

# NIOS Class 12 Physics Sample Paper-8

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 electric field between two parallel metal plates separated by distance  $d$  with potential difference  $V$  is: (1)

(A)  $\frac{V}{d}$

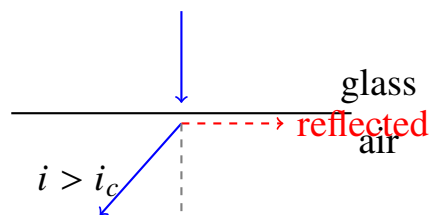


- (B)  $V \times d$
- (C)  $\frac{d}{V}$
- (D)  $\frac{V}{d^2}$

**Q2.** A rocket ejects exhaust gases at a rate of  $10 \text{ kg s}^{-1}$  with a velocity of  $500 \text{ m s}^{-1}$ . The thrust force on the rocket is: (1)

- (A) 500 N
- (B) 5000 N
- (C) 50 N
- (D) 50000 N

**Q3.** The diagram shows total internal reflection at a glass–air interface. For this to occur, which condition must be satisfied? (1)



- (A) Angle of incidence must be less than the critical angle
- (B) Light must travel from denser to rarer medium and angle of incidence exceeds the critical angle
- (C) Light must travel from rarer to denser medium
- (D) Angle of incidence must equal  $90^\circ$

**Q4.** In a transistor, the most heavily doped region is: (1)

- (A) Base
- (B) Collector
- (C) Emitter
- (D) Substrate



- Q5.** According to Stokes' law, the viscous drag force on a small sphere of radius  $r$  moving with velocity  $v$  through a fluid of viscosity  $\eta$  is: **(1)**
- (A)  $6\pi\eta r v$   
(B)  $4\pi\eta r v$   
(C)  $6\pi\eta r^2 v$   
(D)  $2\pi\eta r v$
- Q6.** The de Broglie wavelength of an electron accelerated through a potential difference  $V$  is proportional to: **(1)**
- (A)  $V$   
(B)  $V^{1/2}$   
(C)  $V^{-1/2}$   
(D)  $V^{-1}$
- Q7.** In an adiabatic expansion of an ideal gas, the temperature of the gas: **(1)**
- (A) increases  
(B) decreases  
(C) remains the same  
(D) first increases then decreases
- Q8.** The fundamental frequency of an open organ pipe is  $f$ . If one end is closed, its fundamental frequency becomes: **(1)**
- (A)  $f$   
(B)  $2f$   
(C)  $f/2$   
(D)  $4f$
- Q9.** The magnetic force on a stationary charge placed in a uniform magnetic field is: **(1)**



- (A) Maximum
- (B) Minimum
- (C) Zero
- (D) Depends on the direction of the field

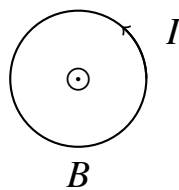
**Q10.** A body of mass 2 kg is thrown vertically upward with speed  $10 \text{ m s}^{-1}$ . The kinetic energy at the highest point is: (1)

- (A) 100 J
- (B) 50 J
- (C) 0 J
- (D) 200 J

**Q11.** The blue colour of the sky is due to: (1)

- (A) reflection of sea water
- (B) Rayleigh scattering of sunlight
- (C) total internal reflection
- (D) dispersion of light by water droplets

**Q12.** A current-carrying circular loop is placed as shown. The direction of the magnetic field at the centre of the loop is: (1)



- (A) into the plane of the loop
- (B) out of the plane of the loop
- (C) zero at the centre
- (D) along the plane of the loop

**Q13.** In a CE transistor amplifier, the voltage gain is: (1)



(A)  $A_v = \beta \frac{R_L}{R_i}$

(B)  $A_v = \alpha \frac{R_L}{R_i}$

(C)  $A_v = \beta + 1$

(D)  $A_v = \alpha + 1$

**Q14.** A motor lifts a 500 kg mass to a height of 20 m in 10 s. The power developed is ( $g = 10 \text{ m s}^{-2}$ ): (1)

(A) 10 kW

(B) 100 kW

(C) 1 kW

(D) 50 kW

**Q15.** The binding energy per nucleon for a medium-mass nucleus is approximately: (1)

(A) 0.8 MeV

(B) 2.2 MeV

(C) 8.5 MeV

(D) 200 MeV

**Q16.** A wire of resistance  $R$  is stretched to double its length. Its new resistance becomes: (1)

(A)  $R$

(B)  $2R$

(C)  $4R$

(D)  $R/2$



Note: Q. No. 17 to 28 are the objective type questions of 2 marks each.

**Q17.** Read the passage given below and answer the following questions:

When a body moves along a circular path with constant speed, its direction of motion changes continuously. This means the velocity is not constant even though the speed is. A force directed towards the centre, called the centripetal force, is required to maintain circular motion. If this force is removed, the body moves along a straight line tangent to the circle at that instant. The work done by the centripetal force on the body is zero. (2)

1. Why is the work done by the centripetal force zero?
2. What happens to the body if the centripetal force is suddenly withdrawn?

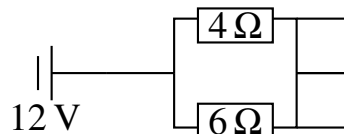
**Q18.** Complete the following by using the options given below:

(superposition, nodes, diffraction, antinodes, refraction) (2)

1. The points on a stationary wave where displacement is always zero are called .....
2. The phenomenon responsible for the bending of light around the edges of a small obstacle is .....

**Q19.** Read the passage and answer the questions that follow it.

A student sets up a circuit with a 12 V battery, a 4 Ω resistor and a 6 Ω resistor connected in series. An ammeter measures the total current. (2)



1. What is the current in the circuit?
2. What is the potential difference across the 6 Ω resistor?

**Q20.** Fill in the blanks:

(2)

1. In an isobaric process, the ..... of the gas remains constant.



2. According to the first law of thermodynamics,  $\Delta U = Q - W$ , where  $W$  is the work done .....the system.

**Q21.** Match the items in Column I with the most appropriate items in Column II: (2)

| Column I                  | Column II  |
|---------------------------|--|
| (a) Pascal’s law          | (i) Falling bodies reach constant terminal velocity  |
| (b) Archimedes’ principle | (ii) Pressure transmitted equally in all directions  |
| (c) Stokes’ law           | (iii) Buoyant force equals weight of displaced fluid |
| (d) Torricelli’s theorem  | (iv) Speed of efflux $v = \sqrt{2gh}$                |

**Q22.** Fill in the blanks: (2)

1. When a pentavalent impurity is added to a pure semiconductor, it is called type semiconductor.
2. The current gain  $\alpha$  of a transistor in CB configuration is always ... than 1.

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

1. The total energy of an electron in a Bohr orbit is negative, indicating the electron is bound to the nucleus.
2. Nuclear fission is the process in which two light nuclei combine to form a heavier nucleus.

**Q24.** Match the items in Column I with the most appropriate items in Column II: (2)

| Column I                      | Column II  |
|-------------------------------|--|
| (a) Ohm’s law                 | (i) Force on a moving charge in a magnetic field |
| (b) Kirchhoff’s junction rule | (ii) $V = IR$                                    |
| (c) Lorentz force             | (iii) Conservation of charge                     |
| (d) Biot–Savart law           | (iv) Magnetic field due to a current element     |



**Q25.** Fill in the blanks: (2)

1. The phenomenon of light bending around the edges of a narrow slit is called .
2. In Young’s double-slit experiment, the fringe width is directly proportional to the .....of light used.

**Q26.** Match the items in Column I with the most appropriate items in Column II: (2)

| Column I                     | Column II  |
|------------------------------|--|
| (a) Newton’s first law       | (i) Rate of change of momentum equals force          |
| (b) Newton’s second law      | (ii) Every action has an equal and opposite reaction |
| (c) Newton’s third law       | (iii) Law of inertia                                 |
| (d) Conservation of momentum | (iv) No external force on an isolated system         |

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

1. The resistivity of a metallic conductor increases with increase in temperature.
2. In a step-up transformer, the output voltage is less than the input voltage.

**Q28.** Match the items in Column I with the most appropriate items in Column II: (2)

| Column I            | Column II  |
|---------------------|--|
| (a) Zener diode     | (i) Signal amplification                         |
| (b) Transistor (CE) | (ii) Voltage regulation                          |
| (c) Solar cell      | (iii) Converts light energy to electrical energy |
| (d) Logic gate      | (iv) Performs Boolean operations                 |



**Section: B**

**Q29.** Define resonance. Give one example of resonance from everyday life. (2)

**Q30.** A car of mass 1000 kg moving at  $20 \text{ m s}^{-1}$  is brought to rest by brakes in 5 s. Calculate the average braking force applied. (2)

**Q31.** (i) Define capacitance of a capacitor. Write its SI unit.

**OR**

(ii) Two capacitors of  $4 \mu\text{F}$  and  $6 \mu\text{F}$  are connected in series across a 100 V supply. Find the equivalent capacitance and charge on each capacitor. (2)

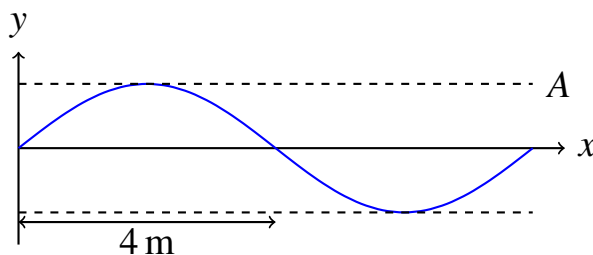
**Q32.** (i) Define critical angle. Derive the relation between critical angle and refractive index.

**OR**

(ii) What is polarisation of light? How does Brewster's law help determine the polarising angle? (2)

**Q33.** A cell of emf 10 V and internal resistance  $1 \Omega$  is connected to an external resistance of  $4 \Omega$ . Calculate the current in the circuit and the terminal voltage of the cell. (2)

**Q34.** The figure shows a transverse wave on a string. From the diagram, determine the amplitude, wavelength and frequency if the wave speed is  $8 \text{ m s}^{-1}$ . (2)



**Q35.** (i) Write three postulates of Bohr's model of the hydrogen atom.



**OR**

(ii) Define nuclear fission. Write one difference between nuclear fission and nuclear fusion. (2)

**Q36.** State Bernoulli's principle. Explain why aeroplane wings are given a special shape (airfoil). (2)

**Q37.** An ideal gas at 300 K is compressed adiabatically to  $\frac{1}{4}$  of its original volume. If  $\gamma = 1.4$ , find the final temperature. (2)

**Q38.** Define the following terms with one example each:

A. Extrinsic semiconductor

B. n-type semiconductor

C. Transistor (3)

**Q39.** (i) A convex mirror has focal length 15 cm. An object is placed 10 cm in front of it. Find the position and nature of the image.

**OR**

(ii) Two thin lenses of focal lengths 20 cm and  $-30$  cm are placed in contact. Find the focal length and power of the combination. (3)

**Q40.** State Ampere's circuital law. Using it, derive the expression for the magnetic field due to a long straight current-carrying wire at a distance  $r$  from it. (3)

**Q41.** (i) A body of mass 5 kg starts from rest and is acted upon by a force  $F = 3t$  newtons (where  $t$  is in seconds). Find the velocity after 4 s and the work done in this time.

**OR**

(ii) A ball of mass 0.2 kg is thrown vertically upward with speed  $20 \text{ m s}^{-1}$ . Using conservation of energy, find the maximum height reached. ( $g = 10 \text{ m s}^{-2}$ ) (3)



- Q42.** (i) (a) Derive the expression for the magnetic field inside a long solenoid carrying current  $I$  with  $n$  turns per unit length.  
(b) State Lenz's law and explain how it is consistent with conservation of energy.

**OR**

- (ii) (a) Explain the working of a p-n junction diode in forward and reverse bias with suitable diagrams.  
(b) Draw the truth table of an AND gate and an OR gate. **(5)**

- Q43.** (i) (a) An object is placed 30 cm from a convex lens of focal length 20 cm. Find the position, nature and magnification of the image.  
(b) State and explain Malus' law of polarisation.  
(c) Write Einstein's photoelectric equation and define work function.

**OR**

- (ii) (a) Derive the expression for the total energy of an electron in the  $n$ -th Bohr orbit of hydrogen atom.  
(b) The half-life of  $^{60}\text{Co}$  is 5.27 years. Calculate its decay constant.  
(c) State one application of nuclear fission. **(5)**



Detailed Solutions

Q1.

Solution

**Concept:** The electrostatic field established between two wide, parallel metal plates maintained at a uniform potential difference is constant in both magnitude and orientation throughout the intermediate space. This uniform spatial distribution means that the electric field vectors are parallel to one another and perpendicular to the conducting boundaries. The field vectors point from the plate at a higher positive potential toward the plate at a lower negative potential, defining the direction of decreasing potential.

**Step 1:** The absolute potential difference  $V$  between the two plates is mathematically related to the internal electric field strength  $E$  and the linear plate separation distance  $d$  through the equation  $V = E \times d$ , assuming a uniform field.

**Step 2:** Rearranging this classical electrostatic formula allows us to isolate the field variable, yielding the expression  $E = V/d$ . This shows that the field strength is directly proportional to the potential difference and inversely proportional to the separation.

**Step 3:** This equation means that the electric field measures the spatial gradient of the potential, and its direction points from the plate at higher potential to the plate at lower potential.

**Final Answer:**  $V/d$

Answer: (A)

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Q2.

Solution

**Concept:** The mechanical thrust generated by an accelerating rocket is a direct application of Newton's third law of motion and the law of conservation of linear momentum. This upward force arises as the continuous reaction to the rate of change of momentum of the ejected exhaust gases. If a discrete mass element  $\Delta m$  is accelerated and expelled with a relative velocity  $v_e$  over a time interval  $\Delta t$ , the continuous force is given by  $F = \frac{\Delta m}{\Delta t} \times v_e = \dot{m}v_e$ .

**Step 1:** The problem provides the operational parameters of the propulsion system: a mass ejection rate of  $\dot{m} = 10 \text{ kg s}^{-1}$  and a relative exhaust velocity of  $v_e = 500 \text{ m s}^{-1}$ .

**Step 2:** Substituting these values into the thrust equation allows us to calculate the mechanical force directly:  $F = 10 \text{ kg s}^{-1} \times 500 \text{ m s}^{-1}$ .

**Step 3:** Performing the multiplication yields a net forward thrust of  $F = 5000 \text{ N}$ . This represents the constant forward force pushing the rocket frame through space.

**Final Answer:** 5000 N

Answer: (B)

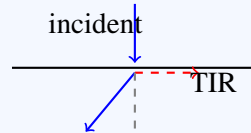
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Q3.

**Solution**

**Concept:** The optical phenomenon of total internal reflection occurs when a traveling light ray fails to cross the boundary between two different media, reflecting completely back into the host material instead. This event requires two conditions: the light ray must travel from an optically denser medium to an optically rarer medium ( $n_1 > n_2$ ), and the angle of incidence must exceed a specific critical angle ( $i_c$ ). This critical threshold angle is defined by the mathematical relationship  $\sin i_c = n_2/n_1$ .



**Step 1:** Total internal reflection requires the light ray to encounter an interface with a medium of lower refractive index, meaning it travels from a denser medium toward a rarer medium.

**Step 2:** The angle of incidence at the interface must exceed the critical threshold angle  $i_c$ . When the incident angle matches  $i_c$ , the refracted ray travels along the boundary, corresponding to a refraction angle of  $90^\circ$ .

**Step 3:** When the angle of incidence is increased beyond  $i_c$ , refraction ceases completely, and the interface acts as a mirror that reflects all the incident wave energy back into the denser medium.

**Final Answer:** Light travels from denser to rarer medium and angle of incidence exceeds the critical angle

**Answer: (B)**

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Q4.

**Solution**

**Concept:** A semiconductor bipolar junction transistor is a three-terminal electronic component that uses three distinct doped regions: the emitter, the base, and the collector. To enable proper transistor action, each region is fabricated with a specific physical size and doping concentration. The emitter region is given the highest doping concentration because its primary function is to inject a large number of majority charge carriers into the base.

**Step 1:** The emitter is heavily doped to ensure a high concentration of mobile majority carriers (electrons in  $n$ - $p$ - $n$  configurations, holes in  $p$ - $n$ - $p$  configurations) that can easily diffuse into the central base layer.

**Step 2:** The central base region is made very thin and lightly doped to minimize carrier recombination within this layer. This design allows most of the injected carriers to pass through to the collector.

**Step 3:** The collector region is moderately doped and has the largest surface area to safely dissipate the heat generated by collecting the charge carriers.

**Final Answer:** Emitter

**Answer:** (C)

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Q5.

**Solution**

**Concept:** Stokes' law describes fluid dynamics by calculating the viscous retarding force that opposes a small spherical object moving slowly through a continuous, viscous fluid medium. This drag force arises from the fluid's shear resistance and is given by the expression  $F = 6\pi\eta r v$ . Here,  $\eta$  represents the dynamic viscosity coefficient of the fluid,  $r$  is the radius of the sphere, and  $v$  is its instantaneous velocity relative to the fluid.

**Step 1:** Stokes' empirical law applies to small spherical bodies moving at low velocities where the fluid flow remains laminar. This condition corresponds to a low Reynolds number, meaning viscous forces dominate over inertial forces.

**Step 2:** The equation shows that the retarding force is directly proportional to the fluid viscosity, the radius of the sphere, and its velocity. This linear dependence on velocity contrasts with high-speed turbulent drag, which scales with the square of the speed.

**Step 3:** Combining these factors yields the standard expression for the viscous drag force:  $F = 6\pi\eta r v$ . This relation forms the foundation for calculating terminal velocities in fluids.

**Final Answer:**  $6\pi\eta r v$

**Answer:** (A)

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Q6.

**Solution**

**Concept:** The de Broglie hypothesis describes particle-wave duality by assigning a quantum wavelength to moving particles, given by the expression  $\lambda = h/p = h/(mv)$ . For a charged particle like an electron accelerated from rest through an electric potential difference  $V$ , its final kinetic energy matches the work done by the field ( $E_k = eV$ ). Since momentum relates to kinetic energy via  $p = \sqrt{2mE_k}$ , substituting this gives  $p = \sqrt{2meV}$ , which yields the wavelength formula  $\lambda = h/\sqrt{2meV}$ .

**Step 1:** In the equation  $\lambda = h/\sqrt{2meV}$ , Planck’s constant  $h$ , the electron mass  $m$ , and the elementary charge  $e$  are invariant physical constants. This allows us to write the proportionality relation as  $\lambda \propto 1/\sqrt{V}$ .

**Step 2:** Using exponent notation, this inverse square root relationship can be written as  $\lambda \propto V^{-1/2}$ . This shows that increasing the accelerating potential increases the particle’s momentum, which shortens its de Broglie wavelength.

**Final Answer:**  $V^{-1/2}$

**Answer: (C)**

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Q7.

**Solution**

**Concept:** An adiabatic process is a thermodynamic transformation during which the working gas system is thermally isolated from its surroundings, meaning no heat energy is exchanged across its boundaries ( $Q = 0$ ). Applying the first law of thermodynamics ( $\Delta Q = \Delta U + W$ ) to this condition simplifies the energy balance to  $\Delta U = -W$ . This equation shows that any mechanical work performed by or on the gas must result in a corresponding change in its internal energy.

**Step 1:** During an adiabatic expansion, the gas pushes against its surroundings, performing positive mechanical work ( $W > 0$ ). Substituting this into the simplified first law expression requires the net change in internal energy to be negative ( $\Delta U < 0$ ).

**Step 2:** Because the internal energy of an ideal gas is a direct function of its absolute temperature, a decrease in internal energy means the system’s temperature must fall. Therefore, an adiabatic expansion causes the gas to cool down.

**Final Answer:** Temperature decreases

**Answer: (B)**

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Q8.

**Solution**

**Concept:** The fundamental resonant frequency of an acoustic air column depends on its physical length and the boundary conditions at its ends. An open cylindrical pipe has antinodes at both open ends, producing a fundamental standing wave with a wavelength of  $\lambda_1 = 2L$  and a frequency of  $f_{\text{open}} = v/(2L)$ . In contrast, a closed pipe has a displacement node at the sealed end and an antinode at the open end, yielding a longer fundamental wavelength of  $\lambda_1 = 4L$  and a lower frequency of  $f_{\text{closed}} = v/(4L)$ .

**Step 1:** The fundamental frequency for an open pipe of length  $L$  is given by  $f = v/(2L)$ . For a closed pipe of the same length, the fundamental frequency is given by the expression  $f' = v/(4L)$ .

**Step 2:** Comparing these two mathematical expressions shows that the closed pipe's frequency can be written as  $f' = \frac{1}{2}[v/(2L)]$ . Substituting the open pipe frequency  $f$  into this relation yields  $f' = f/2$ .

**Final Answer:**  $f/2$

**Answer:** (C)

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Q9.

**Solution**

**Concept:** The magnetic force exerted on a charged particle moving through a magnetic field is described by the magnetic component of the Lorentz force equation:  $\vec{F} = q(\vec{v} \times \vec{B})$ . Calculating the magnitude of this vector cross product yields the expression  $F = qvB \sin \theta$ , where  $\theta$  is the angle between the velocity vector  $\vec{v}$  and the magnetic field vector  $\vec{B}$ . This formulation shows that the magnetic force depends directly on the particle's velocity.

**Step 1:** The problem specifies that the electric charge is stationary within the steady magnetic field, which means its instantaneous velocity parameter is  $v = 0 \text{ m s}^{-1}$ .

**Step 2:** Substituting this velocity value into the force magnitude equation yields:  $F = q \times 0 \times B \sin \theta = 0 \text{ N}$ .

**Step 3:** This result shows that a static magnetic field does not perform work or exert forces on stationary charges; a charge must be in motion relative to the field to experience a magnetic deflecting force.

**Final Answer:** Zero

**Answer:** (C)

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Q10.

**Solution**

**Concept:** When an object is thrown vertically upward into a uniform gravitational field, it converts its initial kinetic energy into gravitational potential energy as it rises. The downward acceleration of gravity continuously reduces the object’s vertical velocity until it reaches the apex of its flight. At this highest point, the vertical velocity vector momentarily becomes zero before the object reverses direction and begins its descent.

**Step 1:** The object decelerates uniformly as it moves upward. At the peak of its trajectory, its instantaneous linear velocity drops to  $v = 0 \text{ m s}^{-1}$ , bringing the body to a momentary standstill.

**Step 2:** Translational kinetic energy is defined by the mechanical mass-velocity relationship:  
 $K = \frac{1}{2}mv^2$ .

**Step 3:** Substituting the peak velocity value ( $v = 0 \text{ m s}^{-1}$ ) into the kinetic energy equation gives:  
 $K = \frac{1}{2}m(0)^2 = 0 \text{ J}$ . At this point, the system’s mechanical energy is entirely stored as potential energy.

**Final Answer:** 0 J

**Answer:** (C)

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Q11.

**Solution**

**Concept:** The distinct blue coloration of a clear daytime sky is governed by Rayleigh scattering, an optical phenomenon describing how electromagnetic radiation interacts with particles much smaller than its constituent wavelengths. According to this classical electromagnetic theory, the scattering intensity  $I$  experienced by incoming light is inversely proportional to the fourth power of its wavelength, expressed mathematically as  $I \propto 1/\lambda^4$ . This relationship shows that shorter wavelengths are scattered far more efficiently than longer ones.

**Step 1:** Unpolarized sunlight entering the atmosphere contains a full spectrum of visible wavelengths. Blue light ( $\lambda \approx 400 \text{ nm}$ ) has a much shorter wavelength than red light ( $\lambda \approx 700 \text{ nm}$ ).

**Step 2:** Evaluating the inverse-fourth-power relationship reveals that blue light undergoes approximately  $(700/400)^4 \approx 5.5$  times more lateral scattering than red light.

**Step 3:** As a result, these short blue wavelengths are scattered in every direction across the atmosphere. When an observer looks up, this scattered light populates the field of view, making the sky appear blue.

**Final Answer:** Rayleigh scattering of sunlight

**Answer:** (B)

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Q12.

**Solution**

**Concept:** The spatial orientation of the magnetic field generated by a macroscopic current-carrying circular conductor is determined using the right-hand thumb rule. This geometric convention stems from the Biot-Savart law and establishes a right-handed coordinate system between the current path and the resulting magnetic flux lines. When applied to a closed loop, curling the fingers of the right hand along the path of the current causes the extended thumb to point along the vector of the central magnetic field.

**Step 1:** The schematic diagram shows a flat circular loop carrying an electrical current that flows in an anticlockwise direction when viewed from a standard overhead perspective.

**Step 2:** Aligning and curling the fingers of the right hand to follow this anticlockwise current vector causes the thumb to point directly upward, perpendicular to the plane of the loop.

**Step 3:** This orientation corresponds to a magnetic field vector pointing out of the page. This direction is standardly represented by the dot-in-circle notation ( $\odot$ ), which confirms the field points out of the loop's plane.

**Final Answer:** Out of the plane of the loop

**Answer: (B)**

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Q13.

**Solution**

**Concept:** In solid-state analog electronics, a common-emitter (CE) bipolar junction transistor network serves as a fundamental voltage amplification stage. In this circuit configuration, the input signal is applied across the forward-biased base-emitter junction, while the amplified output is taken across the reverse-biased collector-emitter path. The small-signal open-circuit voltage gain ( $A_v$ ) of this system depends on the forward current gain ( $\beta$ ), the total output load resistance ( $R_L$ ), and the dynamic input resistance ( $R_i$ ).

**Step 1:** The dimensionless common-emitter current gain is defined as the ratio of the output collector current variation to the input base current variation, written as  $\beta = \Delta I_C / \Delta I_B$ .

**Step 2:** The small-signal voltage gain is the ratio of output voltage variation to input voltage variation, expressed as  $A_v = \Delta V_{CE} / \Delta V_{BE}$ . Because  $\Delta V_{CE} = \Delta I_C R_L$  and  $\Delta V_{BE} = \Delta I_B R_i$ , substituting these gives  $A_v = (\Delta I_C / \Delta I_B) \times (R_L / R_i)$ .

**Step 3:** Replacing the current ratio with  $\beta$  yields the voltage gain equation:  $A_v = \beta R_L / R_i$ . This shows why Option A is correct.

**Final Answer:**  $A_v = \beta R_L / R_i$

**Answer: (A)**

[Go Back to Question 13](#)



Q14.

**Solution**

**Concept:** In classical mechanics, mechanical power ( $P$ ) is defined as the time rate at which useful work is performed by a force field, expressed mathematically as  $P = W/t$ . When an object is lifted vertically at a constant speed through a uniform gravitational field, the upward force must balance the downward weight of the object ( $F = mg$ ). The mechanical work performed against gravity to raise a mass  $m$  to a height  $h$  is given by  $W = mgh$ , which yields the power equation  $P = mgh/t$ .

**Step 1:** The problem provides the following parameters for the hoisting system: a load mass of  $m = 500$  kg, a vertical height of  $h = 20$  m, a duration of  $t = 10$  s, and a gravitational acceleration of  $g = 10 \text{ m s}^{-2}$ .

**Step 2:** Substituting these values into the mechanical work equation yields the total energy transferred to the load:  $W = 500 \text{ kg} \times 10 \text{ m s}^{-2} \times 20 \text{ m} = 100000 \text{ J}$ .

**Step 3:** Dividing this total work by the time interval gives the required power output:  $P = 100000 \text{ J}/10 \text{ s} = 10000 \text{ W}$ . Converting this value to kilowatts gives  $P = 10 \text{ kW}$ .

**Final Answer:** 10 kW

**Answer:** (A)

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Q15.

**Solution**

**Concept:** The binding energy per nucleon ( $E_b/A$ ) is a key parameter in nuclear physics that measures nuclear stability. It is calculated by dividing the total nuclear binding energy—the energy released when assembling a nucleus from its constituent protons and neutrons—by the mass number  $A$ . Plotting  $E_b/A$  against the mass number creates the curve of binding energy, which features a distinct peak for intermediate-mass nuclei.

**Step 1:** Light nuclei ( $A < 20$ ) exhibit low binding energy per nucleon, making them candidates for energy-releasing nuclear fusion reactions. Heavy nuclei ( $A > 100$ ) also show lower binding energy values because long-range Coulomb repulsion destabilizes the large nucleus, making them prone to nuclear fission.

**Step 2:** The curve peaks for medium-mass nuclei with mass numbers between  $A \approx 50$  and  $A \approx 80$ . This region corresponds to the most tightly bound and stable isotopes, such as iron ( $^{56}\text{Fe}$ ).

**Step 3:** For these highly stable transition-metal nuclei, the maximum binding energy per nucleon reaches approximately 8.5 MeV, defining the peak stability threshold.

**Final Answer:** 8.5 MeV

**Answer:** (C)

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Q16.

**Solution**

**Concept:** The electrical resistance of a uniform, homogeneous cylindrical conductor depends on its intrinsic material properties and its geometric dimensions, as described by the equation  $R = \rho L/A$ . Here,  $\rho$  represents the material resistivity,  $L$  is the length, and  $A$  is the cross-sectional area. When a malleable wire undergoes plastic deformation like axial stretching, its overall physical volume remains perfectly constant ( $V = A \times L = \text{constant}$ ). This volume conservation links changes in length directly to changes in cross-sectional area.

**Step 1:** The baseline configuration has a resistance of  $R = \rho L/A$ . When the wire is stretched uniformly to double its original length, its new length becomes  $L' = 2L$ .

**Step 2:** Because the volume must remain constant ( $A'L' = AL$ ), doubling the length forces the cross-sectional area to drop to half its original value ( $A' = A/2$ ).

**Step 3:** Substituting these new dimensions into the resistance formula gives:  $R' = \rho L'/A' = \rho(2L)/(A/2) = 4(\rho L/A) = 4R$ . This shows the total resistance increases fourfold.

**Final Answer:** 4R

**Answer:** (C)

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Q17.

**Solution**

**Concept:** In kinematics, the mechanical work performed by a vector force field along a displacement path is given by the dot product  $W = \vec{F} \cdot \vec{d} = Fd \cos \theta$ , where  $\theta$  is the angle between the force and displacement vectors. For an object in uniform circular motion, the centripetal force acts radially inward toward the rotation center, while its instantaneous displacement is directed tangentially along the arc. This makes the force and displacement vectors perpendicular at every point ( $\theta = 90^\circ$ ).

**Step 1:** Because the centripetal force vector  $\vec{F}_c$  acts radially inward, it is always perpendicular to the instantaneous tangential velocity vector  $\vec{v}$ , meaning  $\theta = 90^\circ$ .

**Step 2:** Substituting this right angle into the dot product gives  $W = Fd \cos 90^\circ = 0\text{J}$ . This shows that the centripetal force performs zero work over any arc length.

**Step 3:** If this radial constraint force is suddenly removed, no net force remains to change the object's direction. According to Newton's first law of motion, the body will continue moving in a straight line tangent to its circular path.

**Final Answer:** Work is zero because  $F \perp d$ ; *body flies off tangentially without centripetal force.*

**Answer:** (See above)

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**Q18.**

**Solution**

**Concept:** This problem addresses fundamental principles of wave mechanics, specifically wave interference and boundary conditions. A stationary wave is a spatial interference pattern formed by the superposition of two identical wave trains traveling in opposite directions through a medium. This superposition creates points of zero and maximum oscillation. Additionally, diffraction describes how wavefronts distort and spread when interacting with structural boundaries.

**Step 1:** In a stationary wave, the locations where complete destructive interference occurs are called nodes. At these points, the medium remains completely at rest, while adjacent positions called antinodes oscillate with maximum amplitude.

**Step 2:** When a wavefront encounters an obstacle, edge, or narrow aperture whose dimensions are comparable to its wavelength, the wave bends around the obstacle into its geometric shadow. This wave behavior is known as diffraction.

**Final Answer:** nodes; diffraction

**Answer: (See above)**

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**Q19.**

**Solution**

**Concept:** In a single-loop series circuit network, charge conservation requires that the exact same electrical current flows through every connected component. The total equivalent resistance of resistors wired in a series configuration is calculated by summing their individual values ( $R_{\text{total}} = R_1 + R_2$ ). Once this total resistance is found, the current can be calculated by applying Ohm's law ( $I = V/R_{\text{total}}$ ), and the potential drop across any individual resistor can be determined using  $V_R = IR$ .



**Step 1:** The circuit diagram shows a 12 V voltage source connected to two series resistors ( $R_1 = 4\ \Omega$  and  $R_2 = 6\ \Omega$ ). The total resistance is:  $R_{\text{total}} = 4 + 6 = 10\ \Omega$ .

**Step 2:** Using Ohm's law, we find the steady-state current flowing through the circuit loop:  $I = V/R_{\text{total}} = 12\ \text{V}/10\ \Omega = 1.2\ \text{A}$ .

**Step 3:** The voltage drop across the  $6\ \Omega$  resistor can be found by applying Ohm's law locally:  $V_2 = I \times R_2 = 1.2\ \text{A} \times 6\ \Omega = 7.2\ \text{V}$ .

**Final Answer:**  $I = 1.2\ \text{A}$ ;  $V_{6\Omega} = 7.2\ \text{V}$

**Answer: (See above)**

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Q20.

### Solution

**Concept:** In thermodynamics, fluid systems undergo specific processes defined by which state variables remain constant. An isobaric process is a thermodynamic transformation during which the system's pressure is held perfectly constant ( $\Delta P = 0$ ). The energy balance for this expansion is governed by the first law of thermodynamics, written as  $\Delta U = Q - W$ , where  $W$  represents the mechanical work performed by the system as its volume changes.

**Step 1:** The prefix “iso-” means equal or constant, and the root “baric” relates to pressure. Therefore, an isobaric process is defined as one where the system's pressure remains constant throughout the transformation.

**Step 2:** In the first law equation  $\Delta U = Q - W$ , the term  $W$  measures the mechanical boundary work performed by the working substance on its surroundings. When the gas expands, it performs positive work on the external environment.

**Final Answer:** pressure; by

**Answer:** (See above)

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Q21.

### Solution

**Concept:** This problem links core laws of fluid statics and dynamics to their operational definitions. Pascal's law states that any external static pressure applied to a confined fluid is transmitted equally throughout the fluid in all directions. Archimedes' principle asserts that any object fully or partially submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid it displaces. Stokes' law quantifies the viscous retarding force acting on small spherical particles moving through a fluid medium. Torricelli's theorem determines the exit speed of a fluid through an opening under gravity.

**Step 1:** Matching (a) with (ii): Pascal's law forms the bedrock of hydraulic engineering, demonstrating that localized pressure changes are transmitted undiminished through an enclosed fluid.

**Step 2:** Matching (b) with (iii): Archimedes' principle links the upward buoyant force directly to the weight of the fluid pushed aside by a submerged mass.

**Step 3:** Matching (c) with (i): Stokes' law states that the viscous drag opposing a falling sphere scales with velocity, leading to a constant terminal velocity.

**Step 4:** Matching (d) with (iv): Torricelli's theorem applies Bernoulli's equation to find the speed of efflux from a small hole:  $v = \sqrt{2gh}$ .

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

**Answer:** (See above)

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Q22.

**Solution**

**Concept:** Extrinsic semiconductor fabrication involves adding foreign impurities into a pure tetravalent crystal lattice to alter its electrical behavior. Introducing pentavalent donor elements into silicon supplies extra free conduction electrons, establishing an *n*-type semiconductor where electrons are the majority carriers. In transistor circuit theory, the common-base (CB) current amplification factor ( $\alpha$ ) describes the fraction of charge carriers that cross from the emitter to the collector. It is bounded by the current distribution across the device nodes.

**Step 1:** Doping a semiconductor with a pentavalent impurity introduces atoms with five valence electrons. Four form covalent bonds, while the fifth becomes a free charge carrier, making it an *n*-type material.

**Step 2:** According to Kirchhoff’s current law, the total input emitter current entering a transistor equals the sum of the collector and base currents:  $I_E = I_C + I_B$ .

**Step 3:** Because a small fraction of carriers always recombines in the base ( $I_B > 0$ ), the output collector current must be strictly smaller than the emitter current ( $I_C < I_E$ ). The ratio  $\alpha = I_C/I_E$  is therefore always less than unity.

**Final Answer:** *n*; less

Answer: (See above)

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Q23.

**Solution**

**Concept:** The Bohr model of atomic structure evaluates the discrete energy landscapes of orbiting electrons. The total mechanical energy ( $E_n$ ) of an electron in a stable hydrogenic orbit is given by  $E_n = -13.6/n^2$  eV. This negative value indicates that the electron is bound within the positive potential well of the nucleus. In nuclear physics, high-yield energy release happens through two distinct processes: fission, which splits massive elements, and fusion, which combines light ones.

**Step 1:** The mathematical expression  $E_n = -13.6/n^2$  eV produces negative values for all valid principal quantum integers ( $n = 1, 2, 3, \dots$ ). This negative sign confirms that the electron is trapped in a bound state, making the first statement TRUE.

**Step 2:** The second statement describes nuclear fission as combining light nuclei together. However, nuclear fission is explicitly defined as the splitting of a heavy, unstable nucleus into lighter fragments. It is nuclear fusion that combines light nuclei into a heavier one. Therefore, the second statement is FALSE.

**Final Answer:** T; F

Answer: (See above)

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Q24.

### Solution

**Concept:** This section connects foundational electrodynamic principles with their defining mathematical formulations. Ohm's law establishes a linear relationship between potential difference and electrical current in standard conductors. Kirchhoff's junction rule applies the conservation of electric charge to circuit nodes. The Lorentz force equation defines the mechanical force exerted on a moving charge by an external magnetic field. The Biot-Savart law calculates the differential magnetic field generated by an isolated differential current element.

**Step 1:** Matching (a) with (ii): Ohm's law defines linear electrical resistance, stating that voltage drop scales directly with current through the equation  $V = IR$ .

**Step 2:** Matching (b) with (iii): Kirchhoff's junction rule asserts that the net current entering any node equals the net current leaving it, enforcing charge conservation.

**Step 3:** Matching (c) with (i): The Lorentz force equation describes the deflecting mechanical force acting on a charge moving through a magnetic field:  $\vec{F} = q(\vec{v} \times \vec{B})$ .

**Step 4:** Matching (d) with (iv): The Biot-Savart law provides the inverse-square vector equation for the field due to a current element:  $d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \hat{r}}{r^2}$ .

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

Answer: (See above)

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Q25.

### Solution

**Concept:** Wave optics examines the non-linear propagation of wavefronts when they encounter boundaries or openings. Optical diffraction is a wave phenomenon that occurs when a wavefront bends around the sharp edges of an obstacle or narrow aperture, spreading light energy into areas of geometric shadow. In Young's double-slit interference experiments (YDSE), the spatial separation between adjacent constructive intensity fringes is called the fringe width, defined by the formula  $\beta = \lambda D/d$ .

**Step 1:** When light encounters a narrow slit with a width comparable to its wavelength, it does not travel in straight geometric lines. Instead, the wavefront distorts at the edges and spreads out, an effect known as diffraction.

**Step 2:** The structural arrangement of an interference experiment determines its fringe width via  $\beta = \lambda D/d$ , where  $D$  is the screen distance and  $d$  is the slit separation.

**Step 3:** Assuming the physical geometry of the apparatus ( $D$  and  $d$ ) remains fixed, the fringe width  $\beta$  is directly proportional to the wavelength  $\lambda$ . Longer wavelengths produce wider interference patterns.

**Final Answer:** diffraction; wavelength

Answer: (See above)

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Q26.

**Solution**

**Concept:** Classical Newtonian mechanics describes force and motion through three foundational laws. Newton’s first law defines the intrinsic property of inertia. Newton’s second law quantifies how an unbalanced force alters momentum over time ( $F = dp/dt$ ). Newton’s third law states that forces always occur in equal and opposite action-reaction pairs. The law of conservation of linear momentum states that the total momentum of a system remains constant if it is isolated from external forces.

**Step 1:** Matching (a) with (iii): Newton’s first law explains that an object resists changes to its state of motion, introducing the concept of inertia.

**Step 2:** Matching (b) with (i): Newton’s second law relates force to the time rate of change of linear momentum, yielding the equation  $F = dp/dt$ .

**Step 3:** Matching (c) with (ii): Newton’s third law requires that forces occur in pairs, meaning every action triggers an equal and opposite reaction.

**Step 4:** Matching (d) with (iv): Momentum conservation applies to any system where the net external force is zero, keeping total momentum constant.

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

**Answer:** (See above)

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Q27.

**Solution**

**Concept:** Electrical conduction in metallic solids relies on free electrons navigating through a periodic crystalline lattice. The material resistivity is governed by electron scattering events against these lattice ions. In electromagnetic induction, transformers change alternating voltage levels between coupled circuits. A step-up transformer increases the voltage from its primary input coils to its secondary output coils based on the turn ratio ( $N_s > N_p$ ).

**Step 1:** Raising the temperature of a metal increases the thermal kinetic energy of its lattice ions, causing them to vibrate more intensely. These larger vibrations increase electron scattering events, which raises electrical resistivity. This makes the first statement TRUE.

**Step 2:** A step-up transformer is designed to increase alternating voltage, meaning its secondary output voltage must exceed its primary input voltage ( $V_s > V_p$ ). Because the statement asserts that the output voltage of a step-up transformer is less than its input voltage, it is FALSE.

**Final Answer:** T; F

**Answer:** (See above)

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Q28.

### Solution

**Concept:** This problem matches specialized semiconductor devices with their primary applications. A Zener diode is heavily doped to exploit reverse-bias breakdown, which provides a stable voltage reference. A transistor in a common-emitter (CE) circuit configuration functions as a small-signal current and voltage amplifier. A solar cell is a large-area photodiode that converts incident photon energy directly into electrical energy. A logic gate processes binary inputs to perform Boolean algebraic operations.

**Step 1:** Matching (a) with (ii): A Zener diode operates in its reverse breakdown region, maintaining a constant voltage that makes it ideal for voltage regulation.

**Step 2:** Matching (b) with (i): A bipolar junction transistor in a common-emitter configuration provides high voltage and current gain, making it useful for signal amplification.

**Step 3:** Matching (c) with (iii): A solar cell absorbs incident photons to create electron-hole pairs, converting light energy into electrical power.

**Step 4:** Matching (d) with (iv): A logic gate is a basic building block of digital systems that evaluates binary inputs to execute a specific Boolean function.

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

**Answer: (See above)**

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Q29.

### Solution

**Concept:** Mechanical and acoustic resonance is a condition that occurs when a system is driven by an external periodic force whose frequency matches the system's own natural frequency of vibration. When these frequencies align, the energy transferred to the system is maximized. This efficient energy transfer causes the system to oscillate with a much larger amplitude than it would at other driving frequencies.

**Step 1:** Resonance occurs when the driving frequency matches the system's natural frequency. At this point, the driving force acts in phase with the system's velocity, continuously adding energy and maximizing the oscillation amplitude.

**Step 2:** A classic everyday example of this phenomenon is pushing a child on a playground swing. If you time your pushes to match the natural swinging frequency of the system, each push adds energy in phase with the motion.

**Step 3:** This synchronized timing causes the swing's displacement amplitude to increase dramatically with very little effort. Pushing at a different frequency would oppose the motion and damp the oscillations.

**Final Answer:** Resonance = max amplitude at natural frequency; example: swing pushed in sync.

**Answer: (See above)**

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Q30.

### Solution

**Concept:** Newton's second law of motion states that the net force acting on an object equals the time rate of change of its linear momentum. For an object of constant mass  $m$  changing its velocity from an initial value  $u$  to a final value  $v$  over a time interval  $t$ , this relationship can be written using the average linear acceleration:  $F = m\Delta v/t = m(v - u)/t$ . The braking force required to slow a vehicle is determined by this change in momentum.

**Step 1:** The problem provides the following parameters: a vehicle mass of  $m = 1000$  kg, an initial velocity of  $u = 20$  m s<sup>-1</sup>, a final velocity of  $v = 0$  m s<sup>-1</sup> (rest), and a braking time of  $t = 5$  s.

**Step 2:** Substituting these values into the average force equation gives:  $F = 1000$  kg  $\times$   $(0$  m s<sup>-1</sup> -  $20$  m s<sup>-1</sup>)/ $5$  s =  $1000 \times (-20)/5$ .

**Step 3:** Solving this expression yields a net force of  $F = -4000$  N. The negative sign indicates that the braking force acts in the opposite direction of the initial velocity to slow the vehicle. The magnitude of this average force is 4000 N.

**Final Answer:** 4000 N

**Answer:** (See above)

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Q31.

### Solution

**Concept:** The electrical property known as capacitance quantifies the intrinsic ability of a physical conductor or an arrangement of isolated conducting plates to store separated electric charge per unit of applied potential difference. For a network of multiple independent capacitors connected in a single-loop series configuration, the equivalent system capacitance diminishes and is mathematically calculated using the reciprocal sum formula:  $1/C_{eq} = 1/C_1 + 1/C_2$ . A key feature of a series configuration is that conservation of charge requires the absolute magnitude of the accumulated charge on each individual capacitor to be identical.

**Alternative (i): Step 1:** Electrical capacitance is defined fundamentally as the ratio of the total electric charge  $Q$  residing on either conductor to the resulting potential difference  $V$  developed between them, expressed as  $C = Q/V$ .

**Step 2:** The standard SI unit of capacitance is the farad, represented by the symbol F. One farad corresponds to one coulomb of charge stored per volt of potential drop ( $1$  F =  $1$  C/V).

**Alternative (ii): Step 1:** Given two capacitors of values  $C_1 = 4$   $\mu$ F and  $C_2 = 6$   $\mu$ F connected in series, we substitute them into the reciprocal formula:  $1/C_{eq} = 1/4 + 1/6 = (3+2)/12 = 5/12$   $\mu$ F<sup>-1</sup>, which yields  $C_{eq} = 12/5 = 2.4$   $\mu$ F.

**Step 2:** Because the capacitors are in series, the charge on each is identical to the net system charge:  $Q = C_{eq} \times V = 2.4$   $\mu$ F  $\times$   $100$  V =  $240$   $\mu$ C.

**Final Answer:**  $C = Q/V$ , SI unit: farad (F);  $C_{eq} = 2.4$   $\mu$ F,  $Q = 240$   $\mu$ C

**Answer:** (See above)

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Q32.

**Solution**

**Concept:** This problem addresses wave optics and boundary behavior at optical interfaces. The critical angle is defined as the specific angle of incidence inside an optically denser medium for which the corresponding angle of refraction in the adjacent rarer medium is exactly a right angle ( $r = 90^\circ$ ), causing the refracted light ray to graze along the boundary interface. Brewster’s law describes wave polarization during reflection, stating that the tangent of the specific polarizing angle of incidence equals the refractive index of the medium ( $\tan i_p = n$ ).

**Alternative (i): Step 1:** The critical angle  $i_c$  is the minimum angle of incidence in a denser optical medium that results in a refraction angle of  $90^\circ$  in the rarer medium.

**Step 2:** Applying Snell’s law at this boundary gives  $n_1 \sin i_c = n_2 \sin 90^\circ = n_2$ , leading to  $\sin i_c = n_2/n_1$ . When light transitions into air ( $n_2 = 1$ ), this relationship simplifies to the inverse form:  $\sin i_c = 1/n$ .

**Alternative (ii): Step 1:** Linear polarization is an optical phenomenon where the transverse electric field vector of a light wave is restricted to oscillate within a single geometric plane perpendicular to its propagation direction.

**Step 2:** Brewster’s law states that when unpolarized light strikes an interface at a polarizing angle  $i_p$  such that  $\tan i_p = n$ , the reflected light becomes perfectly plane-polarized.

**Final Answer:**  $\sin i_c = 1/n$ ;  $\tan i_p = n$

**Answer: (See above)**

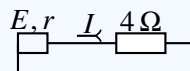
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Q33.

**Solution**

**Concept:** A practical chemical cell or voltage source possesses both an intrinsic electromotive force ( $E$ ) and an internal resistance ( $r$ ) that arises from the physical properties of its internal electrolytes and electrodes. When this cell is connected across an external load resistor ( $R$ ) to form a complete closed-loop circuit, the total loop resistance dictates the current. The steady-state electrical current can be calculated by applying Ohm’s law to the complete circuit:  $I = E / (R + r)$ . The actual terminal voltage ( $V$ ) available across the external load is reduced by the internal voltage drop:  $V = E - Ir = IR$ .



**Step 1:** The circuit has an external resistance  $R = 4\Omega$  connected to a cell with  $E = 10\text{ V}$  and  $r = 1\Omega$ . The combined total resistance of this series loop is  $R + r = 4 + 1 = 5\Omega$ .

**Step 2:** Using Ohm’s law for the entire loop, the current flowing through the circuit is:  $I = E / (R + r) = 10\text{ V} / 5\Omega = 2\text{ A}$ .

**Step 3:** The terminal voltage across the cell drops because of its internal resistance:  $V = E - Ir = 10\text{ V} - (2\text{ A} \times 1\Omega) = 8\text{ V}$ . Alternatively, using the external load gives  $V = IR = 2\text{ A} \times 4\Omega = 8\text{ V}$ .

**Final Answer:**  $I = 2\text{ A}$ ,  $V = 8\text{ V}$

**Answer:** (See above)

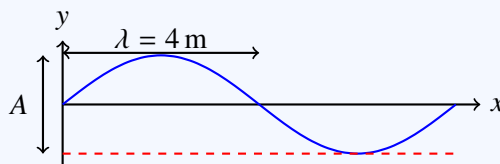
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Q34.

**Solution**

**Concept:** A transverse wave is a periodic disturbance traveling through a medium where the individual particles oscillate perpendicular to the direction of wave propagation. The wave profile can be characterized by its geometric dimensions: the wave amplitude ( $A$ ) is the maximum displacement of a particle from its equilibrium mean position, the wavelength ( $\lambda$ ) is the spatial distance required for one complete repeating oscillation cycle, and the frequency ( $f$ ) represents the number of complete cycles passing a fixed point per unit time, given by  $f = v/\lambda$ .



**Step 1:** Analyzing the provided wave diagram shows that the maximum vertical displacement from the central equilibrium axis is 1.0 m. Therefore, the wave amplitude is  $A = 1.0$  m.

**Step 2:** The spatial tracking along the horizontal axis shows that the waveform completes one full sinusoidal cycle over a distance of 4 m. This identifies the wavelength as  $\lambda = 4$  m.

**Step 3:** Given a wave propagation velocity of  $v = 8 \text{ m s}^{-1}$ , we use the wave speed relation to isolate and calculate the frequency:  $f = v/\lambda = 8 \text{ m s}^{-1}/4 \text{ m} = 2 \text{ Hz}$ .

**Final Answer:**  $A = 1.0$  m,  $\lambda = 4$  m,  $f = 2$  Hz

**Answer:** (See above)

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Q35.

**Solution**

**Concept:** The Bohr model of the atom introduced non-classical postulates to explain the stability of hydrogenic structures and their discrete emission spectra. It proposed stable orbits, quantized momentum, and energy transitions. In nuclear physics, high-yield energy changes occur via two different mechanisms: nuclear fission, which involves breaking apart massive elements, and nuclear fusion, which involves combining light elements.

**Alternative (i): Step 1:** Postulate 1 states that electrons revolve around a central positive nucleus only in specific, non-radiating circular paths known as stationary orbits.

**Step 2:** Postulate 2 asserts that the orbital angular momentum of an electron is restricted to integral multiples of modified Planck’s constants:  $mvr = nh/2\pi$ , where  $n = 1, 2, 3, \dots$

**Step 3:** Postulate 3 establishes that electromagnetic radiation is emitted or absorbed only when an electron jumps between these orbits, satisfying the energy balance  $h\nu = E_i - E_f$ .

**Alternative (ii): Step 1:** Nuclear fission is a process where a heavy, unstable nucleus (like uranium-235) splits into lighter product nuclei after capturing a neutron, releasing energy.

**Step 2:** Fission splits massive isotopes apart, whereas fusion combines light isotopes (like hydrogen) into heavier ones. Both release energy based on mass defects, but fission produces long-lived radioactive waste.

**Final Answer:** Bohr: stationary orbits,  $mvr=nh/2\pi, h\nu = E_i - E_f$ ; Fission splits heavy, fusion combines light nuclei.

**Answer: (See above)**

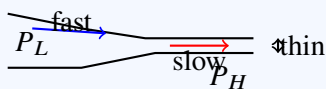
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Q36.

**Solution**

**Concept:** Bernoulli’s principle describes the conservation of mechanical energy in fluid dynamics for the steady, streamline flow of an ideal, incompressible, non-viscous fluid. It states that the total mechanical energy along a streamline—composed of fluid pressure energy, translational kinetic energy density, and gravitational potential energy density—must remain constant:  $P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ . This principle explains how changes in fluid velocity generate perpendicular pressure differences across asymmetric structures.



**Step 1:** Bernoulli’s energy conservation equation states that for a fluid moving along a horizontal streamline ( $\Delta h = 0$ ), any local increase in flow velocity must be accompanied by a simultaneous decrease in local static pressure.

**Step 2:** An aircraft wing or airfoil features an asymmetric cross-section that forces oncoming air to travel faster over its curved upper surface than across its flatter lower surface ( $v_{\text{top}} > v_{\text{bottom}}$ ).

**Step 3:** According to Bernoulli’s relation, this velocity imbalance creates a low-pressure zone on top ( $P_L$ ) and a high-pressure zone underneath ( $P_H$ ). This pressure difference generates a net upward aerodynamic lift force.

**Final Answer:**  $P + \frac{1}{2}\rho v^2 + \rho gh = \text{const.}$  *air foil: faster flow on top  $\Rightarrow$  lower pressure  $\Rightarrow$  upward lift.*

**Answer:** (See above)

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Q37.

### Solution

**Concept:** An adiabatic process is a thermodynamic transformation during which a working gas system changes its state variables without exchanging any heat energy with its surroundings ( $Q = 0$ ). For an ideal gas undergoing a reversible adiabatic process, its state variables are governed by the classical Poisson relation:  $TV^{\gamma-1} = \text{constant}$ . Here,  $T$  represents the absolute temperature,  $V$  is the system volume, and  $\gamma$  is the adiabatic index. When a gas is compressed adiabatically, work is done on the system, which directly increases its internal energy and temperature.

**Step 1:** The initial system state parameters are an absolute temperature of  $T_1 = 300 \text{ K}$  and a gas volume of  $V_1$ . The gas is compressed to a final volume of  $V_2 = V_1/4$ . The ratio of specific heats is given as  $\gamma = 1.4$ .

**Step 2:** Setting up the adiabatic equation between the states gives:  $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$ . Rearranging this expression to isolate the final temperature yields:  $T_2 = T_1(V_1/V_2)^{\gamma-1}$ .

**Step 3:** Substituting the parameters into this relation gives:  $T_2 = 300 \times (V_1/(V_1/4))^{1.4-1} = 300 \times 4^{0.4}$ . Evaluating this power gives  $4^{0.4} \approx 1.7411$ , which yields a final temperature of  $T_2 = 300 \times 1.7411 \approx 522 \text{ K}$ .

**Final Answer:**  $\approx 522 \text{ K}$

Answer: (See above)

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Q38.

### Solution

**Concept:** This problem addresses solid-state device physics and semiconductor doping. An extrinsic semiconductor is formed by deliberately incorporating specific trace impurities into a pure, intrinsic semiconductor crystal lattice to control its electrical conductivity. An  $n$ -type semiconductor is a specific class of extrinsic material fabricated by introducing pentavalent dopant atoms, which creates an abundance of free conduction electrons. A transistor is a three-terminal semiconductor device that manages current flow to perform electronic amplification and switching.

**Step 1:** An extrinsic semiconductor uses intentional doping to increase carrier concentrations. For instance, replacing group-IV silicon atoms with group-V phosphorus atoms adds free charge carriers and significantly boosts conductivity.

**Step 2:** An  $n$ -type semiconductor is created by doping an intrinsic material with pentavalent elements (such as arsenic or antimony). The impurity atom donates an extra electron to the conduction band, making electrons the majority carriers.

**Step 3:** A bipolar junction transistor consists of three sequentially doped regions: the emitter, base, and collector. This configuration allows a small base current to modulate a larger collector current, acting as an amplifier or switch.

**Final Answer:** Extrinsic: doped Si;  $n$ -type: As-doped Si; Transistor:  $n$ - $p$ - $n$  BJT.

Answer: (See above)

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Q39.

**Solution**

**Concept:** This problem covers geometric optics, focusing on image formation by spherical mirrors and thin refracting lenses. For a convex mirror, the focal length is positive ( $f > 0$ ) because its focal point lies behind the reflective surface, and its imaging behavior is governed by the mirror formula:  $1/f = 1/v + 1/u$ . For a thin optical system consisting of multiple coaxial lenses placed in direct contact, the net refractive power combines linearly, and the equivalent focal length is given by:  $1/f = 1/f_1 + 1/f_2$ .

**Alternative (i): Step 1:** A convex mirror has a focal length of  $f = +15$  cm and an object placed at  $u = -10$  cm. Substituting these values into the mirror equation gives:  $1/15 = 1/v + 1/(-10)$ .

**Step 2:** Isolating the image distance yields:  $1/v = 1/15 + 1/10 = (2 + 3)/30 = 5/30 = 1/6$ , which gives  $v = +6$  cm. The positive sign indicates that a virtual, erect, and diminished image forms 6 cm behind the mirror.

**Alternative (ii): Step 1:** Two thin lenses with focal lengths  $f_1 = +20$  cm and  $f_2 = -30$  cm are placed in contact. The equivalent focal length is:  $1/f = 1/20 + 1/(-30) = 3/60 - 2/60 = 1/60$ , yielding  $f = 60$  cm = 0.6 m.

**Step 2:** The net optical power is the reciprocal of the equivalent focal length in meters:  $P = 1/f = 1/0.6 \text{ m} \approx +1.67$  diopters.

**Final Answer:**  $v = +6$  cm (virtual, erect);  $f = 60$  cm,  $P = 1.67$  D

**Answer:** (See above)

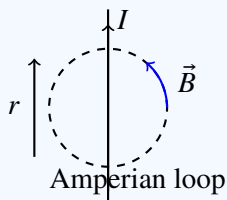
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Q40.

**Solution**

**Concept:** Ampere’s circuital law relates magnetic fields to electrical currents. It states that the line integral of a magnetic field vector  $\vec{B}$  around any closed macroscopic loop equals the permeability of free space  $\mu_0$  multiplied by the net enclosed current  $I_{\text{enc}}$  passing through the bounded surface, written as  $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$ . This law can be used to derive the magnetic field equation around symmetrical current geometries, such as an infinitely long straight wire.



**Step 1:** Consider a long, straight cylindrical wire carrying a steady current  $I$ . To calculate the magnetic field at a radial distance  $r$ , we define a circular Amperian loop of radius  $r$  centered on the conductor.

**Step 2:** By rotational symmetry, the magnetic field magnitude  $B$  is constant at all points along this path and points tangentially along the loop. The line integral simplifies to:  $\oint \vec{B} \cdot d\vec{l} = B \oint dl = B \times 2\pi r$ .

**Step 3:** Equating this result to Ampere’s law gives  $B \times 2\pi r = \mu_0 I$ . Isolating the field strength variable gives the final expression for the magnetic field:  $B = \frac{\mu_0 I}{2\pi r}$ .

**Final Answer:**  $B = \frac{\mu_0 I}{2\pi r}$

Answer: (See above)

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Q41.

**Solution**

**Concept:** Newton’s second law relates force to momentum change. For a variable force,  $F = dp/dt = m dv/dt$ . Conservation of energy relates PE and KE for free fall.

**Alternative (i): Step 1:**  $F = m dv/dt = 3t$ , so  $dv = (3t/5) dt$ . Integrating:  $v = \frac{3}{5} \frac{t^2}{2} = \frac{3t^2}{10}$ .

**Step 2:** At  $t = 4$  s:  $v = 3(16)/10 = 4.8 \text{ m s}^{-1}$ .

**Step 3:** Work done = change in KE =  $\frac{1}{2}mv^2 = \frac{1}{2}(5)(4.8)^2 = \frac{1}{2}(5)(23.04) = 57.6 \text{ J}$ .

**Alternative (ii): Step 1:** By conservation of energy:  $\frac{1}{2}mv^2 = mgh$ , so  $h = v^2/(2g)$ .

**Step 2:**  $h = (20)^2/(2 \times 10) = 400/20 = 20 \text{ m}$ .

**Final Answer:**  $v = 4.8 \text{ m s}^{-1}$ ,  $W = 57.6 \text{ J}$ ;  $h = 20 \text{ m}$

Answer: (See above)

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Q42.

**Solution**

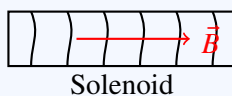
**Concept:** A solenoid produces a uniform magnetic field inside its core. Lenz’s law determines the direction of induced current. A p-n junction conducts in forward bias and blocks in reverse bias.

**Alternative (i):**

**(a) Solenoid field: Step 1:** Consider a long solenoid of length  $L$ , total turns  $N$ , carrying current  $I$ . Turns per unit length  $n = N/L$ .

**Step 2:** Apply Ampere’s circuital law to a rectangular loop of length  $l$  inside the solenoid:  $\oint \vec{B} \cdot d\vec{l} = \mu_0 n I l$ . The contribution from the interior side gives  $Bl$ , while the other sides contribute zero.

**Step 3:** Therefore  $B = \mu_0 n I$ , directed along the axis of the solenoid.

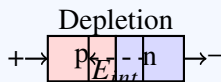


**(b) Lenz’s law:** The direction of induced current is such that it opposes the change in magnetic flux that produces it. This is consistent with conservation of energy because the induced current creates a force that opposes the motion, requiring external work to maintain the flux change.

**Alternative (ii):**

**(a) p-n junction: Step 1:** Forward bias: p-side connected to positive terminal, n-side to negative. Depletion layer narrows, barrier decreases, majority carriers flow, and a large current passes.

**Step 2:** Reverse bias: p-side to negative, n-side to positive. Depletion layer widens, barrier increases, only a small reverse saturation current flows due to minority carriers.



**(b) Truth tables:**

| A | B | AND: Y | A | B | OR: Y |
|---|---|--------|---|---|-------|
| 0 | 0 | 0      | 0 | 0 | 0     |
| 0 | 1 | 0      | 0 | 1 | 1     |
| 1 | 0 | 0      | 1 | 0 | 1     |
| 1 | 1 | 1      | 1 | 1 | 1     |

**Final Answer:**  $B = \mu_0 n I$ ; Lenz’s law opposes flux change; Forward bias conducts, reverse blocks; truth tables shown.

**Answer: (See above)**

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Q43.

**Solution**

**Concept:** The thin lens formula, Malus' law for polarisation, Einstein's photoelectric equation, Bohr's energy levels, and radioactive decay are key topics in optics and modern physics.

**Alternative (i):**

**(a) Image by convex lens: Step 1:** Using lens formula:  $1/f = 1/v - 1/u$ . Here  $u = -30$  cm,  $f = +20$  cm.

**Step 2:**  $1/20 = 1/v - 1/(-30) = 1/v + 1/30$ . So  $1/v = 1/20 - 1/30 = (3 - 2)/60 = 1/60$ , giving  $v = +60$  cm.

**Step 3:** Magnification:  $m = v/u = 60/(-30) = -2$ . Image is real, inverted, and magnified, located 60 cm from the lens.

**(b) Malus' law:** When plane-polarised light of intensity  $I_0$  passes through an analyser at angle  $\theta$  to the polarisation direction, the transmitted intensity is  $I = I_0 \cos^2 \theta$ .

**(c) Photoelectric equation:**  $h\nu = \phi + K_{\max}$ , where  $\phi$  is the work function (minimum energy needed to free an electron) and  $K_{\max} = h\nu - \phi$ .

**Alternative (ii):**

**(a) Bohr energy: Step 1:** In the  $n$ -th orbit, kinetic energy  $K_n = \frac{1}{2}m_e v_n^2 = \frac{me^4}{8\epsilon_0^2 n^2 h^2}$  and potential energy  $U_n = -2K_n$ .

**Step 2:** Total energy:  $E_n = K_n + U_n = K_n - 2K_n = -K_n = -\frac{me^4}{8\epsilon_0^2 n^2 h^2} = -\frac{13.6}{n^2}$  eV.

**(b) Decay constant:**  $\lambda = 0.693/T_{1/2} = 0.693/(5.27 \times 365.25 \times 24 \times 3600) \text{ s}^{-1}$ .

$\lambda = 0.693/(1.664 \times 10^8) = 4.16 \times 10^{-9} \text{ s}^{-1}$ .

**(c) Application of nuclear fission:** Nuclear power plants use controlled fission of  $^{235}\text{U}$  to generate electricity.

**Final Answer:**  $v = 60$  cm,  $m = -2$ ; Malus:  $I = I_0 \cos^2 \theta$ ;  $h\nu = \phi + K_{\max}$ ;  $E_n = -13.6/n^2$  eV;  $\lambda \approx 4.16 \times 10^{-9} \text{ s}^{-1}$ ; fission used in nuclear reactors.

**Answer: (See above)**

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**Answer Key**

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

