NIOS Class 12 Physics Sample Paper-4

Duration: 180 Minutes **Maximum Marks: 80**

Instructions

- This paper contains **43** Questions. The paper is divided into two sections: **Section A – 40** marks, **Section B – 40** marks.
- **Section A** consists of
  - **Q.No. 1 to 16** – Multiple Choice type questions (MCQs) carrying 1 mark each. Select and write the most appropriate option out of the four options given in each of these questions. An internal choice has been provided in some of these questions. You have to attempt only one of the given choices in such questions.
  - **Q. No. 17 to 28** – Objective type questions. Q. No. 17 to 28 carry 02 marks each (with 2 sub- parts of 1 mark each). Attempt these questions as per the instructions given for each of the questions 17 –28.
- **Section B** consists of
  - **Q.No. 29 to 37** – Very Short questions carrying 02 marks each to be answered in the range of 30 to 50 words.
  - **Q.No. 38 to 41** – Short Answer type questions carrying 03 marks each to be answered in the range of 50 to 80 words.
  - **Q.No. 42 and 43** – Long Answer type questions carrying 05 marks each to be answered in the range of 80 to 120 words.
- There is **No Negative marking**.
- Use of mobile phones, smartwatches, calculators, or any electronic gadgets is strictly prohibited.

Section: A

Q1. The dimensional formula for Planck's constant (h) is identical to the dimensional formula of which of the following physical quantities? **(1)**

(A) Linear momentum

(B) Angular momentum

(C) Linear force

(D) Rotational torque

Q2. The moment of inertia of a uniform solid sphere of mass M and radius R about any of its geometric diameters is: **(1)**

(A) $\frac{1}{2}MR^2$

(B) $\frac{2}{3}MR^2$

(C) $\frac{2}{5}MR^2$

(D) $\frac{7}{5}MR^2$

Q3. A constant force $\vec{F} = (3\hat{i} + 4\hat{j} - 5\hat{k})$ N acts on a moving particle, maintaining a uniform velocity of $\vec{v} = (2\hat{i} + 3\hat{j} + 4\hat{k})$ m s^{-1}. The instantaneous power delivered by the force to the particle is: **(1)**

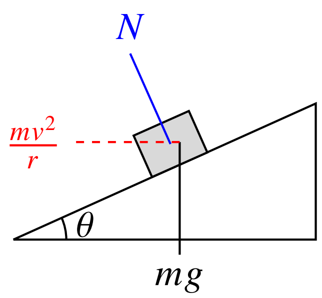
(A) −2 W

(B) 38 W

(C) 18 W

(D) 12 W

Q4. A vehicle of mass m travels along a curved circular road of radius r banked at an angle θ to the horizontal as illustrated below. To negotiate the turn at a safe speed v without any lateral frictional wear on the tires, the banking angle θ must satisfy: **(1)**



(A) $\sin\theta = \frac{v^2}{rg}$

(B) $\cos\theta = \frac{v^2}{rg}$

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

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

Q5. According to Stokes' law, a small spherical metal ball of radius r falling freely under gravity through a viscous fluid attains a steady terminal velocity v_t. The terminal velocity v_t is proportional to: **(1)**

(A) r

(B) r^2

(C) $\frac{1}{r}$

(D) $\frac{1}{r^2}$

Q6. The maximum theoretical efficiency η of a reversible Carnot heat engine operating between a hot source at absolute temperature T_1 and a cold sink at absolute temperature T_2 is given by: **(1)**

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

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

(C) $\eta = \frac{T_1 - T_2}{T_2}$

(D) $\eta = \frac{T_2}{T_1 - T_2}$

Q7. The time period T of a simple pendulum of effective length L oscillating with a small amplitude at a place where acceleration due to gravity is g is: **(1)**

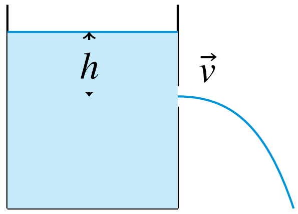
(A) $T = 2\pi\sqrt{\frac{g}{L}}$

(B) $T = \frac{1}{2\pi}\sqrt{\frac{L}{g}}$

(C) $T = 2\pi\sqrt{\frac{L}{g}}$

(D) $T = 2\pi\frac{L}{g}$

Q8. A cylindrical water tank is filled with water to a total height H. A small circular orifice is opened on its side wall at a depth h below the free water surface as shown in the figure below. According to Torricelli's theorem, the speed of efflux v of water emerging from the orifice is: **(1)**



(A) $v = \sqrt{2gH}$

(B) $v = \sqrt{2g(H-h)}$

(C) $v = \sqrt{gh}$

(D) $v = \sqrt{2gh}$

Q9. The electric field intensity $\vec{E}$ at a perpendicular distance r from an infinitely long straight linear conductor having a uniform linear charge density λ in vacuum is: **(1)**

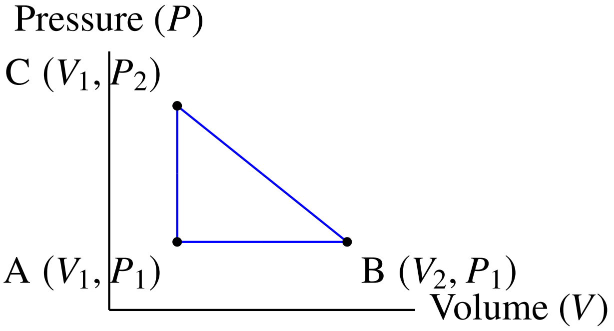
(A) Inversely proportional to r^2 ($E \propto 1/r^2$)

(B) Inversely proportional to r ($E \propto 1/r$)

(C) Directly proportional to r ($E \propto r$)

(D) Independent of distance r ($E = \text{const}$)

Q10. The indicator diagram shown below represents a cyclic thermodynamic process ABCA performed on an ideal working substance. What is the net mechanical work done by the gas during one complete cycle? **(1)**



(A) $\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

(B) $(P_2 - P_1)(V_2 - V_1)$

(C) $-\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

(D) Zero

Q11. A point charge q moving with velocity $\vec{v}$ enters a region containing a uniform magnetic field induction $\vec{B}$ directed perpendicular to its initial velocity ($\theta = 90°$). The radius r of the circular trajectory described by the charge is: **(1)**

(A) $r = \frac{qB}{mv}$

(B) $r = \frac{qv}{mB}$

(C) $r = \frac{mv}{qB}$

(D) $r = \frac{mB}{qv}$

Q12. An cylindrical organ pipe open at both ends vibrates in its fundamental mode (first harmonic) with frequency f_{open}. If one end of the pipe is sealed closed, the new fundamental frequency f_{closed} of the closed pipe of identical length L will be: **(1)**

Open Pipe (L) Closed Pipe (L)

(A) $f_{\text{closed}} = 2f_{\text{open}}$

(B) $f_{\text{closed}} = f_{\text{open}}$

(C) $f_{\text{closed}} = \frac{1}{4}f_{\text{open}}$

(D) $f_{\text{closed}} = \frac{1}{2}f_{\text{open}}$

Q13. A swimming pool appears to be only 3 meters deep when viewed normally from above. If the absolute refractive index of water is $\mu = \frac{4}{3}$, the actual physical depth of water in the pool is: **(1)**

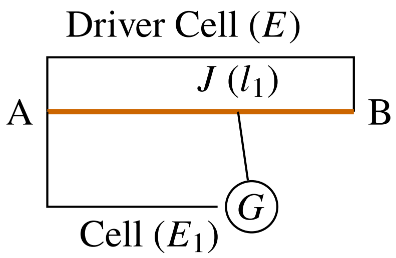
(A) 2.25 m

(B) 4.00 m

(C) 3.33 m

(D) 5.00 m

Q14. In the potentiometer circuit diagram shown below, a uniform resistive wire AB of length L is connected to a driver cell of electromotive force E. When a primary test cell of EMF E_1 is balanced, the null deflection point on wire AB occurs at balancing length l_1. When replaced by another cell of EMF E_2, the balancing length becomes l_2. The ratio of their EMFs (E_1/E_2) is: **(1)**



(A) $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

(B) $\frac{E_1}{E_2} = \frac{l_2}{l_1}$

(C) $\frac{E_1}{E_2} = \frac{l_1^2}{l_2^2}$

(D) $\frac{E_1}{E_2} = \sqrt{\frac{l_1}{l_2}}$

Q15. When a parallel beam of monochromatic light of wavelength λ is incident normally on a narrow rectangular slit of width a, a diffraction pattern is observed on a distant screen. The total angular width (2θ) of the central bright maximum is: **(1)**

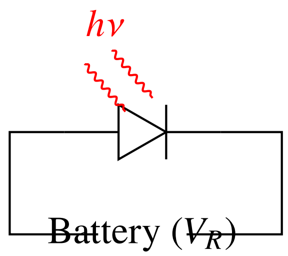
(A) $\frac{\lambda}{2a}$

(B) $\frac{\lambda}{a}$

(C) $\frac{2\lambda}{a}$

(D) $\frac{4\lambda}{a}$

Q16. The optoelectronic semiconductor symbol and circuit schematic shown below depict a p-n junction diode operated under reverse bias through a series load resistor R_L. When illuminated by optical photons having energy $h\nu$ greater than the band gap (E_g), a reverse photocurrent flows. This device is: **(1)**



(A) Light Emitting Diode (LED)

(B) Zener Voltage Regulator Diode

(C) Semiconductor Solar Cell

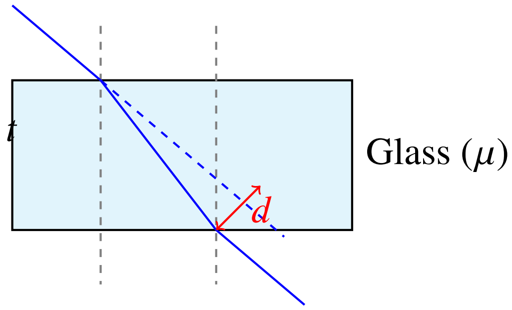
(D) Reverse-biased Photodiode

Note: Q. No. 17 to 28 are objective type questions carrying 02 marks each (with 2 sub-parts of 1 mark each).

Q17. Complete the following statements regarding satellite motion by filling in the blanks:
(Escape Velocity, Orbital Velocity, Geostationary Satellite, Polar Satellite) **(2)**

1. The minimum velocity required to project a body vertically upward from the surface of Earth so that it completely overcomes the gravitational pull and never returns is called ....
2. An artificial satellite orbiting Earth in the equatorial plane with an orbital time period of exactly 24 hours appearing stationary from Earth is called a

Q18. Read the passage given below and answer the two sub-questions:
When a monochromatic ray of light travelling in air is incident at an angle i on the top parallel face of a rectangular glass slab of thickness t and refractive index μ, it refracts at angle r. Upon reaching the bottom parallel face, it refracts again into air. As shown in the ray diagram below, the emergent ray is strictly parallel to the direction of the incident ray but is displaced sideways by a perpendicular distance known as lateral shift d. **(2)**



1. Write the mathematical formula for the lateral shift d in terms of slab thickness t, angle of incidence i, and angle of refraction r.
2. What happens to the magnitude of lateral shift d if the thickness t of the rectangular glass slab is increased while keeping angle of incidence i constant?

Q19. Read the short passage given below regarding metallic conduction and answer the two sub-questions:
When an external electric field $\vec{E}$ is applied across a metallic conductor, the free conduction electrons experience an electrostatic force $\vec{F} = -e\vec{E}$ and accelerate. However, they continuously collide with vibrating positive crystal lattice ions. As a result, they acquire a constant average macroscopic velocity opposite to the electric field direction, termed Drift Velocity ($\vec{v}_d$). **(2)**

1. Write the relation between drift velocity v_d, electric field E, electron charge e, mass m, and average relaxation time τ between collisions.
2. Define electron mobility (μ_e) in a semiconductor or conductor and state its SI unit.

Q20. Read the passage given below regarding photon emission from metal surfaces and answer the two sub-questions:
In 1905, Albert Einstein successfully explained the photoelectric effect using Max Planck's quantum photon theory. He proposed that light energy travels in discrete quanta (photons) of energy $E = h\nu$. When a photon strikes a bound electron in a metal, part of its energy is consumed in liberating the electron from the surface (Work Function Φ_0), and the remaining energy appears as maximum kinetic energy ($K_{\max}$) of the ejected photoelectron. **(2)**

1. Write Einstein's linear photoelectric equation relating photon frequency ν, threshold frequency ν_0 (or work function Φ_0), and maximum kinetic energy $K_{\max}$.
2. Why is no photoelectric emission observed from a metal surface if the frequency ν of incident light is lower than the threshold frequency ν_0, regardless of how high the light intensity is?

Q21. Match the mechanical fluid and surface properties in Column I with their correct defining formulas or phenomena in Column II: **(2)**

Column I	Column II
(a) Elastic Limit	(i) Upward buoyant force equal to weight of displaced fluid
(b) Viscosity	(ii) Maximum stress up to which a body completely regains original shape
(c) Angle of Contact	(iii) Internal fluid friction opposing relative motion between adjacent layers
(d) Archimedes' Principle	(iv) Angle between tangent to liquid meniscus and solid surface inside liquid

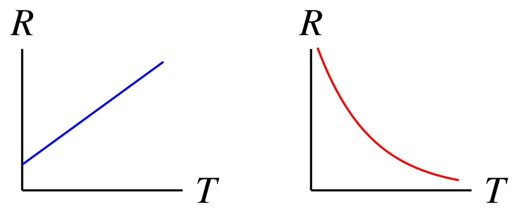
Q22. Match the semiconductor diode breakdown and operational concepts in Column I with their descriptions in Column II: **(2)**

Column I	**Column II**
(a) Zener Breakdown	(i) Diode connection where p-side is connected to negative battery terminal
(b) Avalanche Breakdown	(ii) Occurs in heavily doped junctions via direct tunneling of electrons across thin barrier
(c) Forward Bias	(iii) Occurs in lightly doped junctions via collision multiplication of high-velocity carriers
(d) Reverse Bias	(iv) Diode connection where p-side is connected to positive battery terminal

Q23. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement regarding acoustics and acoustics phenomena: **(2)**

1. When a sound source moves toward a stationary listener, the apparent pitch (frequency) heard by the listener is strictly higher than the actual emitted frequency due to the Doppler Effect.
2. When two sound waves of slightly different frequencies f_1 and f_2 travel in the same direction, they produce periodic waxing and waning of sound intensity called beats, with beat frequency given by $f_{\text{beat}} = f_1 + f_2$.

Q24. Read the short passage given below regarding electrical resistance and observe the characteristic curves:
The electrical resistance of materials varies with absolute temperature T. For pure metallic conductors, resistance increases linearly with temperature ($R_t = R_0[1 + \alpha(t - t_0)]$) because increased lattice ion vibrations shorten the electron relaxation time τ. Conversely, for semiconductors, resistance drops exponentially with rising temperature because thermal energy breaks covalent bonds, liberating exponential densities of free charge carriers. **(2)**



Pure Metal ($\alpha > 0$) Semiconductor ($\alpha < 0$)

1. What is the algebraic sign of the temperature coefficient of resistance (α) for pure metallic conductors like copper and silver?
2. State why the electrical conductivity of an intrinsic semiconductor (such as pure silicon or germanium) increases rapidly when heated.

Q25. Complete the following statements regarding wave optics by filling in the blanks: (Spherical Wavefront, Plane Wavefront, Cylindrical Wavefront, Huygens' Principle) **(2)**

1. The geometric locus of all optical ether particles vibrating in identical phase emitted from an isotropic point source of light in a homogeneous medium is a ....
2. According to .., every point on a primary wavefront acts as a fresh source of secondary spherical disturbance wavelets propagating forward with the speed of light.

Q26. Match the hydrogen atom spectral series in Column I with their corresponding electromagnetic spectral regions in Column II: **(2)**

Column I	**Column II**
(a) Lyman Series ($n_1 = 1$)	(i) Visible optical region of electromagnetic spectrum
(b) Balmer Series ($n_1 = 2$)	(ii) Near Infrared region of electromagnetic spectrum
(c) Paschen Series ($n_1 = 3$)	(iii) Ultraviolet region of electromagnetic spectrum
(d) Pfund Series ($n_1 = 5$)	(iv) Far Infrared region of electromagnetic spectrum

Q27. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement regarding radioactive emissions: **(2)**

1. Alpha (α) particles are doubly ionized helium nuclei ($^4_2He^{2+}$) having the highest ionizing power but lowest penetrating power among nuclear radiations.
2. Gamma (γ) rays are high-energy neutral electromagnetic photons that suffer severe deflection when passing through strong external magnetic or electric fields.

Q28. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement regarding electronic communication systems: **(2)**

1. In Amplitude Modulation (AM), the instantaneous amplitude of the high-frequency carrier wave is varied in accordance with the instantaneous amplitude of the low-frequency audio modulating signal.
2. Frequency Modulation (FM) broadcasting systems are inherently more susceptible to atmospheric electrical static noise and interference than Amplitude Modulation (AM) systems.

Section: B

Q29. (i) Define mechanical torque ($\vec{\tau}$) and angular momentum ($\vec{L}$) of a rotating rigid body. State the fundamental mathematical relation connecting torque and rate of change of angular momentum ($\vec{\tau} = d\vec{L}/dt$).

OR

(ii) State Kepler's Second Law of planetary motion (Law of Equal Areas). Explain clearly which fundamental physical quantity remains strictly conserved during the orbital motion of a planet around the Sun. **(2)**

Q30. State the Zeroth Law of Thermodynamics. Explain briefly how this foundational law establishes the thermodynamic concept of temperature and thermal equilibrium between distinct bodies. **(2)**

Q31. (i) Define the magnetic dipole moment (M) of an electron revolving in a circular

Bohr orbit of radius r with linear speed v. Define Bohr Magneton (μ_B) and write its formula ($\mu_B = \frac{eh}{4\pi m_e}$).

OR

(ii) Define electric flux (Φ_E) through a surface. State Gauss's Law in electrostatics and write its integral mathematical equation relating total electric flux through a closed Gaussian surface to the net enclosed charge Q_{enc}. **(2)**

Q32. State the two fundamental laws of reflection of light from a polished optical surface. Explain briefly how Huygens' principle of secondary wavelets geometrically confirms the equality of angle of incidence and angle of reflection ($i = r$). **(2)**

Q33. State Faraday's two experimental laws of electromagnetic induction and Lenz's law of induced current direction. Why is Lenz's law universally regarded as a direct consequence of the fundamental principle of conservation of energy? **(2)**

Q34. Calculate the energy of the emitted photon (in electron-volts, eV) and its frequency (ν, in Hz) when a hydrogen atom undergoes an electronic quantum transition from the third excited state ($n = 4$) down to the ground state ($n = 1$). (Given: Ground state energy of hydrogen atom $E_1 = -13.6$ eV, Planck's constant $h = 4.14 \times 10^{-15}$ eV s $= 6.63 \times 10^{-34}$ J s). **(2)**

Q35. Explain the optical phenomenon of Total Internal Reflection. State the two mandatory conditions required for total internal reflection to occur at an interface separating two media. Mention any one important practical application of this phenomenon in modern technology. **(2)**

Q36. (i) Define mass defect (Δm) and nuclear binding energy of an atomic nucleus. Using Einstein's mass-energy equivalence relation, derive the energy equivalent of 1 atomic mass unit (u) in MeV (1 u $\approx$ 931.5 MeV).

OR

(ii) Define radioactive half-life period ($T_{1/2}$) and mean life period (τ) of an unstable radioisotope. Establish the exact numerical relation between half-life and mean life ($\tau = 1.44 T_{1/2}$). **(2)**

Q37. (i) Draw the standard logic gate symbol and write the complete truth table for a two-input NAND gate. Write its Boolean algebraic expression ($Y = \overline{A \cdot B}$).

OR

(ii) What is meant by modulation in electronic communication systems? Why is high-frequency carrier wave modulation mandatory for wireless transmission of low-frequency audio signals over long distances? (State any two technical reasons). **(2)**

Q38. (i) Derive an expression for the orbital velocity (v_0) and orbital time period (T) of an artificial satellite revolving in a circular orbit at an altitude h above the Earth's surface of radius R and mass M. Show that for a near-Earth grazing satellite ($h \ll R$), orbital velocity is given by $v_0 = \sqrt{gR}$.

OR

(ii) Derive an expression for the moment of inertia (I) of a uniform thin circular ring of total mass M and geometric radius R about an axis passing through its geometric center and directed perpendicular to its plane ($I = MR^2$). **(3)**

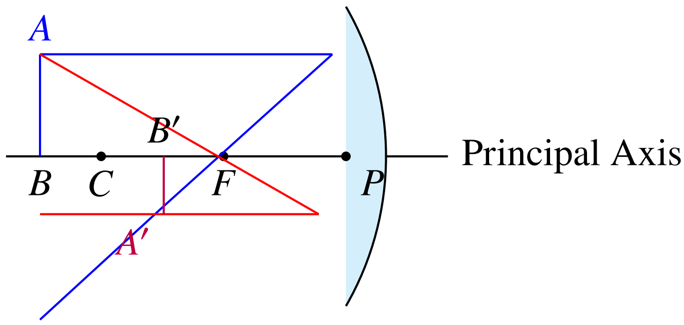
Q39. State and mathematically formulate the two fundamental theorems of moment of inertia used for computing rotational inertia of rigid bodies:

A. Theorem of Parallel Axes ($I = I_{cm} + Md^2$)

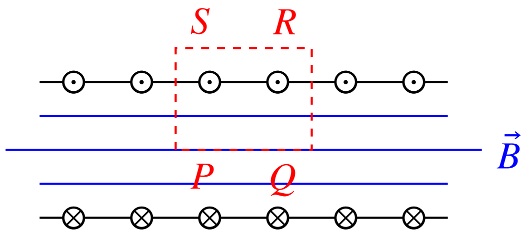
B. Theorem of Perpendicular Axes ($I_z = I_x + I_y$ for laminar bodies) **(3)**

Q40. Derive an expression for the total electrostatic potential energy (U) stored in a parallel plate capacitor of capacitance C charged to a potential difference V ($U = \frac{1}{2}CV^2$). Hence, deduce the expression for the electrostatic energy density (u) in vacuum ($u = \frac{1}{2}\varepsilon_0 E^2$). **(3)**

Q41. Derive the spherical mirror equation $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ for a concave spherical mirror forming a real, inverted image of an object placed on the principal axis beyond its center of curvature C, where f is focal length, u is object distance, and v is image distance. Include a clean labeled ray diagram. **(3)**



Q42. (i) State Ampere's Circuital Law. Using this law, derive the expression for the magnetic field induction B inside a long solenoid of toroidal turn density n ($n = N/L$) carrying a steady current I ($B = \mu_0 n I$).



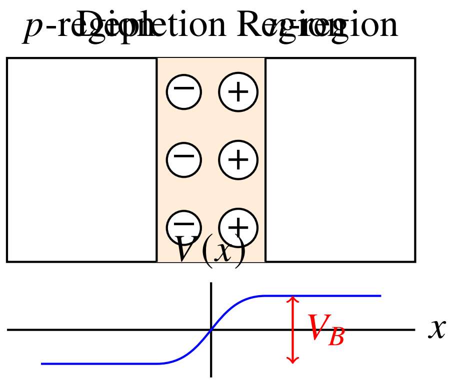
(ii) What is a Toroid? Write the formula for the magnetic field induction inside the core of a toroidal solenoid of mean radius r having N turns.

OR

(iii) Describe the principle, construction, and working of an AC Generator (Dynamo) with a clean labeled diagram. Derive the equation for instantaneous induced Electromotive Force $e = E_0 \sin \omega t$, where peak voltage $E_0 = NAB\omega$.

(5)

Q43. (i) Explain the physical formation of a semiconductor p-n junction diode. Describe clearly how the processes of majority carrier diffusion and minority carrier drift establish the immobile charge Depletion Region and junction Potential Barrier (V_B).



(ii) Distinguish clearly between Forward Bias and Reverse Bias operational connections of a *p*-*n* junction diode, explaining their effects on depletion width and barrier height.

OR

(iii) Explain the construction and transistor action of an *n*-*p*-*n* Bipolar Junction Transistor (BJT) in Common-Emitter (CE) configuration. Define current amplification factor $\beta_{dc} = I_C/I_B$ and derive its mathematical relation with common-base current gain α_{dc} ($\beta = \frac{\alpha}{1-\alpha}$). **(5)**

Detailed Solutions

Q1.

Solution

Concept: Planck's constant relates photon energy to frequency via $E = h\nu$, hence $h = E/\nu$.

Step 1 — Dimensional formula of energy $E = [\mathrm{M^1L^2T^{-2}}]$ and frequency $\nu = [\mathrm{T^{-1}}]$:

$$[h] = \frac{[\mathrm{M^1L^2T^{-2}}]}{[\mathrm{T^{-1}}]} = [\mathrm{M^1L^2T^{-1}}]$$

Step 2 — Dimensional formula of angular momentum $L = rp = r(mv)$:

$$[L] = [\mathrm{L}][\mathrm{M^1L^1T^{-1}}] = [\mathrm{M^1L^2T^{-1}}]$$

Since $[h] = [L]$, Planck's constant is dimensionally identical to angular momentum.

Why other options are wrong:

- **Option A:** Linear momentum is $[\mathrm{M^1L^1T^{-1}}]$.
- **Option C:** Linear force is $[\mathrm{M^1L^1T^{-2}}]$.
- **Option D:** Rotational torque is $[\mathrm{M^1L^2T^{-2}}]$.

Final Answer: Angular momentum (Option B)

Answer: (B) Go Back to Question 1

Q2.

Solution

Concept: The rotational inertia of a rigid body depends on mass distribution relative to the axis of rotation. For a solid sphere of density ρ, integration over volume elements gives $I = \frac{2}{5}MR^2$.

Step 1 — By standard derivation using spherical coordinates or slicing into elemental discs, the moment of inertia about any central diameter axis is:

$$I_{\text{sphere}} = \frac{2}{5}MR^2 = 0.4MR^2$$

Why other options are wrong:

- **Option A:** $\frac{1}{2}MR^2$ is the moment of inertia of a uniform solid cylinder or disc about its geometric central axis.
- **Option B:** $\frac{2}{3}MR^2$ is the moment of inertia of a thin hollow spherical shell about its diameter.
- **Option D:** $\frac{7}{5}MR^2$ is the moment of inertia about a tangential axis on the surface ($I_{\text{tan}} = I_{\text{cm}} + MR^2$).

Final Answer: $\boxed{\frac{2}{5}MR^2}$ (Option C)

Answer: (C) Go Back to Question 2

Q3.

Solution

Concept: Instantaneous mechanical power P delivered by a force $\vec{F}$ moving a body with velocity $\vec{v}$ is the scalar dot product: $P = \vec{F} \cdot \vec{v}$.

Step 1 — Given $\vec{F} = (3\hat{i} + 4\hat{j} - 5\hat{k})$ N and $\vec{v} = (2\hat{i} + 3\hat{j} + 4\hat{k})$ m s^{-1}.

Step 2 — Compute the scalar dot product using orthogonal unit vectors ($\hat{i} \cdot \hat{i} = 1, \hat{i} \cdot \hat{j} = 0$, etc.):

$$P = (3)(2) + (4)(3) + (-5)(4) = 6 + 12 - 20 = -2 \text{ W}$$

The negative sign indicates that the external force is doing negative work (opposing motion or absorbing energy).

Why other options are wrong:

- **Option B:** 38 W results from adding all products without negative sign on the z-component.
- **Option C:** 18 W is simply 6 + 12 ignoring the z-component entirely.
- **Option D:** 12 W is the magnitude of the y-axis contribution alone.

Final Answer: $\boxed{-2 \text{ W}}$ (Option A)

Answer: (A) Go Back to Question 3

Q4.

Solution

Concept: On a frictionless banked road, the horizontal inward component of normal reaction provides the necessary centripetal force ($N \sin\theta = mv^2/r$), while the vertical component balances weight ($N \cos\theta = mg$).

Step 1 — Dividing the centripetal force equation by the vertical weight equilibrium equation:

$$\frac{N\sin\theta}{N\cos\theta} = \frac{\frac{mv^2}{r}}{mg} \implies \tan\theta = \frac{v^2}{rg}$$

Step 2 — Therefore, the optimum banking angle is given by $\tan\theta = \frac{v^2}{rg}$.

Why other options are wrong:

- **Option A:** $\sin\theta$ cannot equal v^2/rg because hypotenuse N is greater than both components.
- **Option B:** $\cos\theta$ corresponds to vertical equilibrium factor.
- **Option C:** Inverted fraction (rg/v^2 corresponds to $\cot\theta$).

Final Answer: $\boxed{\tan\theta = \frac{v^2}{rg}}$ (Option D)

Answer: (D) Go Back to Question 4

Q5.

Solution

Concept: Terminal velocity occurs when downward gravitational weight minus buoyant force equals upward viscous drag: $\frac{4}{3}\pi r^3(\rho - \sigma)g = 6\pi\eta r v_t$.

Step 1 — Solving the force balance equation for steady terminal velocity v_t:

$$v_t = \frac{2r^2(\rho - \sigma)g}{9\eta}$$

Step 2 — Since density ρ, fluid density σ, gravity g, and viscosity η are constant, $v_t \propto r^2$.

Why other options are wrong:

- **Option A:** Viscous drag force is proportional to radius r, but weight scales as r^3, resulting in net r^2 velocity dependence.
- **Option C:** Inverse proportionality applies to viscosity η, not radius.
- **Option D:** Inverse square applies to acceleration in inverse-square fields.

Final Answer: $\boxed{r^2}$ (Option B)

Answer: (B) Go Back to Question 5

Q6.

Solution

Concept: Carnot engine efficiency is defined as the ratio of net mechanical work output W to heat absorbed Q_1 from the hot reservoir: $\eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$.

Step 1 — For a reversible ideal Carnot cycle, heat quantities exchanged are strictly proportional to absolute thermodynamic temperatures ($Q_2/Q_1 = T_2/T_1$).

Step 2 — Substituting temperature ratio gives:

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

Why other options are wrong:

- **Option B:** Inverted temperature ratio ($T_1/T_2 > 1$, which would yield negative efficiency).
- **Option C:** Uses cold sink temperature T_2 as denominator instead of source temperature T_1.
- **Option D:** Coefficient of performance (COP) formula for a refrigeration heat pump.

Final Answer: $\boxed{\eta = 1 - \frac{T_2}{T_1}}$ (Option A)

Answer: (A) Go Back to Question 6

Q7.

Solution

Concept: For small angular displacements ($\theta \ll 1$ rad), the restoring torque on a pendulum of length L is $\tau \approx -mgL\theta$. Since $\tau = I\alpha = (mL^2)\alpha$, angular acceleration is $\alpha = -(g/L)\theta$.

Step 1 — Comparing with standard SHM differential equation $\alpha = -\omega^2\theta$, angular frequency is $\omega = \sqrt{\frac{g}{L}}$.

Step 2 — Time period of oscillation is:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{L}{g}}$$

Why other options are wrong:

- **Option A:** Inverted square root ($\sqrt{g/L}$ represents angular frequency ω).
- **Option B:** Reciprocal factor of 2π representing frequency f.
- **Option D:** Missing square root; dimensions would be seconds squared per meter.

Final Answer: $\boxed{T = 2\pi\sqrt{\frac{L}{g}}}$ (Option C)

Answer: (C) Go Back to Question 7

Q8.

Solution

Concept: Torricelli's theorem is derived from Bernoulli's equation applied between top free water surface and the side orifice: $P_0 + \rho g H + 0 = P_0 + \rho g(H - h) + \frac{1}{2}\rho v^2$.

Step 1 — Canceling atmospheric pressure P_0 and density ρ across both sides:

$$gH - g(H - h) = \frac{1}{2}v^2 \implies gh = \frac{1}{2}v^2$$

Step 2 — Solving for efflux velocity v:

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

The speed of efflux depends solely on the vertical depth h below the free surface, identical to free fall from rest through height h.

Why other options are wrong:

- **Option A:** Uses total tank height H instead of depth h below surface.
- **Option B:** Uses height above bottom base $(H - h)$.
- **Option C:** Missing factor of 2 from kinetic energy term.

Final Answer: $\boxed{v = \sqrt{2gh}}$ (Option D)

Answer: (D) Go Back to Question 8

Q9.

Solution

Concept: Using Gauss's law for a cylindrical Gaussian surface of radius r and length l coaxial with the linear charge: $\oint \vec{E} \cdot d\vec{A} = E(2\pi r l) = \frac{q_{\text{enc}}}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0}$.

Step 1 — Solving for electric field intensity E:

$$E = \frac{\lambda}{2\pi\varepsilon_0 r} \implies E \propto \frac{1}{r}$$

Why other options are wrong:

- **Option A:** Inverse square law $(1/r^2)$ holds for point charges and spherically symmetric distributions.
- **Option C:** Direct proportionality $(E \propto r)$ holds inside uniformly charged insulating spheres or cylinders.
- **Option D:** Uniform field $(E = \text{const})$ occurs between infinite charged parallel plates.

Final Answer: Inversely proportional to r $(E \propto 1/r)$ (Option B)

Answer: (B) Go Back to Question 9

Q10.

Solution

Concept: The net mechanical work done by a thermodynamic system during a cyclic process on a P-V diagram equals the area enclosed by the cycle loop. Clockwise circulation represents positive work.

Step 1 — Cycle ABCA forms a right-angled triangle with base $\Delta V = (V_2 - V_1)$ along the isobaric path AB at pressure P_1, and vertical height $\Delta P = (P_2 - P_1)$ along the isochoric path CA at volume V_1.

Step 2 — Area of right-angled triangle ABCA:

$$W = \text{Area} = \frac{1}{2} \times \text{Base} \times \text{Height} = \frac{1}{2}(V_2 - V_1)(P_2 - P_1)$$

Since cycle ABCA proceeds clockwise, work done by the gas is positive.

Why other options are wrong:

- **Option B:** $(P_2 - P_1)(V_2 - V_1)$ is the area of a complete rectangle, twice the area of triangle ABCA.
- **Option C:** Negative work occurs if the cycle circulates in a counter-clockwise direction.
- **Option D:** Zero net work occurs only in reversible equilibrium without area enclosure.

Final Answer: $\boxed{\frac{1}{2}(P_2 - P_1)(V_2 - V_1)}$ (Option A)

Answer: (A) **Go Back to Question 10**

Q11.

Solution

Concept: When a charged particle moves perpendicular to a uniform magnetic field, magnetic Lorentz force $qvB\sin 90^\circ = qvB$ acts radially inward, providing centripetal force mv^2/r.

Step 1 — Equating magnetic Lorentz force to centripetal requirement:

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

Why other options are wrong:

- **Option A:** Inverted ratio (qB/mv represents specific charge over velocity).
- **Option B:** qv/mB is dimensionally incorrect (velocity over B).
- **Option D:** mB/qv is reciprocal velocity scaling.

Final Answer: $\boxed{r = \frac{mv}{qB}}$ (Option C)

Answer: (C) Go Back to Question 11

Q12.

Solution

Concept: For an organ pipe open at both ends, fundamental wavelength is $\lambda_{\text{open}} = 2L$, giving frequency $f_{\text{open}} = \frac{v}{2L}$. For a pipe closed at one end, a node forms at the closed wall and an antinode at the open end, giving fundamental wavelength $\lambda_{\text{closed}} = 4L$.

Step 1 — Fundamental frequency of closed pipe:

$$f_{\text{closed}} = \frac{v}{\lambda_{\text{closed}}} = \frac{v}{4L} = \frac{1}{2}\left(\frac{v}{2L}\right) = \frac{1}{2}f_{\text{open}}$$

Why other options are wrong:

- **Option A:** Double frequency occurs if an open pipe is shortened to half length.
- **Option B:** Equal frequency is impossible since sealing one end doubles fundamental wavelength.
- **Option C:** One-fourth frequency would require a pipe of double length closed at one end.

Final Answer: $\boxed{f_{\text{closed}} = \frac{1}{2}f_{\text{open}}}$ (Option D)

Answer: (D) Go Back to Question 12

Q13.

Solution

Concept: When viewed normally from air into a denser medium of refractive index μ, the apparent depth d_{app} is shallower than real depth d_{real} according to $\mu = \frac{d_{real}}{d_{app}}$.

Step 1 — Given apparent depth $d_{app} = 3$ m and refractive index $\mu = \frac{4}{3}$.

Step 2 — Calculate real physical depth:

$$d_{real} = \mu \times d_{app} = \left(\frac{4}{3}\right) \times 3 \text{ m} = 4.00 \text{ m}$$

Why other options are wrong:

- **Option A:** 2.25 m results from dividing apparent depth by μ $(3/(4/3))$.
- **Option C:** 3.33 m is simply $10/3$ or reciprocal arithmetic.
- **Option D:** 5.00 m would require a refractive index of $5/3 \approx 1.67$.

Final Answer: $\boxed{4.00 \text{ m}}$ (Option B)

Answer: (B) Go Back to Question 13

Q14.

Solution

Concept: A potentiometer operates on the principle that potential drop V across any portion of a uniform wire carrying steady current is directly proportional to its length l ($V = kl$, where k is potential gradient).

Step 1 — At balance point l_1, the EMF of cell 1 is balanced by wire potential drop: $E_1 = kl_1$.

Step 2 — At balance point l_2 for cell 2: $E_2 = kl_2$.

Step 3 — Dividing the two balance equations:

$$\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2}$$

Why other options are wrong:

- **Option B:** Inverted length ratio (l_2/l_1 equals E_2/E_1).
- **Option C:** Squared ratio would apply if potential gradient scaled with length.
- **Option D:** Square root ratio is mathematically incorrect for linear resistance.

Final Answer: $\boxed{\frac{E_1}{E_2} = \frac{l_1}{l_2}}$ (Option A)

Answer: (A) Go Back to Question 14

Q15.

Solution

Concept: In single-slit Fraunhofer diffraction, the first dark minimum on either side of the central bright maximum occurs at diffraction angle $\sin\theta \approx \theta = \frac{\lambda}{a}$.

Step 1 — Angular position of first dark minimum above central axis: $\theta_1 = +\frac{\lambda}{a}$.

Step 2 — Angular position of first dark minimum below central axis: $\theta_{-1} = -\frac{\lambda}{a}$.

Step 3 — Total angular width (2θ) of central maximum between these two minima:

$$2\theta = \theta_1 - \theta_{-1} = \frac{\lambda}{a} - \left(-\frac{\lambda}{a}\right) = \frac{2\lambda}{a}$$

Why other options are wrong:

- **Option A:** $\lambda/2a$ is half the half-width angle.
- **Option B:** λ/a is the angular half-width from center to first minimum.
- **Option D:** $4\lambda/a$ is the width between second secondary minima.

Final Answer: $\boxed{\frac{2\lambda}{a}}$ (Option C)

Answer: (C) Go Back to Question 15

Q16.

Solution

Concept: A photodiode is an optoelectronic p-n junction diode specifically designed to operate under reverse bias. When incident photons ($h\nu > E_g$) illuminate the depletion region, electron-hole pairs are generated, producing a reverse photocurrent proportional to light intensity.

Step 1 — Under reverse bias without light, only a negligible dark current flows.

Step 2 — When optical photons strike the junction, generated minority carriers are swept across the barrier by the reverse electric field, creating an observable photocurrent.

Why other options are wrong:

- **Option A:** LEDs operate under forward bias to emit photons via carrier recombination.
- **Option B:** Zener diodes operate in reverse breakdown to stabilize voltage without optical excitation.
- **Option C:** Solar cells generate photovoltaic EMF without any connected external bias battery.

Final Answer: Reverse-biased Photodiode (Option D)

Answer: (D) Go Back to Question 16

Q17.

Solution

Concept: Gravitational escape and orbital mechanics define distinct satellite trajectories and velocity thresholds.

Step 1 — The minimum launch speed required to permanently escape Earth's gravitational field ($v_e = \sqrt{2gR} \approx 11.2\ \text{km s}^{-1}$) is called **Escape Velocity**.

Step 2 — An artificial satellite orbiting Earth in the equatorial plane from west to east with a period of 24 hours (matching Earth's axial rotation) appears stationary from any point on Earth and is called a **Geostationary Satellite**.

Final Answer: 1. Escape Velocity 2. Geostationary Satellite

Answer: (See above) Go Back to Question 17

Q18.

Solution

Concept: Refraction across parallel boundaries of a transparent slab causes lateral shift without angular deviation ($i = e$).

Step 1 — From right-angled triangle geometry inside the glass slab of thickness t, lateral shift d is mathematically expressed as:

$$d = \frac{t \sin(i - r)}{\cos r}$$

where i is angle of incidence and r is angle of refraction inside glass.

Step 2 — Since d is directly proportional to slab thickness t, increasing the thickness of the glass slab causes the magnitude of lateral shift d to **increase linearly**.

Final Answer: 1. $d = \dfrac{t \sin(i - r)}{\cos r}$ 2. Lateral shift increases

Answer: (See above) Go Back to Question 18

Q19.

Solution

Concept: Drift velocity is the average velocity acquired by free electrons in a conductor under an electric field; mobility measures drift velocity per unit electric field.

Step 1 — Equating electrostatic acceleration $a = eE/m$ and multiplying by relaxation time τ, the drift velocity formula is:

$$v_d = \frac{eE\tau}{m}$$

Step 2 — Electron mobility (μ_e) is defined as the magnitude of drift velocity acquired per unit electric field applied:

$$\mu_e = \frac{v_d}{E} = \frac{e\tau}{m}$$

Its SI unit is $\mathrm{m^2V^{-1}s^{-1}}$ (meter squared per volt per second).

Final Answer: 1. $v_d = \frac{eE\tau}{m}$ 2. $\mu_e = \frac{v_d}{E}$; SI unit: $\mathrm{m^2V^{-1}s^{-1}}$

Answer: (See above) Go Back to Question 19

Q20.

Solution

Concept: Photoelectric emission is a one-to-one quantum interaction requiring photon energy to exceed metal surface work function ($\Phi_0 = h\nu_0$).

Step 1 — Einstein's photoelectric equation expresses conservation of photon energy:

$$h\nu = \Phi_0 + K_{\max} = h\nu_0 + K_{\max} \implies K_{\max} = h(\nu - \nu_0)$$

Step 2 — If incident frequency $\nu < \nu_0$, individual photon energy $h\nu$ is less than the binding work function Φ_0. Since an electron absorbs only a single photon at a time, it cannot overcome the surface barrier regardless of light intensity (photon arrival rate).

Final Answer: 1. $\mathrm{h}\nu = \Phi_0 + K_{\max}$ 2. Single photon energy $h\nu < \Phi_0$ cannot overcome surface barrier

Answer: (See above) Go Back to Question 20

Q21.

Solution

Concept: Defining mechanical limits, viscous drag, meniscus angle, and buoyancy.

Step 1 — Elastic Limit is the maximum stress up to which a deformed body completely regains its original dimensions upon load removal, so (a) matches (ii).

Step 2 — Viscosity is internal fluid friction between adjacent moving layers, so (b) matches (iii).

Step 3 — Angle of Contact is the angle between liquid meniscus tangent and solid surface inside liquid, so (c) matches (iv).

Step 4 — Archimedes' Principle affirms upward buoyant force equals weight of displaced fluid, so (d) matches (i).

Final Answer: (a)-(ii), (b)-(iii), (c)-(iv), (d)-(i)

Answer: (See above) Go Back to Question 21

Q22.

Solution

Concept: Diode biasing connections and mechanisms of reverse electrical breakdown.

Step 1 — Zener breakdown occurs in heavily doped thin junctions via quantum field tunneling of valence electrons, so (a) matches (ii).

Step 2 — Avalanche breakdown occurs in lightly doped wide junctions via high-velocity carrier collision multiplication, so (b) matches (iii).

Step 3 — Forward bias connects p-side to positive battery terminal and n-side to negative, so (c) matches (iv).

Step 4 — Reverse bias connects p-side to negative battery terminal and n-side to positive, so (d) matches (i).

Final Answer: (a)-(ii), (b)-(iii), (c)-(iv), (d)-(i)

Answer: (See above) Go Back to Question 22

Q23.

Solution

Concept: Doppler effect increases apparent frequency on approach; beat frequency equals absolute difference of interfering frequencies.

Step 1 — Statement 1 is **TRUE (T)**. When a sound source moves toward a stationary listener, wavefronts are compressed into smaller effective wavelengths, increasing apparent frequency ($f' = f\frac{v}{v-v_s} > f$).

Step 2 — Statement 2 is **FALSE (F)**. Beat frequency is the absolute difference between the two interfering frequencies ($f_{beat} = |f_1 - f_2|$), not their additive sum.

Final Answer: 1. T 2. F

Answer: (See above) Go Back to Question 23

Q24.

Solution

Concept: Temperature dependence of resistance in conductors vs semiconductors depends on relaxation time and carrier concentration.

Step 1 — For pure metallic conductors, resistance increases with temperature, so the algebraic sign of temperature coefficient (α) is **Positive** ($\alpha > 0$).

Step 2 — When an intrinsic semiconductor is heated, thermal energy breaks covalent bonds between silicon/germanium atoms, releasing an exponential surge of free conduction electrons and valence holes. This carrier density increase far outweighs lattice scattering, increasing conductivity.

Final Answer:
1. Positive ($\alpha > 0$)
2. Thermal heating generates exponential electron-hole charge pairs

Answer: (See above) Go Back to Question 24

Q25.

Solution

Concept: Wavefront shapes depend on source geometry; Huygens' principle explains wave propagation via secondary disturbances.

Step 1 — An isotropic point source in a uniform 3D medium emits light uniformly in all directions; loci of equal phase form concentric spheres called a **Spherical Wavefront**.

Step 2 — According to **Huygens' Principle**, every point on a primary wavefront acts as a fresh source of secondary disturbances emitting spherical wavelets that construct the next wavefront.

Final Answer: 1. Spherical Wavefront 2. Huygens' Principle

Answer: (See above) Go Back to Question 25

Q26.

Solution

Concept: Bohr hydrogen atom spectral series fall into specific electromagnetic wavelength bands based on transition energy $\Delta E = hc/\lambda$.

Step 1 — Lyman series ($n_1 = 1$) involves highest energy transitions, emitting in the Ultraviolet region, so (a) matches (iii).

Step 2 — Balmer series ($n_1 = 2$) emits visible optical photons, so (b) matches (i).

Step 3 — Paschen series ($n_1 = 3$) emits in the Near Infrared region, so (c) matches (ii).

Step 4 — Pfund series ($n_1 = 5$) involves low-energy infrared transitions in the Far Infrared region, so (d) matches (iv).

Final Answer: (a)-(iii), (b)-(i), (c)-(ii), (d)-(iv)

Answer: (See above) **Go Back to Question 26**

Q27.

Solution

Concept: Alpha particles have high mass and charge (+2e) causing dense ionization; gamma rays are neutral photons unaffected by electromagnetic fields.

Step 1 — Statement 1 is **TRUE (T)**. Alpha particles ($^4_2He^{2+}$) carry $+2e$ charge and heavy mass (4 u), causing intense collision ionization but suffering rapid energy loss and minimal penetration.

Step 2 — Statement 2 is **FALSE (F)**. Gamma (γ) rays are uncharged electromagnetic photons; having zero electric charge ($q = 0$), they experience **zero** deflection in magnetic or electric fields.

Final Answer: 1. T 2. F

Answer: (See above) **Go Back to Question 27**

Q28.

Solution

Concept: Amplitude Modulation varies carrier amplitude with audio signal; FM is highly resistant to atmospheric static noise.

Step 1 — Statement 1 is **TRUE (T)**. In Amplitude Modulation (AM), high-frequency carrier wave amplitude is modulated proportionally to instantaneous audio modulating voltage.

Step 2 — Statement 2 is **FALSE (F)**. Atmospheric electrical static and lightning noise primarily corrupt signal **amplitude**. Since FM encodes audio in frequency variations while clipping amplitude spikes, FM is far **less** susceptible to noise than AM.

Final Answer: 1. T 2. F

Answer: (See above) **Go Back to Question 28**

Q29.

Solution

Concept: Torque is the rotational analogue of linear force ($\vec{\tau} = \vec{r} \times \vec{F}$), and angular momentum is the rotational analogue of linear momentum ($\vec{L} = \vec{r} \times \vec{p}$).

Step 1 — Alternative (i): Torque ($\vec{\tau}$) is the turning effect of a force about an axis, defined as the vector cross product of position vector $\vec{r}$ and applied force $\vec{F}$: $\vec{\tau} = \vec{r} \times \vec{F}$. Angular momentum ($\vec{L}$) is the moment of linear momentum about the axis: $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$.

Step 2 — Differentiating angular momentum with respect to time t:

$$\frac{d\vec{L}}{dt} = \frac{d}{dt}(\vec{r} \times \vec{p}) = \left(\frac{d\vec{r}}{dt} \times \vec{p}\right) + \left(\vec{r} \times \frac{d\vec{p}}{dt}\right) = (\vec{v} \times m\vec{v}) + (\vec{r} \times \vec{F}) = 0 + \vec{\tau} = \vec{\tau}$$

Hence, external torque equals rate of change of angular momentum: $\vec{\tau} = \frac{d\vec{L}}{dt}$.

Step 3 — Alternative (ii): Kepler's Second Law (Law of Equal Areas) states that the line joining a planet to the Sun sweeps out equal areas in equal intervals of time (dA/dt = const).

Step 4 — Since gravitational force from the Sun is purely radial, torque about the Sun is zero ($\vec{\tau} = 0$). By $\vec{\tau} = d\vec{L}/dt = 0$, the orbital **Angular Momentum** ($\vec{L}$) of the planet remains strictly conserved.

Final Answer: $\tau = r \times F,\ L = r \times p,\ \tau = dL/dt$; or Kepler 2nd law conserves $\vec{L}$

Answer: (See above) Go Back to Question 29

Q30.

Solution

Concept: The Zeroth Law of Thermodynamics establishes the empirical basis for temperature measuring devices and thermal equilibrium.

Step 1 — Statement: If two thermodynamic systems A and B are each separately in thermal equilibrium with a third macroscopic system C, then systems A and B are in mutual thermal equilibrium with each other.

Step 2 — Concept of Temperature: Thermal equilibrium implies that when bodies are placed in thermal contact, no net heat flows between them. The Zeroth Law implies the existence of a scalar property that has the exact same value for all systems in mutual thermal equilibrium.

Step 3 — This thermodynamic scalar property is universally defined as **Temperature** (T). System C acts as a thermometer, allowing quantitative temperature measurement across different bodies.

Final Answer: Zeroth law: mutual thermal equilibrium with third body implies equal temperature $T_A = T_B = T_C$

Answer: (See above) Go Back to Question 30

Q31.

Solution

Concept: An orbiting electron constitutes a closed current loop producing a magnetic dipole; Gauss's law relates normal electric flux to total enclosed charge.

Step 1 — Alternative (i): An electron of charge e revolving with period $T = 2\pi r/v$ constitutes orbital current $I = e/T = ev/2\pi r$. The magnetic dipole moment is:

$$M = IA = \left(\frac{ev}{2\pi r}\right)(\pi r^2) = \frac{1}{2}evr = \frac{e}{2m_e}(m_e vr) = \frac{e}{2m_e}L$$

Bohr Magneton (μ_B) is the minimum fundamental magnetic dipole moment of an electron in the first Bohr orbit ($L = h/2\pi$): $\mu_B = \frac{eh}{4\pi m_e} \approx 9.27 \times 10^{-24}$ A m^2.

Step 2 — Alternative (ii): Electric flux (Φ_E) is the total number of electric field lines passing perpendicularly through a given surface area: $\Phi_E = \int \vec{E} \cdot d\vec{A}$.

Step 3 — Gauss's Law states that the total normal electric flux through any closed hypothetical surface in vacuum is equal to $1/\varepsilon_0$ times the net electric charge Q_{enc} enclosed by the surface:

$$\Phi_E = \oint_{\text{closed}} \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\varepsilon_0}$$

Final Answer: $\boxed{M = \frac{1}{2}evr,\ \mu_B = \frac{eh}{4\pi m_e};\text{ or } \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\varepsilon_0}}$

Answer: (See above) Go Back to Question 31

Q32.

Solution

Concept: Huygens' principle constructs reflection wavefront geometry where incident and reflected wave trains travel equal distances in equal time.

Step 1 — Laws of Reflection: (1) The incident ray, reflected ray, and normal to the reflecting surface at the point of incidence all lie in the exact same plane. (2) The angle of incidence (i) equals the angle of reflection (r).

Step 2 — Huygens' Verification: Let a plane wavefront AB strike a reflecting surface at angle i. While end B travels in air to touch the surface at C in time t ($BC = vt$), a secondary wavelet from A spreads out into hemisphere of radius $AD = vt$.

Step 3 — Drawing tangent CD to this wavelet forms the reflected wavefront. In right-angled triangles $\triangle ABC$ and $\triangle CDA$: hypotenuse AC is common, and sides $BC = AD = vt$.

Step 4 — By RHS congruency, $\triangle ABC \cong \triangle CDA$. Therefore, angle $\angle BAC = \angle DCA$, proving geometric angle of incidence equals angle of reflection ($i = r$).

Final Answer: Laws of reflection stated; Huygens proof by triangle congruency $\triangle ABC \cong \triangle CDA \implies i = r$

Answer: (See above) **Go Back to Question 32**

Q33.

Solution

Concept: Induced EMF opposes the magnetic flux change producing it, ensuring mechanical work is transformed into electrical energy.

Step 1 — Faraday's Laws: (1) Whenever the magnetic flux threading a closed circuit changes, an induced EMF is produced in the circuit which lasts as long as the flux change continues. (2) The magnitude of induced EMF is directly proportional to the rate of change of magnetic flux: $E \propto \frac{d\Phi_B}{dt}$.

Step 2 — Lenz's Law: The direction of induced EMF and current is always such that it opposes the cause or magnetic flux variation that produces it: $E = -N\frac{d\Phi_B}{dt}$.

Step 3 — Conservation of Energy: When a magnet is pushed toward a coil, induced current creates a repelling magnetic pole, opposing the approach. To maintain movement against this magnetic repulsive drag, external mechanical work must be done. This mechanical work is directly conserved and transformed into electrical Joule heat in the coil, obeying energy conservation.

Final Answer: $E = -N\frac{d\Phi_B}{dt}$; Lenz's drag requires mechanical work transformed to electrical energy

Answer: (See above) **Go Back to Question 33**

Q34.

Solution

Concept: In Bohr's hydrogen atom, energy of the n^{th} orbit is $E_n = \frac{E_1}{n^2} = -\frac{13.6}{n^2}$ eV. Photon energy emitted during downward transition is $\Delta E = E_{\text{high}} - E_{\text{low}} = h\nu$.

Step 1 — Calculate energies of initial state ($n_i = 4$) and final state ($n_f = 1$):

$$E_4 = -\frac{13.6}{4^2} = -\frac{13.6}{16} = -0.85 \text{ eV}, \quad E_1 = -13.6 \text{ eV}$$

Step 2 — Emitted photon energy ΔE:

$$\Delta E = E_4 - E_1 = -0.85 - (-13.6) = 12.75 \text{ eV}$$

Step 3 — Calculate frequency $\nu = \frac{\Delta E}{h}$ using Planck's constant in eV s:

$$\nu = \frac{12.75 \text{ eV}}{4.14 \times 10^{-15} \text{ eV s}} \approx 3.08 \times 10^{15} \text{ Hz}$$

Final Answer: $\boxed{\Delta E = 12.75 \text{ eV}, \quad \nu \approx 3.08 \times 10^{15} \text{ Hz}}$

Answer: (See above) **Go Back to Question 34**

Q35.

Solution

Concept: Total internal reflection traps light inside a denser refractive medium when angle of incidence exceeds critical angle $i_c = \sin^{-1}(1/\mu)$.

Step 1 — Definition: When light traveling in an optically denser medium strikes the boundary of a rarer medium at an angle of incidence greater than the critical angle ($i > i_c$), no refraction occurs; the entire light energy is reflected back into the denser medium according to laws of reflection.

Step 2 — Mandatory Conditions: (1) The light ray must strictly travel from an optically denser medium toward an optically rarer medium ($\mu_1 > \mu_2$). (2) The angle of incidence at the interface must be greater than the critical angle for that specific pair of media ($i > i_c$).

Step 3 — Practical Application: Optical Fibers used in telecommunications and endoscopy utilize TIR to transmit high-speed laser data signals over transcontinental distances with virtually zero optical attenuation.

Final Answer: TIR conditions: 1. Denser to rarer medium 2. $i > i_c$; Application: Optical Fibers

Answer: (See above) **Go Back to Question 35**

Q36.

Solution

Concept: Nuclear mass defect ($\Delta m = [Zm_p + Nm_n] - M_{\text{nuc}}$) represents the binding energy holding nucleons together via $E = \Delta mc^2$.

Step 1 — Alternative (i): Mass defect is the difference between the total rest mass of individual free protons and neutrons and the actual mass of the assembled nucleus. Binding energy is the minimum energy needed to disassemble a nucleus into individual nucleons: $BE = \Delta mc^2$.

Step 2 — Derivation of 1 u in MeV: By definition, $1 \text{ u} = 1.6605 \times 10^{-27}$ kg and $c = 2.998 \times 10^8 \text{ m s}^{-1}$.

$$E = (1.6605 \times 10^{-27} \text{ kg}) \times (2.998 \times 10^8 \text{ m s}^{-1})^2 \approx 1.4924 \times 10^{-10} \text{ Joules}$$

Converting Joules to MeV ($1 \text{ MeV} = 1.602 \times 10^{-13}$ J):

$$E = \frac{1.4924 \times 10^{-10} \text{ J}}{1.602 \times 10^{-13} \text{ J MeV}^{-1}} \approx 931.5 \text{ MeV}$$

Step 3 — Alternative (ii): Half-life ($T_{1/2} = \frac{0.693}{\lambda}$) is the time required for half the radioactive nuclei to disintegrate. Mean life ($\tau = \frac{1}{\lambda}$) is the average lifetime of all nuclei.

$$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693} \approx 1.44T_{1/2}$$

Final Answer: $\boxed{1 \text{ u} \approx 931.5 \text{ MeV; or } \tau = 1.44T_{1/2}}$

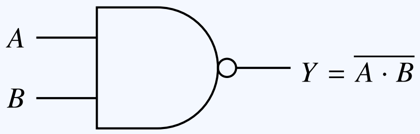
Answer: (See above) Go Back to Question 36

Q37.

Solution

Concept: A NAND gate is an AND gate followed by a NOT inverter ($Y = \overline{A \cdot B}$); modulation superimposes audio on high-frequency RF carrier.

Step 1 — Alternative (i): NAND gate symbol is an AND gate with an output inverter bubble. Boolean expression: $Y = \overline{A \cdot B}$.



Truth Table: $(A = 0, B = 0 \implies Y = 1)$; $(0, 1 \implies 1)$; $(1, 0 \implies 1)$; $(1, 1 \implies 0)$.

Step 2 — Alternative (ii): Modulation is the process of varying some characteristic parameter (amplitude, frequency, or phase) of a high-frequency radio carrier wave in linear accordance with the instantaneous voltage of a low-frequency audio information signal.

Step 3 — Why mandatory: (1) **Antenna Height:** Efficient radiation requires antenna length $L \approx \lambda/4$. For audio (20 kHz), $L \approx 3750$ m (impractical), whereas for RF carrier (10 MHz), $L \approx 7.5$ m (practical). (2) **Radiated Power:** Radiated power $P \propto (l/\lambda)^2 \propto f^2$; high carrier frequencies ensure powerful wireless propagation.

Final Answer: NAND symbol & truth table; or Modulation mandatory for antenna size & RF power

Answer: (See above) Go Back to Question 37

Q38.

Solution

Concept: For a circular orbit of radius $r = R+h$, gravitational pull provides centripetal acceleration: $\frac{GMm}{(R+h)^2} = \frac{mv_0^2}{R+h}$.

Step 1 — Alternative (i) - Orbital Velocity (v_0): Equating gravitational force to centripetal force:

$$\frac{GMm}{(R+h)^2} = \frac{mv_0^2}{R+h} \implies v_0 = \sqrt{\frac{GM}{R+h}}$$

For a near-Earth grazing satellite ($h \ll R$), $R + h \approx R$. Using surface gravity $g = \frac{GM}{R^2} \implies GM = gR^2$:

$$v_0 = \sqrt{\frac{gR^2}{R}} = \sqrt{gR} \approx \sqrt{9.8 \times 6.4 \times 10^6} \approx 7.9 \text{ km s}^{-1}$$

Step 2 — Orbital Period (T): Time taken for one revolution of circumference $2\pi(R + h)$:

$$T = \frac{2\pi(R+h)}{v_0} = \frac{2\pi(R+h)}{\sqrt{GM/(R+h)}} = 2\pi\sqrt{\frac{(R+h)^3}{GM}}$$

Step 3 — Alternative (ii) - Ring Moment of Inertia: Let a thin ring of mass M and radius R lie in the xy-plane with center at origin. Consider an elemental mass dm on the ring perimeter.

Step 4 — Since every mass element dm is at the exact same perpendicular radial distance R from the central z-axis, the total moment of inertia is:

$$I = \int R^2 dm = R^2 \int dm = MR^2$$

Final Answer: $v_0 = \sqrt{\frac{GM}{R+h}} \approx \sqrt{gR}$, $T = 2\pi\sqrt{\frac{(R+h)^3}{GM}}$; or Ring $I = MR^2$

Answer: (See above) Go Back to Question 38

Q39.

Solution

Concept: Moment of inertia theorems simplify rotational inertia calculations about shifted or orthogonal rotational axes.

Step 1 — Part A - Theorem of Parallel Axes: The moment of inertia I of any rigid body about any axis is equal to its moment of inertia I_{cm} about a parallel axis passing through its center of mass, plus the product of total body mass M and the square of perpendicular distance d between the two axes:

$$I = I_{\text{cm}} + Md^2$$

This theorem holds universally for 1D, 2D laminar, and 3D solid bodies.

Step 2 — Part B - Theorem of Perpendicular Axes: For a flat planar laminar body lying in the xy-plane, the moment of inertia I_z about an axis perpendicular to its plane passing through origin O is equal to the sum of its moments of inertia I_x and I_y about two mutually perpendicular axes lying in the plane of the lamina and intersecting at O:

$$I_z = I_x + I_y$$

Step 3 — Mathematical Proof of Perpendicular Axes: For any mass element dm at (x, y), its distance from z-axis is $r = \sqrt{x^2 + y^2}$. Therefore:

$$I_z = \int r^2 dm = \int (x^2 + y^2) dm = \int x^2 dm + \int y^2 dm = I_y + I_x$$

Final Answer: Parallel: $I = I_{\text{cm}} + Md^2$; Perpendicular: $I_z = I_x + I_y$

Answer: (See above) **Go Back to Question 39**

Q40.

Solution

Concept: Charging a capacitor requires external battery work to transfer charge against electrostatic repulsion; this work is stored as electric field energy.

Step 1 — Let a capacitor of capacitance C have instantaneous charge q and potential difference $v = q/C$. The small work dW done by an external source to transfer an additional infinitesimal charge dq is:

$$dW = v\,dq = \left(\frac{q}{C}\right) dq$$

Step 2 — Integrating from uncharged state ($q = 0$) to total final charge Q:

$$W = \int_0^Q \frac{q}{C}\,dq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q = \frac{Q^2}{2C}$$

Substituting $Q = CV$, stored potential energy is $U = \frac{1}{2}CV^2 = \frac{1}{2}QV$.

Step 3 — Energy Density (u): For a parallel plate capacitor in vacuum, $C = \frac{\varepsilon_0 A}{d}$ and potential difference $V = Ed$. Stored energy becomes:

$$U = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\varepsilon_0 E^2 (Ad)$$

Since (Ad) is the total enclosed vacuum volume between the plates, electrostatic energy density (energy per unit volume) is:

$$u = \frac{U}{\text{Volume}} = \frac{\frac{1}{2}\varepsilon_0 E^2 (Ad)}{Ad} = \frac{1}{2}\varepsilon_0 E^2$$

Final Answer: $\boxed{U = \frac{1}{2}CV^2 = \frac{Q^2}{2C}, \quad u = \frac{1}{2}\varepsilon_0 E^2}$

Answer: (See above) Go Back to Question 40

Q41.

Solution

Concept: Spherical mirror reflection geometry relates object distance u, image distance v, and radius of curvature $R = 2f$ via similar triangles formed by paraxial rays.

Step 1 — Consider an object AB placed on the principal axis beyond center of curvature C of a concave mirror of pole P. A ray parallel to the axis reflects through focus F. A ray through C reflects normally along its own path. The intersection forms a real, inverted image A'B' between C and F.

Step 2 — In similar right-angled triangles $\triangle ABC$ and $\triangle A'B'C$:

$$\frac{AB}{A'B'} = \frac{CB}{CB'} = \frac{u - R}{R - v} \quad \text{— (Eq. 1)}$$

Step 3 — In similar right-angled triangles $\triangle ABP$ and $\triangle A'B'P$ (by law of reflection at pole P, $\angle APB = \angle A'PB'$):

$$\frac{AB}{A'B'} = \frac{PB}{PB'} = \frac{u}{v} \quad \text{— (Eq. 2)}$$

Step 4 — Equating Eq. 1 and Eq. 2:

$$\frac{u - R}{R - v} = \frac{u}{v} \implies uR - uv = uv - vR \implies uR + vR = 2uv$$

Step 5 — Dividing all terms by uvR:

$$\frac{1}{v} + \frac{1}{u} = \frac{2}{R}$$

Since focal length of a spherical mirror is $f = \frac{R}{2} \implies \frac{2}{R} = \frac{1}{f}$, we obtain the Mirror Formula:

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

Final Answer: $\boxed{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$

Answer: (See above) Go Back to Question 41

Q42.

Solution

Concept: Ampere's circuital law evaluates magnetic field inside symmetric current distributions; AC generators rotate armature coils in magnetic fields to generate sinusoidal motional EMF.

Step 1 — Part (i) - Solenoid Magnetic Field: Ampere's Circuital Law states $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$. Consider a long solenoid having n turns per unit length carrying current I. To find axial field B, construct a rectangular Amperian loop PQRS of axial length L where side PQ lies inside along the axis and RS lies outside in zero field.

Step 2 — Evaluating line integral along the four sides of loop PQRS:

$$\oint \vec{B} \cdot d\vec{l} = \int_P^Q B dl \cos 0^\circ + \int_Q^R B dl \cos 90^\circ + \int_R^S 0 + \int_S^P B dl \cos 90^\circ = BL + 0 + 0 + 0 = BL$$

Step 3 — The total number of turns enclosed by rectangular loop PQRS is $N = nL$. Total enclosed current is $I_{enc} = (nL)I$. Equating line integral to $\mu_0 I_{enc}$:

$$BL = \mu_0(nLI) \implies B = \mu_0 nI$$

Step 4 — Part (ii) - Toroid: A Toroid is a hollow circular ring or donut-shaped core around which a large number of turns of insulated copper wire are closely wound (a solenoid bent into an endless circle). For mean radius r and total turns N, turn density is $n = \frac{N}{2\pi r}$, giving internal magnetic field:

$$B = \mu_0 nI = \frac{\mu_0 NI}{2\pi r}$$

Step 5 — Alternative (iii) - AC Generator (Dynamo): An AC generator converts mechanical rotational energy into electrical energy using electromagnetic induction. When an armature coil of N turns and area A rotates with angular velocity ω in uniform magnetic field B, angle between normal and field is $\theta = \omega t$. Magnetic flux is $\Phi_B = NBA\cos(\omega t)$.

Step 6 — By Faraday's law, instantaneous induced EMF e is:

$$e = -\frac{d\Phi_B}{dt} = -NBA\frac{d}{dt}[\cos(\omega t)] = NAB\omega\sin(\omega t) = E_0\sin(\omega t)$$

where peak voltage amplitude is $E_0 = NAB\omega$.

Final Answer: $B = \mu_0 nI,\ B_{toroid} = \frac{\mu_0 NI}{2\pi r}$; or Dynamo $e = NAB\omega\sin\omega t$

Answer: (See above) Go Back to Question 42

Q43.

Solution

Concept: A p-n junction creates a directional potential barrier via diffusion charge transfer; BJT transistors amplify current by controlling emitter-to-collector electron injection via a thin base.

Step 1 — Part (i) - Depletion Region & Barrier: In a newly formed p-n junction, free majority electrons in n-region diffuse across the junction into p-region and recombine with holes. This leaves behind unneutralized immobile positive donor ions in n-side and negative acceptor ions in p-side.

Step 2 — This narrow region of immobile ionized atoms devoid of free mobile charge carriers is called the **Depletion Region**. The resulting internal electric field directed from n to p opposes further diffusion, creating an electrostatic equilibrium junction **Potential Barrier** (V_B).

Step 3 — Part (ii) - Biasing Comparison:

Forward Bias (p **to** $+$, n **to** $-$)	**Reverse Bias** (p **to** $-$, n **to** $+$)
1. External voltage opposes barrier potential ($V_{net} = V_B - V$).	1. External voltage reinforces barrier potential ($V_{net} = V_B + V_R$).
2. Depletion region width narrows down significantly.	2. Depletion region width widens significantly.
3. Low resistance; heavy majority carrier forward current flows.	3. High resistance; tiny minority carrier saturation current flows.

Step 4 — Alternative (iii) - n-p-n BJT in CE Configuration: In an n-p-n transistor, emitter is heavily doped, base is extremely thin and lightly doped (p-type), and collector is moderately doped. In CE amplifier, emitter-base junction is forward-biased and collector-base is reverse-biased.

Step 5 — Electrons injected from emitter into thin base mostly ($\sim 95\%$) diffuse straight through into the reverse-biased collector, giving $I_E = I_B + I_C$.

Step 6 — Common-base current gain is $\alpha = \frac{I_C}{I_E}$ and common-emitter current gain is $\beta = \frac{I_C}{I_B}$. Substituting $I_B = I_E - I_C$:

$$\beta = \frac{I_C}{I_E - I_C} = \frac{I_C/I_E}{1 - (I_C/I_E)} = \frac{\alpha}{1-\alpha}$$

Final Answer: Junction barrier & Biasing table; or BJT action & $\beta = \frac{\alpha}{1-\alpha}$

Answer: (See above) Go Back to Question 43

Answer Key

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