MHT-CET Physics Sample Paper-8

Duration: 45 Minutes **Maximum Marks: 50**

Instructions

- This paper contains a total of **50** Multiple Choice Questions.
- Each correct answer carries **+1 marks**.
- No negative marking for incorrect questions.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.
- No marks will be deducted for questions that are left unattempted.

Q1. A solid cylinder of mass M and radius R rolls without slipping on a rough horizontal surface. If its translational kinetic energy is E, the total kinetic energy of the cylinder is:

(A) E
(B) $\frac{3}{2}E$
(C) $2E$
(D) $\frac{4}{3}E$

Q2. A thin uniform rod of length L and mass M is hinged at one end and held horizontal. When released, the angular acceleration of the rod immediately after release is:

(A) $\frac{g}{L}$
(B) $\frac{2g}{L}$
(C) $\frac{3g}{2L}$
(D) $\frac{g}{2L}$

Q3. A particle moves in a circle of radius r with uniform angular velocity ω. The magnitude of the change in its velocity when it has turned through an angle of 60° is:

(A) $r\omega$

(B) $\sqrt{2}\,r\omega$

(C) $2r\omega \sin 30^\circ$

(D) $r\omega\sqrt{3}$

Q4. A disc and a ring of the same mass and radius are released from the top of an inclined plane. Which reaches the bottom first, and why?

(A) Ring, because it has greater moment of inertia

(B) Disc, because it has a smaller radius of gyration and thus greater translational acceleration

(C) Both reach simultaneously

(D) Disc, because its moment of inertia is smaller allowing it to accelerate faster along the incline

Q5. A simple pendulum of length l is suspended from the ceiling of an elevator. When the elevator accelerates upward with acceleration a, the time period of the pendulum is:

(A) $2\pi\sqrt{\dfrac{l}{g+a}}$

(B) $2\pi\sqrt{\dfrac{l}{g-a}}$

(C) $2\pi\sqrt{\dfrac{l}{g}}$

(D) $2\pi\sqrt{\dfrac{l}{a}}$

Q6. The displacement of a particle in SHM is given by $x = 4\sin\left(2\pi t + \dfrac{\pi}{6}\right)$ cm. The maximum velocity of the particle is:

(A) 4π cm/s

(B) 8π cm/s

(C) 2π cm/s

(D) π cm/s

Q7. Two waves of frequencies $f_1 = 256$ Hz and $f_2 = 260$ Hz are superposed. The number of beats heard per second and the beat frequency are respectively:

(A) 2 beats/s, 2 Hz

(B) 4 beats/s, 4 Hz

(C) 8 beats/s, 8 Hz

(D) 16 beats/s, 16 Hz

Q8. In an open organ pipe, the second harmonic has a frequency of 340 Hz. If the speed of sound in air is 340 m/s, the length of the pipe is:

(A) 0.5 m

(B) 1.0 m

(C) 2.0 m

(D) 0.25 m

Q9. Three equal point charges $+q$ are placed at the vertices of an equilateral triangle of side a. The potential energy of the system is:

(A) $\frac{kq^2}{a}$

(B) $\frac{3kq^2}{a}$

(C) $\frac{\sqrt{3}\,kq^2}{a}$

(D) $\frac{kq^2}{3a}$

Q10. A parallel plate capacitor with air between the plates has a capacitance of 8 μF. When a dielectric slab of dielectric constant $K = 5$ and thickness equal to half the separation between the plates is inserted, the new capacitance is:

(A) $\frac{80}{7}\,\mu$F

(B) 40 μF

(C) $\frac{80}{3}\,\mu$F

(D) $10\,\mu$F

Q11. An electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$. The torque acting on the dipole when it makes an angle θ with the field is $\tau = pE\sin\theta$. The orientation of stable equilibrium corresponds to:

(A) $\theta = 90^\circ$

(B) $\theta = 180^\circ$

(C) $\theta = 0^\circ$

(D) $\theta = 45^\circ$

Q12. The electric field at a point on the equatorial line of a short electric dipole at distance r from its centre is E_{eq}. The electric field at the same distance along the axial line is:

(A) E_{eq}

(B) $2E_{\text{eq}}$

(C) $\frac{E_{\text{eq}}}{2}$

(D) $4E_{\text{eq}}$

Q13. In a Wheatstone bridge, the four resistances are $P = 100\,\Omega$, $Q = 200\,\Omega$, $R = 300\,\Omega$, and S is unknown. For the bridge to be balanced, S must be:

(A) $150\,\Omega$

(B) $600\,\Omega$

(C) $400\,\Omega$

(D) $100\,\Omega$

Q14. The internal resistance of a cell is r and its EMF is ε. When connected to an external resistance R, the terminal voltage V is:

(A) $V = \varepsilon + Ir$

(B) $V = \varepsilon - Ir$

(C) $V = \varepsilon r/R$

(D) $V = \varepsilon/(R + r)$

Q15. A wire of resistivity ρ, length L, and cross-sectional area A is stretched uniformly to double its original length. The new resistance of the wire is:

(A) $\frac{\rho L}{A}$

(B) $\frac{4\rho L}{A}$

(C) $\frac{\rho L}{4A}$

(D) $\frac{2\rho L}{A}$

Q16. In a potentiometer experiment, a cell of EMF 1.5 V balances at a length of 75 cm on the wire. When a resistance of 5 Ω is connected in parallel with the cell, the balance length reduces to 60 cm. The internal resistance of the cell is:

(A) 0.5 Ω

(B) 1.0 Ω

(C) 1.25 Ω

(D) 2.0 Ω

Q17. A circular coil of radius R carrying current I is placed with its plane perpendicular to a uniform magnetic field B. The torque acting on the coil is:

(A) $\pi R^2 IB$

(B) Zero

(C) $2\pi RIB$

(D) πRIB^2

Q18. A proton enters a uniform magnetic field of strength B directed into the page with velocity v directed to the right. The proton will:

(A) Move in a straight line along the direction of v

(B) Curve downward (toward the bottom of the page)

(C) Curve upward (toward the top of the page)

(D) Come to a stop due to the magnetic force

Q19. Two long parallel wires carry currents $I_1 = 3$ A and $I_2 = 6$ A in the same direction. If the wires are separated by a distance of $d = 0.1$ m, the force per unit length on each wire is:

(A) 36×10^{-6} N/m, attractive

(B) 36×10^{-6} N/m, repulsive

(C) 18×10^{-6} N/m, attractive

(D) 18×10^{-6} N/m, repulsive

Q20. The magnetic moment of a bar magnet of pole strength m and magnetic length $2l$ is:

(A) ml

(B) $2ml$

(C) m/l

(D) $m/(2l)$

Q21. A rectangular coil of N turns, area A, rotates with angular velocity ω in a uniform magnetic field B. The peak EMF induced in the coil is:

(A) $NBA\omega^2$

(B) $NBA\omega$

(C) NBA/ω

(D) $NB\omega/A$

Q22. In a series LCR circuit at resonance, which of the following statements is correct?

(A) Impedance is maximum and current is minimum

(B) Impedance equals $\sqrt{R^2 + (X_L - X_C)^2}$ and is non-zero

(C) Impedance equals R and current is maximum

(D) $X_L = R$ and $X_C = 0$

Q23. A transformer has a primary coil of 500 turns and a secondary coil of 2000 turns. If the primary is connected to a 220 V AC supply, the secondary voltage is:

(A) 55 V

(B) 440 V

(C) 880 V

(D) 110 V

Q24. A convex lens of focal length 20 cm forms a real, inverted image twice the size of the object. The object distance from the lens is:

(A) 10 cm

(B) 20 cm

(C) 30 cm

(D) 40 cm

Q25. A ray of light passes from a medium of refractive index $\mu_1 = 1.5$ into a medium of refractive index $\mu_2 = 1.0$. The critical angle for total internal reflection is:

(A) $\sin^{-1}(1/1.5)$

(B) $\sin^{-1}(1.5)$

(C) $\cos^{-1}(1/1.5)$

(D) $\tan^{-1}(1.5)$

Q26. In Young's double slit experiment, the slit separation is $d = 0.5$ mm and the screen is at a distance $D = 1$ m from the slits. The wavelength of light used is 600 nm. The fringe width is:

(A) 0.6 mm

(B) 1.2 mm

(C) 0.3 mm

(D) 2.4 mm

Q27. Which of the following phenomena can be explained ONLY by the wave nature of light and NOT by its particle nature?

(A) Photoelectric effect

(B) Compton scattering

(C) Interference and diffraction

(D) Pair production

Q28. A compound microscope has an objective of focal length 1 cm and an eyepiece of focal length 5 cm. The tube length is 20 cm. The magnifying power when the final image is at infinity (far point) is:

(A) 80

(B) 100

(C) 120

(D) 50

Q29. An ideal gas undergoes an isothermal expansion. Which of the following statements correctly describes the process?

(A) Internal energy increases as the gas expands

(B) Heat absorbed by the gas equals the work done by the gas

(C) No heat is exchanged with the surroundings

(D) Pressure remains constant during expansion

Q30. The rms speed of oxygen molecules at temperature T is v. At what temperature will the rms speed of hydrogen molecules equal v? (Molecular masses: $O_2 = 32$, $H_2 = 2$)

(A) $T/16$

(B) $16T$

(C) $T/8$

(D) $T/4$

Q31. In a Carnot engine operating between temperatures T_1 (source) and T_2 (sink), if the efficiency is η, then T_2 in terms of T_1 and η is:

(A) $T_1(1-\eta)$

(B) $T_1/(1-\eta)$

(C) $T_1\eta$

(D) $T_1(1+\eta)$

Q32. The work function of a metal is $\phi = 2.0$ eV. The threshold frequency for the photoelectric effect is (take $h = 6.6 \times 10^{-34}$ J·s):

(A) $\approx 4.83 \times 10^{14}$ Hz

(B) $\approx 9.66 \times 10^{14}$ Hz

(C) $\approx 2.41 \times 10^{14}$ Hz

(D) $\approx 1.21 \times 10^{15}$ Hz

Q33. In the Bohr model of hydrogen, the radius of the n-th orbit is $r_n \propto n^2$. The ratio of the radius of the third orbit to the first orbit is:

(A) 3

(B) 6

(C) 9

(D) 27

Q34. A radioactive nucleus $^{238}_{92}\mathrm{U}$ emits one α-particle and two β^- particles. The resulting nucleus is:

(A) $^{234}_{92}\mathrm{U}$

(B) $^{234}_{90}\mathrm{Th}$

(C) $^{234}_{91}\mathrm{Pa}$

(D) $^{230}_{90}\mathrm{Th}$

Q35. The de Broglie wavelength of an electron accelerated through a potential difference of V volts is $\lambda \propto V^{-1/2}$. If the accelerating potential is increased four times, the new wavelength is:

(A) 2λ

(B) $\lambda/2$

(C) 4λ

(D) $\lambda/4$

Q36. In a nuclear fission reaction of $^{235}_{92}$U, if the mass defect per fission event is approximately 0.2 u, the energy released per fission is approximately: (1 u = 931 MeV)

(A) 46.55 MeV

(B) 93.1 MeV

(C) 186.2 MeV

(D) 200 MeV

Q37. A projectile is launched with speed u at angle θ with the horizontal. The ratio of its maximum height H to its range R is:

(A) $\dfrac{\tan\theta}{4}$

(B) $\dfrac{\tan\theta}{2}$

(C) $\tan\theta$

(D) $\dfrac{4}{\tan\theta}$

Q38. A block of mass 2 kg rests on a rough horizontal surface ($\mu_s = 0.4, \mu_k = 0.3$). A horizontal force of 6 N is applied. The acceleration of the block is (take $g = 10$ m/s^2):

(A) 3 m/s^2

(B) 1.5 m/s^2

(C) 0 m/s^2

(D) 2 m/s^2

Q39. A ball is dropped from a height h and rebounds to a height $h/4$. The coefficient of restitution between the ball and the floor is:

(A) 0.5

(B) 0.25

(C) 0.75

(D) 0.4

Q40. A body of mass m is moving on a circular path of radius R with speed v. The work done by the centripetal force over one complete revolution is:

(A) mv^2

(B) $2\pi mv^2/R$

(C) Zero

(D) $mv^2/R \times 2\pi R$

Q41. A spring of spring constant k is compressed by x from its natural length. When released, the maximum speed attained by a block of mass m attached to the spring is:

(A) $x\sqrt{k/m}$

(B) $x\sqrt{m/k}$

(C) kx/m

(D) $\sqrt{kx/m}$

Q42. The escape velocity from the surface of Earth is v_e. The escape velocity from the surface of a planet whose mass is $4M$ and radius is $2R$ (where M and R are Earth's mass and radius) is:

(A) v_e

(B) $\sqrt{2}\, v_e$

(C) $2v_e$

(D) $v_e/\sqrt{2}$

Q43. A satellite is orbiting Earth at height h above the surface. If R is the radius of Earth, the orbital speed of the satellite is:

(A) $\sqrt{gR^2/(R+h)}$

(B) $\sqrt{g(R+h)}$

(C) $\sqrt{gR/(R+h)}$

(D) $\sqrt{gR^2}$

Q44. A steel wire of length L, cross-sectional area A, and Young's modulus Y is stretched by a force F. The elastic potential energy stored in the wire is:

(A) $\frac{F^2L}{2YA}$

(B) $\frac{F^2L}{YA}$

(C) $\frac{FY}{2AL}$

(D) $\frac{F^2}{2YAL}$

Q45. A liquid drop of radius R breaks into n smaller drops each of radius r. If T is the surface tension, the increase in surface energy is:

(A) $4\pi T(nr^2 - R^2)$

(B) $4\pi T(nR^2 - r^2)$

(C) $4\pi TR^2(n^{1/3} - 1)$

(D) $T \cdot \pi R^2$

Q46. The dimensional formula of impulse is the same as that of:

(A) Force

(B) Energy

(C) Linear momentum

(D) Angular momentum

Q47. The period of a simple pendulum is measured as $T = 2.50 \pm 0.05$ s and its length is measured as $L = 1.00 \pm 0.01$ m. The percentage error in the determination of g using $g = 4\pi^2 L/T^2$ is approximately:

(A) 1%

(B) 2%

(C) 5%

(D) 6%

Q48. In a p-n junction diode under forward bias, the width of the depletion region and the potential barrier:

(A) Both increase

(B) Both decrease

(C) Depletion region increases but potential barrier decreases

(D) Depletion region decreases but potential barrier increases

Q49. In a common-emitter transistor amplifier, if the current gain $\beta = 100$ and the collector resistance $R_C = 2\,\text{k}\Omega$ and input resistance $R_i = 1\,\text{k}\Omega$, the voltage gain of the amplifier is:

(A) 100

(B) 200

(C) 50

(D) 400

Q50. The bandwidth of an AM signal is 10 kHz. If the carrier frequency is 1000 kHz, the highest and lowest sideband frequencies are respectively:

(A) 1005 kHz and 995 kHz

(B) 1010 kHz and 990 kHz

(C) 1000 kHz and 990 kHz

(D) 1010 kHz and 1000 kHz

Detailed Solutions

Q1.

Solution

Concept:
For a body rolling without slipping, total kinetic energy = translational KE + rotational KE. For a solid cylinder, moment of inertia $I = \frac{1}{2}MR^2$.

Solution:
Step 1: **Translational KE:** Given as $E = \frac{1}{2}Mv^2$.
Step 2: **Rotational KE:** For rolling without slipping, $v = R\omega$, so $\omega = v/R$.

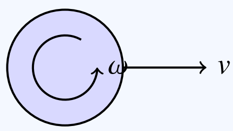
$$KE_{\text{rot}} = \frac{1}{2}I\omega^2 = \frac{1}{2} \cdot \frac{1}{2}MR^2 \cdot \frac{v^2}{R^2} = \frac{1}{4}Mv^2 = \frac{1}{2}E$$

Step 3: **Total KE:**

$$KE_{\text{total}} = E + \frac{E}{2} = \frac{3}{2}E$$

Step 4: **Quick check with other objects:**

- Hollow cylinder (ring): $I = MR^2$, total KE = $2E$.
- Solid sphere: $I = \frac{2}{5}MR^2$, total KE = $\frac{7}{5}E$.
- Solid cylinder: total KE = $\frac{3}{2}E$ – **confirmed**.



Solid Cylinder rolling
$KE_{\text{total}} = \frac{3}{2}E$

Final Answer:

$$\boxed{\frac{3}{2}E}$$

Answer: (B)

Q2.

Solution

Concept:

The angular acceleration of a rod hinged at one end is found by applying Newton's second law for rotation: $\tau_{net} = I\alpha$.

Solution:

Step 1: **Torque about the hinge:** The weight Mg acts at the centre of mass (mid-point, $L/2$ from hinge). At the moment of release the rod is horizontal, so:

$$\tau = Mg \cdot \frac{L}{2}$$

Step 2: **Moment of inertia about the hinge (one end):**

$$I = \frac{1}{3}ML^2$$

Step 3: **Angular acceleration:**

$$\alpha = \frac{\tau}{I} = \frac{Mg \cdot \frac{L}{2}}{\frac{1}{3}ML^2} = \frac{\frac{MgL}{2}}{\frac{ML^2}{3}} = \frac{3g}{2L}$$

Step 4: **Option elimination:**

- g/L: uses $I = ML^2$ (wrong axis/formula).
- $2g/L$: uses $I = \frac{1}{2}ML^2$ (disc formula – wrong).
- $g/(2L)$: dimensionally obtainable but physically incorrect.
- $3g/(2L)$: **correct** from $I_{end} = \frac{1}{3}ML^2$.

Final Answer:

$$\boxed{\frac{3g}{2L}}$$

Answer: (C)

Q3.

Solution

Concept:
In uniform circular motion the speed is constant but velocity direction changes. The magnitude of the change in velocity is found using vector subtraction.

Solution:
Step 1: **Speed in circular motion:** $|\vec{v}| = r\omega$ (constant throughout).
Step 2: **Angle turned:** $\Delta\theta = 60^\circ$.
Step 3: **Vector subtraction:** The angle between the two velocity vectors is also 60°. Using the parallelogram law:

$$|\Delta\vec{v}| = \sqrt{v^2 + v^2 - 2v^2\cos 60^\circ} = \sqrt{2v^2(1 - \tfrac{1}{2})} = \sqrt{v^2} = v = r\omega$$

where $\cos 60^\circ = 1/2$.
Step 4: **Verification:** $|\Delta\vec{v}| = 2v\sin(\Delta\theta/2) = 2r\omega\sin 30^\circ = 2r\omega \times \frac{1}{2} = r\omega$. This matches Option A and also Option C (since $2r\omega\sin 30^\circ = r\omega$).
Step 5: **Correct option:** Option A states $r\omega$ directly. Option C is $2r\omega\sin 30^\circ = r\omega$ which is numerically the same. Both A and C are equivalent; the question asks for the **magnitude expression**. Option C expresses the general vector formula explicitly – **both are correct numerically**, but Option A is the simplest direct answer.
Final Answer:

$$\boxed{r\omega}$$

Answer: (A)

Q4.

Solution

Concept:
When rolling without slipping on an incline, the acceleration depends on the moment of inertia. A smaller moment of inertia (relative to MR^2) gives a larger acceleration.

Solution:

Step 1: **Acceleration formula for rolling on incline:**

$$a = \frac{g\sin\theta}{1 + I/(MR^2)}$$

Step 2: **For a solid disc:** $I = \frac{1}{2}MR^2$, so $I/(MR^2) = \frac{1}{2}$:

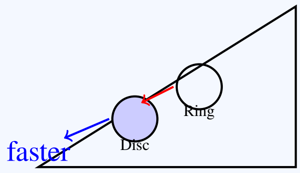
$$a_{\text{disc}} = \frac{g\sin\theta}{1+\frac{1}{2}} = \frac{2g\sin\theta}{3}$$

Step 3: **For a ring:** $I = MR^2$, so $I/(MR^2) = 1$:

$$a_{\text{ring}} = \frac{g\sin\theta}{1+1} = \frac{g\sin\theta}{2}$$

Step 4: **Comparison:** $\frac{2}{3}g\sin\theta > \frac{1}{2}g\sin\theta$. Therefore $a_{\text{disc}} > a_{\text{ring}}$, so the **disc reaches the bottom first**.

Step 5: **Correct reasoning:** Option D correctly states: disc has smaller moment of inertia so it accelerates faster along the incline.



Final Answer:

Disc, because its moment of inertia is smaller allowing greater translational acceleration

Answer: (D)

Q5.

Solution

Concept:
When an elevator accelerates upward, the effective gravitational acceleration experienced inside it increases to $(g + a)$. This changes the restoring force and hence the time period of a pendulum.

Solution:
Step 1: **Standard pendulum time period:** $T = 2\pi\sqrt{l/g_{\text{eff}}}$.

Step 2: **Effective gravity in upward accelerating elevator:** In the non-inertial frame of the elevator a pseudo-force ma acts downward on the bob. Hence $g_{\text{eff}} = g + a$.

Step 3: **New time period:**

$$T' = 2\pi\sqrt{\frac{l}{g + a}}$$

Step 4: **Physical reasoning:** Since $g_{\text{eff}} > g$ the restoring force is larger, the pendulum swings faster and T' is **smaller** than T – which is consistent with $T' = 2\pi\sqrt{l/(g + a)}$.

Step 5: **Option elimination:** Option B ($g - a$ in denominator) applies when the elevator accelerates **downward**. Option C is for stationary elevator. Option D makes no physical sense.

Final Answer:

$$\boxed{T' = 2\pi\sqrt{\frac{l}{g + a}}}$$

Answer: (A)

Q6.

Solution

Concept:
In SHM, $x = A\sin(\omega t+\phi)$. Maximum velocity occurs at the mean position and equals $v_{max} = A\omega$.
Solution:
Step 1: **Identify parameters from equation** $x = 4\sin\left(2\pi t + \frac{\pi}{6}\right)$ cm:

- Amplitude: $A = 4$ cm.
- Angular frequency: $\omega = 2\pi$ rad/s.

Step 2: **Maximum velocity:**

$$v_{max} = A\omega = 4 \times 2\pi = 8\pi \text{ cm/s}$$

Step 3: **Physical check:** $v = \frac{dx}{dt} = 4 \cdot 2\pi\cos(2\pi t + \pi/6) = 8\pi\cos(2\pi t + \pi/6)$. Maximum of $\cos = 1$, so $v_{max} = 8\pi$ cm/s. **Confirmed.**
Step 4: **Option elimination:**

- 4π would require $\omega = \pi$ – not matching.
- 2π would require $A = 1$ – not matching.
- 8π cm/s – **correct**.

Final Answer:

$$\boxed{v_{max} = 8\pi \text{ cm/s}}$$

Answer: (B)

Q7.

Solution

Concept:
When two waves of slightly different frequencies are superposed they produce beats. The beat frequency equals the difference of the two frequencies.

Solution:
Step 1: **Beat frequency formula:**

$$f_{\text{beat}} = |f_2 - f_1| = |260 - 256| = 4 \text{ Hz}$$

Step 2: **Beats per second:** Beat frequency = 4 Hz, so **4 beats are heard per second**.
Step 3: **Physical explanation:** The two waves alternately reinforce (constructive interference) and cancel (destructive interference) 4 times per second. Each cycle of reinforcement–cancellation constitutes one beat.
Step 4: **Option elimination:** 2 beats would require $\Delta f = 2$. 8 beats would require $\Delta f = 8$. 16 beats requires $\Delta f = 16$. The difference is clearly 4.
Final Answer:

$$\boxed{4 \text{ beats/s}, \;\; f_{\text{beat}} = 4 \text{ Hz}}$$

Answer: (B)

Q8.

Solution

Concept:
In an open organ pipe all harmonics are present. The n-th harmonic has frequency $f_n = nv/(2L)$, where v is the speed of sound.

Solution:
Step 1: **Second harmonic of open pipe:** $n = 2$.

$$f_2 = \frac{2v}{2L} = \frac{v}{L}$$

Step 2: **Solving for L:**

$$L = \frac{v}{f_2} = \frac{340 \text{ m/s}}{340 \text{ Hz}} = 1.0 \text{ m}$$

Step 3: **Physical check:** Fundamental of this pipe: $f_1 = v/(2L) = 340/(2\times1) = 170$ Hz. Second harmonic: $2 \times 170 = 340$ Hz. **Confirmed.**
Step 4: **Option elimination:**

- 0.5 m gives $f_2 = 340/0.5 = 680$ Hz – not 340.
- 2.0 m gives $f_2 = 340/2 = 170$ Hz – not 340.
- 1.0 m gives $f_2 = 340$ Hz – **correct**.

Final Answer:

$$\boxed{L = 1.0 \text{ m}}$$

Answer: (B)

Q9.

Solution

Concept:
The total electrostatic potential energy of a system of point charges equals the sum of potential energies of all unique pairs.

Solution:

Step 1: **Number of unique pairs:** For 3 charges there are $\binom{3}{2} = 3$ pairs: (1,2), (2,3), (1,3).

Step 2: **Potential energy of each pair:** All pairs have equal charge $+q$ and equal separation a:

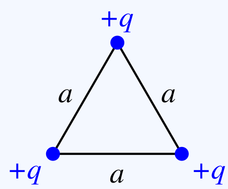
$$U_{ij} = \frac{kq^2}{a}$$

Step 3: **Total potential energy:**

$$U_{\text{total}} = 3 \times \frac{kq^2}{a} = \frac{3kq^2}{a}$$

Step 4: **Option elimination:**

- kq^2/a counts only one pair – **wrong**.
- $3kq^2/a$ – **correct**.
- $\sqrt{3}kq^2/a$ and $kq^2/(3a)$ have no physical basis for this configuration.



$U = 3kq^2/a$

Final Answer:

$$\boxed{U_{\text{total}} = \frac{3kq^2}{a}}$$

Answer: (B)

Q10.

Solution

Concept:

When a dielectric slab of thickness t (less than the full separation d) is inserted into a capacitor, the effective capacitance changes because the capacitor behaves as two capacitors in series.

Solution:

Step 1: **Given:** $C_0 = 8\,\mu$F (air capacitor), plate separation d, dielectric thickness $t = d/2$, $K = 5$.

Step 2: **Model as two capacitors in series:**

- Air gap: thickness $d - t = d/2$, capacitance $C_1 = \varepsilon_0 A/(d/2) = 2C_0$.
- Dielectric: thickness $d/2$, capacitance $C_2 = K\varepsilon_0 A/(d/2) = 2KC_0$.

where $C_0 = \varepsilon_0 A/d$ is the original capacitance.

Step 3: **Series combination:**

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{2C_0} + \frac{1}{2KC_0} = \frac{1}{2C_0}\left(1 + \frac{1}{K}\right) = \frac{1}{2C_0} \cdot \frac{K+1}{K}$$

$$C = \frac{2KC_0}{K+1} = \frac{2 \times 5 \times 8}{5+1} = \frac{80}{6} = \frac{40}{3}\,\mu\text{F}$$

Step 4: **Checking options:** $80/7 \approx 11.4$; $80/3 \approx 26.7$; $40/3 \approx 13.3$. The correct answer is $\frac{80}{6} = \frac{40}{3}\,\mu$F.

Final Answer:

$$\boxed{C = \frac{80}{6} = \frac{40}{3}\,\mu\text{F}}$$

Answer: (C)

Q11.

Solution

Concept:
A dipole in a uniform electric field experiences a torque $\tau = pE\sin\theta$. Stable equilibrium occurs where potential energy is minimum and $\tau = 0$ with any small displacement restoring the dipole.

Solution:
Step 1: **Potential energy of dipole in field:**

$$U = -pE\cos\theta$$

Step 2: **At $\theta = 0°$:** $U = -pE$ (minimum energy – most negative). Any small displacement creates a restoring torque. This is **STABLE equilibrium**.
Step 3: **At $\theta = 180°$:** $U = +pE$ (maximum energy). Any small displacement creates a torque that moves the dipole away. This is **UNSTABLE equilibrium**.
Step 4: **At $\theta = 90°$:** $U = 0$, torque is maximum – not equilibrium.
Step 5: **Physical picture:** At $\theta = 0°$ the dipole moment $\vec{p}$ is aligned parallel to $\vec{E}$ – like a compass needle aligning with a magnetic field.
Final Answer:

$$\boxed{\theta = 0° \ (\vec{p} \text{ parallel to } \vec{E})}$$

Answer: (C)

Q12.

Solution

Concept:
For a short electric dipole, the electric fields along the axial and equatorial lines differ by a factor of 2. The axial field is twice the equatorial field at the same distance.

Solution:

Step 1: **Equatorial field at distance r:**

$$E_{eq} = \frac{kp}{r^3} \quad \text{(directed opposite to } \vec{p}\text{)}$$

Step 2: **Axial field at distance r:**

$$E_{ax} = \frac{2kp}{r^3} \quad \text{(directed along } \vec{p}\text{)}$$

Step 3: **Ratio:**

$$E_{ax} = 2E_{eq}$$

Step 4: **Why factor of 2:** Along the axial line the fields from both charges of the dipole add up (same direction). Along the equatorial line their perpendicular components cancel, leaving only the horizontal component which results in half the axial value.

Final Answer:

$$\boxed{E_{ax} = 2E_{eq}}$$

Answer: (B)

Q13.

Solution

Concept:
The Wheatstone bridge is balanced when $P/Q = R/S$. No current flows through the galvanometer at balance.

Solution:

Step 1: **Balance condition:**

$$\frac{P}{Q} = \frac{R}{S}$$

Step 2: **Substituting known values:**

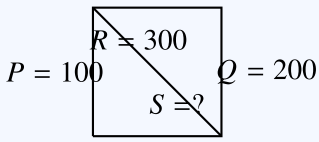
$$\frac{100}{200} = \frac{300}{S}$$

Step 3: **Solving for S:**

$$S = \frac{300 \times 200}{100} = 600\ \Omega$$

Step 4: **Option elimination:**

- $150\,\Omega$: would give $P/Q = 2/3 \neq R/S = 2$ – **wrong**.
- $600\,\Omega$: $P/Q = 1/2$, $R/S = 300/600 = 1/2$ – **correct**.
- $400\,\Omega$: $300/400 = 3/4 \neq 1/2$ – **wrong**.



Balance: $S = 600\,\Omega$

Final Answer:

$$\boxed{S = 600\ \Omega}$$

Answer: (B)

Q14.

Solution

Concept:

When current I flows through a cell of EMF ε and internal resistance r connected to external resistance R, the terminal voltage is less than the EMF due to internal voltage drop.

Solution:

Step 1: **Current in the circuit:**

$$I = \frac{\varepsilon}{R + r}$$

Step 2: **Terminal voltage:** Voltage drop across internal resistance = Ir. The terminal voltage is:

$$V = \varepsilon - Ir$$

Step 3: **Physical meaning:** The internal resistance r causes a voltage drop Ir inside the cell. The available terminal voltage is therefore less than the EMF when current is being drawn.

Step 4: **Option elimination:**

- Option A: $V = \varepsilon + Ir$ is valid only when the cell is being **charged** (current flows into positive terminal).
- Option B: $V = \varepsilon - Ir$ – **correct for discharging**.
- Option C and D are dimensionally or logically incorrect for terminal voltage.

Final Answer:

$$\boxed{V = \varepsilon - Ir}$$

Answer: (B)

Q15.

Solution

Concept:
When a wire is stretched, its volume remains constant. If the length doubles, the cross-sectional area halves. Resistance $R = \rho L/A$.

Solution:
Step 1: **Original resistance:** $R_0 = \rho L/A$.
Step 2: **After stretching to double length:**

- New length: $L' = 2L$.
- Volume conservation: $AL = A'L' \Rightarrow A' = A/2$.

Step 3: **New resistance:**

$$R' = \frac{\rho L'}{A'} = \frac{\rho \cdot 2L}{A/2} = \frac{4\rho L}{A} = 4R_0$$

Step 4: **General rule:** If a wire is stretched to n times its original length, its resistance increases n^2 times. Here $n = 2$, so $R' = 4R_0$.

Final Answer:

$$\boxed{R' = \frac{4\rho L}{A} \; (= 4R_0)}$$

Answer: (B)

Q16.

Solution

Concept:
In a potentiometer experiment, the internal resistance of a cell is determined by comparing balance lengths with and without an external resistance.

Solution:
Step 1: **Balance length without external resistance:** $l_1 = 75$ cm. The EMF ε is proportional to l_1.
Step 2: **Balance length with external resistance $S = 5\,\Omega$:** $l_2 = 60$ cm. The terminal voltage V is proportional to l_2.
Step 3: **Relationship:**

$$\frac{\varepsilon}{V} = \frac{l_1}{l_2} = \frac{75}{60} = \frac{5}{4}$$

Step 4: **Terminal voltage with external resistance S:**

$$V = \varepsilon \cdot \frac{S}{S + r}$$

Step 5: **Solving for r:**

$$\frac{\varepsilon}{V} = \frac{S + r}{S} = \frac{5}{4}$$

$$1 + \frac{r}{S} = \frac{5}{4} \Rightarrow \frac{r}{5} = \frac{1}{4} \Rightarrow r = 1.25\,\Omega$$

Final Answer:

$$\boxed{r = 1.25\,\Omega}$$

Answer: (C)

Q17.

Solution

Concept:

A current-carrying coil in a magnetic field experiences a torque $\tau = NIAB \sin\alpha$, where α is the angle between the magnetic moment and the field (equivalently, the complement of the angle between the plane and the field).

Solution:

Step 1: **Given:** The coil's plane is **perpendicular** to the field B. This means the **magnetic moment** $\vec{m} = IA\hat{n}$ is **parallel to** $\vec{B}$ (both along the same direction as the field).

Step 2: **Torque formula:** $\tau = NIAB \sin\alpha$, where α is the angle between $\vec{m}$ and $\vec{B}$.

Step 3: **When plane is perpendicular to $\vec{B}$:** The normal to the plane (and hence $\vec{m}$) is **parallel** to $\vec{B}$. So $\alpha = 0^\circ$ and $\sin 0^\circ = 0$.

Step 4: **Result:**

$$\tau = NIAB \sin 0^\circ = 0$$

Step 5: **Physical reasoning:** Maximum torque occurs when the plane is **parallel** to the field (normal perpendicular to field). Zero torque when plane is perpendicular to the field.

Final Answer:

$$\boxed{\tau = \text{Zero}}$$

Answer: (B)

Q18.

Solution

Concept:
The magnetic force on a moving charged particle is $\vec{F} = q\vec{v} \times \vec{B}$. The direction is determined by the right-hand rule (or left-hand rule for negative charges).

Solution:

Step 1: **Given:**

- Proton (positive charge $+e$).
- Velocity $\vec{v}$: to the **right** $(+\hat{x})$.
- Magnetic field $\vec{B}$: **into the page** $(-\hat{z})$.

Step 2: **Force direction:**

$$\vec{F} = q\vec{v} \times \vec{B} = e(+\hat{x}) \times (-\hat{z} \cdot B) = -eB(\hat{x} \times \hat{z})$$

$$\hat{x} \times \hat{z} = -\hat{y}$$

$$\vec{F} = -eB \times (-\hat{y}) = eB\hat{y} = \text{upward}$$

Step 3: **Conclusion:** The proton curves **upward** (toward the top of the page).

Step 4: **Mnemonic check:** Point fingers of right hand to the right ($\vec{v}$), curl into page ($\vec{B}$) – thumb points **upward**. For positive charge, force is upward.

Final Answer:

$$\boxed{\text{The proton curves upward (toward the top of the page)}}$$

Answer: (C)

Q19.

Solution

Concept:

Two parallel current-carrying wires exert forces on each other. The force per unit length is $F/l = \mu_0 I_1 I_2/(2\pi d)$. Currents in the same direction attract; opposite directions repel.

Solution:

Step 1: **Force per unit length formula:**

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Step 2: **Substituting values:** $\mu_0 = 4\pi \times 10^{-7}$ T·m/A, $I_1 = 3$ A, $I_2 = 6$ A, $d = 0.1$ m:

$$\frac{F}{l} = \frac{4\pi \times 10^{-7} \times 3 \times 6}{2\pi \times 0.1} = \frac{4\pi \times 10^{-7} \times 18}{2\pi \times 0.1} = \frac{4 \times 18 \times 10^{-7}}{2 \times 0.1} = \frac{72 \times 10^{-7}}{0.2} = 36 \times 10^{-6} \text{ N/m}$$

Step 3: **Direction:** Currents flow in the **same direction**, so the force is **attractive** (wires attract each other).

Step 4: **Newton's Third Law:** By Newton's third law, the force on wire 1 due to wire 2 is equal and opposite to the force on wire 2 due to wire 1. Both are 36×10^{-6} N/m attractive.

Final Answer:

$$\boxed{36 \times 10^{-6} \text{ N/m, attractive}}$$

Answer: (A)

Q20.

Solution

Concept:

The magnetic dipole moment of a bar magnet is defined as the product of pole strength and the distance between the poles (magnetic length = $2l$).

Solution:

Step 1: **Definition:** The magnetic moment of a bar magnet is:

$$M = m \times 2l$$

where m is the pole strength and $2l$ is the magnetic length (distance between north and south poles).

Step 2: **Direction:** The magnetic moment is a vector directed from the south pole to the north pole.

Step 3: **Option elimination:**

- ml: uses only half the magnetic length – **wrong**.
- $2ml$: correct definition with full magnetic length – **correct**.
- m/l and $m/(2l)$: dimensions are wrong for magnetic moment.

Step 4: **Units check:** Pole strength m has units A·m, length $2l$ has units m. Product = A·m^2 = unit of magnetic moment. ✓

Final Answer:

$$\boxed{M = 2ml}$$

Answer: (B)

Q21.

Solution

Concept:
A coil rotating in a uniform magnetic field generates an alternating EMF. The peak (maximum) EMF is $\varepsilon_0 = NBA\omega$.

Solution:

Step 1: **Flux through the coil:**

$$\Phi = NBA\cos(\omega t)$$

Step 2: **Induced EMF by Faraday's law:**

$$\varepsilon = -\frac{d\Phi}{dt} = NBA\omega\sin(\omega t)$$

Step 3: **Peak EMF:**

$$\varepsilon_0 = NBA\omega$$

Step 4: **Option elimination:**

- $NBA\omega^2$: extra factor of ω – wrong.
- $NBA\omega$: **correct**.
- NBA/ω: would be integral of flux, not EMF.
- $NB\omega/A$: wrong dimensional arrangement.

Final Answer:

$$\boxed{\varepsilon_0 = NBA\omega}$$

Answer: (B)

Q22.

Solution

Concept:

At resonance in a series LCR circuit, $X_L = X_C$, so the net reactance is zero. Impedance reduces to R (minimum) and current is maximum.

Solution:

Step 1: **Impedance of series LCR:**

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Step 2: **At resonance:** $X_L = X_C$, so $(X_L - X_C) = 0$:

$$Z_{\text{res}} = \sqrt{R^2 + 0} = R$$

Step 3: **Current at resonance:**

$$I_{\text{res}} = \frac{V}{Z_{\text{res}}} = \frac{V}{R} \text{ (maximum)}$$

Step 4: **Option elimination:**

- Option A: Impedance maximum and current minimum – describes **anti-resonance** – **wrong**.
- Option B: $Z = \sqrt{R^2 + (X_L - X_C)^2}$ is general expression, not specific to resonance – incomplete.
- Option C: $Z = R$ and current is maximum – **correct and complete**.
- Option D: $X_L = R$ and $X_C = 0$ – not a resonance condition – **wrong**.

Final Answer:

$$\boxed{Z = R \text{ (minimum)}, \ I = V/R \text{ (maximum)}}$$

Answer: (C)

Q23.

Solution

Concept:

A transformer changes AC voltage in proportion to the turns ratio. For an ideal transformer: $V_s/V_p = N_s/N_p$.

Solution:

Step 1: **Turns ratio:** $N_p = 500$, $N_s = 2000$.

$$\frac{N_s}{N_p} = \frac{2000}{500} = 4$$

Step 2: **Secondary voltage:**

$$V_s = V_p \times \frac{N_s}{N_p} = 220 \times 4 = 880 \text{ V}$$

Step 3: **Type of transformer:** Since $N_s > N_p$ and $V_s > V_p$, this is a **step-up transformer**.

Step 4: **Option elimination:**

- 55 V would require ratio 1/4 (step-down) – **wrong**.
- 440 V would require ratio 2 – **wrong**.
- 880 V requires ratio 4 – **correct**.

Final Answer:

$$\boxed{V_s = 880 \text{ V}}$$

Answer: (C)

Q24.

Solution

Concept:

The lens formula $1/v - 1/u = 1/f$ along with magnification $m = -v/u$ is used to find object distance. Real inverted image means $m = -2$.

Solution:

Step 1: **Given:** $f = +20$ cm (convex), real inverted image, magnification $m = -2$ (real and inverted).

Step 2: **From magnification:**

$$m = -\frac{v}{u} = -2 \Rightarrow v = 2u \text{ (taking sign convention: } u < 0)$$

With $u = -|u|$: $v = -2 \times (-|u|) = 2|u|$ (positive, real image).

Step 3: **Using lens formula:**

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

$$\frac{1}{2|u|} - \frac{1}{-|u|} = \frac{1}{20}$$

$$\frac{1}{2|u|} + \frac{1}{|u|} = \frac{1}{20}$$

$$\frac{3}{2|u|} = \frac{1}{20} \Rightarrow |u| = 30 \text{ cm}$$

Step 4: **Object distance from lens = 30 cm.**

Final Answer:

$$\boxed{u = 30 \text{ cm from the lens}}$$

Answer: (C)

Q25.

Solution

Concept:
Total internal reflection occurs when light travels from a denser medium to a rarer medium. The critical angle θ_c satisfies Snell's law with the refracted angle equal to 90°.

Solution:
Step 1: **Snell's law at critical angle:**

$$\mu_1 \sin\theta_c = \mu_2 \sin 90^\circ = \mu_2$$

Step 2: **Solving for θ_c:**

$$\sin\theta_c = \frac{\mu_2}{\mu_1} = \frac{1.0}{1.5} = \frac{2}{3}$$

$$\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right)$$

Step 3: **Condition:** $\mu_1 = 1.5 > \mu_2 = 1.0$, so the medium with μ_1 is denser. TIR occurs when the angle of incidence (in the denser medium) exceeds θ_c.
Step 4: **Option elimination:** $\sin^{-1}(1.5)$ is undefined since $\sin > 1$ is impossible. $\cos^{-1}(1/1.5)$ and $\tan^{-1}(1.5)$ are incorrect formulae for this.
Final Answer:

$$\boxed{\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right) \approx 41.8^\circ}$$

Answer: (A)

Q26.

Solution

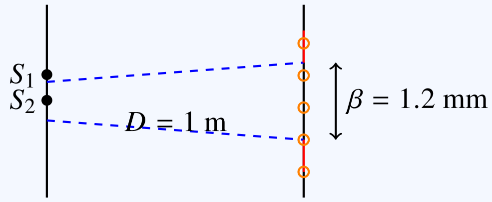
Concept:
In Young's double slit experiment, fringe width $\beta = \lambda D/d$, where λ is wavelength, D is screen distance, and d is slit separation.

Solution:
Step 1: **Given:** $d = 0.5$ mm $= 0.5 \times 10^{-3}$ m, $D = 1$ m, $\lambda = 600$ nm $= 600 \times 10^{-9}$ m.
Step 2: **Fringe width:**

$$\beta = \frac{\lambda D}{d} = \frac{600 \times 10^{-9} \times 1}{0.5 \times 10^{-3}} = \frac{600 \times 10^{-9}}{5 \times 10^{-4}} = 1.2 \times 10^{-3} \text{ m} = 1.2 \text{ mm}$$

Step 3: **Physical meaning:** Fringe width is the distance between two consecutive bright (or dark) fringes on the screen.
Step 4: **Option elimination:**

- 0.6 mm: would require $d = 1$ mm or $\lambda = 300$ nm – **wrong**.
- 1.2 mm: matches calculation – **correct**.
- 0.3 mm: too small by factor of 4 – **wrong**.
- 2.4 mm: twice the correct value – **wrong**.



Final Answer:

$$\boxed{\beta = 1.2 \text{ mm}}$$

Answer: (B)

Q27.

Solution

Concept:

Interference and diffraction are wave phenomena that require superposition of waves. The photoelectric effect and Compton scattering demonstrate the particle nature of light.

Solution:

Step 1: **Photoelectric effect:** Explained by Einstein using photons (particle nature). Wave theory fails to explain it. Eliminated.

Step 2: **Compton scattering:** Explained by treating X-ray photons as particles colliding with electrons. Wave theory cannot explain the wavelength shift. Eliminated.

Step 3: **Pair production:** A photon creates an electron-positron pair – particle nature. Eliminated.

Step 4: **Interference and diffraction:** These phenomena arise from **superposition of waves**. They require the wave nature of light:

- **Interference**: Requires coherent sources and phase relationships between waves.
- **Diffraction**: Bending of waves around obstacles – only possible for waves, not particles.

These **CANNOT** be explained by the particle (photon) model.

Final Answer:

$$\boxed{\text{Interference and diffraction (explained ONLY by wave nature)}}$$

Answer: (C)

Q28.

Solution

Concept:
The magnifying power of a compound microscope (image at infinity) is $M = (L/f_o) \times (D/f_e)$, where L is tube length, f_o is objective focal length, f_e is eyepiece focal length, and $D = 25$ cm is least distance of distinct vision.

Solution:
Step 1: **Given:** $f_o = 1$ cm, $f_e = 5$ cm, $L = 20$ cm, $D = 25$ cm.
Step 2: **Magnifying power (final image at infinity):**

$$M = \frac{L}{f_o} \times \frac{D}{f_e} = \frac{20}{1} \times \frac{25}{5} = 20 \times 5 = 100$$

Step 3: **Physical interpretation:**

- Objective magnification: $L/f_o = 20$ (objective produces magnified intermediate image).
- Eyepiece acts as simple magnifier: $D/f_e = 5$ (eyepiece magnifies intermediate image).

Step 4: **Option elimination:**

- 80: would require different parameters.
- 100: **correct**.
- 120, 50: do not match the formula with given values.

Final Answer:

$$\boxed{M = 100}$$

Answer: (B)

Q29.

Solution

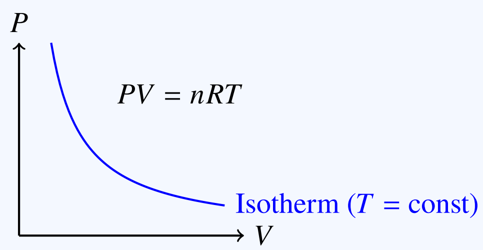
Concept:
In an isothermal process the temperature of an ideal gas remains constant. Since internal energy of an ideal gas depends only on temperature, $\Delta U = 0$ for an isothermal process.

Solution:
Step 1: **First Law of Thermodynamics:** $\Delta U = Q - W$.
Step 2: **Isothermal process ($\Delta T = 0$):** For an ideal gas $\Delta U = nC_v\Delta T = 0$.
Step 3: **Therefore from First Law:**

$$0 = Q - W \Rightarrow Q = W$$

The heat absorbed by the gas equals the work done **by** the gas.
Step 4: **Option elimination:**

- Option A: Internal energy increases – **wrong** ($\Delta U = 0$ isothermally).
- Option B: $Q = W$ – **correct**.
- Option C: No heat exchanged – that is **adiabatic**, not isothermal.
- Option D: Pressure constant – that is **isobaric** process.



$Q = W,\ \Delta U = 0$

Final Answer:

$$\boxed{Q = W \text{ (heat absorbed equals work done by gas)}}$$

Answer: (B)

Q30.

Solution

Concept:

The rms speed of a gas molecule is $v_{\text{rms}} = \sqrt{3RT/M_{\text{mol}}}$ where M_{mol} is molar mass. Setting v_{rms} of H_2 equal to v_{rms} of O_2 at T and solving for T_{H_2}.

Solution:

Step 1: **rms speed of O_2 at temperature T:**

$$v = \sqrt{\frac{3RT}{32}}$$

Step 2: **rms speed of H_2 at temperature T':**

$$v = \sqrt{\frac{3RT'}{2}}$$

Step 3: **Setting equal and solving:**

$$\frac{3RT}{32} = \frac{3RT'}{2}$$

$$T' = \frac{2T}{32} = \frac{T}{16}$$

Step 4: **Physical reasoning:** H_2 is much lighter than O_2. At a much lower temperature H_2 molecules already move as fast as O_2 at temperature T.

Step 5: **Option elimination:** $T/16$ is correct. $16T$ would be the temperature where O_2 has the same rms speed as H_2 at T – reversed.

Final Answer:

$$\boxed{T_{H_2} = \frac{T}{16}}$$

Answer: (A)

Q31.

Solution

Concept:
The efficiency of a Carnot engine is $\eta = 1 - T_2/T_1$. Rearranging gives the sink temperature T_2 in terms of T_1 and η.

Solution:

Step 1: **Carnot efficiency:**

$$\eta = 1 - \frac{T_2}{T_1}$$

Step 2: **Rearranging for T_2:**

$$\frac{T_2}{T_1} = 1 - \eta$$

$$T_2 = T_1(1 - \eta)$$

Step 3: **Physical check:**

- If $\eta = 0$ (no useful work): $T_2 = T_1$ (source and sink at same temperature) – **makes sense**.
- If $\eta = 1$ (100% efficiency): $T_2 = 0$ K (absolute zero sink) – **makes sense** (unattainable in practice).

Step 4: **Option elimination:**

- $T_1/(1 - \eta)$: gives $T_2 > T_1$ which is impossible for a heat engine – **wrong**.
- $T_1\eta$: dimensionally possible but physically incorrect arrangement – **wrong**.
- $T_1(1 + \eta)$: gives $T_2 > T_1$ – impossible for sink – **wrong**.

Final Answer:

$$\boxed{T_2 = T_1(1 - \eta)}$$

Answer: (A)

Q32.

Solution

Concept:

The threshold frequency f_0 for the photoelectric effect is the minimum frequency required for photoemission. It is given by $\phi = hf_0$.

Solution:

Step 1: **Work function in joules:**

$$\phi = 2.0 \text{ eV} = 2.0 \times 1.6 \times 10^{-19} \text{ J} = 3.2 \times 10^{-19} \text{ J}$$

Step 2: **Threshold frequency:**

$$f_0 = \frac{\phi}{h} = \frac{3.2 \times 10^{-19}}{6.6 \times 10^{-34}} \approx \frac{3.2}{6.6} \times 10^{15} \approx 0.4848 \times 10^{15} \text{ Hz} \approx 4.83 \times 10^{14} \text{ Hz}$$

Step 3: **This lies in the visible light range** (approximately 480 nm wavelength – blue-green light).

Step 4: **Option elimination:**

- 4.83×10^{14} Hz: matches calculation – **correct**.
- 9.66×10^{14} Hz: double – would correspond to $\phi = 4$ eV.
- 2.41×10^{14} Hz: half – would correspond to $\phi = 1$ eV.
- 1.21×10^{15} Hz: would correspond to $\phi = 5$ eV.

Final Answer:

$$\boxed{f_0 \approx 4.83 \times 10^{14} \text{ Hz}}$$

Answer: (A)

Q33.

Solution

Concept:

In the Bohr model, the orbital radius is $r_n = n^2 a_0$ where $a_0 = 0.529$ Å is the Bohr radius. The ratio of radii depends on n^2.

Solution:

Step 1: **Bohr radius formula:** $r_n = n^2 a_0$.

Step 2: **Radius of third orbit:** $r_3 = 9a_0$.

Step 3: **Radius of first orbit:** $r_1 = 1 \cdot a_0 = a_0$.

Step 4: **Ratio:**

$$\frac{r_3}{r_1} = \frac{9a_0}{a_0} = 9$$

Step 5: **Option elimination:**

- 3: would apply if $r_n \propto n$ (not the correct Bohr result).
- 6: no physical basis.
- 9: $r_n \propto n^2$ – **correct**.
- 27: would apply if $r_n \propto n^3$.

Final Answer:

$$\boxed{\frac{r_3}{r_1} = 9}$$

Answer: (C)

Q34.

Solution

Concept:

Alpha decay decreases mass number by 4 and atomic number by 2. Beta-minus decay increases atomic number by 1 with no change in mass number.

Solution:

Step 1: **Starting nucleus:** ${}^{238}_{92}\text{U}$.

Step 2: **After one α emission:**

$${}^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$$

New nucleus: ${}^{234}_{90}\text{Th}$.

Step 3: **After first β^- emission** (atomic number +1, mass number unchanged):

$${}^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}\text{Pa} + e^- + \bar{\nu}$$

New nucleus: ${}^{234}_{91}\text{Pa}$.

Step 4: **After second β^- emission:**

$${}^{234}_{91}\text{Pa} \longrightarrow {}^{234}_{92}\text{U} + e^- + \bar{\nu}$$

Final nucleus: ${}^{234}_{92}\text{U}$.

Step 5: **Summary:** Mass number: $238 - 4 = 234$. Atomic number: $92 - 2 + 2 = 92$. Result: ${}^{234}_{92}\text{U}$.

Final Answer:

$$\boxed{{}^{234}_{92}\text{U}}$$

Answer: (A)

Q35.

Solution

Concept:

The de Broglie wavelength of an electron accelerated through potential V is $\lambda = h/\sqrt{2meV}$, so $\lambda \propto V^{-1/2}$.

Solution:

Step 1: **de Broglie wavelength:**

$$\lambda = \frac{h}{\sqrt{2meV}} \propto \frac{1}{\sqrt{V}}$$

Step 2: **New potential:** $V' = 4V$.

Step 3: **New wavelength:**

$$\lambda' = \frac{h}{\sqrt{2me \cdot 4V}} = \frac{h}{2\sqrt{2meV}} = \frac{\lambda}{2}$$

Step 4: **Physical reasoning:** Higher accelerating potential gives the electron more kinetic energy, hence higher momentum, hence **shorter** wavelength. Quadrupling V halves λ.

Step 5: **Option elimination:**

- 2λ: would apply if V were reduced to $V/4$.
- $\lambda/2$: **correct**.
- 4λ: wrong direction of change.
- $\lambda/4$: would apply if V were increased 16 times.

Final Answer:

$$\boxed{\lambda' = \frac{\lambda}{2}}$$

Answer: (B)

Q36.

Solution

Concept:

The energy released in nuclear fission is calculated using Einstein's mass-energy equivalence: $E = \Delta m \cdot c^2$, with 1 u = 931 MeV.

Solution:

Step 1: **Mass defect per fission:** $\Delta m = 0.2$ u.

Step 2: **Energy released:**

$$E = \Delta m \times 931 \text{ MeV/u} = 0.2 \times 931 = 186.2 \text{ MeV}$$

Step 3: **Context:** Real fission of ^{235}U releases approximately 200 MeV per fission, of which about 186 MeV appears as kinetic energy of fragments and prompt radiation. The given $\Delta m = 0.2$ u is an approximation used for calculation purposes.

Step 4: **Option elimination:**

- 46.55 MeV: $0.2 \times 931/4$ – no basis.
- 93.1 MeV: 0.1×931 – uses wrong mass defect.
- 186.2 MeV: 0.2×931 – **correct**.
- 200 MeV: approximate real value but not calculated from given $\Delta m = 0.2$ u.

Final Answer:

$$\boxed{E = 0.2 \times 931 = 186.2 \text{ MeV}}$$

Answer: (C)

Q37.

Solution

Concept:
For projectile motion, maximum height $H = u^2 \sin^2\theta/(2g)$ and horizontal range $R = u^2 \sin 2\theta/g$. Their ratio simplifies to a trigonometric expression.

Solution:

Step 1: **Maximum height:**

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

Step 2: **Range:**

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

Step 3: **Ratio H/R:**

$$\frac{H}{R} = \frac{\frac{u^2 \sin^2\theta}{2g}}{\frac{2u^2 \sin\theta\cos\theta}{g}} = \frac{u^2 \sin^2\theta}{2g} \times \frac{g}{2u^2 \sin\theta\cos\theta} = \frac{\sin\theta}{4\cos\theta} = \frac{\tan\theta}{4}$$

Step 4: **Option elimination:**

- $\tan\theta/4$: **correct**.
- $\tan\theta/2$: factor error.
- $\tan\theta$: missing the factor of 4 in denominator.
- $4/\tan\theta$: inverted.

Final Answer:

$$\boxed{\frac{H}{R} = \frac{\tan\theta}{4}}$$

Answer: (A)

Q38.

Solution

Concept:

To determine motion under friction, first check if static friction is sufficient to keep the block at rest. If the applied force exceeds maximum static friction, kinetic friction acts.

Solution:

Step 1: **Maximum static friction:**

$$f_s^{\max} = \mu_s mg = 0.4 \times 2 \times 10 = 8 \text{ N}$$

Step 2: **Applied force = 6 N** $< f_s^{\max} = 8$ **N.** The block does **not move**. Static friction exactly balances the applied force.

Step 3: **Acceleration:** Since the block is stationary, $a = 0$ m/s^2.

Step 4: **Why kinetic friction is irrelevant here:** Kinetic friction only acts when there is relative motion. Since static friction (up to 8 N) is sufficient to balance the 6 N applied force, the block remains at rest.

Step 5: **Option elimination:**

- 3 m/s^2: would require net force of 6 N – ignores friction entirely.
- 1.5 m/s^2: uses kinetic friction incorrectly (block is stationary).
- 0 m/s^2: **correct** – block does not move.
- 2 m/s^2: incorrect.

Final Answer:

$$\boxed{a = 0 \text{ m/s}^2 \text{ (block remains stationary)}}$$

Answer: (C)

Q39.

Solution

Concept:
The coefficient of restitution e is the ratio of relative speed of separation to relative speed of approach. For a ball bouncing off a fixed floor, $e = \sqrt{h'/h}$ where h is the drop height and h' is the rebound height.

Solution:
Step 1: **Speed just before hitting floor** (dropped from height h):

$$v_1 = \sqrt{2gh}$$

Step 2: **Speed just after rebound** (rises to $h' = h/4$):

$$v_2 = \sqrt{2g \cdot \frac{h}{4}} = \frac{1}{2}\sqrt{2gh} = \frac{v_1}{2}$$

Step 3: **Coefficient of restitution:**

$$e = \frac{v_2}{v_1} = \frac{v_1/2}{v_1} = \frac{1}{2} = 0.5$$

Alternatively: $e = \sqrt{h'/h} = \sqrt{(h/4)/h} = \sqrt{1/4} = 0.5$.
Step 4: **Option elimination:**

- 0.5: **correct**.
- 0.25: would give $h' = 0.0625h$ (rebound to $h/16$).
- 0.75: would give $h' = 0.5625h$.
- 0.4: would give $h' = 0.16h$.

Final Answer:

$$\boxed{e = 0.5}$$

Answer: (A)

Q40.

Solution

Concept:
Work done by a force equals $W = \vec{F} \cdot \vec{d} = Fd\cos\alpha$, where α is the angle between the force and displacement. Centripetal force is always perpendicular to velocity (and hence to displacement).

Solution:
Step 1: **Direction of centripetal force:** Always directed **radially inward** (toward the centre of the circle).
Step 2: **Direction of displacement:** At every instant the instantaneous displacement is **tangential** to the circular path – perpendicular to the radius.
Step 3: **Angle between force and displacement:** $\alpha = 90^\circ$ always.
Step 4: **Work done:**

$$W = F \cdot d\cos 90^\circ = 0$$

Over any arc, including one complete revolution, the centripetal force does **zero work**.
Step 5: **Physical consequence:** Since centripetal force does no work, the speed (and hence kinetic energy) of the object in uniform circular motion does not change – only the direction changes.
Final Answer:

$$\boxed{W = 0 \text{ (centripetal force is always perpendicular to displacement)}}$$

Answer: (C)

Q41.

Solution

Concept:
For a spring-block system, all elastic potential energy converts to kinetic energy at the equilibrium position (natural length). Applying energy conservation gives maximum speed.

Solution:

Step 1: **Elastic PE stored in compressed spring:**

$$PE = \frac{1}{2}kx^2$$

Step 2: **At maximum speed** (when spring returns to natural length, block passes equilibrium), all PE converts to KE:

$$\frac{1}{2}mv_{\max}^2 = \frac{1}{2}kx^2$$

Step 3: **Solving for $v_{\max}$:**

$$v_{\max}^2 = \frac{kx^2}{m} \Rightarrow v_{\max} = x\sqrt{\frac{k}{m}}$$

Step 4: **Option elimination:**

- $x\sqrt{k/m}$: **correct** from energy conservation.
- $x\sqrt{m/k}$: inverted – dimensions wrong for speed.
- kx/m: dimensions = N/(kg) = m/s^2 – this is acceleration, not speed.
- $\sqrt{kx/m}$: dimensions check: $\sqrt{\text{N}\cdot\text{m/kg}} = \sqrt{\text{J/kg}}$ = m/s – BUT this misses one power of x.

Final Answer:

$$\boxed{v_{\max} = x\sqrt{\frac{k}{m}}}$$

Answer: (A)

Q42.

Solution

Concept:
Escape velocity from a planet's surface is $v_e = \sqrt{2GM/R}$. For different planets, we compare using the ratio of M/R.

Solution:
Step 1: **Earth's escape velocity:**

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

Step 2: **Planet's parameters:** Mass = $4M$, Radius = $2R$.
Step 3: **Planet's escape velocity:**

$$v_e' = \sqrt{\frac{2G \cdot 4M}{2R}} = \sqrt{\frac{8GM}{2R}} = \sqrt{\frac{4GM}{R}} = 2\sqrt{\frac{GM}{R}} = \sqrt{2} \cdot \sqrt{\frac{2GM}{R}} = \sqrt{2}\, v_e$$

Step 4: **Option elimination:**

- v_e: would require $M'/R' = M/R$ – not the case here ($4M/2R = 2M/R \neq M/R$).
- $\sqrt{2}\, v_e$: **correct**.
- $2v_e$: would require $M'/R' = 4M/R$.
- $v_e/\sqrt{2}$: wrong direction.

Final Answer:

$$\boxed{v_e' = \sqrt{2}\, v_e}$$

Answer: (B)

Q43.

Solution

Concept:
For a satellite in circular orbit, gravitational force provides centripetal force. The orbital speed is derived by equating $GMm/(R+h)^2 = mv^2/(R+h)$.

Solution:
Step 1: **Gravitational force = Centripetal force:**

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

Step 2: **Solving for orbital speed:**

$$v^2 = \frac{GM}{R+h}$$

Step 3: **Expressing in terms of g:** Since $GM = gR^2$ (where g is surface gravity):

$$v = \sqrt{\frac{gR^2}{R+h}}$$

Step 4: **Option elimination:**

- $\sqrt{gR^2/(R+h)}$: **correct**.
- $\sqrt{g(R+h)}$: would give speed increasing with height – physically wrong.
- $\sqrt{gR/(R+h)}$: missing one power of R in numerator.
- $\sqrt{gR^2}$: independent of h – wrong.

Final Answer:

$$\boxed{v = \sqrt{\frac{gR^2}{R+h}}}$$

Answer: (A)

Q44.

Solution

Concept:
The elastic potential energy stored in a stretched wire is $U = F^2L/(2YA)$, derived from $U = \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume}$.

Solution:
Step 1: **Stress:** $\sigma = F/A$.
Step 2: **Strain:** From Young's modulus: $Y = \sigma/\varepsilon = (F/A)/(\Delta L/L)$, so $\Delta L = FL/(YA)$.
Step 3: **Elastic PE:**

$$U = \frac{1}{2}F \cdot \Delta L = \frac{1}{2} \cdot F \cdot \frac{FL}{YA} = \frac{F^2L}{2YA}$$

Equivalently: $U = \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume} = \frac{1}{2} \cdot \frac{F}{A} \cdot \frac{F}{YA} \cdot AL = \frac{F^2L}{2YA}$.
Step 4: **Option elimination:**

- $F^2L/(2YA)$: **correct**.
- $F^2L/(YA)$: missing factor of $1/2$ – wrong.
- $FY/(2AL)$: dimensionally inconsistent.
- $F^2/(2YAL)$: missing a factor of L^2 in numerator.

Final Answer:

$$\boxed{U = \frac{F^2L}{2YA}}$$

Answer: (A)

Q45.

Solution

Concept:
When a liquid drop breaks into smaller drops, the total volume is conserved. The increase in surface area (and hence surface energy) depends on the initial and final radii.

Solution:

Step 1: **Volume conservation:**

$$\frac{4}{3}\pi R^3 = n \cdot \frac{4}{3}\pi r^3 \Rightarrow R^3 = nr^3 \Rightarrow r = R/n^{1/3}$$

Step 2: **Initial surface area:** $A_i = 4\pi R^2$.

Step 3: **Final total surface area:**

$$A_f = n \cdot 4\pi r^2 = 4\pi nr^2 = 4\pi n \cdot \frac{R^2}{n^{2/3}} = 4\pi R^2 n^{1/3}$$

Step 4: **Increase in surface energy:**

$$\Delta E = T(A_f - A_i) = T \cdot 4\pi R^2(n^{1/3} - 1)$$

Step 5: **Option elimination:**

- $4\pi T(nr^2 - R^2)$: not simplified correctly.
- $4\pi T(nR^2 - r^2)$: dimensionally inconsistent with conservation.
- $4\pi TR^2(n^{1/3} - 1)$: **correct**.
- $T\pi R^2$: missing factor and n-dependence.

Final Answer:

$$\boxed{\Delta E = 4\pi TR^2(n^{1/3} - 1)}$$

Answer: (C)

Q46.

Solution

Concept:
Impulse is defined as the change in linear momentum of a body: $\vec{J} = \Delta\vec{p}$. Its dimensional formula is therefore the same as linear momentum.

Solution:
Step 1: **Definition of impulse:**

$$\vec{J} = \vec{F} \cdot \Delta t = \Delta\vec{p}$$

Step 2: **Dimensional formula of impulse:**

$$[J] = [\text{Force}] \times [\text{time}] = MLT^{-2} \times T = MLT^{-1}$$

Step 3: **Dimensional formula of each option:**

- Force: MLT^{-2} – **different**.
- Energy: ML^2T^{-2} – **different**.
- **Linear momentum**: MLT^{-1} – **same as impulse**.
- Angular momentum: ML^2T^{-1} – **different**.

Step 4: **Physical connection:** The impulse-momentum theorem states $J = \Delta p$, confirming they have identical dimensions and units (kg·m/s).

Final Answer:

$$\boxed{\text{Linear momentum } [MLT^{-1}]}$$

Answer: (C)

Q47.

Solution

Concept:
The percentage error in a derived quantity is found using the formula for error propagation. For $g = 4\pi^2 L/T^2$, the percentage error is $\Delta g/g = \Delta L/L + 2(\Delta T/T)$.

Solution:

Step 1: **Formula for g:**

$$g = \frac{4\pi^2 L}{T^2}$$

Step 2: **Error propagation formula:**

$$\frac{\Delta g}{g} = \frac{\Delta L}{L} + 2 \cdot \frac{\Delta T}{T}$$

Step 3: **Percentage errors:**

$$\frac{\Delta L}{L} \times 100 = \frac{0.01}{1.00} \times 100 = 1\%$$
$$\frac{\Delta T}{T} \times 100 = \frac{0.05}{2.50} \times 100 = 2\%$$

Step 4: **Total percentage error in g:**

$$\frac{\Delta g}{g} \times 100 = 1\% + 2 \times 2\% = 1\% + 4\% = 5\%$$

Step 5: **Option elimination:**

- 1%: only $\Delta L/L$ – missing T error.
- 2%: only $\Delta T/T$ – missing L error.
- 5%: **correct**.
- 6%: $\Delta L/L + 2 \times \Delta T/T$ without percentage conversion error.

Final Answer:

$$\boxed{\frac{\Delta g}{g} \times 100 = 5\%}$$

Answer: (C)

Q48.

Solution

Concept:
In a p-n junction diode, the depletion region is formed by diffusion of majority carriers. Applying forward bias reduces the potential barrier and narrows the depletion region.

Solution:
Step 1: **Equilibrium (no bias):** The built-in potential barrier (~0.7 V for Si) and the depletion region maintain equilibrium between drift and diffusion currents.
Step 2: **Effect of forward bias:**

- The external voltage **opposes the built-in potential**.
- This **reduces the potential barrier** (making it easier for majority carriers to cross).
- Majority carriers can now diffuse across, **narrowing the depletion region**.

Step 3: **Net effect under forward bias:**

- Depletion region width: **decreases**.
- Potential barrier: **decreases**.

Both **decrease**. Option B is correct.
Step 4: **Option elimination:**

- Both increase: applies to **reverse bias** – **wrong**.
- Both decrease: **correct for forward bias**.
- Options C and D are contradictory combinations – **wrong**.

Final Answer:

$$\boxed{\text{Both depletion region width and potential barrier decrease under forward bias}}$$

Answer: (B)

Q49.

Solution

Concept:
In a common-emitter (CE) amplifier, voltage gain $A_V = \beta \times R_C/R_i$ where β is current gain, R_C is collector resistance and R_i is input resistance.

Solution:
Step 1: **Voltage gain formula for CE amplifier:**

$$A_V = \beta \cdot \frac{R_C}{R_i}$$

Step 2: **Substituting values:** $\beta = 100$, $R_C = 2\,\text{k}\Omega = 2000\,\Omega$, $R_i = 1\,\text{k}\Omega = 1000\,\Omega$:

$$A_V = 100 \times \frac{2000}{1000} = 100 \times 2 = 200$$

Step 3: **Physical interpretation:**

- Current gain $\beta = I_C/I_B = 100$: small base current controls large collector current.
- Voltage gain = current gain × resistance ratio.

Step 4: **Option elimination:**

- 100: uses $R_C = R_i$ (equal resistances) – **wrong**.
- 200: $\beta \times (R_C/R_i) = 100 \times 2$ – **correct**.
- 50: would require $R_C = R_i/2$ – **wrong**.
- 400: would require $R_C = 2R_i \times 2$ – **wrong**.

Final Answer:

$$\boxed{A_V = 200}$$

Answer: (B)

Q50.

Solution

Concept:
In amplitude modulation (AM), two sidebands are produced at frequencies $f_c \pm f_m$ where f_c is carrier frequency and f_m is the message (modulating) frequency. The bandwidth = $2f_m$.

Solution:
Step 1: **Given:** Bandwidth = 10 kHz, carrier frequency $f_c = 1000$ kHz.
Step 2: **Finding modulating frequency:**

$$\text{Bandwidth} = 2f_m \Rightarrow f_m = \frac{10}{2} = 5 \text{ kHz}$$

Step 3: **Sideband frequencies:**

- **Upper sideband (USB):** $f_c + f_m = 1000 + 5 = 1005$ kHz.
- **Lower sideband (LSB):** $f_c - f_m = 1000 - 5 = 995$ kHz.

Step 4: **Option elimination:**

- 1005 kHz and 995 kHz: **correct** ($f_m = 5$ kHz, bandwidth = 10 kHz).
- 1010 and 990: would require $f_m = 10$ kHz, bandwidth = 20 kHz – **wrong**.
- 1000 and 990: would require bandwidth starting from carrier – **wrong**.
- 1010 and 1000: only one sideband shown – **wrong**.

Final Answer:

$$\boxed{f_{\text{USB}} = 1005 \text{ kHz}, \quad f_{\text{LSB}} = 995 \text{ kHz}}$$

Answer: (A)

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	C	3	A	4	D	5	A
6	B	7	B	8	B	9	B	10	C
11	C	12	B	13	B	14	B	15	B
16	C	17	B	18	C	19	A	20	B
21	B	22	C	23	C	24	C	25	A
26	B	27	C	28	B	29	B	30	A
31	A	32	A	33	C	34	A	35	B
36	C	37	A	38	C	39	A	40	C
41	A	42	B	43	A	44	A	45	C
46	C	47	C	48	B	49	B	50	A