JEE Main Physics
Sample Paper – 12

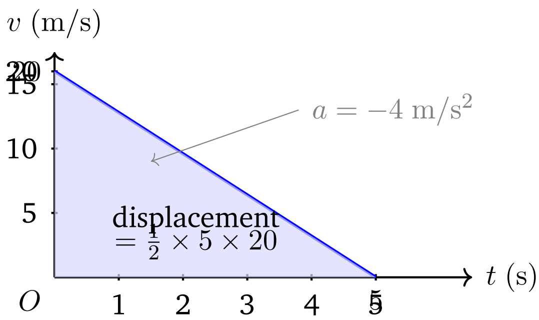
Duration: 60 Minutes | Maximum Marks: 100

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 particle starts with a velocity of $20\ \text{m/s}$ at $t = 0$ and decelerates uniformly to rest at $t = 5\ \text{s}$. The velocity-time graph is shown below. The distance travelled by the particle during this interval is:



(A) $40\ \text{m}$

(B) $100\ \text{m}$

(C) $25\ \text{m}$

(D) $50\ \text{m}$

Q2. A hunter aims a gun horizontally and fires a bullet at the exact moment a monkey, perched at the same horizontal level as the gun barrel, lets go of the branch and begins to fall freely. Neglecting air resistance, what happens?

(A) The bullet passes above the monkey because the monkey falls while the bullet travels horizontally.

(B) The bullet passes below the monkey because gravity acts more strongly on the heavier bullet.

(C) The bullet always hits the monkey regardless of the horizontal distance, because both the bullet and the monkey fall the same vertical distance in the same time.

(D) The bullet misses the monkey if the distance is too large because the bullet slows down.

Q3. A horizontal spring of spring constant $k = 500\ \text{N/m}$ is attached to a rigid wall. A block of mass $2\ \text{kg}$ compresses the spring by $x = 20\ \text{cm} = 0.20\ \text{m}$ and is then released from rest. The work done **by the spring** on the block as the block travels from maximum compression back to the natural length of the spring is:

(A) $10\ \text{J}$

(B) $5\ \text{J}$

(C) $20\ \text{J}$

(D) $2.5\ \text{J}$

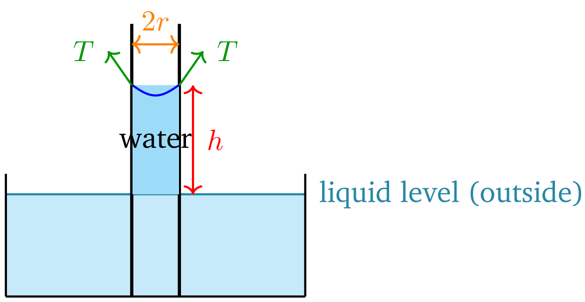
Q4. A figure skater spins on a frictionless ice surface with arms fully extended. At this moment her moment of inertia is $I_1 = 4\ \text{kg} \cdot \text{m}^2$ and her angular velocity is $\omega_1 = 2$ rad/s. She then pulls her arms in close to her body, reducing her moment of inertia to $I_2 = 1\ \mathrm{kg}\cdot\mathrm{m}^2$. Her new angular velocity ω_2 is:

(A) 2 rad/s
(B) 8 rad/s
(C) 4 rad/s
(D) 0.5 rad/s

Q5. A planet moves in an elliptical orbit around the Sun (which is at one focus). As the planet moves from aphelion (farthest point) to perihelion (nearest point), its speed increases. Which of the following laws of planetary motion correctly explains this observation?

(A) Kepler's First Law (Law of Ellipses) — the orbit is an ellipse with the Sun at one focus.
(B) Newton's Law of Gravitation — gravitational force decreases with distance.
(C) Kepler's Third Law (Law of Periods) — $T^2 \propto a^3$ where a is the semi-major axis.
(D) Kepler's Second Law (Law of Areas) — the line joining the planet to the Sun sweeps equal areas in equal times, so the planet moves faster when closer to the Sun.

Q6. Water (surface tension $T = 0.07$ N/m, density $\rho = 1000\ \mathrm{kg/m^3}$, contact angle $\theta = 0^\circ$) rises in a capillary tube of radius $r = 1$ mm $= 10^{-3}$ m (take $g = 10\ \mathrm{m/s^2}$). The diagram below illustrates the setup. The height h to which the water rises is:



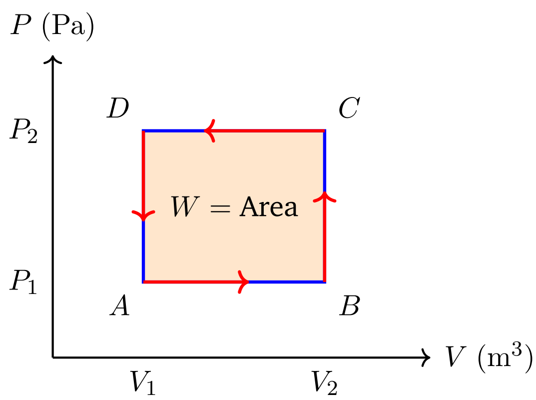
(A) 0.7 cm

(B) 2.8 cm

(C) 1.4 cm

(D) 0.14 cm

Q7. An ideal gas undergoes a cyclic process represented by the rectangular loop $ABCDA$ on the P-V diagram shown below, where $P_1 = 1 \times 10^5$ Pa, $P_2 = 3 \times 10^5$ Pa, $V_1 = 2$ L $= 2 \times 10^{-3}$ m^3, and $V_2 = 4$ L $= 4 \times 10^{-3}$ m^3. The net work done **by** the gas per cycle is:



(A) 400 J

(B) 800 J

(C) 200 J

(D) 1200 J

Q8. For molecules of an ideal gas at a given temperature T, the most probable speed v_{mp}, average speed v_{avg}, and root-mean-square speed v_{rms} are related by the Maxwell-Boltzmann distribution. The correct inequality among these three speeds is:

(A) $v_{rms} < v_{avg} < v_{mp}$

(B) $v_{mp} < v_{avg} < v_{rms}$

(C) $v_{avg} < v_{mp} < v_{rms}$

(D) $v_{mp} = v_{avg} = v_{rms}$

Q9. In an LC oscillator circuit, the capacitor ($C = 0.1$ F) is initially fully charged and the inductor ($L = 0.1$ H) carries no current. The charge on the capacitor oscillates as in SHM. The angular frequency of oscillation ω (in rad/s) is:

(A) 1 rad/s

(B) 100 rad/s

(C) 0.1 rad/s

(D) 10 rad/s

Q10. Two coherent waves of equal amplitude A and same frequency travel along the same path. Their equations are $y_1 = A\sin(kx - \omega t)$ and $y_2 = A\sin(kx - \omega t + \pi)$. The resultant amplitude of the superposed wave is:

(A) $2A$

(B) $A\sqrt{2}$

(C) 0

(D) A

Q11. A hollow metallic spherical shell carries a total charge $+Q$ uniformly distributed on its outer surface. A point P is located **inside** the hollow region (not in the conductor material itself). By Gauss's law, the electric field at point P is:

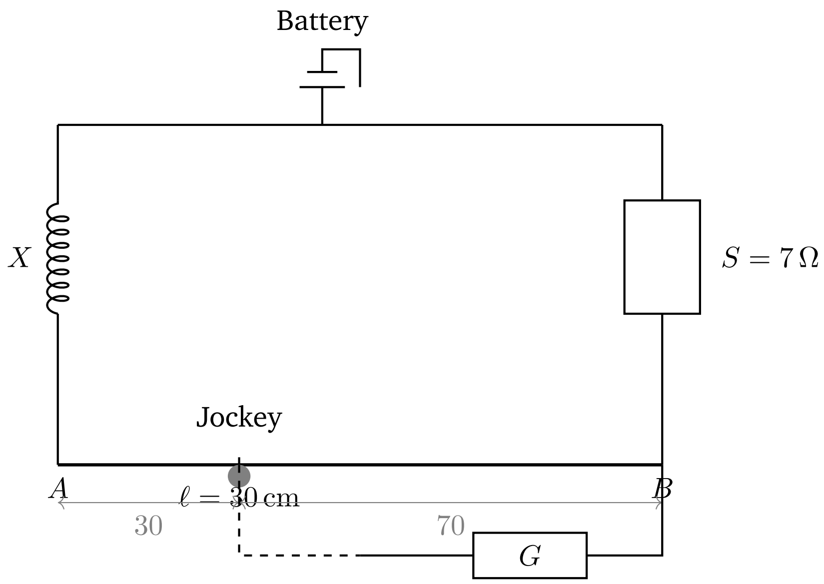
(A) Zero

(B) $\dfrac{kQ}{r^2}$, directed radially outward (where r is the distance from the centre)

(C) $\dfrac{kQ}{R^2}$, directed radially inward (where R is the radius of the shell)

(D) Depends on whether point P is at the centre or off-centre

Q12. In a Wheatstone meter bridge, an unknown resistance X is connected in the left gap and a known standard resistance $S = 7\ \Omega$ is placed in the right gap. The galvanometer shows no deflection (null point) when the jockey touches the wire at a length $\ell = 30$ cm from the left end A. The circuit is shown below. The value of X is:



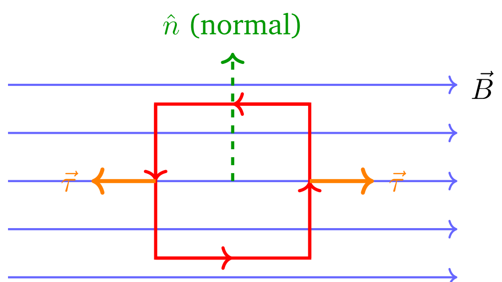
(A) $7\ \Omega$

(B) $3\ \Omega$

(C) $21\ \Omega$

(D) $10\ \Omega$

Q13. A rectangular coil consisting of $N = 100$ turns, each of area $A = 0.01\ \text{m}^2$, carries a current $I = 1$ A. The coil is placed in a uniform magnetic field $B = 0.5$ T with the plane of the coil parallel to the field (i.e., the field is perpendicular to the normal to the coil). The diagram shows the setup. The torque acting on the coil is:



$N = 100,\ I = 1\,\text{A},\ A = 0.01\,\text{m}^2,\ B = 0.5\,\text{T}$

(A) $0.05\ \text{N} \cdot \text{m}$

(B) $0.1\ \mathrm{N \cdot m}$

(C) $1.0\ \mathrm{N \cdot m}$

(D) $0.5\ \mathrm{N \cdot m}$

Q14. Two coaxial solenoids are wound close together such that their mutual inductance is $M = 0.5$ H. The current in the primary solenoid changes at a uniform rate $dI/dt = 4$ A/s. The magnitude of the EMF induced in the secondary solenoid is:

(A) 0.5 V

(B) 8 V

(C) 2 V

(D) 4 V

Q15. An ideal step-up transformer has $N_1 = 100$ turns in the primary coil and $N_2 = 1000$ turns in the secondary coil. An AC voltage of $V_1 = 220$ V is applied to the primary. The output voltage V_2 across the secondary is:

(A) 2200 V

(B) 22 V

(C) 220 V

(D) 440 V

Q16. A biconvex glass lens has both radii of curvature equal in magnitude: $|R_1| = |R_2| = R = 20$ cm. The refractive index of the glass is $\mu = 1.5$. Using the Lensmaker's equation, the focal length of this lens is:

(A) 10 cm

(B) 20 cm

(C) 40 cm

(D) 5 cm

Q17. When unpolarised light is incident on a glass surface at the Brewster angle θ_B, the reflected light is completely plane-polarised. If the refractive index of glass is μ, which of the following correctly expresses Brewster's Law?

(A) $\sin\theta_B = \mu$

(B) $\cos\theta_B = \mu$

(C) $\theta_B = \frac{\mu}{2}$ (in radians)

(D) $\tan\theta_B = \mu$

Q18. In the Compton effect, an X-ray photon of wavelength λ scatters off a free electron at rest and is deflected through a scattering angle ϕ. The scattered photon has a longer wavelength λ'. Which of the following correctly gives the Compton wavelength shift $\Delta\lambda = \lambda' - \lambda$?

(A) $\Delta\lambda = \frac{h}{m_e c}(1 + \cos\phi)$

(B) $\Delta\lambda = \frac{h}{m_e c}\cos\phi$

(C) $\Delta\lambda = \frac{h}{m_e c}(1 - \cos\phi)$

(D) $\Delta\lambda = \frac{2h}{m_e c}\sin^2\phi$

Q19. Uranium-235 undergoes fission when struck by a slow (thermal) neutron, splitting into two smaller nuclei and releasing additional neutrons. Which of the following statements about nuclear fission of ${}^{235}_{92}\mathrm{U}$ is correct?

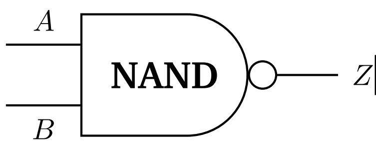
(A) The energy released per fission event is approximately $200\ \mathrm{MeV}$, originating from the mass defect converted via $E = mc^2$.

(B) Nuclear fission releases no neutrons; the energy comes entirely from gamma radiation.

(C) The energy released per fission is approximately $13.6\ \mathrm{eV}$, equivalent to the ionisation energy of hydrogen.

(D) Fission of $^{235}\mathrm{U}$ requires a fast neutron; thermal neutrons cannot cause fission.

Q20. The circuit symbol for a NAND gate is shown below, along with a partial truth table. Which row of the truth table correctly completes the entry for inputs $A = 0$, $B = 1$?



A	B	Z
0	0	1
0	1	?
1	0	1
1	1	0

(A) $A = 0,\ B = 1,\ Z = 0$

(B) $A = 0,\ B = 1,\ Z = 1$

(C) $A = 0,\ B = 1,\ Z =$ undefined

(D) $A = 0,\ B = 1,\ Z = 0.5$

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

Q21. A ball is projected from the ground with an initial speed $u = 20$ m/s at an angle $\theta = 45^\circ$ to the horizontal ($g = 10$ m/s^2). Calculate the horizontal range R of the projectile (in metres).

(Enter the exact numerical value as your answer.)

Q22. A car travels around a circular bend of radius $r = 50$ m on a banked road. For the ideal banking condition (no friction required), the road is inclined at an angle θ to the horizontal such that $\tan\theta = v^2/(rg)$. If the design speed is v m/s such that $\tan\theta = 0.2$ (i.e., $v^2 = 0.2 \times 50 \times 10 = 100$), find θ in degrees correct to one decimal place. (Use $\arctan(0.2) \approx 11.3^\circ$.)

(Enter the numerical value in degrees as your answer.)

Q23. A rubber ball is dropped from a height $h_0 = 10$ m onto a hard floor. It rebounds to a height $h_1 = 6.4$ m. The coefficient of restitution e is defined as $e = \sqrt{h_1/h_0}$. Find the value of e.

(Enter the exact numerical value as your answer.)

Q24. A Carnot engine operates between a hot reservoir at temperature $T_H = 500$ K and a cold reservoir at temperature $T_C = 300$ K. Calculate the efficiency η of the engine (as a percentage).

(Enter the numerical value of the percentage as your answer.)

Q25. Two point charges $+Q = +2\ \mu$C each are placed at diametrically opposite ends of a circle of radius $r = 1$ m. Calculate the electric potential at the centre of the circle (in kV). (Use $k = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$.)

(Enter the numerical value in kV as your answer.)

Q26. A copper wire of cross-sectional area $A = 1\ \mathrm{mm}^2 = 10^{-6}\ \mathrm{m}^2$ carries a steady current of $I = 1$ A. The number density of free electrons in copper is $n = 8.5 \times 10^{28}\ \mathrm{m}^{-3}$ and $e = 1.6 \times 10^{-19}\ \mathrm{C}$. Calculate the drift velocity v_d of the electrons in units of $10^{-5}\ \mathrm{m/s}$, rounded to one decimal place.

(Enter the numerical value in units of $10^{-5}\ \mathrm{m/s}$ as your answer.)

Q27. A proton ($q = 1.6 \times 10^{-19}\ \mathrm{C}$, $m = 1.67 \times 10^{-27}\ \mathrm{kg}$) moves in a uniform magnetic field $B = 1\ \mathrm{T}$ perpendicular to its velocity. Calculate the cyclotron frequency $f = qB/(2\pi m)$ in MHz, correct to one decimal place.

(Enter the numerical value in MHz as your answer.)

Q28. A DC motor is connected to a $220\ \mathrm{V}$ supply. The resistance of the motor coil is $R = 10\ \Omega$ and the current drawn at full speed is $I = 4\ \mathrm{A}$. Using $V = \varepsilon_b + IR$ (where ε_b is the back EMF), calculate the back EMF ε_b (in volts).

(Enter the exact numerical value as your answer.)

Q29. In a Young's Double-Slit Experiment (YDSE), the wavelength of light used is $\lambda = 600\ \mathrm{nm} = 600 \times 10^{-9}\ \mathrm{m}$, the slit separation is $d = 1\ \mathrm{mm} = 10^{-3}\ \mathrm{m}$, and the screen distance is $D = 2\ \mathrm{m}$. Calculate the fringe width $\beta = \lambda D/d$ in mm.

(Enter the exact numerical value in mm as your answer.)

Q30. The nucleus ${}^{7}_{3}\mathrm{Li}$ has 3 protons and 4 neutrons. Given: mass of proton $m_p = 1.00783\ \mathrm{u}$, mass of neutron $m_n = 1.00867\ \mathrm{u}$, mass of ${}^{7}\mathrm{Li}$ nucleus $M = 7.01601\ \mathrm{u}$, and $1\ \mathrm{u} = 931.5\ \mathrm{MeV}/c^2$. Calculate the binding energy per nucleon (in MeV per nucleon), correct to one decimal place.

(Enter the numerical value in MeV per nucleon as your answer.)

DETAILED SOLUTIONS

Solution

Topic: Kinematics — Distance from a Velocity-Time Graph

The v-t graph shows a straight line from $v = 20$ m/s at $t = 0$ to $v = 0$ at $t = 5$ s. The slope (acceleration) is:

$$a = \frac{0-20}{5-0} = -4 \text{ m/s}^2$$

The distance travelled equals the area of the triangle under the v-t graph:

$$s = \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2} \times 5 \text{ s} \times 20 \text{ m/s} = \mathbf{50} \text{ m}$$

Why other options are wrong:

Sol. Q1.

- Option A (40 m): Incorrect; this would arise from using $s = ut$ without accounting for deceleration.
- Option B (100 m): Incorrect; this would be the result of $s = u \times t = 20 \times 5$, ignoring the deceleration.
- Option C (25 m): Incorrect; this is half the correct value (area of a triangle, not a rectangle).

Answer: (D)

Solution

Topic: Laws of Motion — Monkey-and-Gun / Galilean Relativity of Free Fall

Both the bullet (fired horizontally) and the monkey (released from rest and falling freely) experience the **same** downward acceleration g. Starting from the same height, both fall the same vertical distance in the same time interval:

$$y_{\text{fall}} = \frac{1}{2} g t^2$$

The bullet's horizontal motion does not affect its vertical free-fall. Therefore, no matter the horizontal distance, the bullet always hits the monkey.

Why other options are wrong:

Sol. Q2.

- Option A: Incorrect; the monkey also falls, so the bullet does not pass above it.

- Option B: Incorrect; gravity acts equally on all objects regardless of mass (equivalence principle).
- Option D: Incorrect; air resistance is neglected; the bullet's horizontal speed does not affect the vertical drop.

Answer: (C)

Sol. Q3.

Solution

Topic: Work-Energy Theorem — Spring Potential Energy

The elastic potential energy stored in a compressed spring (compressed by x) is:

$$U = \frac{1}{2}kx^2 = \frac{1}{2} \times 500 \text{ N/m} \times (0.20 \text{ m})^2 = \frac{1}{2} \times 500 \times 0.04 = \mathbf{10} \text{ J}$$

As the spring returns to its natural length, it does work equal to the stored energy on the block. By the work-energy theorem:

$$W_{\text{spring}} = \Delta KE = \frac{1}{2}kx^2 = 10 \text{ J}$$

Why other options are wrong:

- Option B (5 J): This would result from forgetting the factor of $\frac{1}{2}$ in $\frac{1}{2}kx^2$, i.e., computing $kx^2/4$.
- Option C (20 J): Incorrect; this doubles the correct answer (equivalent to computing kx^2 without the $\frac{1}{2}$).
- Option D (2.5 J): Incorrect; results from mistakenly using $x = 0.1$ m instead of $x = 0.2$ m.

Answer: (A)

Solution

Topic: Rotational Motion — Conservation of Angular Momentum

In the absence of external torques (frictionless surface), the angular momentum $L = I\omega$ is conserved:

$$I_1\omega_1 = I_2\omega_2$$

$$\omega_2 = \frac{I_1\omega_1}{I_2} = \frac{4 \text{ kg} \cdot \text{m}^2 \times 2 \text{ rad/s}}{1 \text{ kg} \cdot \text{m}^2} = \mathbf{8} \text{ rad/s}$$

The angular velocity increases as moment of inertia decreases (kinetic energy also increases, supplied by the skater's muscles).

Why other options are wrong:

Sol. Q4.

- Option A ($2\ \mathrm{rad/s}$): This would be the answer if angular velocity were constant; it violates the conservation law.
- Option C ($4\ \mathrm{rad/s}$): Results from an error such as using $I_1/I_2 = 4$ instead of computing $\omega_2 = I_1\omega_1/I_2$.
- Option D ($0.5\ \mathrm{rad/s}$): This inverts the ratio, i.e., $\omega_2 = \omega_1 \times (I_2/I_1)$ — incorrectly decreasing ω.

Answer: (B)

Solution

Topic: Gravitation — Kepler's Second Law (Law of Areas)

Kepler's Second Law states that the line joining a planet to the Sun sweeps equal areas in equal intervals of time. This is a direct consequence of the **conservation of angular momentum** (since gravity is a central force). Mathematically:

$$\frac{dA}{dt} = \frac{L}{2m} = \text{constant}$$

A planet sweeps the same area per unit time at all points of its orbit. Therefore, it must move **faster** when closer to the Sun (where the radius vector is shorter) and **slower** when farther away.

Why other options are wrong:

Sol. Q5.

- Option A (Kepler's First Law): States the shape of the orbit is an ellipse; does not address the speed variation.
- Option B (Newton's Law of Gravitation): Correctly increases gravity when closer, but the specific *law* governing equal-area sweeping is Kepler's Second.
- Option C (Kepler's Third Law): Relates the orbital period to the semi-major axis; says nothing about speed variation within one orbit.

Answer: (D)

Sol. Q6.

Solution

Topic: Surface Tension — Capillary Rise Formula

The height of capillary rise is derived by balancing the upward surface tension force against the weight of the liquid column:

$$h = \frac{2T\cos\theta}{\rho r g}$$

Substituting the values ($T = 0.07$ N/m, $\theta = 0°$ so $\cos 0° = 1$, $\rho = 1000$ kg/m^3, $r = 10^{-3}$ m, $g = 10$ m/s^2):

$$h = \frac{2 \times 0.07 \times 1}{1000 \times 10^{-3} \times 10} = \frac{0.14}{10} = 0.014 \text{ m} = \mathbf{1.4} \text{ cm}$$

Why other options are wrong:

- Option A (0.7 cm): This is exactly half the correct value; likely an error in the numerator (using T instead of $2T$).
- Option B (2.8 cm): Doubles the correct value; perhaps using $r = 0.5$ mm by mistake.
- Option D (0.14 cm): Off by a factor of 10; results from using $\rho = 10000$ kg/m^3 instead of 1000 kg/m^3.

$\boxed{\textbf{Answer: (C)}}$

Sol. Q7.

Solution

Topic: Thermodynamics — Work Done in a Cyclic Process

The net work done by the gas in one complete cycle equals the area enclosed by the cycle on the P-V diagram. For a rectangular cycle:

$$W_{\text{net}} = (P_2 - P_1)(V_2 - V_1)$$

Substituting:

$$W_{\text{net}} = (3 \times 10^5 - 1 \times 10^5) \text{ Pa} \times (4 \times 10^{-3} - 2 \times 10^{-3}) \text{ m}^3$$

$$= 2 \times 10^5 \text{ Pa} \times 2 \times 10^{-3} \text{ m}^3 = 4 \times 10^2 \text{ J} = \mathbf{400} \text{ J}$$

Since the cycle proceeds clockwise on the P-V diagram, the net work is positive (work done *by* the gas).

Why other options are wrong:

- Option B (800 J): Incorrectly computes the full rectangle area as $P_2 \times \Delta V$

instead of $\Delta P \times \Delta V$.

- Option C (200 J): Uses only half the pressure difference (confusing $\Delta P/2$).
- Option D (1200 J): Multiplies $P_2 \times V_2$ directly, without taking differences.

Answer: (A)

Sol. Q8.

Solution

Topic: Kinetic Theory — Maxwell-Boltzmann Speed Distribution

For an ideal gas at temperature T with molecular mass m, the three characteristic speeds are:

$$v_{mp} = \sqrt{\frac{2k_B T}{m}} \quad \text{(most probable speed)}$$
$$v_{avg} = \sqrt{\frac{8k_B T}{\pi m}} \quad \text{(mean speed)}$$
$$v_{rms} = \sqrt{\frac{3k_B T}{m}} \quad \text{(root-mean-square speed)}$$

Numerically, for any given T and m: $v_{mp} : v_{avg} : v_{rms} = 1 : 1.128 : 1.225$. Thus:

$$v_{mp} < v_{avg} < v_{rms}$$

Why other options are wrong:

- Option A ($v_{rms} < v_{avg} < v_{mp}$): Completely reversed order.
- Option C ($v_{avg} < v_{mp} < v_{rms}$): Incorrectly places v_{mp} between v_{avg} and v_{rms}.
- Option D ($v_{mp} = v_{avg} = v_{rms}$): This is only true for a monoenergetic distribution, not for a Maxwell-Boltzmann gas.

Answer: (B)

Solution

Topic: Oscillations — LC Circuit Frequency

In an LC circuit, the charge q on the capacitor satisfies the equation:

$$L\frac{d^2q}{dt^2} + \frac{q}{C} = 0$$

This is identical in form to SHM with angular frequency:

$$\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{0.1\text{ H} \times 0.1\text{ F}}} = \frac{1}{\sqrt{0.01}} = \frac{1}{0.1} = \mathbf{10}\ \text{rad/s}$$

Why other options are wrong:

Sol. Q9.

- Option A (1 rad/s): Results from an error such as $\omega = 1/(LC)$ instead of $1/\sqrt{LC}$.
- Option B (100 rad/s): Computes $1/\sqrt{LC}$ with $LC = 10^{-4}$ instead of 10^{-2}, i.e., wrong unit conversion.
- Option C (0.1 rad/s): Takes $\omega = \sqrt{LC}$ instead of $1/\sqrt{LC}$.

Answer: (D)

Solution

Topic: Waves — Principle of Superposition (Destructive Interference)

The resultant amplitude of two waves with equal amplitude A and phase difference δ is:

$$A_R = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\delta}$$

With $A_1 = A_2 = A$ and $\delta = \pi$ (phase difference of π radians, i.e., the waves are in antiphase):

$$A_R = \sqrt{A^2 + A^2 + 2A^2\cos\pi} = \sqrt{2A^2 - 2A^2} = \sqrt{0} = \mathbf{0}$$

This is complete destructive interference; the two waves cancel each other perfectly.

Why other options are wrong:

Sol. Q10.

- Option A ($2A$): Corresponds to $\delta = 0$ (constructive interference), not $\delta = \pi$.
- Option B ($A\sqrt{2}$): Corresponds to $\delta = \pi/2$ (quarter-phase difference).
- Option D (A): Would result from a single wave without superposition.

Answer: (C)

Solution

Topic: Electrostatics — Electric Field Inside a Hollow Conducting Sphere (Gauss's Law)

By Gauss's Law, the electric flux through any closed Gaussian surface is:

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

For any point inside the hollow region of the conducting sphere, we draw a spherical Gaussian surface of radius $r < R$. Since all the charge $+Q$ resides on the *outer* surface of the shell, the charge enclosed by this Gaussian surface is:

$$Q_{\text{enclosed}} = 0 \implies E = \mathbf{0}$$

Why other options are wrong:

Sol. Q11.

- Option B: Gives the field *outside* the sphere at distance $r > R$; not valid inside the hollow.
- Option C: Incorrect formula with wrong direction; the field inside is zero regardless of position.
- Option D: The field is zero everywhere inside the hollow, whether at centre or off-centre.

Answer: (A)

Solution

Topic: Current Electricity — Meter Bridge (Wheatstone Bridge Principle)

At the balance (null) point, the Wheatstone bridge condition gives:

$$\frac{X}{S} = \frac{\ell}{100 - \ell}$$

where ℓ is the balance length from end A (in cm). Substituting $\ell = 30$ cm and $S = 7\ \Omega$:

$$\frac{X}{7} = \frac{30}{100 - 30} = \frac{30}{70} = \frac{3}{7}$$

$$X = 7 \times \frac{3}{7} = \mathbf{3\ \Omega}$$

Why other options are wrong:

Sol. Q12.

- Option A ($7\ \Omega$): This would require $\ell = 50$ cm (equal ratio), not 30 cm.
- Option C ($21\ \Omega$): Inverts the ratio; uses $X/S = (100-\ell)/\ell = 70/30$, which is the balance condition for X and S swapped.
- Option D ($10\ \Omega$): Incorrectly applies $X = \ell/10 = 3\ \Omega$ is right, but $10\ \Omega$ would imply $\ell \approx 59$ cm, not 30 cm.

Answer: (B)

Solution

Sol. Q13.

Topic: Magnetism — Torque on a Current-Carrying Coil in a Uniform Field

The torque on a rectangular coil of N turns, area A, carrying current I, in a uniform field B, when the angle between the plane of the coil and the field is 90° (i.e., the normal to the coil is perpendicular to $\vec{B}$, so $\theta = 90^\circ$) is:

$$\tau = NIAB\sin\theta = NIAB\sin 90^\circ = NIAB$$

Substituting values:

$$\tau = 100 \times 1\ \text{A} \times 0.01\ \text{m}^2 \times 0.5\ \text{T} = 100 \times 0.005 = \mathbf{0.5}\ \text{N}\cdot\text{m}$$

Why other options are wrong:

- Option A ($0.05\ \text{N}\cdot\text{m}$): Omits the factor $N = 100$; computes $\tau = IAB = 0.005\ \text{N}\cdot\text{m}$, then doubles incorrectly.
- Option B ($0.1\ \text{N}\cdot\text{m}$): Uses $N = 20$ or another incorrect value.
- Option C ($1.0\ \text{N}\cdot\text{m}$): Doubles the correct answer; possibly uses $B = 1$ T instead of 0.5 T.

Answer: (D)

Solution

Topic: Electromagnetic Induction — Mutual Inductance

By Faraday's law of mutual induction, the EMF induced in the secondary when the primary current changes at rate dI/dt is:

$$\mathcal{E} = M\frac{dI}{dt} = 0.5\ \text{H} \times 4\ \text{A/s} = \mathbf{2}\ \text{V}$$

Why other options are wrong:

Sol. Q14.

- Option A (0.5 V): Uses only $M = 0.5$ V without multiplying by dI/dt.
- Option B (8 V): Uses $\mathcal{E} = 2M \times dI/dt$ by doubling M incorrectly.
- Option D (4 V): Computes $\mathcal{E} = dI/dt$ alone (ignoring M), then doubles.

Answer: (C)

Solution

Sol. Q15.

Topic: AC Circuits — Ideal Transformer (Turns Ratio)

For an ideal transformer, the voltage transformation ratio equals the turns ratio:

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$V_2 = V_1 \times \frac{N_2}{N_1} = 220 \text{ V} \times \frac{1000}{100} = 220 \times 10 = \mathbf{2200} \text{ V}$$

Since $N_2 > N_1$, this is a step-up transformer; the output voltage is greater than the input.

Why other options are wrong:

- Option B (22 V): Divides V_1 by 10 instead of multiplying; treats it as a step-down.
- Option C (220 V): Uses a turns ratio of 1:1 (no transformation).
- Option D (440 V): Multiplies by 2 instead of 10; confuses N_2/N_1 with 2.

Answer: (A)

Solution

Topic: Ray Optics — Lensmaker's Equation

The Lensmaker's equation for a lens of refractive index μ in air is:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For a biconvex lens with $R_1 = +R$ (first surface, centre of curvature to the right) and $R_2 = -R$ (second surface, centre of curvature to the left):

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{-R}\right) = (\mu - 1) \times \frac{2}{R}$$

Substituting $\mu = 1.5$ and $R = 20$ cm:

$$\frac{1}{f} = 0.5 \times \frac{2}{20 \text{ cm}} = \frac{1}{20 \text{ cm}} \implies f = \mathbf{20} \text{ cm}$$

Why other options are wrong:

Sol. Q16.

- Option A (10 cm): Applies $1/f = (\mu - 1)/R$ (uses only one surface term), giving $f = R/0.5 = 40$ cm; or uses $\mu = 2$ instead.
- Option C (40 cm): Uses $1/f = (\mu - 1)/R$ (one surface only), forgetting the factor of 2 from the biconvex geometry.
- Option D (5 cm): Uses $\mu - 1 = 1$ (as if $\mu = 2$) in the formula.

Answer: (B)

Solution

Topic: Wave Optics — Brewster's Law of Polarisation

When light hits a surface at Brewster's angle θ_B, the reflected ray and refracted ray are **perpendicular** to each other. Applying Snell's law at this condition ($\theta_B + \theta_r = 90^\circ$, so $\theta_r = 90^\circ - \theta_B$):

$$n_1 \sin\theta_B = n_2 \sin\theta_r = n_2 \sin(90^\circ - \theta_B) = n_2 \cos\theta_B$$

$$\tan\theta_B = \frac{n_2}{n_1} = \mu \quad \text{(for air-to-glass, } n_1 = 1,\ n_2 = \mu)$$

This is **Brewster's Law**: $\tan\theta_B = \mu$.

Why other options are wrong:

Sol. Q17.

- Option A ($\sin\theta_B = \mu$): This is Snell's law at $\theta_r = 90^\circ$ (total internal reflection condition), not Brewster's law.
- Option B ($\cos\theta_B = \mu$): Incorrect; $\cos\theta_B$ is always less than 1 for positive θ_B, while $\mu > 1$.
- Option C ($\theta_B = \mu/2$): Dimensionally incorrect; μ is dimensionless but angles must come from a trigonometric relation.

Answer: (D)

Sol. Q18.

Solution

Topic: Dual Nature of Radiation — Compton Effect

The Compton effect describes the inelastic scattering of a photon off a free electron. Using relativistic energy-momentum conservation, the wavelength shift is:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\phi)$$

where ϕ is the photon scattering angle, h is Planck's constant, m_e is the electron rest mass, and c is the speed of light. The quantity $h/(m_e c) \approx 2.43 \times 10^{-12}$ m is the *Compton wavelength*. This formula shows $\Delta\lambda \geq 0$ (scattered photon always has a longer wavelength).

Why other options are wrong:

- Option A [$\Delta\lambda = (h/m_e c)(1 + \cos\phi)$]: The correct formula has $(1 - \cos\phi)$; using $(1+\cos\phi)$ gives a maximum shift at $\phi = 0$, contradicting the physics (no shift at forward scattering).
- Option B [$\Delta\lambda = (h/m_e c)\cos\phi$]: Incorrect; this does not vanish at $\phi = 0$ as required.
- Option D [$\Delta\lambda = (2h/m_e c)\sin^2\phi$]: Although $2\sin^2\phi = 1 - \cos(2\phi) \neq 1 - \cos\phi$; this is a different (incorrect) expression.

$\boxed{\textbf{Answer: (C)}}$

Sol. Q19.

Solution

Topic: Nuclei — Nuclear Fission of $^{235}\mathrm{U}$

A typical fission reaction:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

The energy released comes from the **mass defect**: the total mass of products is less than the total mass of reactants. By $E = \Delta mc^2$, the energy released per fission event is approximately **200** MeV.

Why other options are wrong:

- Option B: Fission releases on average 2–3 neutrons per event; this is essential for the chain reaction.
- Option C (13.6 eV): This is the ionisation energy of the hydrogen atom — an atomic (electron) process, not a nuclear one. Nuclear energies are in the MeV range (10^6 times larger).

- Option D: ^{235}U fissions most readily with *thermal* (slow) neutrons; fast neutrons are less effective for this isotope.

Answer: (A)

Sol. Q20.

Solution

Topic: Semiconductors — NAND Gate (Universal Gate) Truth Table

A NAND gate computes $Z = \overline{A \cdot B}$ (NOT AND). The complete truth table is:

A	B	A · B	Z = $\overline{A \cdot B}$
0	0	0	1
0	1	0	**1**
1	0	0	1
1	1	1	0

For $A = 0$, $B = 1$: $A \cdot B = 0$, so $Z = \overline{0} = \mathbf{1}$.

Why other options are wrong:

- Option A ($Z = 0$): Confuses NAND with AND; $A \cdot B = 0$ gives $Z = 1$, not 0.
- Option C (undefined): Logic gates have a well-defined output for every valid input combination.
- Option D ($Z = 0.5$): Digital logic gates have binary outputs only (0 or 1); there is no intermediate value 0.5.

Answer: (B)

Sol. Q21.

Solution

Topic: Kinematics — Projectile Range

The horizontal range of a projectile launched with speed u at angle θ is:

$$R = \frac{u^2 \sin 2\theta}{g} = \frac{(20)^2 \times \sin(2 \times 45^\circ)}{10} = \frac{400 \times \sin 90^\circ}{10} = \frac{400 \times 1}{10} = \mathbf{40}\ \mathrm{m}$$

At $\theta = 45^\circ$, the range is maximum for a given initial speed.

Answer: (40)

Sol. Q22.

Solution

Topic: Circular Motion — Banking of Roads

For ideal banking (no friction), the required banking angle satisfies:

$$\tan\theta = \frac{v^2}{rg}$$

Given $\tan\theta = 0.2$:

$$\theta = \arctan(0.2) \approx \mathbf{11.3}^\circ$$

This can be verified: $\tan(11.3^\circ) \approx 0.1997 \approx 0.2$.

Answer: (11.3)

Sol. Q23.

Solution

Topic: Collisions — Coefficient of Restitution

The coefficient of restitution e relates the rebound height to the drop height:

$$e = \frac{v_{\text{rebound}}}{v_{\text{impact}}} = \sqrt{\frac{h_1}{h_0}} = \sqrt{\frac{6.4}{10}} = \sqrt{0.64} = \mathbf{0.8}$$

A value of $e = 1$ corresponds to a perfectly elastic bounce; $e = 0$ to a perfectly inelastic one.

Answer: (0.8)

Sol. Q24.

Solution

Topic: Thermodynamics — Carnot Engine Efficiency

The efficiency of a Carnot engine operating between temperatures T_H and T_C is:

$$\eta = 1 - \frac{T_C}{T_H} = 1 - \frac{300\text{ K}}{500\text{ K}} = 1 - 0.6 = 0.4 = \mathbf{40}\%$$

No real engine can exceed the Carnot efficiency for the same temperature limits.

Answer: (40)

Sol. Q25.

Solution

Topic: Electrostatics — Electric Potential (Superposition)

The distance from each charge to the centre of the circle is $r = 1$ m (the radius). The electric potential due to a point charge is a scalar, so we add the contributions:

$$V = \frac{kQ}{r} + \frac{kQ}{r} = \frac{2kQ}{r} = \frac{2 \times 9 \times 10^9 \times 2 \times 10^{-6}}{1} = \frac{3.6 \times 10^4}{1} = 36000 \text{ V} = \mathbf{36} \text{ kV}$$

Answer: (36)

Sol. Q26.

Solution

Topic: Current Electricity — Drift Velocity of Electrons

The relation between current, drift velocity, and carrier density is:

$$I = nAev_d \implies v_d = \frac{I}{nAe}$$

Substituting $I = 1$ A, $n = 8.5 \times 10^{28}$ m^{-3}, $A = 10^{-6}$ m^2, $e = 1.6 \times 10^{-19}$ C:

$$v_d = \frac{1}{8.5 \times 10^{28} \times 10^{-6} \times 1.6 \times 10^{-19}} = \frac{1}{8.5 \times 1.6 \times 10^{28-6-19}} = \frac{1}{13.6 \times 10^3} \approx 7.35 \times 10^{-5} \text{ m/s}$$

Expressed in units of 10^{-5} m/s: $v_d \approx \mathbf{7.4} \times 10^{-5}$ m/s.

Answer: (7.4)

Sol. Q27.

Solution

Topic: Magnetism — Cyclotron Frequency of a Proton

The cyclotron frequency is:

$$f = \frac{qB}{2\pi m} = \frac{1.6 \times 10^{-19} \times 1}{2\pi \times 1.67 \times 10^{-27}} = \frac{1.6 \times 10^{-19}}{1.0493 \times 10^{-26}} \approx 1.525 \times 10^7 \text{ Hz} \approx \mathbf{15.2} \text{ MHz}$$

Note: the cyclotron frequency is independent of the speed of the particle, a key property exploited in the cyclotron accelerator.

Answer: (15.2)

Sol. Q28.

Solution

Topic: Electromagnetic Induction — Back EMF of a DC Motor

Applying Kirchhoff's voltage law around the motor circuit:

$$V = \varepsilon_b + IR$$

Solving for back EMF ε_b:

$$\varepsilon_b = V - IR = 220\ \text{V} - 4\ \text{A} \times 10\ \Omega = 220 - 40 = \mathbf{180}\ \text{V}$$

The back EMF opposes the supply voltage and represents the electrical power converted to mechanical work in the motor.

Answer: (180)

Sol. Q29.

Solution

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

The fringe width (separation between consecutive bright or dark fringes) is:

$$\beta = \frac{\lambda D}{d} = \frac{600 \times 10^{-9}\ \text{m} \times 2\ \text{m}}{10^{-3}\ \text{m}} = \frac{1.2 \times 10^{-6}}{10^{-3}} = 1.2 \times 10^{-3}\ \text{m} = \mathbf{1.2}\ \text{mm}$$

Answer: (1.2)

Sol. Q30.

Solution

Topic: Nuclei — Binding Energy per Nucleon (^7Li)

Step 1: Calculate the mass of the separated constituents (3 protons + 4 neutrons):

$$m_{\text{sep}} = 3m_p + 4m_n = 3 \times 1.00783 + 4 \times 1.00867 = 3.02349 + 4.03468 = 7.05817\ \text{u}$$

Step 2: Mass defect:

$$\Delta m = m_{\text{sep}} - M = 7.05817 - 7.01601 = 0.04216\ \text{u}$$

Step 3: Total binding energy (using $1\ \text{u} = 931.5\ \text{MeV}/c^2$):

$$BE = 0.04216 \times 931.5\ \text{MeV} \approx 39.27\ \text{MeV}$$

Step 4: Binding energy per nucleon ($A = 7$):

$$\frac{BE}{A} = \frac{39.27}{7} \approx \mathbf{5.6}\ \text{MeV per nucleon}$$

Answer: (5.6)

ANSWER KEY

Section A — MCQ Answer Key

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

Section B — Numerical Answer Key

Q	Ans	Q	Ans
21	40	22	11.3
23	0.8	24	40
25	36	26	7.4
27	15.2	28	180
29	1.2	30	5.6