NIOS Class 12 Physics Sample Paper-3

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 Universal Gravitational Constant (G) is: **(1)**

(A) $[M^{-1}L^{3}T^{-2}]$

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

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

(D) $[M^{1}L^{3}T^{-1}]$

Q2. The working principle of a rocket propulsion system in space is based on: **(1)**

(A) Conservation of kinetic energy

(B) Conservation of linear momentum

(C) Conservation of angular momentum

(D) Newton's law of universal gravitation

Q3. If the linear momentum of a moving body is doubled without changing its mass, its kinetic energy will become: **(1)**

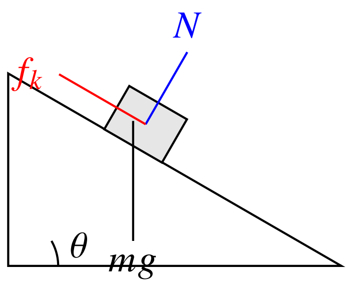
(A) Doubled

(B) Halved

(C) Quadrupled (Four times)

(D) Remain unchanged

Q4. A wooden block of mass m rests on a rough inclined plane of inclination θ. As shown in the free-body diagram below, if the block slides down with a constant velocity, the coefficient of kinetic friction μ_k between the block and the plane is: **(1)**



(A) $\sin\theta$

(B) $\cos\theta$

(C) $\tan\theta$

(D) $\cot\theta$

Q5. According to Hooke's Law of elasticity, within the elastic limit, the ratio of longitudinal stress to longitudinal strain is defined as: **(1)**

(A) Bulk Modulus (B)

(B) Shear Modulus (η)

(C) Young's Modulus (Y)

(D) Poisson's Ratio (σ)

Q6. In an isothermal process performed on an ideal gas, which of the following thermodynamic quantities remains zero across the entire process? **(1)**

(A) Heat transferred (ΔQ)

(B) Work done (ΔW)

(C) Change in internal energy (ΔU)

(D) Change in volume (ΔV)

Q7. For a particle executing Simple Harmonic Motion (SHM), the phase difference between its instantaneous displacement and instantaneous acceleration is: **(1)**

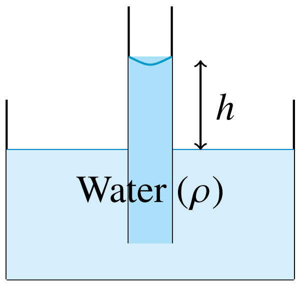
(A) Zero

(B) $\frac{\pi}{2}$ radians (90°)

(C) π radians (180°)

(D) $\frac{3\pi}{2}$ radians (270°)

Q8. When a clean capillary tube of radius r is dipped vertically into water of surface tension T and density ρ, water rises to a height h with a contact angle θ as shown below. The capillary rise h is given by: **(1)**



(A) $h = \frac{T \cos\theta}{r \rho g}$

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

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

(D) $h = \frac{2T\sin\theta}{r\rho g}$

Q9. Two point charges q_1 and q_2 separated by a distance r in vacuum exert an electrostatic force F on each other. If the same charges are placed at the same distance inside an insulating medium of dielectric constant $K = 4$, the electrostatic force between them becomes: **(1)**

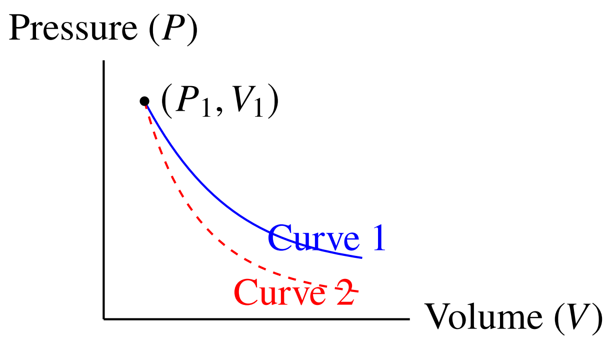
(A) $4F$

(B) $16F$

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

(D) $\frac{F}{16}$

Q10. The indicator diagram (P-V curve) shown below illustrates an ideal gas expanding from an initial state (P_1, V_1) to a final volume V_2 along two distinct paths: curve 1 and curve 2. Which of the following statements is strictly correct? **(1)**



(A) Curve 1 represents an adiabatic process while Curve 2 represents an isothermal process.

(B) Curve 1 represents an isothermal process while Curve 2 represents an adiabatic process.

(C) Both curves represent isobaric expansion at different temperatures.

(D) The work done along Curve 2 is greater than the work done along Curve 1.

Q11. The magnitude of magnetic field induction B at the center of a circular wire loop of radius R carrying a steady current I is given by: **(1)**

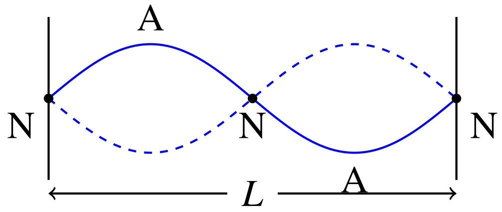
(A) $B = \frac{\mu_0 I}{2\pi R}$

(B) $B = \frac{\mu_0 I}{4\pi R^2}$

(C) $B = \frac{\mu_0 I}{2R}$

(D) $B = \frac{\mu_0 I}{4R}$

Q12. A vibrating string stretched between two fixed supports vibrates in its second harmonic mode (first overtone) as depicted in the standing wave pattern below. If the total length of the string is L, the wavelength λ of the progressive waves forming this standing wave is: **(1)**



(A) $\lambda = 2L$

(B) $\lambda = L$

(C) $\lambda = \frac{L}{2}$

(D) $\lambda = \frac{L}{4}$

Q13. When a ray of light travelling in a denser optical medium of refractive index μ is incident on the boundary of a rarer medium (air), Total Internal Reflection occurs if the angle of incidence i exceeds the critical angle i_c. The relation between i_c and μ is: **(1)**

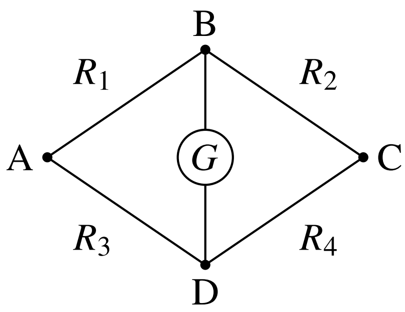
(A) $\sin i_c = \mu$

(B) $\cos i_c = \frac{1}{\mu}$

(C) $\sin i_c = \frac{1}{\mu}$

(D) $\tan i_c = \mu$

Q14. In the electrical circuit schematic shown below, four resistors R_1, R_2, R_3, R_4 and a sensitive galvanometer G form a Wheatstone bridge network. The condition for the bridge to be perfectly balanced (zero deflection in the galvanometer, $I_g = 0$) is: **(1)**



(A) $\frac{R_1}{R_3} = \frac{R_4}{R_2}$

(B) $\frac{R_1}{R_2} = \frac{R_3}{R_4}$

(C) $R_1 + R_2 = R_3 + R_4$

(D) $R_1R_2 = R_3R_4$

Q15. In Young's Double Slit Experiment (YDSE) using monochromatic light of wavelength λ, if the separation between the two coherent slits is d and the screen distance is D, the fringe width β of consecutive bright or dark interference fringes is given by: **(1)**

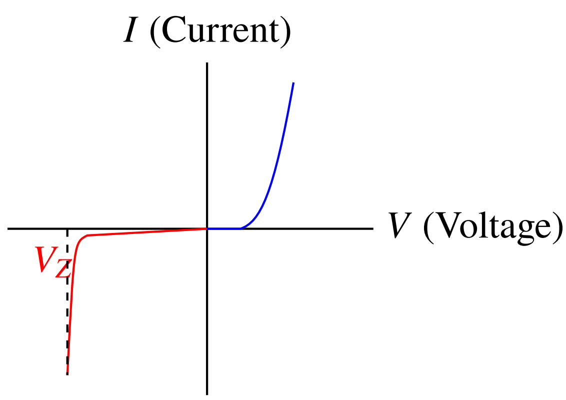
(A) $\beta = \frac{\lambda d}{D}$

(B) $\beta = \frac{\lambda D}{2d}$

(C) $\beta = \frac{\lambda D}{d}$

(D) $\beta = \frac{2\lambda D}{d}$

Q16. The current-voltage (I-V) characteristic graph shown below belongs to a specialized semiconductor diode operated primarily in its reverse breakdown region. This device is widely employed in electronic power supplies as: **(1)**



(A) Light Emitting Diode (LED) for optical display

(B) Photodiode for light intensity detection

(C) Zener Diode as a DC voltage regulator

(D) Solar Cell for solar energy conversion

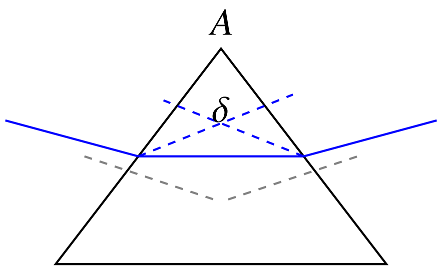
Note: Q. No. 17 to 28 are objective type questions carrying 02 marks each (with 2 sub-parts of 1 mark each).

Q17. Complete the following statements by choosing appropriate terms from the options given below:
(Inertia, Action and Reaction, Impulse, Linear Momentum) **(2)**

1. Newton's First Law of Motion defines the fundamental property of material bodies known as ....

2. According to Newton's Third Law of Motion, forces in nature always occur in pairs known as ....

Q18. Read the short passage given below and answer the two sub-questions:
When a ray of monochromatic light passes through a transparent refracting glass prism of refracting angle A, it undergoes refraction at both inclined surfaces. As shown in the ray diagram below, the ray is deviated through an angle δ. As the angle of incidence i increases, δ decreases to a minimum value δ_m and then increases again. **(2)**



1. Write the mathematical relation between refractive index μ of the prism material, prism angle A, and minimum deviation δ_m.

2. What is the geometric relation between the angle of incidence i and angle of emergence e when the prism is set in the position of minimum deviation $(\delta = \delta_m)$?

Q19. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement regarding Kirchhoff's circuit laws: **(2)**

1. Kirchhoff's First Law (Junction Rule / Current Law) is a direct consequence of the principle of conservation of electric charge.
2. Kirchhoff's Second Law (Loop Rule / Voltage Law) is based on the principle of conservation of linear momentum in electrical circuits.

Q20. Read the short passage given below and answer the two sub-questions:
Niels Bohr proposed a revolutionary quantum model for the hydrogen atom by introducing three fundamental postulates. He postulated that electrons revolve around the positively charged nucleus only in certain stable, non-radiating circular orbits called stationary orbits where their angular momentum is quantized. **(2)**

1. Write the Bohr quantization condition formula for the orbital angular momentum L of an electron in the n^{th} stationary orbit.
2. How does the radius r_n of a Bohr orbit depend on the principal quantum number n? (State the proportionality relation between r_n and n).

Q21. Match the physical concepts/laws in Column I with their correct mathematical expressions or phenomena in Column II: **(2)**

Column I	**Column II**
(a) Bernoulli's Principle	(i) Viscous drag force $F = 6\pi\eta r v$ on a falling sphere
(b) Stokes' Law	(ii) Conservation of fluid energy: $P + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$
(c) Pascal's Law	(iii) Rise or fall of liquid in a narrow capillary tube
(d) Surface Tension phenomenon	(iv) Hydraulic press and transmission of fluid pressure

Q22. Match the semiconductor terms in Column I with their appropriate descriptions in Column II: **(2)**

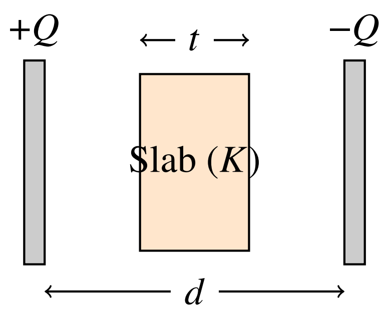
Column I	**Column II**
(a) n-type semiconductor	(i) Optoelectronic device that converts solar light into electrical power
(b) p-type semiconductor	(ii) Doped with pentavalent impurities (e.g., Phosphorus, Arsenic)
(c) Depletion Region	(iii) Doped with trivalent impurities (e.g., Boron, Aluminium, Indium)
(d) Solar Cell	(iv) Region near p-n junction devoid of mobile charge carriers

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

1. Sound waves in air are longitudinal mechanical waves and can travel through a vacuum.
2. Light waves are transverse electromagnetic waves and exhibit the phenomenon of polarization.

Q24. Read the passage given below and observe the diagram of a parallel plate capacitor:

A parallel plate capacitor consists of two large metallic plates of area A separated by a distance d in vacuum, having capacitance $C_0 = \frac{\varepsilon_0 A}{d}$. When a dielectric slab of thickness t ($t < d$) and dielectric constant K is introduced between the plates, the electric field inside the dielectric is reduced due to polarization. **(2)**



1. What happens to the capacitance of the capacitor when a dielectric slab is inserted completely ($t = d$) between the plates? (State whether it increases, decreases, or remains same).

2. Write the expression for the capacitance C when the dielectric slab of thickness t ($t < d$) is inserted between the plates.

Q25. Complete the following statements by filling in the blanks:
(Objective lens, Eyepiece, Compound Microscope, Astronomical Telescope) **(2)**

1. In a compound microscope, the lens placed facing the object has a small aperture and small focal length, and is called the ....
2. In an astronomical telescope used for viewing distant stars, the lens with larger aperture and larger focal length is the ....

Q26. Match the nuclear/atomic phenomena in Column I with their governing concepts or applications in Column II: **(2)**

Column I	**Column II**
(a) Photoelectric Effect	(i) Splitting of a heavy unstable nucleus into two lighter nuclei
(b) De Broglie Hypothesis	(ii) Emission of electrons from a metal surface when illuminated by light
(c) Radioactive Decay Law	(iii) Wave-particle dual nature of moving material particles ($\lambda = h/p$)
(d) Nuclear Fission	(iv) Exponential decay rate: $N = N_0 e^{-\lambda t}$

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

1. The stability of an atomic nucleus is directly measured by its binding energy per nucleon ($\overline{BE}$); higher binding energy per nucleon indicates greater stability.
2. In any nuclear reaction, the total rest mass of the products is strictly greater than the total rest mass of the reactants when energy is released as exothermic heat.

Q28. Write TRUE (T) for the correct statement and FALSE (F) for the incorrect statement regarding digital logic gates: **(2)**

1. A NAND gate produces a LOW (0) output if and only if all of its digital inputs are simultaneously HIGH (1).
2. NAND and NOR gates are termed "Universal Gates" because any basic logic function (OR, AND, NOT) can be implemented using only NAND or only NOR gates.

Section: B

Q29. (i) State the Principle of Conservation of Mechanical Energy. Give one practical everyday example where this principle is strictly obeyed under conservative forces.

OR

(ii) State Newton's Second Law of Motion and derive the mathematical relation $F = ma$ for a body of constant mass m moving with acceleration a. **(2)**

Q30. Explain clearly why the slope of an adiabatic expansion curve is steeper than the slope of an isothermal expansion curve on a P-V indicator diagram. (Use the ratio of specific heats $\gamma = C_p/C_v$). **(2)**

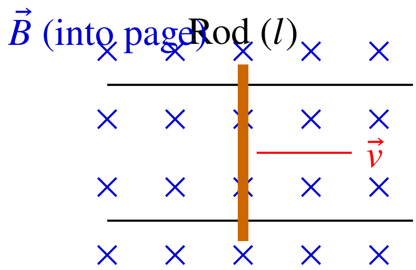
Q31. (i) State Biot-Savart Law for the magnetic field induction $d\vec{B}$ produced at a point by a current-carrying element $Id\vec{l}$. Write its vector mathematical expression.

OR

(ii) State Ampere's Circuital Law and write its integral mathematical form relating magnetic field $\vec{B}$ around a closed loop to the enclosed current I. **(2)**

Q32. What are coherent sources of light? Why can two independent ordinary light sources (such as two incandescent bulbs) not produce a sustained and visible interference pattern on a screen? **(2)**

Q33. A straight conducting rod of length l moves with a uniform velocity v perpendicular to a uniform magnetic field B directed into the plane of the paper as illustrated in the figure below. Using Faraday's law of electromagnetic induction, derive the expression for the motional Electromotive Force (EMF) E induced across the ends of the rod. **(2)**



Q34. Calculate the de Broglie wavelength λ associated with an electron accelerated from rest through a potential difference of $V = 100$ V.
(Given: Planck's constant $h = 6.63 \times 10^{-34}$ J s, mass of electron $m_e = 9.1 \times 10^{-31}$ kg, charge of electron $e = 1.6 \times 10^{-19}$ C). **(2)**

Q35. State Brewster's law of polarization. Using Snell's law of refraction, prove that when unpolarized light is incident on a transparent dielectric surface at Brewster's polarizing angle i_p, the reflected ray and refracted ray are mutually perpendicular to each other ($\tan i_p = \mu$). **(2)**

Q36. (i) State Rutherford-Soddy law of radioactive decay and define the half-life period ($T_{1/2}$) of a radioactive substance. Write the relation between $T_{1/2}$ and decay constant λ.
OR
(ii) State any two fundamental differences between Nuclear Fission and Nuclear Fusion reactions with one suitable chemical/nuclear equation for each. **(2)**

Q37. (i) Distinguish between intrinsic and extrinsic semiconductors on the basis of impurity doping, charge carrier density, and electrical conductivity at room temperature.
OR
(ii) Draw the standard logic symbol and complete truth table for a two-input NOR gate. Why is a NOR gate classified as a universal logic gate? **(2)**

Q38. (i) Derive an expression for the elastic potential energy (U) stored in a stretched spring of spring constant k when it is extended by a distance x from its equilibrium position. Show that $U = \frac{1}{2}kx^2$.

OR

(ii) Derive the equation of trajectory for a projectile fired with an initial velocity u making an angle θ with the horizontal, and hence prove mathematically that the path followed by the projectile is a parabola. **(3)**

Q39. A projectile is fired into the air from ground level with an initial velocity u at an angle of projection θ above the horizontal. Assuming negligible air resistance, derive analytical expressions for:

A. Total time of flight (T)

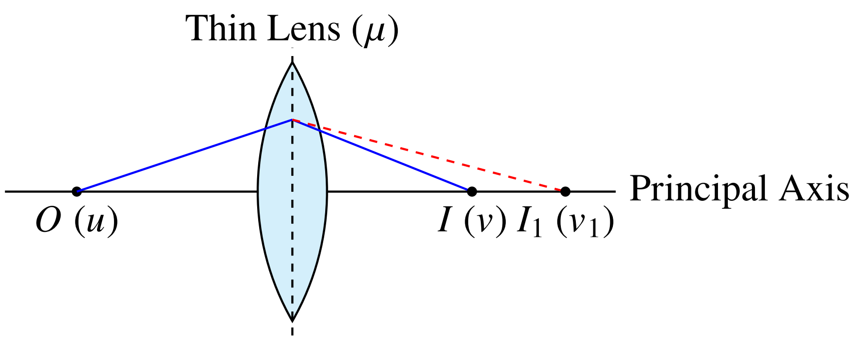
B. Maximum vertical height attained (H) **(3)**

Q40. Derive the expression for the equivalent capacitance C_{eq} when three capacitors having capacitances C_1, C_2, and C_3 are connected in:

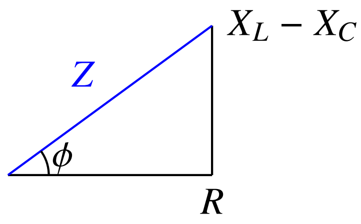
A. Series combination across a DC voltage source V

B. Parallel combination across a DC voltage source V **(3)**

Q41. Derive the Lens Maker's formula $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ for a thin convex lens separating air from a glass medium of refractive index μ, where f is the focal length, and R_1, R_2 are the radii of curvature of the two spherical surfaces. Include the ray diagram showing image formation by both surfaces. **(3)**



Q42. (i) An alternating voltage $V = V_0 \sin \omega t$ is applied across a series LCR circuit containing an inductor L, a capacitor C, and a resistor R. Using a phasor diagram and impedance triangle, derive the expression for total impedance Z and current amplitude I_0.

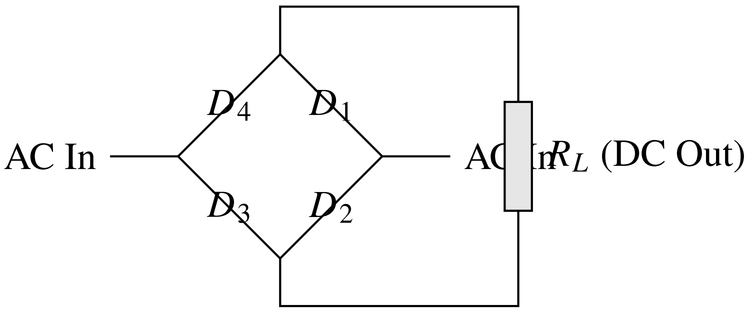


(ii) Define electrical resonance in a series LCR circuit and obtain the condition for resonant frequency ω_0.

OR

(iii) Describe the principle, construction, and working of a step-up transformer with a neat schematic diagram. Mention any two major causes of energy loss in an actual transformer and state how they are minimized in practice. **(5)**

Q43. (i) Explain with the help of a labeled circuit schematic and input/output voltage waveforms, the construction and working principle of a Full-Wave Bridge Rectifier using four semiconductor diodes (D_1, D_2, D_3, D_4).



(ii) Why is the direct current (DC) output voltage obtained across load resistor R_L smoother and more stable when a capacitor filter C is connected in parallel with R_L?

OR

(iii) What are digital logic gates? Name the three fundamental basic logic gates (OR, AND, NOT) and state their circuit symbols, Boolean expressions, and truth tables. Why is the NAND gate regarded as a Universal Logic Gate? **(5)**

Detailed Solutions

Q1.

Solution

Concept: Newton's universal law of gravitation states that gravitational force $F = \frac{Gm_1m_2}{r^2}$, hence $G = \frac{Fr^2}{m_1m_2}$.

Step 1 — Substitute the dimensional formulas for force $F = [\mathrm{M^1L^1T^{-2}}]$, distance $r = [\mathrm{L}]$, and mass $m = [\mathrm{M}]$:

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

Step 2 — Simplifying the indices of mass, length, and time:

$$[G] = [\mathrm{M^{1-2}L^{1+2}T^{-2}}] = [\mathrm{M^{-1}L^3T^{-2}}]$$

Why other options are wrong:

- **Option B:** $[\mathrm{M^1L^2T^{-2}}]$ represents work or energy, not gravitational constant.
- **Option C:** Has incorrect length exponent (L^2 instead of L^3).
- **Option D:** Incorrect mass exponent and time exponent.

Final Answer: $\boxed{[\mathrm{M^{-1}L^3T^{-2}}]}$ (Option A)

Answer: (A) **Go Back to Question 1**

Q2.

Solution

Concept: In the absence of any external unbalanced force in deep space, the total linear momentum of a closed system remains conserved ($d\vec{p}/dt = 0$).

Step 1 — As a rocket burns fuel, high-velocity exhaust gases are ejected backward with momentum $\Delta\vec{p}_{\text{gas}}$.

Step 2 — By the law of conservation of linear momentum (or Newton's third law), the rocket acquires an equal and opposite forward momentum $\Delta\vec{p}_{\text{rocket}} = -\Delta\vec{p}_{\text{gas}}$, propelling it forward.

Why other options are wrong:

- **Option A:** Kinetic energy increases due to chemical fuel combustion and is not conserved.
- **Option C:** Angular momentum relates to rotational motion, whereas rocket propulsion is straight-line thrust.
- **Option D:** Gravitation opposes upward launch; propulsion occurs even in zero-gravity space.

Final Answer: Conservation of linear momentum (Option B)

Answer: (B) Go Back to Question 2

Q3.

Solution

Concept: The kinetic energy K of a moving body of mass m and velocity v is related to its linear momentum $p = mv$ by the formula $K = \frac{p^2}{2m}$.

Step 1 — Let initial momentum be $p_1 = p$ and initial kinetic energy be $K_1 = \frac{p^2}{2m}$. When momentum is doubled, $p_2 = 2p$.

Step 2 — The new kinetic energy K_2 becomes:

$$K_2 = \frac{p_2^2}{2m} = \frac{(2p)^2}{2m} = 4\left(\frac{p^2}{2m}\right) = 4K_1$$

Step 3 — Hence, the kinetic energy becomes four times (quadrupled).

Why other options are wrong:

- **Option A:** Momentum is linear ($p \propto v$), but kinetic energy depends on velocity squared ($K \propto v^2$).
- **Option B:** Halving occurs if momentum is reduced by $\sqrt{2}$.
- **Option D:** Kinetic energy must increase when momentum increases.

Final Answer: Quadrupled (Four times) (Option C)

Answer: (C) Go Back to Question 3

Q4.

Solution

Concept: When a body slides down an incline at constant velocity, its net acceleration is zero ($a = 0$), meaning forces acting along and perpendicular to the incline are completely balanced.

Step 1 — Balancing forces perpendicular to the inclined plane: normal reaction $N = mg\cos\theta$.

Step 2 — Balancing forces along the inclined plane: downward gravitational component equals upward kinetic friction force:

$$mg\sin\theta = f_k = \mu_k N = \mu_k(mg\cos\theta)$$

Step 3 — Dividing both sides by $mg\cos\theta$:

$$\mu_k = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

Why other options are wrong:

- **Option A:** $\sin\theta$ is just the gravitational component factor along the slope.
- **Option B:** $\cos\theta$ is the normal reaction factor.
- **Option D:** $\cot\theta$ is the reciprocal of the correct friction coefficient.

Final Answer: $\boxed{\tan\theta}$ (Option C)

Answer: (C) **Go Back to Question 4**

Q5.

Solution

Concept: Hooke's law states that within the elastic limit, stress is directly proportional to strain. The constant of proportionality depends on the type of deformation.

Step 1 — When a wire or rod undergoes longitudinal (tensile or compressive) deformation, the elastic modulus is defined as the ratio of longitudinal stress (F/A) to longitudinal strain ($\Delta L/L$).

Step 2 — This modulus of elasticity is universally termed Young's Modulus (Y).

Why other options are wrong:

- **Option A:** Bulk modulus B relates volumetric stress (pressure change) to volumetric strain ($\Delta V/V$).
- **Option B:** Shear modulus η relates tangential shear stress to angular shear strain.
- **Option D:** Poisson's ratio σ is the dimensionless ratio of lateral strain to longitudinal strain.

Final Answer: $\boxed{\text{Young's Modulus } (Y)}$ (Option C)

Answer: (C) Go Back to Question 5

Q6.

Solution

Concept: In an isothermal process, the temperature T of the system remains strictly constant ($\Delta T = 0$) throughout the expansion or compression.

Step 1 — For an ideal gas, internal energy U is purely a function of absolute temperature ($U = nC_vT$).

Step 2 — Since temperature does not change ($\Delta T = 0$), the change in internal energy must be zero ($\Delta U = 0$). By the first law of thermodynamics, $\Delta Q = \Delta W$.

Why other options are wrong:

- **Option A:** Heat transferred ΔQ is non-zero because heat must be absorbed to do expansion work.
- **Option B:** Work done $\Delta W = nRT \ln(V_2/V_1)$ is non-zero as volume changes.
- **Option D:** Volume change ΔV is non-zero during expansion or compression.

Final Answer: $\boxed{\text{Change in internal energy } (\Delta U)}$ (Option C)

Answer: (C) Go Back to Question 6

Q7.

Solution

Concept: In Simple Harmonic Motion, instantaneous displacement is given by $x(t) = A\sin(\omega t+\phi)$.

Step 1 — Differentiating displacement with respect to time gives velocity: $v(t) = A\omega\cos(\omega t+\phi) = A\omega\sin(\omega t + \phi + \pi/2)$.

Step 2 — Differentiating velocity gives acceleration:

$$a(t) = -A\omega^2\sin(\omega t + \phi) = A\omega^2\sin(\omega t + \phi + \pi)$$

Step 3 — Comparing the phase angles of displacement $(\omega t + \phi)$ and acceleration $(\omega t + \phi + \pi)$, the phase difference is exactly π radians $(180°)$.

Why other options are wrong:

- **Option A:** Zero phase difference occurs between two identical waveforms in phase.
- **Option B:** $\pi/2$ radians is the phase difference between displacement and velocity.
- **Option D:** $3\pi/2$ radians is equivalent to a $-\pi/2$ shift, not antiparallel opposition.

Final Answer: $\boxed{\pi \text{ radians } (180°)}$ (Option C)

Answer: (C) Go Back to Question 7

Q8.

Solution

Concept: The upward surface tension force acting along the circumference of contact balances the downward weight of the liquid column raised in the capillary tube.

Step 1 — Total upward vertical component of surface tension force around circumference $2\pi r$:

$$F_{up} = (2\pi r T)\cos\theta$$

Step 2 — Downward gravitational weight of liquid cylinder of height h, radius r, density ρ:

$$W = mg = (\pi r^2 h\rho)g$$

Step 3 — Equating upward force and downward weight ($F_{up} = W$):

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

Why other options are wrong:

- **Option A:** Missing the factor of 2 in the numerator from the perimeter-to-area ratio.
- **Option C:** Inverted fraction; height increases with surface tension T and decreases with radius r.
- **Option D:** Uses $\sin\theta$ instead of vertical projection $\cos\theta$.

Final Answer: $\boxed{h = \frac{2T\cos\theta}{r\rho g}}$ (Option B)

Answer: (B) Go Back to Question 8

Q9.

Solution

Concept: According to Coulomb's law, electrostatic force between two charges in a dielectric medium is inversely proportional to the dielectric constant (relative permittivity) $K = \varepsilon_r$ of the medium.

Step 1 — Electrostatic force in vacuum is $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$.

Step 2 — When placed inside a dielectric medium of permittivity $\varepsilon = K\varepsilon_0$, the new force F' is:

$$F' = \frac{1}{4\pi(K\varepsilon_0)}\frac{q_1q_2}{r^2} = \frac{F}{K}$$

Step 3 — Since $K = 4$, the force in the medium becomes $F' = \frac{F}{4}$.

Why other options are wrong:

- **Option A:** Force decreases in a dielectric due to polarization, it does not increase 4 times.
- **Option B:** $16F$ would result if distance were quartered in vacuum.
- **Option D:** $F/16$ would occur if $K = 16$ or if distance r were increased 4 times.

Final Answer: $\boxed{\frac{F}{4}}$ (Option C)

Answer: (C) Go Back to Question 9

Q10.

Solution

Concept: On a P-V indicator diagram, the slope of an adiabatic process ($dP/dV = -\gamma P/V$) is γ times steeper than the slope of an isothermal process ($dP/dV = -P/V$), where $\gamma > 1$.

Step 1 — For expansion from the same initial point (P_1, V_1) to a larger volume V_2, the steeper adiabatic curve drops to a lower pressure than the isothermal curve because internal energy is consumed to do expansion work without heat input.

Step 2 — Therefore, the upper curve (Curve 1) is isothermal and the lower steeper curve (Curve 2) is adiabatic.

Why other options are wrong:

- **Option A:** Reverses the curves; Curve 1 has less pressure drop so it must be isothermal.
- **Option C:** Isobaric expansion is a horizontal straight line (P = const).
- **Option D:** Work done is the area under the curve; area under Curve 1 is greater than under Curve 2.

Final Answer: Curve 1 is isothermal, Curve 2 is adiabatic (Option B)

Answer: (B) Go Back to Question 10

Q11.

Solution

Concept: By Biot-Savart law, the magnetic field induction at the center of a circular current loop is obtained by integrating $d\vec{B}$ over the entire circumference $2\pi R$.

Step 1 — According to Biot-Savart law for a circular loop of radius R:

$$B = \int dB = \frac{\mu_0 I}{4\pi R^2} \int_0^{2\pi R} dl = \frac{\mu_0 I}{4\pi R^2}(2\pi R) = \frac{\mu_0 I}{2R}$$

Why other options are wrong:

- **Option A:** $\frac{\mu_0 I}{2\pi R}$ is the magnetic field due to an infinitely long straight wire.
- **Option B:** $\frac{\mu_0 I}{4\pi R^2}$ is the field contribution from just a unit length element without circumference integration.
- **Option D:** Missing the factor of 2 in the denominator.

Final Answer: $B = \frac{\mu_0 I}{2R}$ (Option C)

Answer: (C) Go Back to Question 11

Q12.

Solution

Concept: In a standing wave on a fixed string, the distance between two consecutive nodes is $\lambda/2$. In the n^{th} harmonic mode, the string contains n half-wavelength loops ($L = n\frac{\lambda}{2}$).

Step 1 — For the second harmonic mode ($n = 2$, first overtone), the string forms exactly two vibrating loops between the fixed ends.

Step 2 — Equating string length L to two half-wavelengths:

$$L = 2\left(\frac{\lambda}{2}\right) = \lambda \implies \lambda = L$$

Why other options are wrong:

- **Option A:** $\lambda = 2L$ corresponds to the fundamental mode (first harmonic, $n = 1$).
- **Option C:** $\lambda = L/2$ corresponds to the fourth harmonic ($n = 4$).
- **Option D:** $\lambda = L/4$ corresponds to the eighth harmonic mode ($n = 8$).

Final Answer: $\boxed{\lambda = L}$ (Option B)

Answer: (B) Go Back to Question 12

Q13.

Solution

Concept: Critical angle i_c is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium (air) becomes exactly 90°.

Step 1 — Applying Snell's law at the denser-to-rarer interface for incidence angle $i = i_c$ and refraction angle $r = 90°$:

$$\mu \sin i_c = 1 \cdot \sin 90°$$

Step 2 — Since $\sin 90° = 1$, we get:

$$\mu \sin i_c = 1 \implies \sin i_c = \frac{1}{\mu}$$

Why other options are wrong:

- **Option A:** $\sin i_c = \mu$ is mathematically impossible since $\mu > 1$ and sine cannot exceed 1.
- **Option B:** Uses cosine instead of sine in Snell's law formulation.
- **Option D:** Tangent relation corresponds to Brewster's polarizing angle, not critical angle.

Final Answer: $\boxed{\sin i_c = \frac{1}{\mu}}$ (Option C)

Answer: (C) Go Back to Question 13

Q14.

Solution

Concept: A Wheatstone bridge network is balanced when the electric potentials at nodes B and D are exactly equal ($V_B = V_D$), resulting in zero current through galvanometer G ($I_g = 0$).

Step 1 — When $I_g = 0$, the same current I_1 flows through resistors R_1 and R_2, and the same current I_2 flows through R_3 and R_4.

Step 2 — Equating voltage drops across parallel arms: $I_1 R_1 = I_2 R_3$ and $I_1 R_2 = I_2 R_4$.

Step 3 — Dividing the two voltage equations:

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_3}{I_2 R_4} \implies \frac{R_1}{R_2} = \frac{R_3}{R_4} \quad \text{or equivalently} \quad \frac{R_1}{R_3} = \frac{R_4}{R_2}$$

Why other options are wrong:

- **Option B:** Inverted diagonal ratio ($\frac{R_1}{R_2} = \frac{R_4}{R_3}$ would be correct, not $\frac{R_3}{R_4}$ here).
- **Option C:** Bridge balance depends on resistance ratios, not additive sums.
- **Option D:** Cross-products equal zero ($R_1 R_4 = R_2 R_3$), not adjacent products.

Final Answer: $\boxed{\frac{R_1}{R_3} = \frac{R_4}{R_2}}$ (Option A)

Answer: (A) Go Back to Question 14

Q15.

Solution

Concept: In interference of light, fringe width β is the linear separation between any two consecutive bright fringes or any two consecutive dark fringes on the observation screen.

Step 1 — The position of the n^{th} bright fringe from central maximum is $y_n = \frac{n\lambda D}{d}$.

Step 2 — The position of the $(n+1)^{\text{th}}$ bright fringe is $y_{n+1} = \frac{(n+1)\lambda D}{d}$.

Step 3 — Subtracting consecutive positions gives the fringe width β:

$$\beta = y_{n+1} - y_n = \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d} = \frac{\lambda D}{d}$$

Why other options are wrong:

- **Option A:** Inverted ratio of screen distance D and slit separation d.
- **Option B:** Half-fringe width representing distance between adjacent bright and dark fringes.
- **Option D:** Double fringe width.

Final Answer: $\boxed{\beta = \frac{\lambda D}{d}}$ (Option C)

Answer: (C) Go Back to Question 15

Q16.

Solution

Concept: A Zener diode is a heavily doped p-n junction diode designed to operate stably in the reverse breakdown voltage region (V_z) without thermal damage.

Step 1 — Once reverse voltage reaches the Zener breakdown voltage V_z, the reverse current increases sharply while the voltage across the diode remains virtually constant.

Step 2 — Because of this property of maintaining a constant output voltage despite wide variations in input voltage or load current, a Zener diode is universally employed as a DC voltage regulator in power supplies.

Why other options are wrong:

- **Option A:** LEDs operate under forward bias to emit visible or IR light.
- **Option B:** Photodiodes operate under reverse bias below breakdown to measure optical photocurrent.
- **Option D:** Solar cells operate in the fourth quadrant without external bias voltage.

Final Answer: Zener Diode as a DC voltage regulator (Option C)

Answer: (C) Go Back to Question 16

Q17.

Solution

Concept: Newton's laws establish foundational mechanical concepts: inertia is resistance to change of state, and forces always arise in equal and opposite mutual interactions.

Step 1 — Newton's first law states that a body continues in its state of rest or uniform motion unless acted upon by an unbalanced external force. This property of resisting motion change is called **Inertia**.

Step 2 — Newton's third law states that for every action, there is an equal and opposite reaction. Hence, forces never exist in isolation but always occur in pairs called **Action and Reaction** forces.

Final Answer: 1. Inertia 2. Action and Reaction

Answer: (See above) Go Back to Question 17

Q18.

Solution

Concept: When prism deviation is minimum ($\delta = \delta_m$), the light ray passes symmetrically through the prism, making incidence angle equal to emergence angle ($i = e$) and internal refraction angle $r = A/2$.

Step 1 — By Snell's law and geometry of symmetrical prism refraction at minimum deviation, the refractive index μ is related to prism angle A and minimum deviation δ_m by the prism formula:

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Step 2 — At the unique position of minimum deviation ($\delta = \delta_m$), the angle of incidence i is strictly equal to the angle of emergence e ($i = e$).

Final Answer: $\boxed{1.\ \mu = \frac{\sin[(A+\delta_m)/2]}{\sin(A/2)} \quad 2.\ i = e}$

Answer: (See above) Go Back to Question 18

Q19.

Solution

Concept: Kirchhoff's laws apply conservation principles to electrical circuits: junctions conserve electric charge, and closed loops conserve electrical potential energy.

Step 1 — Statement 1 is **TRUE (T)**. Kirchhoff's First Law ($\sum I = 0$ at a junction) affirms that electric charge cannot accumulate or vanish at a circuit node, obeying conservation of charge.

Step 2 — Statement 2 is **FALSE (F)**. Kirchhoff's Second Law ($\sum V = 0$ around a closed loop) is based on the conservation of **energy** (electrostatic field is conservative), not linear momentum.

Final Answer: 1. T 2. F

Answer: (See above) Go Back to Question 19

Q20.

Solution

Concept: Bohr's second postulate introduces quantum mechanics into atomic structure by restricting orbital angular momentum to integral multiples of $h/(2\pi)$.

Step 1 — Bohr's quantization condition for orbital angular momentum $L = mvr_n$ of an electron in the n^{th} orbit is:

$$L = mvr_n = \frac{nh}{2\pi} \quad \text{where } n = 1, 2, 3, \ldots$$

Step 2 — Substituting velocity from electrostatic centripetal balance into the quantization formula reveals that the radius of the n^{th} Bohr orbit is directly proportional to the square of the principal quantum number ($r_n \propto n^2$).

Final Answer: $\boxed{1.\ L = \frac{nh}{2\pi} \quad 2.\ r_n \propto n^2}$

Answer: (See above) **Go Back to Question 20**

Q21.

Solution

Concept: Identifying defining formulas and phenomena in fluid mechanics and surface properties.

Step 1 — Bernoulli's Principle represents conservation of mechanical energy in streamline fluid flow, so (a) matches (ii).

Step 2 — Stokes' Law gives viscous drag force $F = 6\pi\eta rv$ on a falling sphere, so (b) matches (i).

Step 3 — Pascal's Law governs equal hydraulic pressure transmission (hydraulic press), so (c) matches (iv).

Step 4 — Surface tension causes liquid meniscus curvature resulting in capillary rise or fall, so (d) matches (iii).

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

Answer: (See above) **Go Back to Question 21**

Q22.

Solution

Concept: Classification of doped semiconductors, junction depletion region, and optoelectronic energy conversion.

Step 1 — n-type semiconductors are formed by doping silicon with pentavalent impurities (e.g., P, As, Sb), so (a) matches (ii).

Step 2 — p-type semiconductors are formed by doping with trivalent impurities (e.g., B, Al, In), so (b) matches (iii).

Step 3 — Depletion region is the thin layer near the p-n junction devoid of free charge carriers, so (c) matches (iv).

Step 4 — A solar cell is a photovoltaic optoelectronic device converting solar photon energy into electrical power, 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: Mechanical waves require a material medium and cannot travel through vacuum; transverse waves exhibit polarization because vibrations occur perpendicular to propagation.

Step 1 — Statement 1 is **FALSE (F)**. Sound waves are longitudinal mechanical waves, but they require a material medium and **cannot** travel through a vacuum.

Step 2 — Statement 2 is **TRUE (T)**. Light waves are transverse electromagnetic waves whose electric field vectors vibrate perpendicular to propagation, enabling them to undergo polarization.

Final Answer: 1. F 2. T

Answer: (See above) **Go Back to Question 23**

Q24.

Solution

Concept: Introducing a dielectric material between capacitor plates reduces effective electric field by factor K, thereby increasing capacitance.

Step 1 — When a dielectric slab is inserted completely ($t = d$), capacitance **increases** by a factor of K ($C = KC_0$).

Step 2 — When a dielectric slab of thickness $t < d$ is inserted, capacitance C is given by:

$$C = \frac{\varepsilon_0 A}{d - t + \frac{t}{K}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{K}\right)}$$

Final Answer: 1. Increases 2. $C = \dfrac{\varepsilon_0 A}{d - t(1 - 1/K)}$

Answer: (See above) Go Back to Question 24

Q25.

Solution

Concept: In optical instruments, lens aperture and focal length are tailored to object distance and light-gathering requirements.

Step 1 — In a compound microscope, the lens close to the tiny specimen has small aperture and short focal length to maximize magnification, called the **Objective lens**.

Step 2 — In an astronomical telescope, the objective lens facing faint distant stars must have a large aperture to gather maximum light and large focal length for high angular magnification; hence it is called the **Objective lens**.

Final Answer: 1. Objective lens 2. Objective lens

Answer: (See above) Go Back to Question 25

Q26.

Solution

Concept: Matching foundational modern physics experiments and nuclear laws with their definitions.

Step 1 — Photoelectric effect is the emission of electrons from metal when illuminated by photon radiation, so (a) matches (ii).

Step 2 — De Broglie hypothesis postulates wave-particle dual nature of matter ($\lambda = h/p$), so (b) matches (iii).

Step 3 — Radioactive decay law governs exponential decay rate $N = N_0 e^{-\lambda t}$, so (c) matches (iv).

Step 4 — Nuclear fission is the splitting of a heavy nucleus into lighter fragments, so (d) matches (i).

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

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

Q27.

Solution

Concept: Binding energy per nucleon measures nuclear binding strength; exothermic nuclear reactions release energy by converting rest mass into kinetic/photon energy ($\Delta E = \Delta mc^2$).

Step 1 — Statement 1 is **TRUE (T)**. Higher binding energy per nucleon ($\overline{BE}$) means more energy is required per nucleon to disassemble the nucleus, signifying greater nuclear stability.

Step 2 — Statement 2 is **FALSE (F)**. In an exothermic nuclear reaction, the total rest mass of products is strictly **less** than the rest mass of reactants; the mass defect (Δm) is released as heat/energy according to $E = \Delta mc^2$.

Final Answer: 1. T 2. F

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

Q28.

Solution

Concept: A NAND gate is an inverted AND gate ($Y = \overline{A \cdot B}$); NAND and NOR gates can implement any Boolean logic circuit.

Step 1 — Statement 1 is **TRUE (T)**. For a NAND gate, output $Y = \overline{A \cdot B}$. If all inputs are HIGH (1), AND output is 1, so inverted NAND output is LOW (0).

Step 2 — Statement 2 is **TRUE (T)**. NAND and NOR gates are universally termed "Universal Gates" because any basic logic gate (NOT, AND, OR) can be constructed using only NAND gates or only NOR gates.

Final Answer: 1. T 2. T

Answer: (See above) Go Back to Question 28

Q29.

Solution

Concept: In a system where only conservative forces (such as gravity or ideal spring elasticity) do work, the total mechanical energy (sum of kinetic and potential energy) remains constant.

Step 1 — Alternative (i): Principle of Conservation of Mechanical Energy states that if the net work done by non-conservative forces (like friction or air resistance) is zero, then:

$$E_{\text{total}} = K + U = \text{constant} \implies \Delta K + \Delta U = 0$$

Step 2 — Practical Example: A freely falling stone under gravity. As it falls, its height decreases (potential energy $U = mgh$ decreases), but its velocity increases (kinetic energy $K = \frac{1}{2}mv^2$ increases by the exact same amount), keeping total energy $E = K + U$ invariant at every point of its path.

Step 3 — Alternative (ii): Newton's Second Law states that the rate of change of linear momentum of a body is directly proportional to the applied external unbalanced force and takes place in the direction of the force:

$$\vec{F} \propto \frac{d\vec{p}}{dt} \implies \vec{F} = k\frac{d(m\vec{v})}{dt}$$

For constant mass m and SI unit definition ($k = 1$): $\vec{F} = m\frac{d\vec{v}}{dt} = m\vec{a}$.

Final Answer: Mechanical energy $K + U = \text{const}$; or $F = dp/dt = ma$

Answer: (See above) Go Back to Question 29

Q30.

Solution

Concept: On a P-V indicator diagram, the slope of any thermodynamic process is given by dP/dV. For ideal gases, adiabatic curves are steeper by a factor of $\gamma = C_p/C_v > 1$.

Step 1 — For an isothermal process (PV = constant), differentiating with respect to V:

$$P + V\left(\frac{dP}{dV}\right)_{\text{iso}} = 0 \implies \left(\frac{dP}{dV}\right)_{\text{iso}} = -\frac{P}{V}$$

Step 2 — For an adiabatic process (PV^γ = constant), differentiating with respect to V:

$$P(\gamma V^{\gamma-1}) + V^\gamma\left(\frac{dP}{dV}\right)_{\text{adia}} = 0 \implies \left(\frac{dP}{dV}\right)_{\text{adia}} = -\gamma\frac{P}{V}$$

Step 3 — Comparing the two slopes:

$$\left(\frac{dP}{dV}\right)_{\text{adia}} = \gamma\left(\frac{dP}{dV}\right)_{\text{iso}}$$

Since $\gamma = C_p/C_v > 1$ for all gases, the magnitude of the adiabatic slope is γ times greater (steeper) than the isothermal slope.

Final Answer: Adiabatic slope $= \gamma \times$ Isothermal slope, where $\gamma > 1$

Answer: (See above) Go Back to Question 30

Q31.

Solution

Concept: Biot-Savart law gives the differential magnetic field induction from a current element; Ampere's circuital law relates line integral of magnetic field around a loop to enclosed current.

Step 1 — Alternative (i): Biot-Savart Law states that the magnitude of magnetic field induction dB produced at a point P located at distance r from a current element Idl is directly proportional to current I, element length dl, sine of angle θ between element and position vector, and inversely proportional to r^2:

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\hat{r})}{r^2} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\vec{r})}{r^3}$$

Step 2 — Alternative (ii): Ampere's Circuital Law states that the line integral of magnetic field induction $\vec{B}$ around any closed boundary loop in vacuum is equal to μ_0 times the total net conduction current I_{enc} threading through the loop:

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$$

Final Answer: $\boxed{d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\hat{r})}{r^2} \text{ or } \oint \vec{B}\cdot d\vec{l} = \mu_0 I}$

Answer: (See above) **Go Back to Question 31**

Q32.

Solution

Concept: Coherent sources emit light waves having identical frequencies and a zero or constant phase difference over time, which is essential for observable interference.

Step 1 — Definition: Coherent sources are two or more sources of light that continuously emit light waves of the exact same wavelength (and frequency) having a constant (time-independent) phase difference between them.

Step 2 — Why independent bulbs fail: In an ordinary light bulb, light is emitted by millions of excited atoms undergoing random, independent de-excitations. Each atomic emission lasts only about 10^{-8} seconds.

Step 3 — Consequently, the phase difference between light waves emitted by two independent bulbs changes rapidly and randomly millions of times per second. The resulting interference maxima and minima shift faster than the human eye can resolve, averaging out to uniform general illumination.

Final Answer: Coherent sources maintain constant phase difference; independent bulbs undergo random atomic phase jumps

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

Q33.

Solution

Concept: When a conductor moves across a magnetic field, free electrons experience a magnetic Lorentz force $q(\vec{v} \times \vec{B})$, creating charge separation and motional EMF.

Step 1 — Let a conducting rod of length l slide with constant velocity v to the right along parallel conducting rails in a uniform magnetic field B directed into the page ($\times$).

Step 2 — In time dt, the rod sweeps through a distance $dx = vdt$. The area enclosed by the circuit changes by $dA = ldx = lvdt$.

Step 3 — The magnetic flux threading the circuit at any instant is $\Phi_B = BA = Blx$. According to Faraday's law of electromagnetic induction, the magnitude of induced EMF E is the rate of change of magnetic flux:

$$E = \left|\frac{d\Phi_B}{dt}\right| = \frac{d(Blx)}{dt} = Bl\left(\frac{dx}{dt}\right) = Blv$$

Step 4 — By Lenz's law (or Fleming's right-hand rule), free electrons are driven toward one end of the rod, making the opposite end positive and establishing a motional EMF of $E = Blv$.

Final Answer: $\boxed{E = Blv}$

Answer: (See above) Go Back to Question 33

Q34.

Solution

Concept: The de Broglie wavelength of an electron accelerated through a potential difference V is given by $\lambda = \frac{h}{\sqrt{2m_e eV}} \approx \frac{1.227}{\sqrt{V}}$ nm.

Step 1 — When an electron is accelerated from rest through potential V, its kinetic energy is $K = eV = (1.6 \times 10^{-19}\text{ C})(100\text{ V}) = 1.6 \times 10^{-17}$ J.

Step 2 — The momentum of the electron is $p = \sqrt{2m_e K}$:

$$p = \sqrt{2(9.1 \times 10^{-31}\text{ kg})(1.6 \times 10^{-17}\text{ J})} = \sqrt{2.912 \times 10^{-47}} \approx 5.396 \times 10^{-24}\text{ kg m s}^{-1}$$

Step 3 — Using de Broglie's formula $\lambda = \frac{h}{p}$:

$$\lambda = \frac{6.63 \times 10^{-34}\text{ J s}}{5.396 \times 10^{-24}\text{ kg m s}^{-1}} \approx 1.228 \times 10^{-10}\text{ m} = 0.123\text{ nm} = 1.23\text{ Å}$$

Final Answer: $\boxed{\lambda \approx 1.23 \times 10^{-10}\text{ m (0.123 nm)}}$

Answer: (See above) Go Back to Question 34

Q35.

Solution

Concept: Brewster's law states that when unpolarized light is incident on a transparent medium at the polarizing angle i_p, the reflected light is completely plane-polarized and $\tan i_p = \mu$.

Step 1 — Brewster's Law: For a dielectric interface of refractive index μ, the tangent of the polarizing angle of incidence i_p equals the refractive index of the medium: $\tan i_p = \mu$.

Step 2 — According to Snell's law of refraction: $\mu = \frac{\sin i_p}{\sin r}$, where r is the angle of refraction.

Step 3 — Equating Brewster's relation and Snell's law:

$$\frac{\sin i_p}{\cos i_p} = \frac{\sin i_p}{\sin r} \implies \cos i_p = \sin r \implies \sin(90^\circ - i_p) = \sin r$$

Therefore, $r = 90^\circ - i_p$, or $i_p + r = 90^\circ$.

Step 4 — From geometry at the boundary, the angle between the reflected ray and refracted ray is $\theta = 180^\circ - (i_p + r) = 180^\circ - 90^\circ = 90^\circ$, proving they are mutually perpendicular.

Final Answer: $\boxed{\text{Proved: } i_p + r = 90^\circ \implies \text{Reflected and refracted rays are perpendicular}}$

Answer: (See above) Go Back to Question 35

Q36.

Solution

Concept: Radioactive decay is a statistical process governed by $-\frac{dN}{dt} = \lambda N$. Nuclear fission splits heavy nuclei, whereas fusion merges light nuclei.

Step 1 — Alternative (i): Rutherford-Soddy Law states that the rate of spontaneous radioactive disintegration is directly proportional to the number of undecayed nuclei present at that instant:

$$-\frac{dN}{dt} \propto N \implies \frac{dN}{dt} = -\lambda N \implies N(t) = N_0 e^{-\lambda t}$$

Half-life ($T_{1/2}$) is the time duration in which half of the radioactive nuclei decay: $T_{1/2} = \frac{\ln 2}{\lambda} \approx \frac{0.693}{\lambda}$.

Step 2 — Alternative (ii):

Nuclear Fission	**Nuclear Fusion**
1. Heavy nucleus ($A > 230$) splits into lighter nuclei.	1. Light nuclei ($A \le 4$) combine into a heavier nucleus.
2. Occurs at room temperature upon neutron capture.	2. Requires extreme thermal temperatures ($\sim 10^7$ K).
Example: $^{235}_{9}2\text{U} +^{1}_{0}\text{n} \rightarrow^{141}_{5} 6\text{Ba} +^{92}_{3} 6\text{Kr} + 3^{1}_{0}\text{n}$	Example: $^{2}_{1}\text{H} +^{2}_{1}\text{H} \rightarrow^{3}_{2}\text{He} +^{1}_{0}\text{n} + 3.27\,\text{MeV}$

Final Answer: $T_{1/2} = 0.693/\lambda;$ or Fission/Fusion differences table above

Answer: (See above) Go Back to Question 36

Q37.

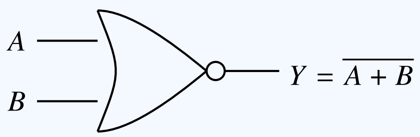
Solution

Concept: Semiconductor conductivity is modified by impurity doping; logic gates implement Boolean algebraic functions.

Step 1 — Alternative (i):

Intrinsic Semiconductor	Extrinsic Semiconductor
1. Pure semiconductor without any impurity doping.	1. Doped with trivalent or pentavalent impurity atoms.
2. Electron density equals hole density ($n_e = n_h = n_i$).	2. Unequal carrier densities ($n_e \gg n_h$ in n-type).
3. Low electrical conductivity at room temperature.	3. High electrical conductivity tailored by doping level.

Step 2 — Alternative (ii): A NOR gate is an OR gate followed by an inverter NOT gate ($Y = \overline{A + B}$).



Truth Table: ($A = 0, B = 0 \implies Y = 1$); ($0, 1 \implies 0$); ($1, 0 \implies 0$); ($1, 1 \implies 0$). It is a universal gate because all basic logic functions (NOT, AND, OR) can be built using only NOR gates.

Final Answer: Intrinsic/Extrinsic table; or NOR gate $Y = \overline{A + B}$

Answer: (See above) Go Back to Question 37

Q38.

Solution

Concept: Work done against spring restoring force is stored as elastic potential energy; projectile motion under constant gravity combines uniform horizontal velocity with accelerated vertical motion.

Step 1 — Alternative (i): When a spring of stiffness constant k is stretched by extension x, the restoring force is $F = -kx$. The external force required to maintain extension is $F_{\text{ext}} = kx$.

Step 2 — The small work dW done in stretching the spring further by an infinitesimal displacement dx is:

$$dW = F_{\text{ext}}dx = kxdx$$

Integrating from equilibrium ($x = 0$) to total extension x:

$$W = \int_0^x kxdx = k\left[\frac{x^2}{2}\right]_0^x = \frac{1}{2}kx^2$$

This work is stored as elastic potential energy: $U = \frac{1}{2}kx^2$.

Step 3 — Alternative (ii): Let a projectile be launched from $(0, 0)$ with initial velocity u at projection angle θ. Horizontal component is $u_x = u\cos\theta$ and vertical is $u_y = u\sin\theta$.

Step 4 — Since horizontal acceleration is zero, horizontal coordinate at time t is $x = (u\cos\theta)t \implies t = \frac{x}{u\cos\theta}$.

Step 5 — Vertical motion under gravity ($a_y = -g$): $y = (u\sin\theta)t - \frac{1}{2}gt^2$. Substituting t:

$$y = (u\sin\theta)\left(\frac{x}{u\cos\theta}\right) - \frac{1}{2}g\left(\frac{x}{u\cos\theta}\right)^2 \implies y = x\tan\theta - \left(\frac{g}{2u^2\cos^2\theta}\right)x^2$$

This equation is of the quadratic form $y = \alpha x - \beta x^2$, which represents a parabola.

Final Answer: $\boxed{U = \frac{1}{2}kx^2;\ \text{or parabolic trajectory } y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}}$

Answer: (See above) Go Back to Question 38

Q39.

Solution

Concept: Projectile motion kinematics apply uniform linear motion horizontally ($a_x = 0$) and uniform gravitational acceleration vertically ($a_y = -g$).

Step 1 — Part A - Total Time of Flight (T): When the projectile returns to the ground level, its net vertical displacement is zero ($y = 0$). Using $y = u_y t - \frac{1}{2}gt^2$:

$$0 = (u\sin\theta)T - \frac{1}{2}gT^2 \implies T\left(u\sin\theta - \frac{1}{2}gT\right) = 0$$

Since $T > 0$ at landing:

$$T = \frac{2u\sin\theta}{g}$$

Step 2 — Part B - Maximum Vertical Height (H): At the highest point of the parabolic trajectory, the vertical velocity component becomes momentarily zero ($v_y = 0$).

Step 3 — Using the kinematic equation $v_y^2 - u_y^2 = 2a_y y$, substitute $v_y = 0$, $u_y = u\sin\theta$, $a_y = -g$, and $y = H$:

$$0 - (u\sin\theta)^2 = 2(-g)H \implies -u^2\sin^2\theta = -2gH \implies H = \frac{u^2\sin^2\theta}{2g}$$

Final Answer: $\boxed{T = \frac{2u\sin\theta}{g}, \quad H = \frac{u^2\sin^2\theta}{2g}}$

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

Q40.

Solution

Concept: In series capacitors, charge Q is identical on all plates and total voltage is additive; in parallel capacitors, voltage V is identical across all branches and total charge is additive.

Step 1 — Part A - Series Combination: Three capacitors C_1, C_2, C_3 are connected in series across DC voltage V. The same charge Q is deposited on each capacitor. Total voltage is the sum of potential drops:

$$V = V_1 + V_2 + V_3 = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

For an equivalent single capacitor C_s, $V = \frac{Q}{C_s}$. Equating the two expressions:

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Step 2 — Part B - Parallel Combination: When connected in parallel across voltage V, potential difference across each capacitor is identical to V. Total charge drawn from the battery is:

$$Q = Q_1 + Q_2 + Q_3 = C_1V + C_2V + C_3V = V(C_1 + C_2 + C_3)$$

For an equivalent parallel capacitance C_p, $Q = C_pV$. Equating gives:

$$C_p = C_1 + C_2 + C_3$$

Final Answer: Series: $\frac{1}{C_s} = \sum \frac{1}{C_i}$; Parallel: $C_p = \sum C_i$

Answer: (See above) Go Back to Question 40

Q41.

Solution

Concept: Refraction at a spherical surface separating two optical media obeys $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R}$. A thin lens combines two such successive refractions.

Step 1 — Let a thin convex lens of glass (μ_2) be placed in air ($\mu_1 = 1$). For the first convex surface of radius of curvature R_1, light from point object O at distance u forms a virtual/real intermediate image I_1 at distance v_1:

$$\frac{\mu_2}{v_1} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R_1} \quad \text{— (Eq. 1)}$$

Step 2 — For the second surface of radius of curvature R_2, the intermediate image I_1 acts as a virtual object at distance v_1 (since lens thickness $t \approx 0$). Rays refract from glass (μ_2) into air (μ_1), forming final image I at distance v:

$$\frac{\mu_1}{v} - \frac{\mu_2}{v_1} = \frac{\mu_1 - \mu_2}{R_2} = -\frac{\mu_2 - \mu_1}{R_2} \quad \text{— (Eq. 2)}$$

Step 3 — Adding Eq. 1 and Eq. 2 eliminates the intermediate distance term μ_2/v_1:

$$\mu_1\left(\frac{1}{v} - \frac{1}{u}\right) = (\mu_2 - \mu_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \implies \frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Step 4 — By definition of lens focal length, when object is at infinity ($u = \infty$), image is formed at focus ($v = f$). Letting $\mu = \mu_2/\mu_1$:

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

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

Answer: (See above) Go Back to Question 41

Q42.

Solution

Concept: In a series LCR AC circuit, inductive reactance X_L leads resistance R by 90° and capacitive reactance X_C lags by 90°; resonance occurs when reactive impedances cancel ($X_L = X_C$).

Step 1 — Part (i) - Impedance Derivation: In a series LCR circuit carrying current $I = I_0 \sin(\omega t - \phi)$, the voltage drops are: $V_R = I_0 R$ (in phase), $V_L = I_0 X_L$ (leads by 90°), and $V_C = I_0 X_C$ (lags by 90°).

Step 2 — From the right-angled phasor impedance triangle, the net reactive voltage is $(V_L - V_C)$ perpendicular to V_R. The applied peak voltage V_0 is the vector hypotenuse:

$$V_0^2 = V_R^2 + (V_L - V_C)^2 = I_0^2 \left[R^2 + (X_L - X_C)^2\right]$$

Taking square root and defining total impedance $Z = V_0/I_0$:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \quad \text{and} \quad I_0 = \frac{V_0}{Z}$$

Step 3 — Part (ii) - Electrical Resonance: Resonance is the phenomenon where circuit impedance becomes minimum ($Z = R$) and alternating current amplitude reaches its absolute maximum for a given voltage. This occurs when $X_L = X_C$:

$$\omega_0 L = \frac{1}{\omega_0 C} \implies \omega_0^2 = \frac{1}{LC} \implies \omega_0 = \frac{1}{\sqrt{LC}} \quad \text{and resonant frequency } f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Step 4 — Alternative (iii) - Step-Up Transformer: A step-up transformer operates on Faraday's mutual induction to increase AC alternating voltage ($V_s > V_p$) with $N_s > N_p$.

Major Cause of Energy Loss	Practical Minimization Method
1. Eddy Current Loss in iron core.	1. Use laminated, mutually insulated thin iron sheets.
2. Hysteresis Loss during AC magnetization.	2. Use soft iron core having narrow hysteresis loop area.
3. Copper Joule Heating (I^2R loss in windings).	3. Use thick low-resistance copper wires for heavy current coils.

Final Answer: $Z = \sqrt{R^2 + (\omega L - 1/\omega C)^2}$, $\omega_0 = \frac{1}{\sqrt{LC}}$; or Transformer losses table

Answer: (See above) Go Back to Question 42

Q43.

Solution

Concept: A bridge rectifier utilizes diode unidirectional forward-bias conductivity to convert bilateral AC alternating voltage into unidirectional pulsed DC voltage during both half-cycles.

Step 1 — Part (i) - Bridge Rectifier Working: A full-wave bridge rectifier employs four diodes (D_1, D_2, D_3, D_4) arranged in a closed bridge loop across AC secondary terminals.

Step 2 — Positive Half-Cycle: Terminal A is positive and B is negative. Diodes D_1 and D_3 become forward-biased and conduct current through load resistor R_L from left to right, while D_2 and D_4 are reverse-biased and open-circuited.

Step 3 — Negative Half-Cycle: Terminal B becomes positive and A is negative. Diodes D_2 and D_4 become forward-biased and conduct current through R_L in the exact same direction (left to right), while D_1 and D_3 are reverse-biased. Thus, both half-cycles produce unidirectional output pulses.

Step 4 — Part (ii) - Capacitor Filter Role: Pulsed DC output contains unwanted AC ripples. A capacitor C connected in parallel across R_L charges up to peak voltage during pulses and discharges slowly through R_L when voltage drops, effectively smoothing out ripples into steady DC voltage.

Step 5 — Alternative (iii) - Basic Logic Gates Universal NAND Gate:

Gate	Boolean Expression	Symbol Description	Truth Table Highlights
OR	$Y = A + B$	Curved input shield, pointed tip	Output 1 if any input is 1
AND	$Y = A \cdot B$	Flat straight input, D-shaped tip	Output 1 only if all inputs are 1
NOT	$Y = \overline{A}$	Triangle with inverter bubble	Inverts input ($0 \to 1, 1 \to 0$)

The NAND gate ($Y = \overline{A \cdot B}$) is termed a **Universal Gate** because all fundamental gates (NOT, AND, OR) can be built by interconnecting only NAND gates.

Final Answer: Full-Wave Bridge Rectifier working & filter; or Logic gates table & NAND universality

Answer: (See above) Go Back to Question 43

Answer Key

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