JEE Main Physics Sample Paper – 9

Duration: 60 Minutes | Maximum Marks: 100

Instructions

- **Section A** contains 20 Multiple Choice Questions (Q1–Q20). Each question has four options with only one correct answer. Correct answer: **+4** marks; Wrong answer: $-$**1** mark; Unattempted: **0** marks.
- **Section B** contains 10 Numerical Value Questions (Q21–Q30). Attempt **any 5** questions. Correct answer: **+4** marks; Wrong or unattempted: **0** marks (no negative marking).
- The syllabus is based on Class 11 & 12 NCERT Physics as per the JEE Main official syllabus.
- Use of personal calculators, log tables, and electronic devices is strictly prohibited.
- A simple on-screen virtual calculator is provided in the CBT interface.
- Rough work may be done in the space provided within the question paper. Do not write anything on the Answer Sheet that is not required.

SECTION A (Single Correct MCQ) Q1 – Q20 [+4 / −1]

Q1. A ball is projected from the ground with speed u at an angle of 30° to the horizontal ($g = 10\ \mathrm{m/s^2}$). The range of the projectile is R. At which other angle of projection (with the same speed u) will the projectile have the **same range** R?

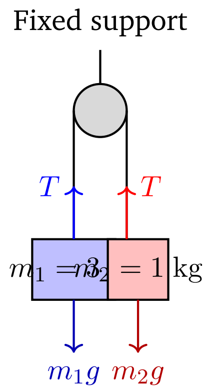
(A) 45°

(B) 60°

(C) 75°

(D) 90°

Q2. Two masses $m_1 = 3$ kg and $m_2 = 1$ kg are connected by a light inextensible string over a frictionless, massless pulley (Atwood machine), as shown. The system is released from rest. The acceleration of the system is ($g = 10\ \mathrm{m/s^2}$):



(A) $5\ \mathrm{m/s^2}$

(B) $2.5\ \mathrm{m/s^2}$

(C) $10\ \mathrm{m/s^2}$

(D) $3.3\ \mathrm{m/s^2}$

Q3. A pump lifts $500\ \mathrm{kg}$ of water through a vertical height of $10\ \mathrm{m}$ in $50\ \mathrm{s}$ ($g = 10\ \mathrm{m/s^2}$). The power output of the pump is:

(A) $500\ \mathrm{W}$

(B) $250\ \mathrm{W}$

(C) $1000\ \mathrm{W}$

(D) $5000\ \mathrm{W}$

Q4. A constant torque of $\tau = 6\ \mathrm{N \cdot m}$ acts on a rigid body that is initially at rest. The torque acts for $\Delta t = 4\ \mathrm{s}$. The magnitude of the final angular momentum of the body is:

(A) $6\ \mathrm{N \cdot m \cdot s}$

(B) $4\ \mathrm{N \cdot m \cdot s}$

(C) $10\ \mathrm{N \cdot m \cdot s}$

(D) $24\ \mathrm{N \cdot m \cdot s}$

Q5. Two satellites orbit the same planet. Satellite A orbits at a radius R from the planet's centre, and satellite B orbits at a radius $4R$. According to Kepler's Third Law, the ratio of the orbital period of B to that of A, T_B/T_A, is:

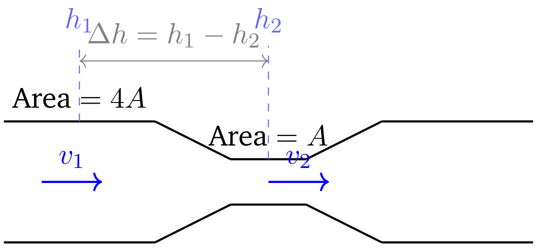
(A) 4

(B) 8

(C) 16

(D) 2

Q6. Water flows through a horizontal venturimeter. The cross-sectional area of the wide section is $4A$ and that of the narrow (throat) section is A. Using the equation of continuity, the ratio of the speed at the throat to the speed at the wide section, v_2/v_1, is:



(A) 4

(B) 2

(C) 8

(D) $\frac{1}{4}$

Q7. An ideal gas undergoes an **isochoric** (constant-volume) process in which its temperature increases from T_1 to T_2. The work done **by** the gas during this process is:

(A) $nR(T_2 - T_1)$

(B) $nC_v(T_2 - T_1)$

(C) Zero

(D) $nC_p(T_2 - T_1)$

Q8. The rms (root-mean-square) speed of molecules of an ideal gas at absolute temperature T is given by $v_{\text{rms}} = \sqrt{3RT/M}$. Which of the following correctly states how v_{rms} depends on absolute temperature T (at fixed molar mass M)?

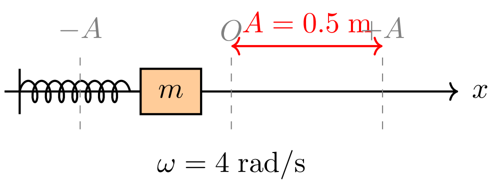
(A) $v_{\text{rms}} \propto T$

(B) $v_{\text{rms}} \propto T^2$

(C) $v_{\text{rms}} \propto \dfrac{1}{T}$

(D) $v_{\text{rms}} \propto \sqrt{T}$

Q9. A particle executes simple harmonic motion with angular frequency $\omega = 4\ \text{rad/s}$ and amplitude $A = 0.5\ \text{m}$, as shown. The magnitude of the maximum acceleration of the particle is:



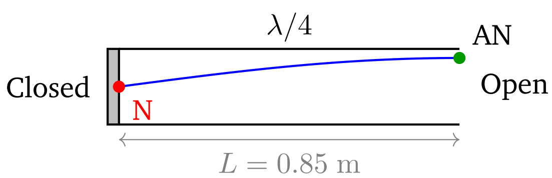
(A) $2\ \text{m/s}^2$

(B) $8\ \text{m/s}^2$

(C) $16\ \text{m/s}^2$

(D) $4\ \text{m/s}^2$

Q10. A closed organ pipe has length $L = 0.85\ \text{m}$. The speed of sound in air is $v = 340\ \text{m/s}$. The fundamental frequency of this pipe is:



(A) 100 Hz

(B) 200 Hz

(C) 50 Hz

(D) 400 Hz

Q11. A long straight wire carries a uniform linear charge density λ. The magnitude of the electric field at a perpendicular distance r from the wire (in free space, permittivity ε_0) is given by:

(A) $\dfrac{\lambda}{4\pi\varepsilon_0 r^2}$

(B) $\dfrac{\lambda}{2\varepsilon_0}$

(C) $\dfrac{\lambda}{2\pi\varepsilon_0 r}$

(D) $\dfrac{\lambda}{4\varepsilon_0 r}$

Q12. A battery has an EMF of $\varepsilon = 12$ V and internal resistance $r = 2\ \Omega$. When the battery delivers a current of $I = 2$ A to an external circuit, the terminal voltage of the battery is:

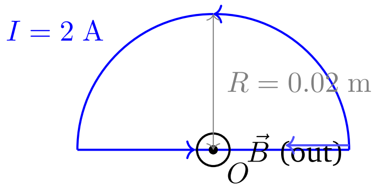
(A) 12 V

(B) 10 V

(C) 6 V

(D) 8 V

Q13. A semicircular arc of radius $R = 0.02$ m carries a steady current $I = 2$ A, as shown. The magnitude of the magnetic field at the centre O of the semicircle is $B = \mu_0 I/(4R)$. Taking $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$, the value of B is:



(A) $\pi \times 10^{-6}$ T

(B) $\pi \times 10^{-5}$ T

(C) $2\pi \times 10^{-6}$ T

(D) $5\pi \times 10^{-6}$ T

Q14. A conducting rod of length $L = 0.5$ m moves with velocity $v = 4$ m/s perpendicular to a uniform magnetic field $B = 1$ T (the rod, velocity, and field are mutually perpendicular). The magnitude of the induced EMF in the rod is:

(A) 2 V

(B) 0.5 V

(C) 4 V

(D) 8 V

Q15. A purely resistive AC circuit has an rms voltage $V_{\text{rms}} = 220$ V applied across a resistance $R = 100\ \Omega$. The average power dissipated in the circuit is:

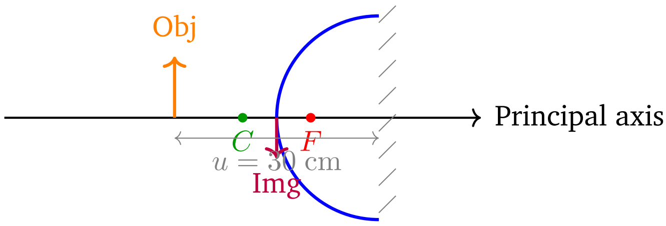
(A) 220 W

(B) 242 W

(C) 484 W

(D) 968 W

Q16. An object is placed 30 cm in front of a concave mirror of focal length $f = 10$ cm. Using the mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ (with the standard sign convention), the distance of the image from the mirror is:



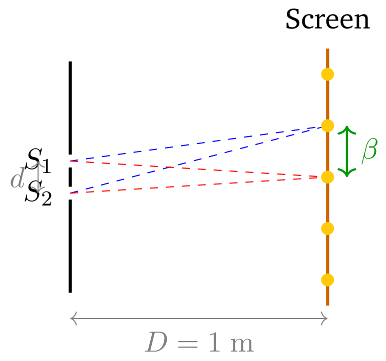
(A) $20\ \mathrm{cm}$ (on the same side as the object)

(B) $10\ \mathrm{cm}$ (behind the mirror)

(C) $30\ \mathrm{cm}$ (on the same side as the object)

(D) $15\ \mathrm{cm}$ (on the same side as the object)

Q17. In a Young's double-slit experiment (YDSE), monochromatic light of wavelength $\lambda = 600\ \mathrm{nm}$ is used. The distance between the two slits is $d = 0.6\ \mathrm{mm}$, and the screen is placed at a distance $D = 1\ \mathrm{m}$ from the slits, as shown. The fringe width β on the screen is:



(A) $0.5\ \mathrm{mm}$

(B) $1\ \mathrm{mm}$

(C) $2\ \mathrm{mm}$

(D) $0.1\ \mathrm{mm}$

Q18. A particle of mass m has kinetic energy KE. The de Broglie wavelength associated with the particle is:

(A) $\dfrac{h}{\sqrt{2m \cdot KE}}$

(B) $\dfrac{h}{m \cdot KE}$

(C) $\dfrac{h\sqrt{KE}}{\sqrt{2m}}$

(D) $\dfrac{h}{2m \cdot KE}$

Q19. A hydrogen atom makes a transition from the $n = 3$ energy level to the $n = 1$ energy level (ground state). The energy emitted in this transition (using $E_n = -13.6/n^2$ eV) is:

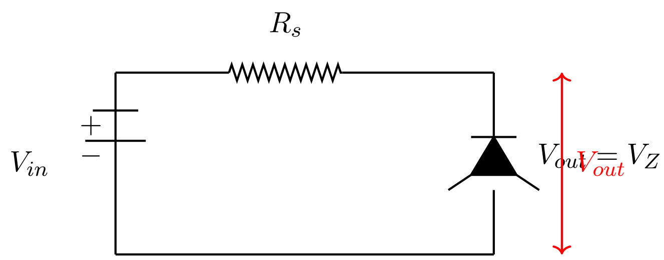
(A) 10.2 eV

(B) 3.4 eV

(C) 12.1 eV

(D) 13.6 eV

Q20. In the Zener diode voltage regulator circuit shown, the input voltage V_{in} may vary between 15 V and 20 V. The Zener diode has a breakdown voltage $V_Z = 10$ V and is connected in reverse bias across the load. The output voltage V_{out} across the Zener diode is:



(A) Varies between 15 V and 20 V

(B) 0 V (Zener is reverse biased so no conduction)

(C) Depends on the value of R_s

(D) 10 V (remains constant at the Zener breakdown voltage)

SECTION B (Numerical Value Questions)
Q21 – Q30 Attempt ANY 5 [+4 / 0]

Q21. A projectile is launched from the ground with speed $u = 20$ m/s at an angle of 45° to the horizontal ($g = 10$ m/s^2). Calculate the horizontal range of the projectile (in metres).

(Enter the exact numerical value as your answer.)

Q22. A car moves in a horizontal circular path of radius $r = 200$ m at a constant speed of 72 km/h. Calculate the centripetal acceleration of the car (in m/s^2).

(Enter the exact numerical value as your answer.)

Q23. A spring of spring constant $k = 1000$ N/m is compressed by $x = 10$ cm from its natural length. Calculate the elastic potential energy stored in the spring (in joules).

(Enter the exact numerical value as your answer.)

Q24. Three resistors of $2\ \Omega$, $3\ \Omega$, and $6\ \Omega$ are connected in parallel. Calculate the equivalent resistance of the combination (in Ω).

(Enter the exact numerical value as your answer.)

Q25. A spring-mass system has a spring of spring constant $k = \pi^2$ N/m and a block of mass $m = 1$ kg. Calculate the time period of oscillation T (in seconds).

(Enter the exact numerical value as your answer.)

Q26. An ideal gas is enclosed at constant pressure at temperature $T_1 = 300$ K with volume V_1. The gas is heated at constant pressure until its volume doubles to $V_2 = 2V_1$. Find the new temperature T_2 (in kelvin).

(Enter the exact numerical value as your answer.)

Q27. A capacitor of capacitance $C = 10\ \mu\text{F}$ is charged to a potential difference of $V = 100\ \text{V}$. Calculate the energy stored in the capacitor (in mJ).

(Enter the exact numerical value as your answer.)

Q28. An electron (charge $q = 1.6 \times 10^{-19}\ \text{C}$, mass $m_e = 9.1 \times 10^{-31}\ \text{kg}$) moves with speed $v = 10^6\ \text{m/s}$ perpendicular to a uniform magnetic field $B = 0.1\ \text{T}$. The electron moves in a circular arc. Calculate the radius of the circular orbit (in cm). Give your answer correct to one decimal place.

(Enter the exact numerical value as your answer.)

Q29. An object is placed $20\ \text{cm}$ in front of a convex lens of focal length $f = 10\ \text{cm}$. Using the lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ with sign convention ($u = -20\ \text{cm}$, $f = +10\ \text{cm}$), calculate the image distance v (in cm).

(Enter the exact numerical value as your answer.)

Q30. A radioactive sample initially contains $N_0 = 1600$ nuclei. After 4 complete half-lives, the number of remaining undecayed nuclei is:

(Enter the exact numerical value as your answer.)

DETAILED SOLUTIONS

Sol. Q1.

Solution

Topic: Kinematics — Projectile Range and Complementary Angles

The horizontal range of a projectile is given by:

$$R = \frac{u^2 \sin 2\theta}{g}$$

For $\theta = 30°$: $\sin(2 \times 30°) = \sin 60° = \frac{\sqrt{3}}{2}$, so $R = \frac{u^2\sqrt{3}}{2g}$.

For the same range at a different angle θ', we need $\sin 2\theta' = \sin 60°$. This is satisfied when:

$$2\theta' = 180° - 60° = 120° \implies \theta' = 60°$$

This follows from the identity $\sin(180° - x) = \sin x$. In general, a projectile launched at angle θ and at its complementary angle $90° - \theta$ have the same range. Here $90° - 30° = 60°$.

Why other options are wrong:

- (A) $45°$: $\sin 90° = 1 \neq \sin 60°$. This gives the *maximum* range, not the same as $30°$.
- (C) $75°$: $\sin 150° = 0.5 \neq \frac{\sqrt{3}}{2}$. Incorrect.
- (D) $90°$: $\sin 180° = 0$, so range $= 0$. Incorrect.

Answer: (B)

Sol. Q2.

Solution

Topic: Laws of Motion — Atwood Machine

For an Atwood machine with masses $m_1 = 3$ kg and $m_2 = 1$ kg connected over a frictionless pulley, applying Newton's second law to each mass:

$$m_1 g - T = m_1 a \quad \text{(heavier mass descends)}$$

$$T - m_2 g = m_2 a \quad \text{(lighter mass ascends)}$$

Adding these two equations:

$$(m_1 - m_2)g = (m_1 + m_2)a \implies a = \frac{(m_1 - m_2)g}{m_1 + m_2}$$

$$a = \frac{(3-1) \times 10}{3+1} = \frac{2 \times 10}{4} = \frac{20}{4} = \mathbf{5}\ \mathrm{m/s^2}$$

Why other options are wrong:

- (B) $2.5\ \mathrm{m/s^2}$: This would result from using $(m_1 - m_2)/m_1$ instead of the correct formula.
- (C) $10\ \mathrm{m/s^2}$: This would be the free-fall acceleration if the pulley were absent.
- (D) $3.3\ \mathrm{m/s^2}$: Incorrect; arises from a wrong substitution.

Answer: (A)

Sol. Q3.

Solution

Topic: Work and Energy — Power of a Pump

Work done by the pump equals the gravitational potential energy gained by the water:

$$W = mgh = 500 \times 10 \times 10 = 50{,}000\ \mathrm{J}$$

Power is the rate of doing work:

$$P = \frac{W}{t} = \frac{50{,}000}{50} = \mathbf{1000}\ \mathrm{W}$$

Why other options are wrong:

- (A) $500\ \mathrm{W}$: This would result from using only half the height or half the mass.
- (B) $250\ \mathrm{W}$: A factor-of-four error in the calculation.
- (D) $5000\ \mathrm{W}$: Forgetting to divide by time $t = 50\ \mathrm{s}$.

Answer: (C)

Sol. Q4.

Solution

Topic: Rotational Motion — Angular Impulse-Momentum Theorem

The angular impulse-momentum theorem states:

$$\tau \cdot \Delta t = \Delta L = L_f - L_i$$

Since the body is initially at rest, $L_i = 0$. Therefore:

$$L_f = \tau \cdot \Delta t = 6 \text{ N} \cdot \text{m} \times 4 \text{ s} = \mathbf{24} \text{ N} \cdot \text{m} \cdot \text{s}$$

This is the rotational analogue of the linear impulse-momentum theorem ($F \cdot \Delta t = \Delta p$).

Why other options are wrong:

- (A) $6 \text{ N} \cdot \text{m} \cdot \text{s}$: Only uses the torque value, ignoring time.
- (B) $4 \text{ N} \cdot \text{m} \cdot \text{s}$: Only uses the time value, ignoring torque.
- (C) $10 \text{ N} \cdot \text{m} \cdot \text{s}$: Adds torque and time instead of multiplying.

Answer: (D)

Sol. Q5.

Solution

Topic: Gravitation — Kepler's Third Law

Kepler's Third Law states that the square of the orbital period is proportional to the cube of the orbital radius:

$$T^2 \propto r^3 \implies \frac{T_B^2}{T_A^2} = \frac{r_B^3}{r_A^3} = \frac{(4R)^3}{R^3} = 64$$

$$\frac{T_B}{T_A} = \sqrt{64} = \mathbf{8}$$

Why other options are wrong:

- (A) 4: This would be the ratio if $T \propto r$ (not $T^2 \propto r^3$).
- (C) 16: This is the ratio of r^2, not $r^{3/2}$.
- (D) 2: Incorrect; this would only apply if $T \propto r^{1/2}$.

Answer: (B)

Sol. Q6.

Solution

Topic: Fluid Mechanics — Equation of Continuity (Venturimeter)

The equation of continuity for an incompressible fluid requires that the volume flow rate is constant throughout the pipe:

$$A_1 v_1 = A_2 v_2$$

Here $A_1 = 4A$ (wide section) and $A_2 = A$ (narrow throat). Solving for the speed ratio:

$$\frac{v_2}{v_1} = \frac{A_1}{A_2} = \frac{4A}{A} = \mathbf{4}$$

The fluid accelerates as it passes through the narrow throat, and by Bernoulli's equation the pressure drops at the throat.

Why other options are wrong:

- (B) 2: Would only be correct if the area ratio were $2:1$, not $4:1$.
- (C) 8: Incorrectly squares the area ratio.
- (D) $1/4$: Inverts the ratio; actually $v_1/v_2 = 1/4$, not v_2/v_1.

Answer: (A)

Sol. Q7.

Solution

Topic: Thermodynamics — Work Done in an Isochoric Process

In an isochoric (constant-volume) process, the volume of the gas does not change: $\Delta V = 0$.

The work done by the gas is given by:

$$W = \int P\,dV = P \cdot \Delta V = P \times 0 = \mathbf{0}$$

Although the internal energy and temperature of the gas change (heat is absorbed or released), no work is done because there is no displacement of the boundary.

Why other options are wrong:

- (A) $nR(T_2 - T_1)$: This is the work done in an *isobaric* process.
- (B) $nC_v(T_2 - T_1)$: This is the change in *internal energy* ΔU, not work.
- (D) $nC_p(T_2 - T_1)$: This is the heat added in an isobaric process.

Answer: (C)

Sol. Q8.

Solution

Topic: Kinetic Theory of Gases — RMS Speed

The rms speed of an ideal gas molecule is:

$$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$$

At fixed molar mass M, $v_{\text{rms}} = \sqrt{\frac{3R}{M}} \cdot \sqrt{T}$.

Therefore $v_{\text{rms}} \propto \sqrt{T}$.

Why other options are wrong:

- (A) $v_{\text{rms}} \propto T$: Incorrect; this would require $v_{\text{rms}}^2 \propto T^2$, but $v_{\text{rms}}^2 = 3RT/M \propto T^1$.
- (B) $v_{\text{rms}} \propto T^2$: Grossly incorrect.
- (C) $v_{\text{rms}} \propto 1/T$: Incorrect; rms speed *increases* with temperature.

Answer: (D)

Sol. Q9.

Solution

Topic: Oscillations — Maximum Acceleration in SHM

In simple harmonic motion, the displacement is $x = A\sin(\omega t + \phi)$. Differentiating twice:

$$a = \frac{d^2x}{dt^2} = -\omega^2 x$$

The maximum acceleration occurs at the extreme positions ($|x| = A$):

$$|a|_{\max} = \omega^2 A = (4)^2 \times 0.5 = 16 \times 0.5 = \mathbf{8}\ \mathrm{m/s^2}$$

Why other options are wrong:

- (A) $2\ \mathrm{m/s^2}$: Uses $\omega \cdot A$ instead of $\omega^2 A$.
- (C) $16\ \mathrm{m/s^2}$: Computes $\omega^2 A$ with $A = 1$ m instead of 0.5 m.
- (D) $4\ \mathrm{m/s^2}$: Confuses ω with ω^2 in the formula.

Answer: (B)

Sol. Q10.

Solution

Topic: Waves — Closed Organ Pipe Fundamental Frequency

A closed organ pipe has a node at the closed end and an antinode at the open end. The fundamental mode has one quarter-wavelength fitting inside the pipe:

$$L = \frac{\lambda_1}{4} \implies \lambda_1 = 4L$$

The fundamental frequency is:

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L} = \frac{340}{4 \times 0.85} = \frac{340}{3.4} = \mathbf{100}\ \mathrm{Hz}$$

Why other options are wrong:

- (B) $200\ \mathrm{Hz}$: This is the first overtone (third harmonic) of a closed pipe, not the fundamental.
- (C) $50\ \mathrm{Hz}$: Results from using $\lambda_1 = 2L$ (applies to open pipes, not closed).
- (D) $400\ \mathrm{Hz}$: Uses $L = \lambda$ (fourth harmonic), not the fundamental.

Answer: (A)

Sol. Q11.

Solution

Topic: Electrostatics — Electric Field of an Infinite Line Charge

Using Gauss's law with a cylindrical Gaussian surface of radius r and length ℓ coaxial with the wire:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\varepsilon_0}$$

The enclosed charge is $Q_{\text{enc}} = \lambda\ell$. By symmetry, $\vec{E}$ is radial and uniform over the curved surface (area $= 2\pi r\ell$):

$$E \cdot 2\pi r\ell = \frac{\lambda\ell}{\varepsilon_0} \implies E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

Why other options are wrong:

- (A) $\frac{\lambda}{4\pi\varepsilon_0 r^2}$: This is the field of a point charge, not a line charge.
- (B) $\frac{\lambda}{2\varepsilon_0}$: Missing the factor of πr in the denominator.
- (D) $\frac{\lambda}{4\varepsilon_0 r}$: Incorrect coefficient; arises from confusing with point charge formula.

Answer: (C)

Sol. Q12.

Solution

Topic: Current Electricity — Terminal Voltage of a Battery

The terminal voltage of a battery is less than its EMF by the voltage drop across the internal resistance:

$$V_{\text{terminal}} = \varepsilon - I \cdot r = 12 - (2 \times 2) = 12 - 4 = \mathbf{8}\text{ V}$$

Why other options are wrong:

- (A) 12 V: This is the EMF itself; the terminal voltage equals EMF only when $I = 0$ (open circuit).

- (B) 10 V: Corresponds to $Ir = 2 \times 1 = 2$ V drop, but $r = 2\ \Omega$ here, so $Ir = 4$ V.
- (C) 6 V: Incorrectly subtracts $\varepsilon/2$ or uses wrong formula.

Answer: (D)

Sol. Q13.

Solution

Topic: Magnetic Effects of Current — Field at Centre of Semicircular Arc

The magnetic field at the centre of a complete circular loop of radius R carrying current I is $B_{\text{circle}} = \mu_0 I/(2R)$. A semicircular arc contributes exactly half of this:

$$B = \frac{\mu_0 I}{4R}$$

The straight wire segments at the two ends of the arc pass through the centre O, so they produce zero field at O (since $I\, d\vec{l} \times \hat{r} = 0$ when $d\vec{l} \parallel \hat{r}$).

Substituting $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$, $I = 2$ A, $R = 0.02$ m:

$$B = \frac{4\pi \times 10^{-7} \times 2}{4 \times 0.02} = \frac{8\pi \times 10^{-7}}{0.08} = 100\pi \times 10^{-7}\ \mathrm{T} = \pi \times 10^{-5}\ \mathrm{T}$$

Why other options are wrong:

- (A) $\pi \times 10^{-6}$ T: Off by factor of 10; arises from using $R = 0.2$ m instead of 0.02 m.
- (C) $2\pi \times 10^{-6}$ T: Off by factor of 5; incorrect exponent handling.
- (D) $5\pi \times 10^{-6}$ T: Off by factor of 2; arises from using the full-circle formula.

Answer: (B)

Sol. Q14.

Solution

Topic: Electromagnetic Induction — Motional EMF

When a conducting rod of length L moves with velocity v perpendicular to a magnetic field B (all three mutually perpendicular), the motional EMF is:

$$\mathcal{E} = BLv = 1 \times 0.5 \times 4 = \mathbf{2}\text{ V}$$

This arises because the free charges in the rod experience a magnetic force $F = qvB$, which drives them to one end of the rod, creating a potential difference.

Why other options are wrong:

- (B) 0.5 V: Uses L divided by v or similar error.
- (C) 4 V: Forgetting to multiply by $L = 0.5$ m (uses $L = 1$ m instead).
- (D) 8 V: Doubles the correct answer; possible error of using $2BLv$.

Answer: (A)

Sol. Q15.

Solution

Topic: AC Circuits — Average Power in a Purely Resistive Circuit

In a purely resistive AC circuit, the current and voltage are in phase (power factor $\cos\phi = 1$). The average power dissipated is:

$$P = \frac{V_{\text{rms}}^2}{R} = \frac{(220)^2}{100} = \frac{48{,}400}{100} = \mathbf{484}\text{ W}$$

Equivalently, $P = V_{\text{rms}} \cdot I_{\text{rms}} = V_{\text{rms}}^2/R$ since $I_{\text{rms}} = V_{\text{rms}}/R = 2.2$ A and $P = 220 \times 2.2 = 484$ W.

Why other options are wrong:

- (A) 220 W: Confuses $P = V_{\text{rms}}$ (not a valid formula for power).
- (B) 242 W: Divides the correct answer by 2, perhaps confusing with $\frac{1}{2}V_{\text{peak}}^2/R$.
- (D) 968 W: Doubles the correct answer; incorrect use of peak voltage formula.

Answer: (C)

Sol. Q16.

Solution

Topic: Ray Optics — Image Formation by a Concave Mirror

Using the standard sign convention (incident light travels in the negative x-direction):

$$u = -30 \text{ cm}, \quad f = -10 \text{ cm}$$

Applying the mirror formula:

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

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{-30} = -\frac{1}{10} + \frac{1}{30} = \frac{-3+1}{30} = \frac{-2}{30} = -\frac{1}{15}$$

$$v = -15 \text{ cm}$$

The negative sign indicates the image is on the same side as the object (in front of the mirror), i.e., a real, inverted image at 15 cm from the mirror.

Why other options are wrong:

- (A) 20 cm: Incorrect computation; would arise from $u = -20$ cm instead of -30 cm.
- (B) 10 cm behind mirror: A virtual image cannot form for an object beyond f in a concave mirror.
- (C) 30 cm: Only happens when the object is placed at C (centre of curvature $= 2f = 20$ cm, not 30 cm).

Answer: (D)

Sol. Q17.

Solution

Topic: Wave Optics — Young's Double-Slit Experiment (Fringe Width)

The fringe width (distance between consecutive bright or dark fringes) in YDSE is:

$$\beta = \frac{\lambda D}{d}$$

Substituting $\lambda = 600\text{ nm} = 600 \times 10^{-9}\text{ m}$, $D = 1\text{ m}$, $d = 0.6\text{ mm} = 0.6 \times 10^{-3}\text{ m}$:

$$\beta = \frac{600 \times 10^{-9} \times 1}{0.6 \times 10^{-3}} = \frac{600 \times 10^{-9}}{6 \times 10^{-4}} = 10^{-3}\text{ m} = \mathbf{1}\text{ mm}$$

Why other options are wrong:

- (A) 0.5 mm: Off by a factor of 2; perhaps used $d = 1.2\text{ mm}$.
- (C) 2 mm: Off by factor of 2; perhaps used $d = 0.3\text{ mm}$.
- (D) 0.1 mm: Off by factor of 10; a decimal error in conversion.

Answer: (B)

Sol. Q18.

Solution

Topic: Dual Nature of Radiation and Matter — de Broglie Wavelength

The de Broglie wavelength is $\lambda = h/p$ where p is the linear momentum of the particle.

The kinetic energy and momentum are related by:

$$KE = \frac{p^2}{2m} \implies p = \sqrt{2m \cdot KE}$$

Therefore:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m \cdot KE}}$$

Why other options are wrong:

- (B) $\dfrac{h}{m \cdot KE}$: Incorrect; confuses momentum with $m \cdot KE$.
- (C) $\dfrac{h\sqrt{KE}}{\sqrt{2m}}$: Inverts the relationship; λ should decrease as KE increases.

- (D) $\frac{h}{2m \cdot KE}$: Missing the square root sign on the denominator.

Answer: (A)

Sol. Q19.

Solution

Topic: Atoms — Hydrogen Spectrum (Energy of Transition)

The energy of the n-th level in the hydrogen atom is $E_n = -13.6/n^2$ eV.

For the transition from $n = 3$ to $n = 1$:

$$\Delta E = E_1 - E_3 = \left(-\frac{13.6}{1^2}\right) - \left(-\frac{13.6}{3^2}\right) = 13.6\left(\frac{1}{1} - \frac{1}{9}\right) = 13.6 \times \frac{8}{9}$$

$$\Delta E = 13.6 \times 0.8\overline{8} \approx \mathbf{12.1} \text{ eV}$$

This corresponds to the emission of a photon in the Lyman series (UV region).

Why other options are wrong:

- (A) 10.2 eV: This is the energy of the $n = 2 \to n = 1$ transition, not $n = 3 \to n = 1$.
- (B) 3.4 eV: Magnitude of the energy of the $n = 2$ level ($|E_2| = 3.4$ eV), not a transition energy.
- (D) 13.6 eV: This is the ionization energy (transition from $n = 1$ to $n = \infty$), not $n = 3 \to n = 1$.

Answer: (C)

Sol. Q20.

Solution

Topic: Electronic Devices — Zener Diode Voltage Regulator

In a Zener diode voltage regulator circuit, the Zener diode is connected in reverse bias. When the reverse voltage across the Zener reaches its breakdown voltage V_Z, the diode conducts and maintains a constant voltage V_Z across its terminals, regardless of variations in the input voltage (within operating limits) or load current.

Therefore, the output voltage:

$$V_{out} = V_Z = \mathbf{10}\ \text{V} \quad \text{(constant)}$$

The series resistor R_s absorbs the excess voltage drop $(V_{in} - V_Z)$ and limits the current.

Why other options are wrong:

- (A) "Varies between 15 V and 20 V": The Zener clamps the output; it does not simply pass the input voltage.
- (B) "0 V": The Zener does conduct in reverse breakdown; that is precisely its function here.
- (C) "Depends on R_s": The output voltage equals V_Z as long as R_s is chosen to keep the Zener in the breakdown region. R_s affects the Zener current, not V_{out}.

Answer: (D)

Sol. Q21.

Solution

Topic: Kinematics — Projectile Range at $45°$

The range of a projectile is maximised and given by:

$$R = \frac{u^2 \sin 2\theta}{g}$$

At $\theta = 45°$, $\sin 90° = 1$:

$$R = \frac{u^2}{g} = \frac{(20)^2}{10} = \frac{400}{10} = \mathbf{40}\ \text{m}$$

Answer: (40)

Sol. Q22.

Solution

Topic: Circular Motion — Centripetal Acceleration

Converting speed: $72\ \text{km/h} = 72 \times \dfrac{1000}{3600} = 20\ \text{m/s}.$

Centripetal acceleration:

$$a_c = \frac{v^2}{r} = \frac{(20)^2}{200} = \frac{400}{200} = \mathbf{2}\ \text{m/s}^2$$

Answer: (2)

Sol. Q23.

Solution

Topic: Work and Energy — Elastic Potential Energy of a Spring

Converting compression: $x = 10\ \text{cm} = 0.10\ \text{m}.$

Elastic PE stored in the spring:

$$U = \frac{1}{2}kx^2 = \frac{1}{2} \times 1000 \times (0.10)^2 = \frac{1}{2} \times 1000 \times 0.01 = \mathbf{5}\ \text{J}$$

Answer: (5)

Sol. Q24.

Solution

Topic: Current Electricity — Resistors in Parallel

For three resistors $R_1 = 2\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 6\ \Omega$ in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3}{6} + \frac{2}{6} + \frac{1}{6} = \frac{6}{6} = 1$$

$$R_{eq} = \mathbf{1}\ \boldsymbol{\Omega}$$

Answer: (1)

Sol. Q25.

Solution

Topic: Oscillations — Time Period of Spring-Mass System

The time period of a spring-mass system is:

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{1}{\pi^2}} = 2\pi \times \frac{1}{\pi} = \mathbf{2}\ \mathrm{s}$$

Answer: (2)

Sol. Q26.

Solution

Topic: Thermodynamics — Isobaric Process and Charles's Law

At constant pressure, Charles's Law states $V \propto T$:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \implies T_2 = T_1 \times \frac{V_2}{V_1} = 300 \times 2 = \mathbf{600}\ \mathrm{K}$$

Answer: (600)

Sol. Q27.

Solution

Topic: Electrostatics — Energy Stored in a Capacitor

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\times 10\times 10^{-6}\times (100)^2 = \frac{1}{2}\times 10^{-5}\times 10^4 = \frac{1}{2}\times 10^{-1} = 0.05\ \mathrm{J} = \mathbf{50}\ \mathrm{mJ}$$

Answer: (50)

Sol. Q28.

Solution

Topic: Magnetic Effects of Current — Radius of Circular Orbit of a Charged Particle

When a charged particle moves perpendicular to a magnetic field, it undergoes circular motion. The magnetic force provides the centripetal force:

$$qvB = \frac{m_e v^2}{r} \implies r = \frac{m_e v}{qB}$$

$$r = \frac{9.1 \times 10^{-31} \times 10^6}{1.6 \times 10^{-19} \times 0.1} = \frac{9.1 \times 10^{-25}}{1.6 \times 10^{-20}} = \frac{9.1}{1.6} \times 10^{-5} = 5.6875 \times 10^{-2} \text{ m} \approx 5.7 \times 10^{-2} \text{ m} = \mathbf{5.7} \text{ cm}$$

Answer: (5.7)

Sol. Q29.

Solution

Topic: Ray Optics — Convex Lens Image Distance

Using the lens formula with sign convention ($u = -20$ cm, $f = +10$ cm):

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \implies \frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{10} + \frac{1}{-20} = \frac{1}{10} - \frac{1}{20} = \frac{2-1}{20} = \frac{1}{20}$$

$$v = \mathbf{20} \text{ cm}$$

The positive value of v indicates a real image on the other side of the lens.

Answer: (20)

Sol. Q30.

Solution

Topic: Nuclei — Radioactive Decay after Multiple Half-Lives

After each half-life, the number of undecayed nuclei is halved. After $n = 4$ half-lives:

$$N = N_0 \times \left(\frac{1}{2}\right)^4 = 1600 \times \frac{1}{16} = \mathbf{100\ nuclei}$$

Answer: (100)

ANSWER KEY

Section A — MCQ Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	A	3	C	4	D	5	B
6	A	7	C	8	D	9	B	10	A
11	C	12	D	13	B	14	A	15	C
16	D	17	B	18	A	19	C	20	D

Section B — Numerical Answer Key

Q	Ans	Q	Ans
21	40	22	2
23	5	24	1
25	2	26	600
27	50	28	5.7
29	20	30	100