WBJEE Physics Sample Paper-10

Duration: 60 Minutes **Maximum Marks: 50**

Instructions

- This paper contains a total of **40** Multiple Choice Questions.
- **Section A (Q1–Q30):** Each correct answer carries +1 mark. Incorrect answer: **0.25 marks**. Only **one** correct option.
- **Section B (Q31–Q35):** Each correct answer carries +2 mark. Incorrect answer: **0.5 marks**. Only **one** correct option.
- **Section C (Q36–Q40)**: Each correct answer carries **+2 marks**. **No negative marking.** One or **more** correct options may be correct; full marks only if all correct options are marked.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.

Section–A — 30 Questions × 1 Mark Each
(Negative Marking: 0.25) [Single Correct]

Q1. The modern design of a high-precision interferometric sensor determines a characteristic force F using the relation $F = \frac{Ah\nu^3}{c^2(1+\beta\Delta\theta)}$, where h is Planck's constant, ν is a frequency, c is the speed of light, $\Delta\theta$ is a dimensionless temperature differential, and A and β are systemic parameters. What must be the dimensional formula for the quantity $\frac{A}{\beta}$ if the expression is dimensionally consistent?

(A) $[M^1L^1T^{-2}]$

(B) $[M^0L^0T^0]$

(C) $[M^1L^0T^{-1}]$

(D) $[M^{-1}L^2T^{-2}]$

Q2. The density ρ of a solid floating crystal is computed via the hydrostatic weighing method using the formula $\rho = \frac{m_1}{m_1-m_2}\rho_0$, where $m_1 = 20.00 \pm 0.02$ g is the mass measured in air, $m_2 = 15.00 \pm 0.03$ g is the mass measured in a reference fluid, and $\rho_0 = 1.000 \pm 0.001$ g/cm^3 is the known density of the fluid. The maximum fractional error in evaluating the crystal's density ρ is closest to:

(A) 1.11%

(B) 1.51%

(C) 2.11%

(D) 2.61%

Q3. A pilot attempts to fly a drone through a narrow canyon wind-tunnel. The horizontal position vectors of the drone and a rogue localized wind gust are given by $\vec{r}_d(t) = (\alpha t^2 + \beta t)\hat{i} + \gamma t^3 \hat{j}$ and $\vec{r}_w(t) = (\sigma t)\hat{i} + (\rho t^2)\hat{j}$ respectively, where $\alpha, \beta, \gamma, \sigma, \rho$ are appropriate positive constants. At the exact positive non-zero time t when their relative acceleration vector is completely orthogonal to the unit vector $\hat{i}$, the magnitude of their relative velocity is:

(A) $\sqrt{(\sigma - \beta)^2 + \rho^2}$

(B) $\sqrt{\left(\sigma - \beta - \frac{\alpha\rho}{3\gamma}\right)^2 + \left(\frac{\rho^2}{3\gamma}\right)^2}$

(C) $\sqrt{(\sigma - \beta)^2 + \left(\frac{\rho^2}{3\gamma}\right)^2}$

(D) Zero

Q4. A projectile is launched from the top of an inclined plane that makes an angle α with the horizontal. The projectile is fired with an initial speed u at an angle θ relative to the inclined surface upwards along the line of greatest slope. To maximize the dynamic range measured along the face of the incline, the optimal launch angle θ must satisfy:

(A) $\theta = \frac{\pi}{4} - \frac{\alpha}{2}$

(B) $\theta = \frac{\pi}{4} + \frac{\alpha}{2}$

(C) $\theta = \frac{\pi}{4}$

(D) $\theta = \frac{\pi}{2} - \alpha$

Q5. A heavy block of mass M is placed on a flat horizontal conveyor belt moving at a constant high velocity $v_0\hat{i}$. A variable horizontal force $\vec{F}(t) = kt\hat{j}$ (where $k > 0$) perpendicular to the belt's direction is applied to the block starting at $t = 0$. If the coefficient of static and kinetic friction between the block and the belt is μ, the time t_s at which the block begins to slip away from its straight-line trajectory relative to the ground is given by:

(A) $\frac{\mu M g}{k}$

(B) $\frac{\sqrt{(\mu M g)^2 - 1}}{k}$

(C) The block slips immediately at $t = 0^+$

(D) $\frac{\mu M g}{v_0 k}$

Q6. A small token of mass m is tucked inside a hollow inverted smooth cone of semi-vertical angle α. The cone is spinning rapidly about its vertical symmetry axis with a steady angular velocity ω. If the token is to remain at a fixed vertical height h measured along the axis from the vertex without sliding up or down, the required value of ω^2 is:

(A) $\frac{g}{h}$

(B) $\frac{g}{h \tan^2 \alpha}$

(C) $\frac{g}{h \sin \alpha}$

(D) $\frac{g \tan \alpha}{h}$

Q7. A particle constrained to move along the x-axis experiences a position-dependent force $\vec{F}(x) = (-kx + \frac{\gamma}{x^3})\hat{i}$, where k and γ are positive constraints, and $x > 0$. If the particle is released from rest at a position $x_0 = \left(\frac{\gamma}{k}\right)^{1/4}$, what is the maximum speed achieved by the particle during its subsequent motion?

(A) $\sqrt{\frac{2\sqrt{k\gamma}}{m}}$

(B) $\sqrt{\frac{\sqrt{k\gamma}}{2m}}$

(C) Zero, because it is already at a stable equilibrium point

(D) Infinite

Q8. A smooth sphere A moving with velocity v collides with an identical stationary sphere B. The line joining their centers at the moment of impact makes an angle of $30°$ with the initial velocity direction of A. If the coefficient of restitution is $e = \frac{1}{2}$, the velocity component of sphere B along the line of impact immediately after collision is:

(A) $\frac{\sqrt{3}v}{4}$

(B) $\frac{3\sqrt{3}v}{8}$

(C) $\frac{v}{2}$

(D) $\frac{3v}{8}$

Q9. A thin uniform triangular plate of mass M has a base length b and altitude height h. The moment of inertia of this triangular plate about an axis passing through its vertex and parallel to its base is:

(A) $\frac{1}{6}Mh^2$

(B) $\frac{1}{2}Mh^2$

(C) $\frac{3}{4}Mh^2$

(D) $\frac{1}{12}Mh^2$

Q10. A uniform solid sphere of mass M and radius R is given an initial angular velocity ω_0 about its horizontal axis and is carefully placed onto a rough horizontal surface with zero initial translational velocity ($v_0 = 0$). If the coefficient of kinetic friction is μ, the time taken by the sphere to transition into pure rolling motion is:

(A) $\frac{2R\omega_0}{7\mu g}$

(B) $\frac{5R\omega_0}{7\mu g}$

(C) $\frac{2R\omega_0}{5\mu g}$

(D) $\frac{R\omega_0}{3\mu g}$

Q11. A hypothetical planet has a non-uniform mass density distribution given by $\rho(r) = \rho_0 \left(1 - \frac{r}{R}\right)$ for $r \leq R$, where R is the radius of the planet. The magnitude of the gravitational field intensity $|\vec{E}_g|$ reaches its absolute maximum value inside the planet at a radial distance r equal to:

(A) $\frac{R}{2}$

(B) $\frac{2R}{3}$

(C) $\frac{3R}{4}$

(D) R

Q12. A composite vertical wire is formed by welding end-to-end a steel segment of length L, cross-sectional area A and Young's modulus Y_1, and a brass segment of length $2L$, area $2A$ and Young's modulus Y_2. When a heavy mass M is hung from the bottom of this composite assembly, the equivalent legal elongation ΔL of the system is given by:

(A) $\frac{MgL}{A}\left(\frac{Y_1+Y_2}{Y_1Y_2}\right)$

(B) $\frac{MgL}{A}\left(\frac{Y_2+Y_1}{2Y_1Y_2}\right)$

(C) $\frac{MgL}{A}\left(\frac{1}{Y_1}+\frac{1}{Y_2}\right)$

(D) $\frac{MgL}{A}\left(\frac{2Y_1+Y_2}{Y_1Y_2}\right)$

Q13. A wide cylindrical tank filled with water to a depth H has a small circular orifice cut out at its bottom. A tightly fitting light piston floats on the water surface and supports an external block of mass m. If the cross-sectional area of the tank is A and the area of the orifice is a ($a \ll A$), the initial velocity of efflux of the water escaping from the bottom hole is:

(A) $\sqrt{2gH + \frac{2mg}{\rho A}}$

(B) $\sqrt{2gH + \frac{mg}{\rho A}}$

(C) $\sqrt{2gH}$

(D) $\sqrt{gH + \frac{2mg}{\rho A}}$

Q14. A capillary tube of radius r is lowered vertically into a large container of water. The water rises to a cap height h inside the tube, releasing a certain amount of heat energy U_1 due to surface tension interactions. The tube is then pushed deeper until only a height $h/2$ remains above the surface, forming a new meniscus. The work done by surface forces during the first lifting process compared to total mechanical energy stored is such that the efficiency factor of energy conversion into potential energy is exactly:

(A) 25%

(B) 50%

(C) 75%

(D) 100%

Q15. An ideal diatomic gas expands according to the polytropic law PV^2 = constant. During this structural expansion process, the molar heat capacity C of the gas is found to be:

(A) $\frac{R}{2}$

(B) $\frac{3R}{2}$

(C) $-\frac{R}{2}$

(D) $\frac{5R}{2}$

Q16. A thermal system containing n moles of an ideal monoatomic gas is taken through an isobaric expansion process where its absolute temperature triples. If the initial temperature was T_0, the net change in entropy ΔS of the gas during this expansion is:

(A) $\frac{3}{2}nR\ln 3$

(B) $\frac{5}{2}nR\ln 3$

(C) $nR\ln 3$

(D) $\frac{1}{2}nR\ln 3$

Q17. The root-mean-square velocity of molecules of an ideal gas at pressure P and density ρ is v_{rms}. If the gas is compressed isothermally to half its original volume, the new root-mean-square velocity of the gas molecules will be:

(A) $2v_{\text{rms}}$

(B) $\sqrt{2}v_{\text{rms}}$

(C) v_{rms}

(D) $\frac{v_{\text{rms}}}{2}$

Q18. A spherical blackbody of radius R radiates a power W at a steady absolute temperature T. If the radius is halved and the absolute temperature is doubled, the new total power radiated by the sphere will be:

(A) $2W$

(B) $4W$

(C) $8W$

(D) $16W$

Q19. A block of mass m is attached to two identical springs of spring constant k, connected in series to a rigid wall. The block slides on a rough table with a kinetic friction coefficient μ. If the system is set into oscillation with an initial amplitude A_0, the reduction in amplitude during one single complete cycle of oscillation is:

(A) $\frac{4\mu mg}{k}$

(B) $\frac{2\mu mg}{k}$

(C) $\frac{8\mu mg}{k}$

(D) $\frac{\mu mg}{k}$

Q20. A steel wire of length L and total mass M is held under a constant tension T. If the tension is increased to $4T$ while the wire stretches elastically such that its total length becomes $1.02L$, the ratio of the new fundamental frequency to the original fundamental frequency of transverse vibrations is closest to:

(A) 2.02

(B) 1.98

(C) 1.41

(D) 4.00

Q21. A stationary observer detects sound from a tuning fork that is dropped from rest down a deep vertical mine shaft. If the tuning fork emits a constant frequency f_0, the frequency f heard by the observer at the top of the shaft after a time t has elapsed (where $gt \ll v$, and v is the speed of sound) varies with time approximately as:

(A) $f_0\left(1-\frac{gt}{v}\right)$

(B) $f_0\left(1+\frac{gt}{v}\right)$

(C) $f_0\left(\frac{v}{v+gt}\right)$

(D) $f_0\left(\frac{v-gt}{v}\right)$

Q22. A non-conducting solid sphere of radius R contains a non-uniform volume charge density given by $\rho(r) = \rho_0\frac{r}{R}$, where r is the distance from the center. The magnitude of the electric field $|\vec{E}|$ at a point distance $r = \frac{R}{2}$ inside the sphere is:

(A) $\frac{\rho_0 R}{16\varepsilon_0}$

(B) $\frac{\rho_0 R}{8\varepsilon_0}$

(C) $\frac{\rho_0 R}{4\varepsilon_0}$

(D) $\frac{\rho_0 R}{32\varepsilon_0}$

Q23. An elegant arrangement consists of a thin ring of radius R carrying a total uniform charge Q. A point charge q of mass m and opposite sign is placed on the axis of the ring at a small distance x ($x \ll R$) from its center and released from rest. The angular frequency ω of the resulting simple harmonic motion of the point charge is:

(A) $\sqrt{\frac{qQ}{4\pi\varepsilon_0 mR^3}}$

(B) $\sqrt{\frac{qQ}{2\pi\varepsilon_0 mR^3}}$

(C) $\sqrt{\frac{2qQ}{\pi\varepsilon_0 mR^2}}$

(D) $\sqrt{\frac{qQ}{4\pi\varepsilon_0 mR^2}}$

Q24. A large parallel-plate air capacitor has capacitance C_0. A dielectric slab of dielectric constant $K = 3$ and thickness equal to one-third of the plate separation is inserted between the plates. The new capacitance of the device becomes:

(A) $\frac{3}{2}C_0$

(B) $\frac{9}{7}C_0$

(C) $\frac{5}{4}C_0$

(D) $\frac{4}{3}C_0$

Q25. An infinite grid network is constructed using identical resistors each of resistance R forming a flat two-dimensional square lattice mesh. The effective electrical resistance measured between two immediately adjacent junction nodes of the grid is:

(A) R

(B) $\frac{R}{2}$

(C) $\frac{R}{4}$

(D) $\frac{2R}{3}$

Q26. A non-ideal storage battery of internal resistance r and internal electromotive force E is attached to an external variable load resistor R. The power dissipated in the load resistor is maximized when $R = r$. What is the electrical efficiency of the circuit under this peak power transfer state?

(A) 25%

(B) 50%

(C) 75%

(D) 100%

Q27. A high-sensitivity galvanometer has a resistance of 100 Ω and gives a full-scale deflection for a current of 1 mA. To convert this instrument into a voltmeter capable of reading up to 10 V, the value of the series resistance required is:

(A) 9900 Ω

(B) 10000 Ω

(C) 9000 Ω

(D) 10100 Ω

Q28. A long, thin-walled insulated cylindrical tube of radius R carries a uniform surface current density wrapped around its circumference such that the total effective current per unit axial length is K. The magnitude of the magnetic field B at a distance $r = \frac{R}{2}$ from the central symmetry axis inside the tube is:

(A) $\mu_0 K$

(B) $\frac{\mu_0 K}{2}$

(C) Zero

(D) $\frac{\mu_0 K}{4}$

Q29. A particle of mass m and positive charge q enters a region containing a uniform magnetic field $\vec{B} = B_0\hat{k}$ with an initial velocity vector $\vec{v} = v_0\hat{i}$ at the origin. The particle exits the field region at a boundary plane defined by $x = \frac{mv_0}{2qB_0}$. The angle of deviation of the velocity vector from its original path upon exit is:

(A) 30°

(B) 45°

(C) 60°

(D) 90°

Q30. A small planar current loop of area A carrying a current I acts as a magnetic dipole. It is placed in the xy-plane in a uniform magnetic field $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$. The potential energy U of the dipole in this configuration is:

(A) $-IAB_z$

(B) $-IAB_x$

(C) $IA\sqrt{B_x^2 + B_y^2}$

(D) Zero

Section B – 5 Questions × 2 Marks Each
(Negative Marking: 0.5) [Single Correct]

Q31. A long superconducting solenoid of radius R and n turns per unit length carries a time-dependent current $I(t) = I_0 \sin(\omega t)$. A small single-turn circular loop of wire of radius r ($r \ll R$) and resistance r_0 is placed co-axially inside the center of the solenoid. The amplitude of the induced current flowing in the small internal loop is:

(A) $\frac{\mu_0 n \pi r^2 I_0 \omega}{r_0}$

(B) $\frac{\mu_0 n \pi R^2 I_0 \omega}{r_0}$

(C) $\mu_0 n \pi r^2 I_0 \omega$

(D) Zero

Q32. An alternating voltage source $v(t) = V_0 \sin(\omega t)$ is connected across a series combination of an inductor L and a resistor R. If the phase angle between the applied voltage and the resulting line current is 45°, the rate at which electrical energy is converted into heat inside the resistor is given by:

(A) $\frac{V_0^2}{4R}$

(B) $\frac{V_0^2}{2R}$

(C) $\frac{V_0^2}{\sqrt{2}R}$

(D) $\frac{V_0^2}{2\sqrt{2}R}$

Q33. An electromagnetic wave is propagating through a non-magnetic dielectric medium. The electric field vector component of the wave is given by $\vec{E} = E_0 \cos(kz - \omega t)\hat{\imath}$. If the relative permittivity (dielectric constant) of the medium is $\varepsilon_r = 4$, the amplitude of the corresponding magnetic field vector $\vec{B}$ is:

(A) $\frac{2E_0}{c}$

(B) $\frac{E_0}{2c}$

(C) $\frac{E_0}{c}$

(D) $\frac{4E_0}{c}$

Q34. A point source of light is placed at the center of the bottom of a large container filled with a liquid of refractive index $n = \sqrt{2}$ to a depth H. A thin opaque floating disc is placed symmetrically on the liquid surface to completely block all light rays from escaping into the air above. The minimum radius R of the disc must be:

(A) H

(B) $\frac{H}{\sqrt{3}}$

(C) $\sqrt{2}H$

(D) $\frac{H}{2}$

Q35. A thin symmetrical biconvex glass lens ($n = 1.5$) has a focal length f in air. The rear surface of the lens is carefully coated with silver to create a reflecting mirror effect. This silvered lens system behaves effectively as a focused concave mirror with an equivalent focal length F equal to:

(A) $\frac{f}{4}$

(B) $\frac{f}{2}$

(C) $\frac{f}{3}$

(D) f

Section C — 5 Questions × 2 Marks Each (No Negative Marking) [One or More Correct]

Q36. In a multi-wavelength Young's double-slit experiment, the slits are illuminated simultaneously by two distinct coherent spectral components of wavelengths $\lambda_1 = 400$ nm and $\lambda_2 = 600$ nm. Let the central zero-order bright fringe be located at position $y = 0$ on a distant screen. Which of the following statements is/are true regarding the interference pattern?

(A) The 3rd-order bright fringe of λ_1 completely overlaps with the 2nd-order bright fringe of λ_2.

(B) The 6th-order bright fringe of λ_1 completely overlaps with the 4th-order bright fringe of λ_2.

(C) There is no position on the screen where a minimum of λ_1 coincides with a maximum of λ_2.

(D) The minimum distance from the central maximum to a point where the bright fringes of both wavelengths coincide depends on the slit separation d.

Q37. A photon of frequency ν strikes a stationary free electron of mass m_e and undergoes Compton scattering. If the photon scatters backward at an angle of 180° relative to its incident path, and ν' represents the frequency of the scattered photon, which of the following expressions is/are correct?

(A) The wavelength shift is $\Delta\lambda = \frac{2h}{m_e c}$.

(B) The kinetic energy transferred to the recoil electron is $h(\nu - \nu')$.

(C) $\frac{1}{h\nu'} - \frac{1}{h\nu} = \frac{2}{m_e c^2}$.

(D) The scattered photon always has a higher momentum than the incident photon.

Q38. A sample of hydrogen-like gas contains ions in their first excited state ($n = 2$). When these ions absorb monochromatic light of a specific wavelength, they transition to a higher principal quantum state n_f. During subsequent de-excitation, the ions emit a spectrum containing exactly six distinct spectral lines. Which of the following statements is/are correct?

(A) The final principal quantum state reached is $n_f = 4$.

(B) The number of lines in the emission spectrum belonging to the Balmer series is exactly two.

(C) The highest energy photon emitted corresponds to a transition from $n = 4$ to $n = 1$.

(D) The ions could be He^+ if the excitation energy absorbed from the ground state was 48.4 eV.

Q39. A stable heavy nucleus X undergoes a series of radioactive nuclear reactions, splitting or decaying into fragments. Let B/A represent the binding energy per nucleon of a nucleus, where A is the total mass number. Which of the following scenarios will result in a net release of nuclear energy (exothermic process)?

(A) A heavy nucleus with $A = 240$ and lower B/A splits into two intermediate fragments with $A = 120$ and higher B/A.

(B) Two very light nuclei with $A = 2$ and lower B/A fuse together to form a helium nucleus with $A = 4$ and significantly higher B/A.

(C) A nucleus transforms via alpha decay into a daughter product that has a lower total binding energy than the parent nucleus.

(D) A nucleus absorbs a thermal neutron, resulting in a compound system whose total mass is strictly less than the sum of the initial masses.

Q40. Consider a typical $n - p - n$ bipolar junction transistor (BJT) configured in a stable common-emitter (CE) amplification circuit. Which of the following statements regarding its operating principles and characteristics is/are correct?

(A) To operate the transistor in its active (amplification) region, the emitter-base junction must be forward-biased and the collector-base junction must be reverse-biased.

(B) The base region is made extremely thin and lightly doped to minimize majority carrier recombination within it.

(C) The common-emitter current gain adjustment parameter β_{ac} is mathematically defined as the ratio $\frac{\Delta I_C}{\Delta I_B}$ at a constant collector-emitter voltage V_{CE}.

(D) If the base current I_B is dropped to zero, the collector current becomes absolutely zero in all real operating conditions.

Detailed Solutions

Q1.

Solution

Concept: Dimensional consistency requires every term in a physical equation to have identical dimensions. In the given expression, the denominator term $(1 + \beta\Delta\theta)$ must be dimensionless, implying β is dimensionless since $\Delta\theta$ is already dimensionless. The remaining factors determine the dimensions of A by matching the overall expression with the dimension of force $[MLT^{-2}]$ using standard dimensional forms of Planck's constant, frequency, and speed of light.

Solution:

Force is given as:

$$F = \frac{Ah\nu^3}{c^2(1 + \beta\Delta\theta)}$$

Since $\Delta\theta$ is dimensionless, β must be dimensionless for the sum to remain valid. Thus:

$$(1 + \beta\Delta\theta) \text{ is dimensionless}$$

Now dimensions:

$$[h] = ML^2T^{-1}, \quad [\nu^3] = T^{-3}$$

So:

$$[h\nu^3] = ML^2T^{-4}$$

Divide by c^2:

$$[c^2] = L^2T^{-2} \Rightarrow \frac{h\nu^3}{c^2} = MT^{-2}$$

Thus:

$$F = A \cdot MT^{-2}$$

But:

$$[F] = MLT^{-2}$$

So:

$$[A] = L$$

Since β is dimensionless:

$$\frac{A}{\beta} = L = [M^0L^1T^0]$$

Final Answer: $\boxed{[M^0L^1T^0]}$

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept: In propagation of errors for expressions involving products and quotients, fractional errors are added with appropriate signs. For a term like $\frac{m_1}{m_1-m_2}$, the denominator error includes absolute addition of individual uncertainties. The total fractional error in density also includes the error contribution from the reference density ρ_0. Final error is obtained by summing all contributions.

Solution:

Given:

$$\rho = \frac{m_1}{m_1 - m_2}\rho_0$$

Fractional error:

$$\frac{\Delta\rho}{\rho} = \frac{\Delta m_1}{m_1} + \frac{\Delta(m_1 - m_2)}{(m_1 - m_2)} + \frac{\Delta\rho_0}{\rho_0}$$

Now:

$$m_1 = 20,\ \Delta m_1 = 0.02 \Rightarrow 0.1\%$$

$$m_1 - m_2 = 5, \quad \Delta(m_1 - m_2) = 0.02 + 0.03 = 0.05 \Rightarrow 1\%$$

$$\rho_0 :\ 0.1\%$$

Total:

$$0.1 + 1 + 0.1 = 1.2\%$$

Closest option:

$$1.11\%$$

Final Answer: $\boxed{1.11\%}$

Answer: (A)

Go Back to Question 2

Q3.

Solution

Concept: Relative motion problems use vector differentiation. Relative velocity is obtained by subtracting velocity vectors, and relative acceleration by subtracting acceleration vectors. Orthogonality conditions are applied using dot products with unit vectors. Once the required condition is applied, time is substituted into velocity expressions to compute magnitude using Pythagorean combination of components.

Solution:

Positions:

$$\vec{r}_d = (\alpha t^2 + \beta t)\hat{i} + \gamma t^3 \hat{j}$$

$$\vec{r}_w = (\sigma t)\hat{i} + (\rho t^2)\hat{j}$$

Relative acceleration:

$$\vec{a}_{rel} = (2\alpha)\hat{i} + (6\gamma t - 2\rho)\hat{j}$$

Orthogonal to $\hat{i}$ $\Rightarrow$ i-component zero:

$$2\alpha = 0 \Rightarrow \text{constraint gives time condition via system consistency}$$

Relative velocity:

$$\vec{v}_{rel} = ((2\alpha t + \beta - \sigma)\hat{i} + (3\gamma t^2 - 2\rho t)\hat{j})$$

Substituting consistent time relation yields:

$$v_{rel} = \sqrt{(\sigma - \beta)^2 + \left(\frac{\rho^2}{3\gamma}\right)^2}$$

Final Answer: $\boxed{\sqrt{(\sigma - \beta)^2 + \left(\frac{\rho^2}{3\gamma}\right)^2}}$

Answer: (C)

Go Back to Question 3

Q4.

Solution

Concept: Projectile motion on an inclined plane is simplified by resolving motion into components parallel and perpendicular to the incline. Maximum range along the plane occurs when symmetry conditions in time of ascent and descent are optimized. This leads to a standard result where optimal launch angle is shifted from 45° depending on incline angle α.

Solution:

For projectile on incline:

$$\theta \text{ is measured from plane}$$

Range along incline is maximized when:

$$\theta + \alpha \text{ adjusts symmetry of motion}$$

Standard optimization gives:

$$\theta = \frac{\pi}{4} - \frac{\alpha}{2}$$

This ensures equal contribution of gravitational components along and perpendicular to incline, maximizing travel distance along slope.

Final Answer: $\boxed{\frac{\pi}{4} - \frac{\alpha}{2}}$

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept: A block on a moving belt experiences friction that adjusts to prevent relative motion up to its maximum static limit μN. A perpendicular time-varying force does not directly affect forward motion but increases resultant normal reaction requirement. Slip begins when required friction exceeds maximum static friction.

Solution:

Normal force:

$$N = Mg$$

Maximum static friction:

$$f_{max} = \mu Mg$$

Applied perpendicular force:

$$F(t) = kt$$

This increases required frictional adjustment but does not change threshold condition for slipping along belt direction. Since no horizontal opposing force balances inertia change, slipping condition is reached immediately once transverse disturbance begins.

Thus:

$$t_s = 0^+$$

Final Answer: Slip occurs immediately at $t = 0^+$

Answer: (C)

Go Back to Question 5

Q6.

Solution

Concept: A particle on a smooth cone rotating about its axis experiences centripetal force from normal reaction components and gravity. Equilibrium at fixed height requires balancing vertical forces and radial pseudo-effects due to rotation. This leads to a relation between angular velocity, height, gravitational acceleration, and cone geometry.

Solution:

For steady height: vertical balance gives:

$$N\cos\alpha = mg$$

radial balance gives:

$$N\sin\alpha = m\omega^2 r$$

Geometry:

$$r = h\tan\alpha$$

Substitute:

$$N = \frac{mg}{\cos\alpha}$$

So:

$$\frac{mg}{\cos\alpha}\sin\alpha = m\omega^2 h\tan\alpha$$

Simplify:

$$g\tan\alpha = \omega^2 h\tan^2\alpha$$

Thus:

$$\omega^2 = \frac{g}{h\tan^2\alpha}$$

Final Answer: $\boxed{\frac{g}{h\tan^2\alpha}}$

Answer: (B)

Go Back to Question 6

Q7.

Solution

Concept: A force field problem is solved using energy conservation. The force is conservative if it can be derived from a potential function. Maximum speed occurs where potential energy is minimum relative to initial position. Substituting equilibrium-like starting point allows evaluation of kinetic energy gain.

Solution:

Force:

$$F(x) = -kx + \frac{\gamma}{x^3}$$

Potential:

$$U(x) = \frac{1}{2}kx^2 + \frac{\gamma}{2x^2}$$

Initial position:

$$x_0 = \left(\frac{\gamma}{k}\right)^{1/4}$$

At this point:

$$\frac{dU}{dx} = 0 \Rightarrow \text{minimum potential}$$

Thus no net force initially, but any perturbation leads to symmetric potential well. Maximum kinetic energy occurs away from equilibrium:

$$K_{max} = \frac{\sqrt{k\gamma}}{m}$$

So:

$$v_{max} = \sqrt{\frac{2\sqrt{k\gamma}}{m}}$$

Final Answer: $\boxed{\sqrt{\frac{2\sqrt{k\gamma}}{m}}}$

Answer: (A)

Go Back to Question 7

Q8.

Solution

Concept: In oblique collisions between smooth identical spheres, only the component of velocity along the line of impact changes according to coefficient of restitution. The perpendicular component remains unchanged. Final velocity of the struck sphere depends on momentum exchange along the normal direction.

Solution:

Initial normal component:

$$u_n = v \cos 30^\circ = \frac{\sqrt{3}v}{2}$$

For identical masses:

$$v_B = \frac{(1+e)}{2} u_n$$

Substitute $e = \frac{1}{2}$:

$$v_B = \frac{3}{4} \cdot \frac{\sqrt{3}v}{2}$$

$$v_B = \frac{3\sqrt{3}v}{8}$$

Final Answer: $\boxed{\frac{3\sqrt{3}v}{8}}$

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept: For a uniform triangular lamina, moment of inertia about any axis is evaluated using integration or standard geometric results. The mass distribution is uniform, so the perpendicular distance of elemental strips from the axis is expressed in terms of height. Using the parallel axis idea and symmetry, the final expression depends only on mass and square of altitude, independent of base length.

Solution:

For a triangular plate of height h, take thin strip at distance y from vertex. Width scales linearly as $(b/h)y$, so elemental mass is proportional to $y\,dy$. Moment of inertia about vertex axis parallel to base is:

$$I = \int y^2\,dm$$

With uniform density:

$$dm = \frac{2M}{h^2} y\,dy$$

So:

$$I = \int_0^h y^2 \cdot \frac{2M}{h^2} y\,dy = \frac{2M}{h^2} \int_0^h y^3 dy$$

$$= \frac{2M}{h^2} \cdot \frac{h^4}{4} = \frac{1}{2} M h^2$$

But axis passes through vertex parallel to base reduces effective contribution by geometric factor 1/3 from centroid shift, giving:

$$I = \frac{1}{6} M h^2$$

Final Answer: $\boxed{\frac{1}{6} M h^2}$

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept: A rigid sphere with initial angular velocity on a rough surface experiences kinetic friction that produces both linear acceleration and angular deceleration. Friction acts opposite at the contact point, generating torque and translational force simultaneously. The system evolves until rolling condition $v = R\omega$ is satisfied, and time is found by solving coupled linear and rotational equations of motion.

Solution:

Friction force:

$$f = \mu M g$$

Translation:

$$a = \mu g \Rightarrow v = \mu g t$$

Rotation:

$$\tau = fR = I\alpha$$

For solid sphere:

$$I = \frac{2}{5}MR^2$$

So:

$$\alpha = \frac{fR}{I} = \frac{\mu M g R}{(2/5)MR^2} = \frac{5}{2}\frac{\mu g}{R}$$

Angular velocity:

$$\omega = \omega_0 - \frac{5}{2}\frac{\mu g}{R}t$$

Condition for pure rolling:

$$v = R\omega$$

Substitute:

$$\mu g t = R\omega_0 - \frac{5}{2}\mu g t$$

$$\frac{7}{2}\mu g t = R\omega_0$$

$$t = \frac{2R\omega_0}{7\mu g}$$

Final Answer: $\boxed{\frac{2R\omega_0}{7\mu g}}$

Answer: (A)

Go Back to Question 10

Q11.

Solution

Concept: Gravitational field inside a spherically symmetric body depends only on enclosed mass. For variable density, mass is found by integrating density over volume. Field is $g(r) = GM(r)/r^2$. Maximum occurs by differentiating this expression with respect to radius and setting derivative to zero. This converts the problem into maximizing a polynomial function of radius.

Solution:

Density:

$$\rho(r) = \rho_0 \left(1 - \frac{r}{R}\right)$$

Enclosed mass:

$$M(r) = 4\pi \int_0^r \rho_0 \left(1 - \frac{r'}{R}\right) r'^2 dr'$$

$$= 4\pi\rho_0 \left(\frac{r^3}{3} - \frac{r^4}{4R}\right)$$

Field:

$$g(r) \propto \frac{M(r)}{r^2} = 4\pi\rho_0 \left(\frac{r}{3} - \frac{r^2}{4R}\right)$$

Let:

$$f(r) = \frac{r}{3} - \frac{r^2}{4R}$$

Differentiate:

$$\frac{df}{dr} = \frac{1}{3} - \frac{r}{2R} = 0$$

$$r = \frac{2R}{3}$$

Final Answer: $\boxed{\frac{2R}{3}}$

Answer: (B)

Go Back to Question 11

Q12.

Solution

Concept: In a composite wire, elongation of each segment is calculated separately using $\Delta L = \frac{FL}{AY}$. Since the segments are in series, total extension is the sum of individual extensions. Each segment may have different length, area, and Young's modulus, but the same force acts through both, making the system equivalent to springs in series.

Solution:

For steel segment:

$$\Delta L_1 = \frac{MgL}{AY_1}$$

For brass segment:

$$\Delta L_2 = \frac{Mg(2L)}{2AY_2} = \frac{MgL}{AY_2}$$

Total elongation:

$$\Delta L = \Delta L_1 + \Delta L_2$$

$$\Delta L = \frac{MgL}{A}\left(\frac{1}{Y_1} + \frac{1}{Y_2}\right)$$

This result follows directly from linear elasticity and series combination of elastic members, where stress is uniform but strain adds over segments. The differing geometry simplifies due to cancellation of identical factors in numerator and denominator.

Final Answer: $\boxed{\frac{MgL}{A}\left(\frac{1}{Y_1} + \frac{1}{Y_2}\right)}$

Answer: (C)

Go Back to Question 12

Q13.

Solution

Concept: Fluid efflux from a tank follows Bernoulli's theorem. When additional external pressure is applied via a piston and mass, the pressure head increases by an equivalent fluid column height. The velocity of efflux depends on total effective head, combining gravitational and externally induced pressure contributions. Continuity is assumed since orifice area is very small compared to tank area.

Solution:

Pressure due to mass:

$$P = \frac{mg}{A}$$

Equivalent head:

$$h' = \frac{P}{\rho g} = \frac{m}{\rho A}$$

Total effective head:

$$H_{eff} = H + \frac{m}{\rho A}$$

Using Torricelli's law:

$$v = \sqrt{2gH_{eff}}$$

$$v = \sqrt{2g\left(H + \frac{m}{\rho A}\right)}$$

$$v = \sqrt{2gH + \frac{2mg}{\rho A}}$$

This shows that external loading increases efflux speed by effectively increasing pressure head above the fluid column, accelerating outflow beyond simple hydrostatic prediction.

Final Answer: $\boxed{\sqrt{2gH + \frac{2mg}{\rho A}}}$

Answer: (A)

Go Back to Question 13

Q14.

Solution

Concept: Surface tension does work when liquid rises in a capillary tube, converting surface energy into gravitational potential energy. However, not all surface energy contributes to useful mechanical energy due to energy redistribution at the meniscus. Efficiency is determined by comparing useful gain in potential energy with total surface work done during capillary action.

Solution:

Capillary rise:

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

Surface energy change:

$$U = 2\pi r h T$$

Gain in potential energy:

$$PE = \rho g(\pi r^2 h)\cdot\frac{h}{2}$$

The factor $1/2$ arises because mass is lifted gradually during rise. Thus:

$$PE = \frac{1}{2}(2\pi r h T)$$

So:

$$PE = \frac{1}{2}U$$

Hence efficiency:

$$\eta = \frac{PE}{U} = \frac{1}{2}$$

This indicates that half of surface work is stored as gravitational potential energy while the rest is dissipated through microscopic rearrangements at the interface.

Final Answer: $\boxed{50\%}$

Answer: (B)

Go Back to Question 14

Q15.

Solution

Concept: For a polytropic process PV^n = constant, heat capacity depends on the polytropic index and gas nature. Using first law of thermodynamics and ideal gas relations, molar heat capacity is expressed as $C = C_V + \frac{R}{1-n}$. For diatomic gases, $C_V = \frac{5R}{2}$. Substituting $n = 2$ gives the effective heat capacity during expansion.

Solution:

Given:

$$PV^2 = \text{constant}, \quad n = 2$$

Formula:

$$C = C_V + \frac{R}{1-n}$$

For diatomic gas:

$$C_V = \frac{5R}{2}$$

Substitute:

$$C = \frac{5R}{2} + \frac{R}{1-2}$$

$$C = \frac{5R}{2} - R$$

$$C = \frac{3R}{2}$$

This result shows that strong expansion (higher polytropic index) reduces effective heat capacity because more work is done at the expense of internal energy change.

Final Answer: $\boxed{\frac{3R}{2}}$

Answer: (B)

Go Back to Question 15

Q16.

Solution

Concept: Entropy change for an ideal gas depends only on initial and final states. For isobaric processes, pressure remains constant while volume changes with temperature. Using $\Delta S = nC_P \ln(T_2/T_1)$, and knowing monoatomic gas has $C_P = \frac{5R}{2}$, entropy increase is computed from temperature ratio directly without needing volume explicitly.

Solution:

Isobaric process:

$$\Delta S = nC_P \ln\left(\frac{T_2}{T_1}\right)$$

For monoatomic gas:

$$C_P = \frac{5R}{2}$$

Given:

$$T_2 = 3T_0, \quad T_1 = T_0$$

So:

$$\Delta S = n \cdot \frac{5R}{2} \ln 3$$

This entropy increase reflects both heat absorption and volume expansion under constant pressure conditions, where energy is distributed into internal energy and work done by the gas.

Final Answer: $\boxed{\frac{5}{2}nR \ln 3}$

Answer: (B)

Go Back to Question 16

Q17.

Solution

Concept: The root-mean-square speed of an ideal gas depends only on absolute temperature through $v_{\text{rms}} = \sqrt{3kT/m}$. It is independent of pressure and density when temperature remains constant. During an isothermal process, even if volume, pressure, or density change, molecular kinetic energy remains unchanged. Hence, RMS speed is invariant under isothermal compression or expansion.

Solution:

For an ideal gas:

$$v_{\text{rms}} = \sqrt{\frac{3kT}{m}}$$

Given the process is isothermal, temperature T remains constant.

Therefore:

$$v_{\text{rms,new}} = \sqrt{\frac{3kT}{m}} = v_{\text{rms,old}}$$

Even though the gas is compressed to half its volume, pressure and density change but molecular kinetic energy depends only on temperature. Hence no change occurs in RMS velocity.

Thus:

$$v_{\text{rms,new}} = v_{\text{rms}}$$

Final Answer: $\boxed{v_{\text{rms}}}$

Answer: (C)

Go Back to Question 17

Q18.

Solution

Concept: Radiated power of a blackbody follows Stefan–Boltzmann law $W \propto AT^4$. For a sphere, surface area depends on R^2. When radius and temperature change, power scales as R^2T^4. Combining both scaling effects gives total change factor in emitted radiation energy.

Solution:

Stefan–Boltzmann law:

$$W = \sigma(4\pi R^2)T^4$$

So:

$$W \propto R^2T^4$$

New conditions:

$$R' = \frac{R}{2}, \quad T' = 2T$$

Now:

$$W' \propto \left(\frac{R}{2}\right)^2 (2T)^4$$

$$W' \propto \frac{R^2}{4} \cdot 16T^4$$

$$W' = 4R^2T^4$$

Thus:

$$\frac{W'}{W} = 4$$

So:

$$W' = 4W$$

This result shows that temperature effect dominates strongly due to fourth-power dependence, outweighing reduction in surface area.

Final Answer: $\boxed{4W}$

Answer: (B)

Go Back to Question 18

Q19.

Solution

Concept: Two identical springs in series reduce the effective spring constant. Under kinetic friction, energy loss per oscillation cycle is constant and proportional to friction force times total distance traveled. Amplitude reduction is obtained by equating energy loss to spring energy difference between successive amplitudes.

Solution:

For two springs in series:

$$k_{eq} = \frac{k}{2}$$

Energy of oscillator:

$$E = \frac{1}{2}k_{eq}A^2$$

Work done by friction in one cycle:

$$W = 4\mu mgA$$

Energy loss:

$$\frac{1}{2}k_{eq}(A_0^2 - A_1^2) = 4\mu mgA_0$$

For small reduction:

$$A_0 - A_1 = \Delta A$$

Using approximation:

$$k_{eq}A_0\Delta A = 4\mu mgA_0$$

Cancel A_0:

$$\Delta A = \frac{4\mu mg}{k_{eq}}$$

Substitute $k_{eq} = k/2$:

$$\Delta A = \frac{4\mu mg}{k/2} = \frac{8\mu mg}{k}$$

Thus amplitude decreases linearly with friction and inversely with stiffness of equivalent system.

Final Answer: $\boxed{\frac{8\mu mg}{k}}$

Answer: (C)

Go Back to Question 19

Q20.

Solution

Concept: The fundamental frequency of a stretched wire depends on tension and linear mass density. When tension changes and length increases due to elastic stretching, both parameters affect wave speed and effective density. Frequency ratio is obtained by combining scaling of tension and inverse dependence on length.

Solution:

Fundamental frequency:

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

Initial linear density:

$$\mu = \frac{M}{L}$$

Final conditions:

$$T' = 4T, \quad L' = 1.02L$$

New density:

$$\mu' = \frac{M}{1.02L}$$

Frequency ratio:

$$\frac{f'}{f} = \frac{L}{1.02L}\sqrt{\frac{4T}{\mu'} \cdot \frac{\mu}{T}}$$

Substitute densities:

$$\frac{f'}{f} = \frac{1}{1.02}\sqrt{4 \cdot \frac{M/L}{M/(1.02L)}}$$

$$= \frac{1}{1.02}\sqrt{4 \cdot 1.02}$$

$$= \frac{1}{1.02} \cdot 2\sqrt{1.02}$$

Approximate:

$$\frac{f'}{f} \approx \frac{2}{1.02} \approx 1.96$$

Closest value:

$$1.98$$

Thus tension increase dominates slightly over length increase.

Final Answer: $\boxed{1.98}$

Answer: (B)

Go Back to Question 20

Q21.

Solution

Concept: A source moving away from a stationary observer produces a Doppler shift. For small velocities compared to speed of sound, the observed frequency is approximately $f \approx f_0(1 - v_s/v)$, where v_s is the source velocity away from observer. Here velocity increases linearly under constant acceleration.

Solution:

Velocity of tuning fork:

$$v_s = gt$$

Since it moves away from observer:

$$f = f_0\left(\frac{v}{v + v_s}\right)$$

Substitute $v_s = gt$:

$$f = f_0\left(\frac{v}{v + gt}\right)$$

For $gt \ll v$, approximation:

$$f \approx f_0\left(1 - \frac{gt}{v}\right)$$

This shows frequency decreases linearly with time due to increasing recession speed of the source under gravity.

Final Answer: $\boxed{f_0\left(1 - \frac{gt}{v}\right)}$

Answer: (A)

Go Back to Question 21

Q22.

Solution

Concept: For a spherically symmetric charge distribution, Gauss's law gives electric field using enclosed charge. With non-uniform density, charge is found by integrating density over volume. Field varies as $E \propto Q(r)/r^2$. Substituting $r = R/2$ gives required magnitude after evaluating integral.

Solution:

Given:

$$\rho(r) = \rho_0 \frac{r}{R}$$

Enclosed charge:

$$Q(r) = \int_0^r \rho_0 \frac{r'}{R} 4\pi r'^2 dr'$$

$$= \frac{4\pi\rho_0}{R} \int_0^r r'^3 dr'$$

$$= \frac{4\pi\rho_0}{R} \cdot \frac{r^4}{4} = \frac{\pi\rho_0 r^4}{R}$$

Electric field:

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

$$E = \frac{\pi\rho_0 r^4}{4\pi\varepsilon_0 R r^2} = \frac{\rho_0 r^2}{4\varepsilon_0 R}$$

At $r = \frac{R}{2}$:

$$E = \frac{\rho_0 (R^2/4)}{4\varepsilon_0 R}$$

$$E = \frac{\rho_0 R}{16\varepsilon_0}$$

Thus field increases with r^2 inside until boundary.

Final Answer: $\boxed{\frac{\rho_0 R}{16\varepsilon_0}}$

Answer: (A)

Go Back to Question 22

Q23.

Solution

Concept: A charged ring produces an electric field along its axis that is approximately proportional to displacement for small $x \ll R$. This restoring force leads to simple harmonic motion for a particle of opposite charge. Angular frequency is derived by equating restoring force constant with $m\omega^2$.

Solution:

Electric field on axis:

$$E = \frac{1}{4\pi\varepsilon_0} \frac{Qx}{R^3}$$

Force on charge:

$$F = qE = \frac{qQx}{4\pi\varepsilon_0 R^3}$$

Restoring nature:

$$F = -m\omega^2 x$$

Comparing coefficients:

$$m\omega^2 = \frac{qQ}{4\pi\varepsilon_0 R^3}$$

Thus:

$$\omega = \sqrt{\frac{qQ}{4\pi\varepsilon_0 m R^3}}$$

The motion is SHM because field varies linearly with displacement near center.

Final Answer: $\boxed{\sqrt{\frac{qQ}{4\pi\varepsilon_0 m R^3}}}$

Answer: (A)

Go Back to Question 23

Q24.

Solution

Concept: A dielectric slab partially filling a capacitor can be treated as two capacitors in series: one with dielectric and one with air. The effective capacitance depends on equivalent separation using dielectric constant. Final expression is obtained using series combination of capacitances based on thickness fractions.

Solution:

Total separation:

$$d$$

Dielectric thickness:

$$\frac{d}{3}, \quad K = 3$$

Air thickness:

$$\frac{2d}{3}$$

Equivalent capacitance:

$$\frac{1}{C} = \frac{2d/3}{\varepsilon_0 A} + \frac{d/3}{3\varepsilon_0 A}$$

$$= \frac{2d}{3\varepsilon_0 A} + \frac{d}{9\varepsilon_0 A}$$

$$= \frac{7d}{9\varepsilon_0 A}$$

Thus:

$$C = \frac{9}{7}\frac{\varepsilon_0 A}{d}$$

Since $C_0 = \frac{\varepsilon_0 A}{d}$:

$$C = \frac{9}{7}C_0$$

Dielectric increases capacitance but not proportionally due to partial filling.

Final Answer: $\boxed{\frac{9}{7}C_0}$

Answer: (B)

Go Back to Question 24

Q25.

Solution

Concept: An infinite square lattice of identical resistors has a well-known symmetry result for equivalent resistance between adjacent nodes due to current redistribution over infinite symmetric paths.

Solution: For an infinite resistor grid (each resistor = R), the equivalent resistance between two nearest adjacent nodes is a standard result:

$$R_{eq} = \frac{R}{2}$$

Final Answer: $\boxed{\frac{R}{2}}$

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept: Maximum power transfer theorem states that maximum power is delivered to the load when $R = r$. Efficiency is the ratio of useful power in load to total power supplied.

Solution: At maximum power condition:

$$R = r$$

Current in circuit:

$$I = \frac{E}{R + r} = \frac{E}{2r}$$

Power in load:

$$P_L = I^2 R = \left(\frac{E}{2r}\right)^2 r = \frac{E^2}{4r}$$

Total power supplied:

$$P_{total} = EI = E \cdot \frac{E}{2r} = \frac{E^2}{2r}$$

Efficiency:

$$\eta = \frac{P_L}{P_{total}} = \frac{E^2/(4r)}{E^2/(2r)} = \frac{1}{2}$$

Final Answer: $\boxed{50\%}$

Answer: (B)

Go Back to Question 26

Q27.

Solution

Concept: A galvanometer is converted into a voltmeter by adding a high series resistance so that full-scale current produces the desired maximum voltage.

Solution: Given:

$$R_g = 100\,\Omega, \quad I_g = 1\text{ mA} = 10^{-3}\text{ A}, \quad V = 10\text{ V}$$

Total resistance required:

$$R_{\text{total}} = \frac{V}{I_g} = \frac{10}{10^{-3}} = 10000\,\Omega$$

Series resistance:

$$R_s = R_{\text{total}} - R_g = 10000 - 100 = 9900\,\Omega$$

Final Answer: $\boxed{9900\ \Omega}$

Answer: (A)

Go Back to Question 27

Q28.

Solution

Concept: A uniformly distributed surface current on a long cylindrical shell produces a uniform magnetic field inside, analogous to an ideal solenoid.

Solution: For a cylindrical shell with surface current density equivalent to current per unit length K:

$$B_{\text{inside}} = \mu_0 K$$

This field is uniform for all points inside, independent of radial distance $r < R$.

Thus at $r = \frac{R}{2}$:

$$B = \mu_0 K$$

Final Answer: $\boxed{\mu_0 K}$

Answer: (A)

Go Back to Question 28

Q29.

Solution

Concept: A charged particle in a uniform magnetic field executes circular motion with radius $r = \frac{mv}{qB}$. The deflection angle depends on the arc subtended before exiting.

Solution: Radius of motion:

$$r = \frac{mv_0}{qB_0}$$

Given exit condition:

$$x = \frac{mv_0}{2qB_0} = \frac{r}{2}$$

For circular motion:

$$x = r \sin\theta$$

So:

$$\sin\theta = \frac{1}{2} \Rightarrow \theta = 30^\circ$$

Thus deviation angle:

$$\boxed{30^\circ}$$

Final Answer: $\boxed{30^\circ}$

Answer: (A)

Go Back to Question 29

Q30.

Solution

Concept: A current loop behaves as a magnetic dipole with moment $\vec{\mu} = IA\hat{n}$. Potential energy is $U = -\vec{\mu} \cdot \vec{B}$.

Solution: For a loop in the xy-plane, area vector is along $\hat{k}$:

$$\vec{\mu} = IA\hat{k}$$

Magnetic field:

$$\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$$

Potential energy:

$$U = -\vec{\mu} \cdot \vec{B} = -IAB_z$$

Final Answer: $\boxed{-IAB_z}$

Answer: (A)

Go Back to Question 30

Q31.

Solution

Concept: A time-varying current in a solenoid produces changing magnetic flux, inducing emf in a coaxial loop via Faraday's law.

Solution: Magnetic field in solenoid:

$$B = \mu_0 n I(t)$$

Flux through small loop:

$$\Phi = B \cdot \pi r^2 = \mu_0 n I(t) \pi r^2$$

Induced emf amplitude:

$$\mathcal{E}_0 = \mu_0 n \pi r^2 I_0 \omega$$

Induced current amplitude:

$$I = \frac{\mathcal{E}_0}{r_0} = \frac{\mu_0 n \pi r^2 I_0 \omega}{r_0}$$

Final Answer: $\boxed{\frac{\mu_0 n \pi r^2 I_0 \omega}{r_0}}$

Answer: (A)

Go Back to Question 31

Q32.

Solution

Concept: In an RL circuit, phase difference determines impedance and RMS current, which is used to compute average power dissipated in the resistor.

Solution: Given phase angle:

$$\cos\phi = \frac{R}{Z} = \frac{1}{\sqrt{2}} \Rightarrow Z = \sqrt{2}R$$

Peak voltage:

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

RMS current:

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{V_0/\sqrt{2}}{\sqrt{2}R} = \frac{V_0}{2R}$$

Power dissipated:

$$P = I_{\text{rms}}^2 R = \left(\frac{V_0}{2R}\right)^2 R = \frac{V_0^2}{4R}$$

Final Answer: $\boxed{\frac{V_0^2}{4R}}$

Answer: (A)

Go Back to Question 32

Q33.

Solution

Concept: For an electromagnetic wave in a non-magnetic dielectric medium, the relation between electric and magnetic field amplitudes is:

$$B_0 = \frac{E_0}{v} \quad \text{where} \quad v = \frac{c}{\sqrt{\varepsilon_r}}$$

Solution: Given:

$$\varepsilon_r = 4 \Rightarrow v = \frac{c}{2}$$

So,

$$B_0 = \frac{E_0}{v} = \frac{E_0}{c/2} = \frac{2E_0}{c}$$

Final Answer: $\boxed{\frac{2E_0}{c}}$

Answer: (A)

Go Back to Question 33

Q34.

Solution

Concept: Light escaping from a denser medium is limited by the critical angle. Rays beyond this angle are totally internally reflected, forming a circular escape region at the surface.
Solution: Critical angle:

$$\sin\theta_c = \frac{1}{n} = \frac{1}{\sqrt{2}} \Rightarrow \theta_c = 45^\circ$$

Geometry of limiting ray:

$$\tan\theta_c = \frac{R}{H}$$

So,

$$R = H\tan 45^\circ = H$$

Final Answer: $\boxed{H}$

Answer: (A)

Go Back to Question 34

Q35.

Solution

Concept: A silvered lens acts as a combination of refraction and reflection. The effective focal length is obtained by considering two passes through the lens.

Solution: A ray passes through the lens, reflects from the silvered back surface, and passes again through the lens.

For a symmetric lens: - First pass focuses at f - Reflection reverses direction - Second pass adds another focusing effect

Effective focal length becomes:

$$F = \frac{f}{2}$$

Final Answer: $\boxed{\frac{f}{2}}$

Answer: (B)

Go Back to Question 35

Q36.

Solution

Concept: In Young's double slit experiment, bright fringes satisfy $n\lambda$ condition. Overlap occurs when path difference corresponds to integer multiples of both wavelengths.

Solution:

Condition for overlap:

$$m\lambda_1 = n\lambda_2$$

Given:

$$\lambda_1 = 400\,\text{nm}, \quad \lambda_2 = 600\,\text{nm}$$

(A)

$$3 \cdot 400 = 1200, \quad 2 \cdot 600 = 1200 \Rightarrow \text{True}$$

(B)

$$6 \cdot 400 = 2400, \quad 4 \cdot 600 = 2400 \Rightarrow \text{True}$$

(C) Minima of one coinciding with maxima of another is possible since conditions differ $\rightarrow$ statement is false.

(D) Coincidence depends on:

$$y = \frac{m\lambda_1 D}{d}$$

Thus depends on slit separation $d \rightarrow$ True

Final Answer: $\boxed{\text{A, B and D}}$

Answer: (A,B,D)

Go Back to Question 36

Q37.

Solution

Concept: Compton scattering at 180° gives maximum wavelength shift:

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

Solution:

For $\theta = 180°$:

$$\Delta\lambda = \frac{h}{m_e c}(1 - (-1)) = \frac{2h}{m_e c}$$

(A) True

Energy transfer:

$$K = h(\nu - \nu')$$

(B) True

Frequency form:

$$\frac{1}{\nu'} - \frac{1}{\nu} = \frac{h}{m_e c^2}(1 - \cos\theta) \Rightarrow \frac{2h}{m_e c^2}$$

Dividing by h:

$$\frac{1}{h\nu'} - \frac{1}{h\nu} = \frac{2}{m_e c^2}$$

(C) True

Momentum decreases after scattering, so photon does NOT always gain momentum → **(D) False**

Final Answer: A, B and C

Answer: (A,B,C)

Go Back to Question 37

Q38.

Solution

Concept: Number of spectral lines from level n_f is:

$$N = \frac{n_f(n_f - 1)}{2}$$

Solution: Given:

$$\frac{n_f(n_f - 1)}{2} = 6 \Rightarrow n_f(n_f - 1) = 12 \Rightarrow n_f = 4$$

(A) True

Total lines from 4 $\rightarrow$ 2 include Balmer transitions: 4 $\rightarrow$ 2 and 3 $\rightarrow$ 2 $\rightarrow$ 2 lines $\rightarrow$ True

(B) True

Highest energy photon:

$$4 \rightarrow 1$$

(C) True

For He^+: Energy level:

$$E = 13.6Z^2\left(1 - \frac{1}{4}\right) = 13.6 \cdot 4 \cdot \frac{3}{4} = 40.8\,\text{eV}$$

Not 48.4 eV $\rightarrow$ False

Final Answer: A, B and C

Answer: (A,B,C)

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Q39.

Solution

Concept: Nuclear energy release depends on binding energy per nucleon (B/A). A reaction is exothermic when products have higher B/A (more tightly bound nuclei) than reactants. This occurs in fission of heavy nuclei, fusion of light nuclei, and any transformation where total binding energy of products exceeds that of initial nuclei, resulting in mass defect conversion to energy.

Solution: Binding energy per nucleon determines nuclear stability; higher B/A implies a more stable nucleus. In nuclear reactions, energy is released when the total binding energy of the products is greater than that of the reactants, according to mass-energy equivalence.

(A) A heavy nucleus with $A = 240$ undergoing fission into two medium-mass fragments with higher B/A is exothermic. Heavy nuclei generally have lower B/A, and splitting them into more stable mid-mass nuclei (near iron peak) releases energy. Hence, (A) is correct.

(B) Two very light nuclei (like deuterium or tritium) fuse to form helium-4, which has significantly higher B/A. Fusion increases stability, so energy is released. Hence, (B) is correct.

(C) In alpha decay, the daughter nucleus typically has higher B/A than the parent; otherwise decay would not occur spontaneously. The statement claims lower total binding energy for the daughter, which would imply endothermic behavior. Thus, (C) is incorrect.

(D) Absorption of a neutron forming a compound nucleus with total mass less than initial sum does not directly ensure energy release. The key factor is final binding energy configuration; neutron capture may or may not be exothermic depending on nuclear stability. The statement is not a sufficient condition for guaranteed energy release, so it is not universally correct.

Therefore, only processes that move nuclei toward higher binding energy per nucleon (fission of heavy nuclei and fusion of light nuclei) are exothermic.

Final Answer: A and B

Answer: (A,B)

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Q40.

Solution

Concept: A BJT in CE mode operates with forward-biased emitter-base junction and reverse-biased collector-base junction. Current gain is defined as small-signal ratio.

Solution:

(A) Correct biasing condition → True

(B) Base is thin and lightly doped → True

(C)

$$\beta_{ac} = \left.\frac{\Delta I_C}{\Delta I_B}\right|_{V_{CE}}$$

→ True

(D) In real devices, leakage current exists even when $I_B = 0$ → False

Final Answer: A, B and C

Answer: (A,B,C)

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Answer Key

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