the particles move in a circular path of radius \(r\) with a speed \(v\), the centripetal force required is

\[
\frac{mv^2}{r}. \text{ This is provided by the electric force } eE.
\]

\[
\Rightarrow \frac{mv^2}{r} = eE \Rightarrow e = \frac{mv^2}{rE}
\]

12. Charge carried by each electron is \(-1.6 \times 10^{-19} \text{ C}\).

\[
Q = n|e| = 10^{10} \times 1.6 \times 10^{-19} \text{ C/s} = 1.6 \times 10^{-9} \text{ C/s}
\]

Therefore, the time required to transfer 1 C of charge is

\[
t = \frac{1 \text{ C}}{Q} = \frac{1 \text{ C}}{1.6 \times 10^{-9} \text{ C/s}} = 6.25 \times 10^8 \text{ s}
\]
13. From figure, which illustrates the problem, by geometry of figure
PC = 10\sqrt{2} \text{ cm} = 0.14 \text{ m}
PA = 10\sqrt{2} \text{ cm} = 0.14 \text{ m}
The electric field at P(0, 10) due to the charge q_1 is
\[ E_1 = \frac{1}{4\pi \varepsilon_0} \cdot \frac{q_1}{PA^2} \text{ in the direction } P \text{ to } A \]
\[ \Rightarrow |E_1| = (9 \times 10^9 \text{ N m}^2\text{C}^{-2}) \left(\frac{20 \times 10^{-9} \text{ C}}{0.1414 \text{ m}^2}\right) \]
The electric field at P(0, 10) due to the charge q_2 is
\[ E_2 = \frac{1}{4\pi \varepsilon_0} \cdot \frac{q_2}{PC^2} \text{ in the direction } C \text{ to } P \]
\[ \Rightarrow |E_2| = (9 \times 10^9 \text{ N m}^2\text{C}^{-2}) \left(\frac{20 \times 10^{-9} \text{ C}}{0.1414 \text{ m}^2}\right) \]
From the geometry of the figure,
\[ \sqrt{(PA)^2 + (PC)^2} = \sqrt{(10\sqrt{2} \text{ cm})^2 + (10\sqrt{2} \text{ cm})^2} = 20 \text{ cm} = AC \]
\[ \therefore \angle APC = 90^\circ \text{ and } \angle PAB = \angle PCB = 45^\circ, \text{ as } PA = PC. \]
It follows that \(E_1\) and \(E_2\) are equal in magnitude and are inclined at an angle of 90\(^\circ\). Their resultant \(E_p\), therefore, bisects the angle between them and is parallel to the negative x-axis. The magnitude of \(E_p\) is
\[ E_p = \sqrt{E_1^2 + E_2^2} = \sqrt{2} \times E_1, \text{ as } E_1 = E_2 \]
\[ \Rightarrow E_p = \sqrt{2} \times E_1 \Rightarrow E_p = 3\sqrt{2} \times 10^3 \text{ N C}^{-1}. \]
The electric field at Q(20, 0) due to the charge q_1 is
\[ E_3 = \frac{1}{4\pi \varepsilon_0} \cdot \frac{q_1}{QA^2} \text{ in the direction } Q \text{ to } A \]
\[ \Rightarrow |E_3| = (9 \times 10^9 \text{ N m}^2\text{C}^{-2}) \left(\frac{20 \times 10^{-9} \text{ C}}{0.3 \text{ m}^2}\right) \]
The electric field at Q(20, 0) due to the charge q_2 is
\[ E_4 = \frac{1}{4\pi \varepsilon_0} \cdot \frac{q_2}{CQ^2} \text{ in the direction } C \text{ to } Q. \]
\[ \Rightarrow |E_4| = (9 \times 10^9 \text{ N m}^2\text{C}^{-2}) \left(\frac{20 \times 10^{-9} \text{ C}}{0.1 \text{ m}^2}\right) \]
The two fields \(E_3\) and \(E_4\) are along the same straight line, but oppositely directed. Hence, the resultant field at Q is
\[ E_Q = E_4 - E_3, \text{ along the positive x-axis} \]
\[ \Rightarrow E_Q = 5.33 \times 10^3 \text{ N C}^{-1}, \text{ along the positive x-axis.} \]

14. Let the electric field expressed in terms of its components be
\[ \vec{E} = E_x \hat{i} + E_y \hat{j} + E_z \hat{k} \]
\[ \Rightarrow \vec{E} = \left(-\frac{\partial V}{\partial x}\right) \hat{i} + \left(-\frac{\partial V}{\partial y}\right) \hat{j} + \left(-\frac{\partial V}{\partial z}\right) \hat{k} \]
Given that \(V(x, y, z) = (10 \text{ V m}^{-2})(xy + yz + zx)\)
\[ \Rightarrow \frac{\partial V}{\partial x} = (10 \text{ V m}^{-2})(y + z), \]
\[ \frac{\partial V}{\partial y} = (10 \text{ V m}^{-2})(x + z), \]
\[ \frac{\partial V}{\partial z} = (10 \text{ V m}^{-2})(x + y). \]
Substituting for the partial derivatives in equation 1,
\[ \vec{E} = -(10 \text{ V m}^{-2})[(y + z)\hat{i} + (x + z)\hat{j} + (x + y)\hat{k}] \]
For the given point P, x = y = z = 1 m.
\[ \Rightarrow \vec{E}_p = -(10 \text{ V m}^{-2})[(2m)\hat{i} + (2m)\hat{j} + (2m)\hat{k}] \]
\[ = -(20 \text{ V m}^{-1})(\hat{i} + \hat{j} + \hat{k}). \]
\[ \therefore \text{ The magnitude of the electric field} \]
\[ |\vec{E}_p| = (20 \text{ V m}^{-1}) \sqrt{1 + 1 + 1} = (20\sqrt{3}) \text{ V m}^{-1}. \]

15. When the charge \(q_2 = 5 \times 10^{-9} \text{ C}\) is at a distance of \(r = 0.1 \text{ m}\) from the fixed charge \(q_1 = 10^{-8} \text{ C}\), its kinetic energy is \(\frac{1}{2}mv^2\), where \(m\) is its mass and \(v\) is its speed. The total energy of the two charges consists of the kinetic energy of the charge \(q_2\) and their mutual potential energy. Hence, the total initial energy of the system is
\[ E_i = \frac{1}{2}mv^2 + \frac{1}{4\pi \varepsilon_0} \left(\frac{q_1q_2}{r}\right) \]
\[ \Rightarrow E_i = \frac{1}{2} \times 40 \times 10^{-6} \text{ kg} \times (0.5 \text{ m s}^{-1})^2 \]
\[ + 9 \times 10^9 \text{ N m}^2\text{C}^{-2} \times \left(\frac{5 \times 10^{-9} \text{ C} \times 10^{-8} \text{ C}}{0.1 \text{ m}}\right) \]
\[ E_i = 9.5 \times 10^{-6} \text{ J}. \]
As the charge \(q_2\) moves towards the charge \(q_1\), its velocity goes on decreasing because the repulsive force between
the two charges increases as the distance between them decreases. The body comes to rest momentarily at a distance of \( r' \) from the charge \( q_1 \) before retracing its path. The total energy of the system in this case is entirely potential and is equal to

\[
E_f = \frac{1}{4\pi \varepsilon_0} \left( \frac{q_1 q_2}{r'} \right)
\]

\[
= 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2} \times \left( 5 \times 10^{-9} \text{ C} \times 10^{-8} \text{ C} \right) \frac{1}{r'}
\]

\[
\Rightarrow E_f = \frac{4.5 \times 10^{-7}}{r'} \text{ J}
\]

From the principle of conservation of energy, \( E_f = E_i \).

\[
\therefore \quad \frac{4.5 \times 10^{-7}}{r'} = 9.5 \times 10^{-6} \text{ J}
\]

\[
\Rightarrow r' = 4.737 \times 10^{-2} \text{ m}
\]

The force between the charges obeys an inverse-square law, i.e., it increases with decreasing distance. Therefore, the acceleration will not be constant during the motion.

16. Initially, the particles are at a large distance from one another. Hence, the potential energy of the two particle system is zero. The entire initial energy of the system is, therefore, kinetic and is equal to

\[
E_i = \frac{1}{2} mv^2.
\]

As the particle projected with a speed \( v \) approaches the particle at rest, a force of repulsion acts between them. This force increases as the distance between the particles decreases. As a result, the particle moving with the initial speed \( v \) is decelerated, while the particle at rest is accelerated. At the distance of closest approach \( d \), both the particles move with the same speed, say \( v' \), as their masses are equal. Applying the principle of conservation of linear momentum, we get

\[
mv = mv' + mv'
\]

\[
\Rightarrow v' = \frac{v}{2}
\]

The final energy of the system at the distance of closest approach is the sum of the kinetic energies of the particles and the potential energy of the system. Thus,

\[
E_f = \frac{1}{2} mv'^2 + \frac{1}{2} mv'^2 + \frac{1}{4\pi \varepsilon_0} \frac{QQ}{d}
\]

\[
= \frac{mv'^2}{2} + \frac{1}{4\pi \varepsilon_0} \frac{Q^2}{d}
\]

\[
\Rightarrow E_f = \frac{mv'^2}{4} + \frac{1}{4\pi \varepsilon_0} \frac{Q^2}{d}
\]

By the principle of conservation of energy,

\[
E_i = E_f
\]

\[
\Rightarrow \quad \frac{1}{2} mv^2 = \frac{mv'^2}{4} + \frac{1}{4\pi \varepsilon_0} \frac{Q}{d}
\]

\[
\Rightarrow \quad \frac{1}{4\pi \varepsilon_0} \frac{Q^2}{d} = \frac{mv^2}{4}
\]

\[
\Rightarrow \quad d = \frac{4\pi \varepsilon_0}{4\pi \varepsilon_0} \frac{mv'^2}{4} = \frac{Q^2}{\pi \varepsilon_0 mv^2}.
\]

17. The ball will remain suspended in the oil if the electric force acting on it is equal to its apparent weight in the oil. The apparent weight of the ball is

\[
W = \text{actual weight of the ball} - \text{weight of oil displaced by the ball}
\]

\[
\Rightarrow W = \frac{4}{3} \pi r^3 \rho_{Cu} g - \frac{4}{3} \pi r^3 \rho_{Oil} g
\]

\[
= \frac{4}{3} \pi r^3 (\rho_{Cu} - \rho_{Oil}) g
\]

\[
W = \frac{4}{3} \pi (0.5 \times 10^{-2} \text{ m})^3 \times \frac{[(8600 - 800) \text{ kg m}^{-3}] \times 9.8 \text{ m s}^{-2}}{[(8600 - 800) \text{ kg m}^{-3}] \times 9.8 \text{ m s}^{-2}}
\]

\[
\Rightarrow q = 1.1 \times 10^{-5} \text{ C}
\]

18. (i) To maintain constant voltage, we have to use ideal battery. Change in capacitance

\[
\Delta C = C_0 - KC_0 = -(K-1)C_0
\]

\[\text{(i)}\]

Charge supplied by battery

\[
\Delta q = V\Delta C
\]

Work done by battery

\[
W_b = V\Delta q = V^2\Delta C
\]

Change in energy of capacitor

\[
\Delta U = \frac{1}{2} V^2 \Delta C
\]

Now using work energy theorem

\[
W_{\text{mechanical}} + W_b = \Delta K + \Delta U
\]

\[
\Rightarrow W_{\text{mechanical}} = \Delta K + \Delta U - W_b
\]

\[
= 0 + \frac{1}{2} V^2 \Delta C - V^2 \Delta C = -\frac{1}{2} V^2 \Delta C = \frac{1}{2} (K-1)C_0 V^2
\]

\[
\text{(using (i))}
\]

(ii) To maintain constant charge, capacitor should not be connected with the battery or any thing else.

\[
\Delta q = 0
\]

\[
\Delta U = \frac{Q_2}{2C_0} - \frac{Q_2}{2KC_0} = \frac{Q_2}{2C_0} \left(1 - \frac{1}{K}\right)
\]
\[ W_{\text{mechanical}} = \Delta K + \Delta U - W_k = 0 + \frac{Q_2}{2C_0} \left(1 - \frac{1}{K}\right) - 0 \]
\[ = \frac{Q_2}{2C_0} \left(1 - \frac{1}{K}\right) \]

19. The potential at any point on the surface of the conductor having radius \( r \) and charge \( q \) is given by
\[ V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r} \]
where \( \varepsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2} \)
The capacitance of the spherical conductor situated in vacuum is given by
\[ C = \frac{q}{V} = \frac{q}{\frac{1}{4\pi\varepsilon_0} \frac{q}{r}} \]
\[ = \frac{4\pi\varepsilon_0 r}{q} \]
Hence, the capacitance of an isolated spherical conductor situated in vacuum is \( 4\pi\varepsilon_0 \) times its radius.

20. (a) Initial electric field between the plates of parallel plate capacitor \( E_0 = \frac{\sigma}{\varepsilon_0} = \frac{\sigma}{\frac{q}{A}} = \frac{q}{A\varepsilon_0} \)
After introduction of dielectric, the permittivity of medium becomes \( K\varepsilon_0 \).
So, final electric field between the plates of parallel plate capacitor, \( E = \frac{q}{A K\varepsilon_0} = \frac{E_0}{K} \)
i.e., electric field reduces to \( \frac{1}{K} \) times.

(b) Consider a parallel plate capacitor, area of each plate being \( A \), the separation between the plates being \( d \). Let a dielectric slab of dielectric constant \( K \) and thickness \( t < d \) be placed between the plates. The thickness of air between the plates is \( (d - t) \). If charges on plates are \( +Q \) and \( -Q \), then surface charge density
\[ \sigma = \frac{Q}{A} \]
The electric field between the plates in air,
\[ E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} \]
The electric field between the plates in the slab,
\[ E_2 = \frac{\sigma}{K\varepsilon_0} = \frac{Q}{K\varepsilon_0 A} \]

\[ \therefore \text{The potential difference between the plates} \]
\[ V_{AB} = \text{work done in carrying unit positive charge from one plate to another} \]
\[ = \sum \Delta E_x \text{ (as field between the plates is not constant)} \]
\[ = E_1(d-t) + E_2 t = \frac{Q}{\varepsilon_0 A}(d-t) + \frac{Q}{K\varepsilon_0 A} t \]
\[ \therefore V_{AB} = \frac{Q}{\varepsilon_0 A} \left[ d-t + \frac{t}{K} \right] \]
\[ \therefore \text{Capacitance of capacitor,} \]
\[ C = V_{AB} \]
\[ = \frac{Q}{\varepsilon_0 A} \left( d-t + \frac{t}{K} \right) \]
or
\[ C = \frac{\varepsilon_0 A}{d-t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d-t(1 - \frac{1}{K})} \]

Here, \( t = \frac{d}{2} \)
\[ \therefore C = \frac{\varepsilon_0 A}{d - \frac{d}{2} \left(1 - \frac{1}{K}\right)} = \frac{\varepsilon_0 A}{d \left(1 + \frac{1}{K}\right)} \]

21. (i) According to Gauss's law, total flux over a closed surface \( S \) in vacuum is \( \frac{1}{\varepsilon_0} \) times the total charge enclosed by closed surface \( S \).
i.e., \( \phi = \oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\varepsilon_0} \)

(ii) Assume a cylindrical gaussian surface \( S \) with charged wire on its axis and point \( P \) on its surface, then net electric flux through surface \( S \) is

\[ \phi = \oint \vec{E} \cdot d\vec{S} = \int_{\text{upper plane face}} EdS \cos 90^\circ + \int_{\text{curved surface}} EdS \cos 0^\circ + \int_{\text{lower plane face}} EdS \cos 90^\circ \]
or \( \phi = 0 + EA + 0 \) or \( \phi = E 2\pi rl \)
But by Gauss's theorem \( \phi = \frac{q}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0} \)

Where \( q \) is the charge on length \( l \) of wire enclosed by cylindrical surface \( S \), and \( \lambda \) is uniform linear charge density of wire.

\[ E \times 2\pi rl = \frac{\lambda l}{\varepsilon_0} \text{ or } E = \frac{\lambda}{2\pi\varepsilon_0 r} \]

directed normal to the surface of charged wire.

22.

Consider an elementary area \( \delta S \) on the surface of the charged conductor.

Enclose this area element with a cylindrical gaussian surface as shown in figure.

Now electric field inside a charged conductor is zero. Therefore, direction of field, just outside \( \delta S \) will be normally outward i.e. in direction of \( n \).

According to Gauss's theorem, total electric flux coming out is

\[ \vec{E} \cdot \delta S = \frac{\sigma \delta S}{\varepsilon_0} \quad [\vec{E} \text{ is electric field at the surface}] \]

\[ \Rightarrow E \delta S \cos \theta = \frac{\sigma \delta S}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{\varepsilon_0} \]

23. Let \( A \rightarrow \) area of each plate and \( C_1 \) and \( C_2 \) are capacitance of each slab.

Let initially \( C_1 = C = \frac{e_0 A}{d} = C_2 \)

After inserting respective dielectric slabs, \( C_1 = KC \)

and \( C_2 = K_1 \frac{e_0 (A/2)}{d} + K_2 \frac{e_0 (A/2)}{d} \)

\[ = \frac{e_0 A}{2d} (K_1 + K_2); \quad C_2 = \frac{C}{2} (K_1 + K_2) \]

From (i) and (ii),

\[ C_1 = C_2; \quad KC = \frac{C}{2} (K_1 + K_2) \]

\[ K = \frac{1}{2} (K_1 + K_2) \]

24. Consider two infinite plane parallel sheets of charge \( A \) and \( B \). Let \( \sigma_1 = + \sigma \) and \( \sigma_2 = - \sigma \) be the uniform surface densities of charge on \( A \) and \( B \) respectively.

The electric field between two plates is given by

\[ E = E_1 - E_2 = \frac{\sigma_1}{2e_0} - \frac{\sigma_2}{2e_0} = \frac{\sigma}{2e_0} - \frac{\sigma}{2e_0} = \frac{\sigma + \sigma}{2e_0} \]

\[ \Rightarrow E = \frac{\sigma}{2e_0} \quad \Rightarrow E = \frac{\sigma}{e_0} \]

25. Refer to answer 48, page no.17 (MTG CBSE Champion Physics Class 12).

OR

(a) Refer to answer 24, page no.34 (MTG CBSE Champion Physics Class 12).

(b) Refer to answer 6, page no.32 (MTG CBSE Champion Physics Class 12).

26. (a) Refer to answer 70 (a), page no.44 (MTG CBSE Champion Physics Class 12).

(b) Refer to answer 46, page no.38 (MTG CBSE Champion Physics Class 12).

OR

Refer to answer 24, page no.13 (MTG CBSE Champion Physics Class 12).

27. (i) Refer to answer 33, page no.14 (MTG CBSE Champion Physics Class 12).

(ii) Refer to answer 43, page no.16 (MTG CBSE Champion Physics Class 12).

(iii) Refer to answer 60 (iii), page no.19 (MTG CBSE Champion Physics Class 12).

OR

(i) \( C_1 = \frac{e_0 A/2}{d} + K \frac{e_0 A/2}{d} = \frac{e_0 A}{2d} (1 + K) = 5 \frac{e_0 A}{d} \)

or \( C_1 = 5 \times 8.85 \times 10^{-12} \times 0.04 = 2 \times 10^{-9} \text{ F} \)

\[ U_1 = \frac{1}{2} C_1 \times V^2 = \frac{1}{2} \times 2 \times 10^{-9} \times (110)^2 \]

\[ = 1.2 \times 10^{-5} \text{ J} \]

(ii) When slab is removed,

\[ C_1' = \frac{e_0 A}{d} = \frac{C_1}{5} \quad \therefore \quad C_1' = \frac{5e_0 A}{d} \]

\[ \because \quad U_f = \frac{Q^2}{2C_1} = 5U_1 \quad \because \quad U_1 = \frac{1}{2} \frac{Q^2}{C_1} \]

\[ W_{ext} = U_f - U_1 = 4U_1 = 4 \times 8.4 \times 10^{-5} \text{ J} \]

\[ \therefore \quad U_1 = 1.2 \times 10^{-5} \text{ J} \]
Machines know more about us than we do

Forget Facebook. Your body emits data that could be used to read your emotions, check your health as well as track aggression.

Even if you opt out of Facebook and all its data-sharing tendencies, avoid using a smartphone, and generally stay off the internet, you are still emitting data every second of every day. As Poppy Crum, the chief scientist at Dolby Labs, demonstrated during a talk at TED Conference in Vancouver, new technologies could soon make it possible for companies and institutions to track your emotions and health using this data.

Crum showed the audience a frightening video. She then offered a data visualisation showing the carbon dioxide exhaled by people in the theatre while the video played. Crum had, it turned out, been tracking the audience’s carbon dioxide emissions. “You can see where some of us jumped as a deep red cloud. It’s our collective suspense creating a spike in CO2,” she says.

This is the kind of passive data collection technology, according to Crum, that could one day be used to reveal our inner lives to teachers, doctors, and of course, corporations.

Crum, a neurophysiologist by training, does related research. At Dolby, she studies how people watch movies using EEG caps, trackers that measure heart rate and sweat response, and thermal imaging cameras. The idea is to answer a variety of questions that could be used to change the ways films and TV shows are made, including what kinds of scenes cause people to sweat, fall asleep, or get nervous.

Crum believes this kind of technology could eventually be pervasive in our everyday lives. And while some might see it as an invasion of privacy, she thinks it will be used for good — if we let it.

“There are so many opportunities right now for tech to know these things about us, and it’s not always bad,” she says. In practice, according to her, this could mean allowing healthcare providers access to speech data that could detect diseases (speech changes can be a sign of Alzheimer’s, for example) or letting teachers have access to information about how students are reacting to certain lessons.

Robot builds a chair in no time

Puts together a ‘build-it-yourself’ furniture in just 8 minutes and 55 seconds

Scientists have developed a robot with a 3D camera and two arms equipped with grippers that can autonomously put together ready-to-assemble furniture without interruption.

The robot assembled a ‘build-it-yourself’ chair in 8 minutes and 55 seconds. Prior to the assembly, the robot took 11 minutes and 21 seconds to independently plan the motion pathways and 3 seconds to locate the parts.

Breaking down tasks

“The job of assembly, which may come naturally to humans, has to be broken down into different steps, such as identifying where the different chair parts are, the force required to grip the parts, and making sure the robotic arms move without colliding into each other,” said Pham Quang Cuong, assistant professor at Nanyang Technological University in Singapore.

“Through considerable engineering effort, we developed algorithms that will enable the robot to take the necessary steps to assemble the chair on its own,” said Mr. Pham.

“We are looking to integrate more artificial intelligence into this approach to make the robot more autonomous so it can learn the different steps of assembling a chair through human demonstration or by reading the instruction manual, or even from an image of the assembled product,” said Mr. Pham.

Researchers believe that their robot could be of greatest value in performing specific tasks with precision in industries where tasks are varied and do not merit specialised machines or assembly lines.
1. Let \( q_1 \) and \( q_2 \) are charges on A and B respectively. From given conditions: Charge on A and C after connection with wire are \( q_1 \) and \( Q - q_1 \), on B charge is \( q_2 \). \( V_A = V_C \) and \( V_B = 0 \).

Using \( V_B = 0 \),

\[
\therefore \, V_B = \frac{k(Q - q_1)}{3a} + \frac{kq_2}{2a} + \frac{kq_1}{4a} = 0
\]

where \( k = \frac{1}{4\pi\epsilon_0} \)

\( \Rightarrow \, 2Q + q_1 + 3q_2 = 0 \) \hspace{1cm} \text{(i)}

Using \( V_C = V_A \),

\[
\frac{k(Q - q_1)}{3a} + \frac{kq_2}{3a} + \frac{kq_1}{3a} = \frac{kq_1}{3a} + \frac{k(Q - q_1)}{2a} + \frac{kq_2}{4a}
\]

\( \Rightarrow \, q_1 = -\frac{q_2}{4} \) \hspace{1cm} \text{(ii)}

Substituting it in (i), \( q_2 = -\frac{8Q}{11} \).

2. Assume \( \rho \) and \( -\rho \) in the cavity then

\[
V_p = \frac{3}{2} \frac{k}{R} \left( \frac{4}{3} \pi R^3 \right) = \frac{2}{3} \pi k \rho R^2
\]

and

\[
V_p = \frac{\rho - \frac{4}{3} \pi R^2}{2} = \frac{-\pi k \rho R^2}{3}
\]

\( \therefore \, V_C = V_p + V_{-\rho} = 2 \pi k \rho R^2 - \frac{5}{3} \pi k \rho R^2 = \frac{3k}{3} \pi k \rho R^2 \)

\( \therefore \, V_C = \frac{5k}{12} \rho R^2 \) \hspace{1cm} \text{\( \therefore \, k = \frac{1}{4\pi \epsilon_0} \)}

3. Given that potential varies due to charged ball as \( V = ar^2 + b \).

Let electric field at distance \( r \) is \( \vec{E} \).

Then, \( |\vec{E}| = \frac{dV}{dr} = +2ar \) \hspace{1cm} \text{(i)}

Also,

\[
|\vec{E}| = \frac{Q_{\text{enclosed}}}{4\pi \epsilon_0 \, r^2}
\]

where \( Q_{\text{enclosed}} \) the charge enclosed by sphere. Comparing eqns. (i) and (ii) we get

\( 2ar^2 = Q_{\text{enclosed}}/4\pi \epsilon_0 \).

Differentiating with respect to \( r \)

\[
6ar = \frac{1}{4\pi \epsilon_0} \frac{dQ_{\text{enclosed}}}{dr} = \frac{1}{4\pi \epsilon_0} \times 4\pi r^2 \rho
\]

\( \therefore \, \rho = 6a\epsilon_0 \).

4. We replace the inner triangle consisting of an infinite number of elements by a resistor of resistance \( R_{AB}/2 \), where the resistance \( R_{AB} \) is such that \( R_{AB} = R_c \) and \( R = a\rho \).

After simplification, the circuit becomes a system of series and parallel connected conductors. In order to find \( R_x \), we write the equation

\[
R_x = R \left( R + \frac{RR_x}{2} \right) \left( \frac{R + R}{R + R_x/2} \right) \left( \frac{R + R}{R + R_x/2} \right)^{-1}
\]

\( \Rightarrow \, 3R_x^2 + 2RR_x - 2R^2 = 0 \) \hspace{1cm} \text{(i)}

Solving the equation, we obtain

\[
R_{AB} = R_x = \frac{R(\sqrt{7} - 1)}{3} = \frac{ap(\sqrt{7} - 1)}{3}
\]

5. When switch is open, \( C_{eq} = \frac{15}{2} \mu F \)

\( q_i = C_{eq}V = \frac{15}{2} \times 200 = 1500 \mu C \)

When switch is closed, \( C_{eq} = 30 \mu F \)

\( q_i = 30 \times 200 = 6000 \mu C \)

Charge flowing through \( A = q_i - q_i = 4500 \mu C = 4.5 \times 10^{-3} \) C

6. Let at time \( t \) particle be at point \( P(x, y) \) and its velocity be \( \vec{v} = (v_x, v_y) \) \hspace{1cm} \text{\( \vec{v} \times \vec{v} \)} \hspace{1cm} \text{\( v_0 = v_x + v_y \)}

\( \text{(work done by magnetic field is always zero so there is no change in magnitude of velocity)} \)

Then, magnetic force on the particle at point \( P \) is

\[
\vec{F} = q(v_x \hat{j} + v_y \hat{i}) \times B_0 \left( 1 + \frac{y}{d} \right) \left( -\hat{k} \right)
\]

Solution Senders of Physics Musing

SET-58

1. Akshit Aggarwal, Lucknow (UP)
2. S. N. Ankit, Patna (Bihar)
3. Shweta Banerjee, Kolkata (WB)
For $x$-component,
\[ -qB_0 \left[ 1 + \frac{v_y}{d} \right] \frac{dv_x}{dt} = m dv_x \quad \therefore \frac{dv_y}{dt} = \frac{dy}{dt} \]
Now the particle will be coming out of the field at point $y = d$. Let the velocity in $x$-direction be $v_x$ then integrating we get,
\[ v_x = v_0 - \frac{3qB_0d}{2m} \]
so \[ v_y = \sqrt{v_0^2 - v_x^2} = \sqrt{v_0^2 - \left( v_0 - \frac{3qB_0d}{2m} \right)^2} \]
Now, \[ \frac{dv_y}{dt} = \sqrt{v_0^2 - v_x^2} = \sqrt{v_0^2 - \left( v_0 - \frac{3qB_0d}{2m} \right)^2} \]

7. \[ m \frac{d^2 \mathbf{v}}{dt^2} = qE_0 \hat{j} + q(v_x \hat{i} + v_y \hat{j}) \times B_0 \hat{k} \]
\[ m \frac{dv_y}{dt} + m \frac{dv_x}{dt} = [qE_0 - qv_x B_0] \hat{j} + qv_y B_0 \hat{i} \]
\[ m \frac{dv_x}{dt} = qv_y B_0 \]
From (i) and (ii),
\[ \frac{m}{q} \frac{d}{dt} \left[ \frac{q}{m} E_0 - m \frac{dv_x}{dt} \right] = qv_y B_0 \]
\[ \frac{d^2 v_y}{dt^2} = \frac{q^2 v_y B_0^2}{m^2} - \frac{d^2 v_y}{dt^2} \]
\[ \frac{m}{q} \frac{d}{dt} \left[ \frac{q}{m} E_0 - m \frac{dv_x}{dt} \right] = qv_y B_0 \]
Solution of above equation
\[ v_y = A \sin(\omega t + \phi), \text{ where } \omega = \frac{qB_0}{m} \]
At $t = 0, v_y = 0, \phi = 0, v_y = A \sin \omega t$
At $t = 0, a = \frac{qE_0}{m}$ and $a = \frac{dv_y}{dt} = A \omega \cos \omega t$
\[ \frac{qE_0}{m} = B_0 A \quad \Rightarrow \quad A = \frac{E_0}{B_0} \quad \text{[Using (iii)]} \]
\[ \frac{qE_0}{m} \frac{E_0}{B_0} \sin \omega t \frac{dv_y}{dt} = \frac{E_0}{B_0} \sin \omega t \Rightarrow y = \int_0^t \frac{E_0}{B_0} \sin \omega t \ dt \]
\[ y = \frac{E_0 m}{qB_0^2} \left[ 1 - \cos \frac{qB_0}{m} t \right] \]

8. Let $I_0$ be the initial current in the steady state condition before shifting the switch. \[ \therefore \quad I_0 = \epsilon / R \]
Let $I'$ be the current in the circuit at time $t = 0$.
Since the flux associated with inductors will be same just before and after the shifting of switch, (otherwise the induced emf would be infinite)
\[ \phi = I'L = I'_0 (L + 2L) \]
\[ \therefore \quad I'_0 = \frac{I_0}{3} = \frac{\epsilon}{3R} \]
If $I$ is the instantaneous current in the circuit at time $t$, then
\[ \epsilon - 3L \frac{di}{dt} - IR = 0 
\Rightarrow \quad 3L \frac{di}{dt} = \epsilon - IR \]
or \[ \int_{I_0}^I \epsilon - IR = \int_{I_0}^I \frac{dt}{3L} \]
Solving on get, \[ I = \frac{\epsilon}{R} \left( 1 - \frac{2}{3} \times e^{-\frac{R}{3L}} \right) \]

9. By Newton's law,
\[ mg - IIB \frac{dv}{dt} = m \frac{dv}{dt} \quad \text{...}(i) \]
By KVL, \[ Blv = IR + \frac{q}{C} \quad \text{...}(ii) \]
Differentiate (i) w.r.t. time
\[ B l \frac{dv}{dt} = R \frac{di}{dt} + \frac{I}{C} \quad \text{...}(iii) \]
Eliminate $\frac{dv}{dt}$ by (i) and (ii)
\[ mg - IIB = m \frac{B}{B} \left[ R \frac{di}{dt} + \frac{I}{C} \right] \]
\[ \Rightarrow \quad \frac{Rdf}{dt} = gBl - \frac{IB^2}{m} - \frac{I}{C} \quad \text{...}(iv) \]
For maximum $I$, \[ \frac{df}{dt} = 0 \]
Using this in eqn. (iv),
\[ mgBl = I_{\text{max}} (B^2 \ell C + m) \quad \text{or} \quad I_{\text{max}} = \frac{mgBlC}{m + B^2 \ell C} \]

10. Time taken by the pulse to reach from $P$ to $Q$.
\[ t_0 = \frac{F_0}{k} \text{, where } F_0 = 3 \text{ N} \quad \text{...}(i) \]
Now, \[ \frac{F_0}{m} \Rightarrow \frac{dx}{dt} = \sqrt{\frac{F_0 - kt}{m}} \]
\[ \therefore \quad \int_0^t \frac{1}{\sqrt{m}} \left( F_0 - kt \right)^{1/2} dt = \frac{L}{3k} \sqrt{m} F_0^{3/2} \]
(Using (i))
\[ \therefore \quad k = \frac{2}{3L} \sqrt{\frac{F_0^3}{m}} = \frac{2}{3} \times \left( \frac{3 \times 3 \times 3}{3 \times 10^{-2}} \right) = 20 \text{ N}^{-1} \]
Units and Measurement

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’ names will be published in next issue.

ACROSS
2. The most widely used system of units in the world (2)
6. A prefix denoting $10^{-18}$ (4)
7. The apparent change in the position of an object when viewed from two different positions (8)
10. A source of very intense, monochromatic and unidirectional beam of light (5)
11. The number of significant figures in 0.0180 m (5)
12. The distance at which average radius of earth’s orbit subtends at an angle of 1 arc second (6)
14. The smallest value that can be measured by the measuring instrument (5, 5)
17. The SI unit used to express the amount of substance (4)
19. A technique used in locating position of an aeroplane in space (5)

DOWN
1. A balance used to measure the weight of an object (6, 7)
3. The physical quantity whose dimensional formula is the same as that of momentum (7)
4. The year in which there is total solar eclipse (8, 4)
5. The most precise time measuring device (6, 5)
6. A unitless and dimensionless physical quantity (6)
9. The SI unit whose symbol is Gy (4)
13. The physical quantity whose dimensions are the same as that of potential energy gradient (5)
15. The closeness of a measurement to the true value of the physical quantity (8)
16. A fundamental quantity usually indicating duration (4)
18. The quantity of matter contained in a body (4)

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