UP Board Class 12 Physics 2024 (Code 346 FW) Question Paper with Solutions

collegedunia

General Instructions

(i) This booklet contains 9 questions, each provided with a complete, step-by-step solution.

(ii) It has multiple-choice questions as well as questions that need a written answer.

(iii) Attempt each question on your own before reviewing the given solution.

1(a).

The unit of magnetic field is

(A) $\text{newton} \cdot \text{metre}^{-1} \cdot \text{ampere}^{-1}$

(B)

(ii) $\text{newton} \cdot \text{metre}^{-2} \cdot \text{ampere}^{-2}$

(C)

(iii) $\text{newton} \cdot \text{metre}^{-2} \cdot \text{ampere}^{-1}$

(D)

(iv) $\text{newton} \cdot \text{metre}^{-1} \cdot \text{ampere}^{-2}$

Correct Answer: (A) $\text{newton} \cdot \text{metre}^{-1} \cdot \text{ampere}^{-1}$

Solution:

The unit of magnetic field is derived from the definition of force $F = q(\mathbf{v} \times \mathbf{B})$, where magnetic force $B = \frac{F}{qv}$. In terms of SI units:

$$B = \frac{\text{N}}{\text{A} \cdot \text{m}} \quad \Rightarrow \quad \text{newton} \cdot \text{metre}^{-1} \cdot \text{ampere}^{-1}.$$

Quick Tip: The SI unit of the magnetic field (B) is Tesla, which is equivalent to **newton · metre^{-1} · ampere^{-1}**.

1(b).

If the radius of the nucleus of $^{13}Al^{27}$ is 3.6 fermi, then the radius of the nucleus of $^{52}Te^{125}$ is:

(A) 8 fermi

(B) 6 fermi

(C) 5 fermi

(D) 4 fermi

Correct Answer: (B) 6 fermi

Solution:

The radius of a nucleus is proportional to the cube root of its mass number (A):

$$R \propto A^{1/3}.$$

For $^{13}Al^{27}$,

$$R_1 = 3.6\,\text{fermi}, \quad A_1 = 27, \quad A_2 = 125.$$

$$\frac{R_2}{R_1} = \left(\frac{A_2}{A_1}\right)^{1/3} \quad \Rightarrow \quad R_2 = R_1 \cdot \left(\frac{125}{27}\right)^{1/3}.$$

$$R_2 = 3.6 \cdot 2 \quad \Rightarrow \quad R_2 = 6 \text{ fermi.}$$

Quick Tip: The nuclear radius is proportional to $A^{1/3}$, where A is the mass number.

1(c).

Which of the following laws of conservation holds in Einstein's photoelectric equation?

(A) Charge

(B) Mass

(C) Momentum

(D) Energy

Correct Answer: (D) Energy

Solution:

Einstein's photoelectric equation states that:

$$h\nu = \phi + K_{\text{max}},$$

where $h\nu$ is the energy of the incident photon, ϕ is the work function, and K_{max} is the maximum kinetic energy of the ejected electron. This conservation equation explicitly describes the conservation of energy.

Quick Tip: The law of conservation of energy is fundamental in all physical processes, including photoelectric emission.

1(d).

If V_L, V_R, V_C, and V_O are readings of AC voltmeter across the inductor, resistor, capacitor, and source respectively in a certain L-C-R circuit, then:

(A) $V_O = V_L + V_R + V_C$

(B)

$V_O = (V_L - V_C) + V_R$

(C)

($V_O^2 = V_L^2 + V_R^2 + V_C^2$

(D)

$V_O^2 = (V_L - V_C)^2 + V_R^2$

Correct Answer: (D)

$V_O^2 = (V_L - V_C)^2 + V_R^2$

Solution:

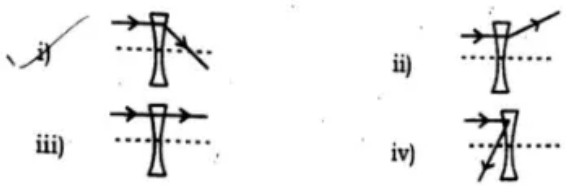
In an L-C-R circuit, the voltage V_O of the source is the vector sum of voltages across the resistor (V_R), inductor (V_L), and capacitor (V_C). Due to phase differences, the net voltage satisfies:

$$V_O^2 = (V_L - V_C)^2 + V_R^2.$$

Quick Tip: Use the phasor addition technique to derive voltage relationships in L-C-R circuits.

1(e).

Which of the following ray diagrams is correct, when n_1 is the refractive index of the medium and n_2 is of the lens material ($n_1 > n_2$)?



(A)

(B)

(C)

(D)

Correct Answer: (A)

Solution:

For $n_1 > n_2$, light rays bend away from the normal upon passing from a denser to a rarer medium. The first diagram (i) correctly demonstrates this refraction.

Quick Tip: The bending of light depends on the refractive index of the materials: it bends towards the normal when entering a denser medium and away when entering a rarer medium.

1(f).

The sides of two solid cubes of the same material are l and $3l$ respectively. The ratio of their resistances will be:

(A) 3 : 1

(B) 1 : 3

(C) 9 : 1

(D) 1 : 1

Correct Answer: (B) 1 : 3

Solution:

The resistance R of a material is given by:

$$R \propto \frac{1}{\text{Cross-sectional area}}.$$

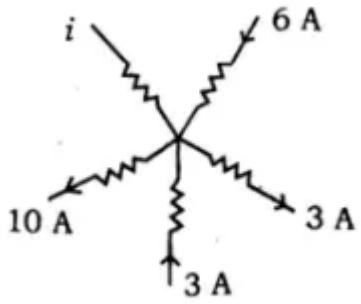
For a cube, the cross-sectional area scales with l^2, and resistance is inversely proportional to the square of the side length:

$$R_1 : R_2 = \frac{1}{l^2} : \frac{1}{(3l)^2} \quad \Rightarrow \quad R_1 : R_2 = 9 : 1.$$

Quick Tip: The resistance of a material is inversely proportional to its cross-sectional area.

2(a).

What is the magnitude of the current i in the given circuit?



Correct Answer: —

Solution:

Using Kirchhoff's Current Law (KCL), the sum of currents entering a junction equals the sum of currents leaving it:

$$i = (6\,\text{A} + 3\,\text{A}) - (10\,\text{A} + 3\,\text{A}) = 4\,\text{A}.$$

Quick Tip:

Kirchhoff's Current Law states that at any junction, the sum of currents entering equals the sum of currents leaving.

2(b).

What is Lenz's law?

Correct Answer: —

Solution:

Lenz's law states that the direction of the induced current is such that it opposes the change in magnetic flux that produced it.
When the magnetic flux linked with a circuit changes, an electromotive force (EMF) is induced, and the induced current opposes this change.

Quick Tip:

Lenz's law is a consequence of the principle of conservation of energy in electromagnetic induction.

2(c).

What is meant by the depletion layer in a *p*-*n* junction?

Correct Answer: —

Solution:

The depletion layer is the region around the *p*-*n* junction where mobile charge carriers are depleted, leaving behind immobile ions. In a *p*-*n* junction, due to diffusion, electrons and holes recombine near the junction, leaving behind a region with immobile ions. This region forms the depletion layer, acting as a potential barrier for current flow.

Quick Tip: The depletion layer thickness determines the behavior of the *p*-*n* junction under different biasing conditions.

2(d).

Find out the angle of refraction in a medium of refractive index $\sqrt{3}$, when the angle of incidence is $60°$.

Correct Answer: —

Solution:

Using Snell's law:

$$n_1 \sin i = n_2 \sin r,$$

where $n_1 = 1$ (air), $n_2 = \sqrt{3}$, $i = 60°$:

$$\sin r = \frac{n_1 \sin i}{n_2} = \frac{1 \times \sin 60°}{\sqrt{3}} = \frac{\sqrt{3}/2}{\sqrt{3}} = \frac{1}{2}.$$

Thus, $r = 30°$.

Quick Tip: Snell's law helps calculate refraction at the boundary between two media of different refractive indices.

2(e).

The amplitude of the magnetic field of an electromagnetic wave in vacuum is $B_0 = 510\,\text{nT}$. What is the amplitude of the electric field of the wave?

Correct Answer: —

Solution:

The amplitude of the electric field (E_0) and magnetic field (B_0) are related by:

$$E_0 = cB_0,$$

where $c = 3 \times 10^8$ m/s. Substituting the values:

$$E_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153\,\text{V/m}.$$

Quick Tip: In electromagnetic waves, the electric and magnetic fields are related by the speed of light: $E_0 = cB_0$.

2(f).

What is the main difference between paramagnetic and ferromagnetic substances?

Correct Answer: —

Solution:

Paramagnetic substances are weakly attracted by a magnetic field and do not retain magnetism, while ferromagnetic substances are strongly attracted and can retain magnetism.
- Paramagnetic substances have unpaired electrons and exhibit weak magnetic moments.
- Ferromagnetic substances have domains aligned in a magnetic field and show strong magnetic behavior even when the external field is removed.

Quick Tip: The retention of magnetism distinguishes ferromagnetic materials from paramagnetic materials.

3(a). Explain the energy bands in solids.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
An isolated atom has sharp, separate energy levels, and each level can hold only a fixed number of electrons. In a solid, about 10^{28} atoms per cubic metre sit very close to each other, so the outer orbits of neighbouring atoms overlap.
The Pauli exclusion principle says no two electrons in the solid can share the same energy state. So every single atomic level has to split into a huge number of levels that lie extremely close together.

Step 2: How a band forms:
Because the split levels are crowded so tightly (the spacing is of the order of 10^{-22} eV), they behave like a continuous strip of allowed energies. This strip is called an energy band.
Between two bands there can be a region of energies where no electron state exists. This region is called the forbidden energy gap, written E_g.

Step 3: The important bands:
Valence band: the band formed by the outer (valence) electron levels. At absolute zero it is completely filled in an insulator or semiconductor.

Conduction band: the band just above the valence band. Electrons in it are free to move through the crystal and carry current.
Forbidden gap: the energy difference $E_g = E_c - E_v$ between the bottom of the conduction band and the top of the valence band.

Step 4: Energy bands in conductors, insulators and semiconductors:
Picture the diagram with energy on the vertical axis. The valence band sits at the bottom, the conduction band above it, and the forbidden gap in between.
Conductor (metal): the conduction band is partly filled, or the valence and conduction bands overlap, so $E_g = 0$ and electrons move freely.
Insulator: the gap is large, $E_g > 3$ eV (diamond is about 5.4 eV). Thermal energy cannot lift electrons across, so the conduction band stays empty and no current flows.
Semiconductor: the gap is small, $E_g < 3$ eV (silicon 1.1 eV, germanium 0.67 eV). At room temperature some electrons get enough energy to cross the gap, leaving holes behind in the valence band, so a small current flows.

Final Answer:
Energy bands are the continuous ranges of allowed electron energies that form when atomic levels split in a solid. They are the valence band, the forbidden gap and the conduction band, and the size of the gap decides whether the solid is a conductor, a semiconductor or an insulator.

$$\boxed{\text{Valence band} + \text{forbidden gap } E_g + \text{conduction band}}$$

Quick Tip: Atomic levels split into closely spaced levels when atoms come together in a solid, forming bands.

Name the valence band, the conduction band and the forbidden gap, and link the size of the gap to conductors, semiconductors and insulators.

3(b).

State the conclusions of Rutherford's α-particle scattering experiment.

Correct Answer: —

Solution:

Rutherford's experiment concluded the existence of a small, dense, and positively charged nucleus at the center of the atom.
Key conclusions from the α-particle scattering experiment:
1. Most α-particles passed through the gold foil, indicating atoms are mostly empty space.
2. A few α-particles were deflected at small angles, suggesting a positively charged region in the atom.
3. Very few were deflected back, confirming that the nucleus is small, massive, and positively charged.

Quick Tip:

Rutherford's model of the atom replaced Thomson's "plum pudding" model by introducing the nucleus.

3(c).

If the corresponding de Broglie wavelengths of a proton and a neutron are obtained as same, then which of the two will have greater kinetic energy?

Correct Answer: —

Solution:

From de Broglie wavelengths formula:

$$\lambda = \frac{h}{\sqrt{2mK}},$$

where m is the mass and K is the kinetic energy. For the same wavelength:

$$K \propto \frac{1}{m}.$$

Since the proton has less mass than the neutron, its kinetic energy will be greater for the same wavelength.

Quick Tip: For the same de Broglie wavelength, a lighter particle will always have higher kinetic energy.

3(d).

A current is passed in a wire of $4\,\Omega$ resistance by a battery. Find out the internal resistance of the battery, when current is passed in another $9\,\Omega$ resistor by the same battery; while the same heat is produced during the same time in both wires.

Correct Answer: —

Solution:

Let the EMF of the battery be E and its internal resistance be r. The heat H is proportional to I^2R, where I is the current and R is the resistance. For both cases, the heat is equal:

$$I_1^2 \cdot 4 = I_2^2 \cdot 9.$$

Using Ohm's law:

$$I_1 = \frac{E}{4+r}, \quad I_2 = \frac{E}{9+r}.$$

Substituting these:

$$\left(\frac{E}{4+r}\right)^2 \cdot 4 = \left(\frac{E}{9+r}\right)^2 \cdot 9.$$

Simplifying:

$$\frac{4}{(4+r)^2} = \frac{9}{(9+r)^2}.$$

Taking the square root:

$$\frac{2}{4+r} = \frac{3}{9+r}.$$

Cross-multiplying:

$$2(9 + r) = 3(4 + r).$$

Expanding and solving:

$$18 + 2r = 12 + 3r \quad \Rightarrow \quad r = 6\,\Omega.$$

Quick Tip: The internal resistance of a battery affects the total current and power delivered to external resistors.

4(a).

A charge Q is distributed over two concentric hollow spheres of radii r and R ($R > r$) such that their surface charge densities are equal. Find the electric potential at their common center.

Correct Answer: —

Solution:

The surface charge density for both spheres is equal:

$$\sigma = \frac{Q_1}{4\pi r^2} = \frac{Q_2}{4\pi R^2}.$$

This implies that the charge on the inner sphere is:

$$Q_1 = \frac{Qr^2}{R^2}, \quad Q_2 = Q - Q_1 = Q\left(1 - \frac{r^2}{R^2}\right).$$

The potential at the common center is:

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{Q_1}{r} + \frac{Q_2}{R}\right).$$

Substituting values:

$$V = \frac{3Q}{4\pi\epsilon_0 R}.$$

Quick Tip: When dealing with concentric spheres, use charge distribution rules and superposition principles to calculate the potential.

4(b). What are electromagnetic waves ? Explain two characteristics of these waves.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

An accelerated charge produces a changing electric field, and a changing electric field produces a changing magnetic field. Maxwell showed these two fields can keep creating each other and travel through space on their own.

Electromagnetic waves are these waves. They are made of electric and magnetic fields that vary with time and position, and they carry energy from one place to another.

Step 2: Definition:

Electromagnetic waves are waves made of oscillating electric and magnetic fields. The two fields are perpendicular to each other and also perpendicular to the direction in which the wave travels.

For a wave moving along the x-axis, we can write $E_y = E_0 \sin(kx - \omega t)$ and $B_z = B_0 \sin(kx - \omega t)$.

Step 3: Characteristic 1, they are transverse waves:

The vectors $\vec{E}$, $\vec{B}$ and the direction of propagation are mutually perpendicular, so the wave is transverse. This is why electromagnetic waves can be polarised.
The two fields rise and fall together, in the same phase. At every point their magnitudes are related by $E_0/B_0 = c$.

Step 4: Characteristic 2, they need no medium and travel at speed c in vacuum:
Sound or water waves need matter to travel through. Electromagnetic waves do not, because each field keeps regenerating the other. Sunlight reaches us across empty space for this reason.
In vacuum all of them travel with the same speed

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}$$

In a material medium the speed becomes less than c.

Step 5: Other useful facts:
The waves carry energy and momentum, and they are not deflected by electric or magnetic fields because they carry no charge. The spectrum runs from radio waves to gamma rays, and all of them share the characteristics above.

Final Answer:
Electromagnetic waves are self-sustaining, transverse waves of oscillating, mutually perpendicular electric and magnetic fields. Two characteristics are that they are transverse with $E_0 = cB_0$, and that they travel in vacuum at $c = 3 \times 10^8$ m/s without needing any medium.

$$\boxed{c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}}$$

Quick Tip: Electromagnetic waves are oscillating, mutually perpendicular electric and magnetic fields travelling through space.
Pick two properties: transverse with $E_0 = cB_0$, and speed $c = 1/\sqrt{\mu_0 \varepsilon_0}$ in vacuum with no medium needed.

4(c).

What is Biot-Savart law? Obtain the formula and direction for the intensity of the magnetic field on the axis of an anti-clockwise current-carrying loop with its help.

Correct Answer: —

Solution:

The Biot-Savart law states that the magnetic field dB due to a small current element Idl at a point is given by:

$$dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}.$$

For a circular current loop, the magnetic field on its axis is:

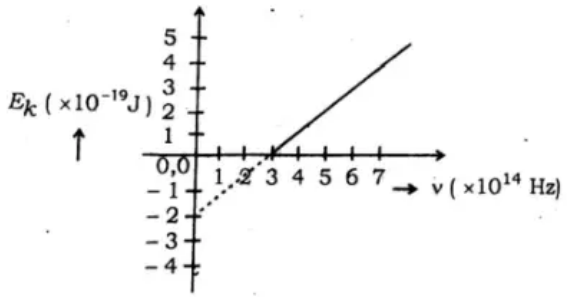
$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}},$$

where R is the radius of the loop, x is the distance from the center, and I is the current. The direction of the magnetic field follows the right-hand thumb rule.

Quick Tip: Use Biot-Savart law for problems involving magnetic fields due to current elements or loops.

4(d).

A graph is shown between the maximum kinetic energy (E_k) of emitted photoelectrons and frequency (ν) of the incident light in an experiment of the photoelectric effect. Find:
(i) Threshold frequency
(ii) Work function (in eV)
(iii) Planck's constant



Correct Answer: —

Solution:

From the graph: The threshold frequency (ν_0) is the x-intercept of the graph:

$$\nu_0 = 2.5 \times 10^{14}\ \text{Hz}.$$

The work function (ϕ) is given by:

$$\phi = h\nu_0 = (6.6 \times 10^{-34})(2.5 \times 10^{14}) = 1.65 \times 10^{-19}\ \text{J}.$$

Converting to eV:

$$\phi = \frac{1.65 \times 10^{-19}}{1.6 \times 10^{-19}} = 1\,\text{eV}.$$

\item From the slope of the graph, Planck's constant h is:

$$h = \frac{\Delta E_k}{\Delta \nu} = \frac{5 \times 10^{-19}}{7 \times 10^{14} - 2.5 \times 10^{14}} = 6.6 \times 10^{-34}\,\text{Js}.$$

Quick Tip: For photoelectric effect problems, use the equation $E_k = h(\nu - \nu_0)$ and determine values from the graph.

4(e).

Define the coefficient of mutual inductance.

The coefficient of mutual inductance (M) is a measure of the ability of one coil to induce an electromotive force (EMF) in a nearby coil due to a changing current in the first coil. It is given by:

$$e = -M\frac{di}{dt}$$

If a current $i = 10\sin(100\pi t)$ A is flowing in a primary coil, and the maximum induced electromotive force in the secondary coil placed near it is 5π volt, then the coefficient of mutual induction between these coils needs to be determined.

Correct Answer: —

Solution:

The maximum induced emf is related to mutual inductance M by:

$$\text{emf}_{\text{max}} = M\frac{di}{dt}.$$

For $i = 10\sin(100\pi t)$:

$$\frac{di}{dt} = 1000\pi\cos(100\pi t).$$

The maximum value of $\frac{di}{dt}$ is 1000π. Substituting values:

$$5\pi = M(1000\pi) \quad \Rightarrow \quad M = 0.005\,\text{H}.$$

Quick Tip: The coefficient of mutual inductance can be calculated using $\text{emf}_{\text{max}} = M\frac{di}{dt}$. Use the derivative of current to find $\frac{di}{dt}$.

5(a).

A concave mirror forms a real image 4 times the size of an object. The magnification is 3 times by moving the object 3 cm away from the mirror. Find out the radius of curvature of the mirror.

Correct Answer: —

Solution:

For a concave mirror, the magnification $m = -\frac{v}{u}$, where v is the image distance and u is the object distance. Case 1 ($m = -4$):

$$v = -4u.$$

The mirror formula is:

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

Substituting $v = -4u$:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{-4u} = \frac{3}{4u}.$$

Case 2 ($m = -3$, object moved by 3 cm):

$$u' = u + 3, \quad v' = -3u'.$$

Using the mirror formula:

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

Substituting $v' = -3u'$:

$$\frac{1}{f} = \frac{1}{u+3} + \frac{1}{-3(u+3)} = \frac{2}{3(u+3)}.$$

Equating $\frac{1}{f}$ from both cases:

$$\frac{3}{4u} = \frac{2}{3(u+3)}.$$

Solving for u:

$$u = 12\,\text{cm}, \quad f = 9\,\text{cm}.$$

The radius of curvature is:

$$R = 2f = 18\,\text{cm}.$$

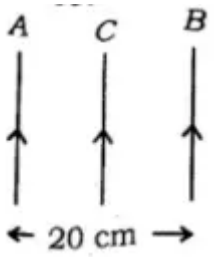
Quick Tip: For mirrors, magnification is given by $m = -\frac{v}{u}$. Use the mirror formula to relate object distance, image distance, and focal length.

5(b).

Currents of 10 A and 20 A are passed in two long parallel wires A and B, as shown in the figure. A wire C of 15 cm length is placed just in between these two wires, in which 5 A of current is passed. Then what will be the force acting on the wire C?

(i) Calculate the number of turns in the secondary coil.

(ii)Input power.



Correct Answer: —

Solution:

Part 1: Force on wire C The magnetic field at the position of wire C due to A and B is:

$$B_A = \frac{\mu_0 I_A}{2\pi d}, \quad B_B = \frac{\mu_0 I_B}{2\pi d}.$$

Since $d = 0.075\,\text{m}$, the net magnetic field B:

$$B = B_B - B_A = \frac{\mu_0}{2\pi d}(I_B - I_A).$$

Substituting values:

$$B = \frac{4\pi \times 10^{-7}}{2\pi \times 0.075}(20 - 10) = 2.67 \times 10^{-5}\,\text{T}.$$

The force on wire C is:

$$F = I_C B l = 5 \times 2.67 \times 10^{-5} \times 0.15 = 2.0 \times 10^{-5}\,\text{N}.$$

--- **Part 2: Step-down transformer** The transformation ratio is:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}.$$

Given $V_s = 220\,\text{V}, V_p = 2200\,\text{V}, N_p = 5000$:

$$N_s = \frac{V_s}{V_p} \times N_p = \frac{220}{2200} \times 5000 = 500.$$

Efficiency (η):

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \quad \Rightarrow \quad \text{Input Power} = \frac{\text{Output Power}}{\eta}.$$

Substituting values:

$$\text{Input Power} = \frac{8000}{0.9} = 8888.89\,\text{W}.$$

Quick Tip: For transformers, use the transformation ratio $\frac{V_s}{V_p} = \frac{N_s}{N_p}$. Efficiency relates input and output power.

OR

What is meant by the transformation ratio of a transformer ? In a step-down transformer, the transmission line voltage of 2200 volt is changed to 220 volt. Number of turns in primary coil is 5000. The efficiency of transformer is 90% and output power is 8 kW. Calculate :
i) Number of turns in secondary coil
ii) Input power.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A transformer changes an alternating voltage using two coils wound on one iron core. The primary coil has N_p turns and the secondary coil has N_s turns.

The transformation ratio (turns ratio) is the ratio of secondary turns to primary turns:

$$K = \frac{N_s}{N_p} = \frac{V_s}{V_p}$$

If $K < 1$ the transformer is a step-down transformer, and if $K > 1$ it is a step-up transformer.

Step 2: Key Formula or Approach:

1. Voltage and turns are in the same ratio: $\frac{V_s}{V_p} = \frac{N_s}{N_p}$.

2. Efficiency $\eta = \frac{P_{out}}{P_{in}}$.

Step 3: Data from the question:

$V_p = 2200$ V, $V_s = 220$ V, $N_p = 5000$, $\eta = 90\% = 0.90$, $P_{out} = 8$ kW $= 8000$ W.

Here $V_s < V_p$, so this is a step-down transformer. Its transformation ratio is $K = 220/2200 = 0.1 = 1/10$.

Step 4: Part (i), turns in the secondary coil:

Use the voltage-turns relation and solve for N_s:

$$N_s = N_p \times \frac{V_s}{V_p} = 5000 \times \frac{220}{2200}$$

$$N_s = 5000 \times 0.1 = 500$$

Step 5: Part (ii), input power:

Efficiency is output power divided by input power, so input power is output power divided by efficiency:

$$P_{in} = \frac{P_{out}}{\eta} = \frac{8000}{0.90}$$

$$P_{in} = 8888.9\ \text{W} \approx 8.9\ \text{kW}$$

The extra 888.9 W (about 0.89 kW) is lost as heat in the coils and the core.

Final Answer:

The transformation ratio is $K = N_s/N_p = V_s/V_p$. Here the secondary coil has 500 turns and the input power is about 8.9 kW.

$$\boxed{N_s = 500, \quad P_{in} \approx 8.9\ \text{kW}}$$

Quick Tip: Transformation ratio $K = N_s/N_p = V_s/V_p$.
$N_s = 5000 \times 220/2200 = 500$ and $P_{in} = P_{out}/\eta = 8000/0.9 \approx 8.9$ kW.

5(c).

What is plane polarized light? How is polarized light obtained by refraction? State the uses of polaroid.

Correct Answer: —

Solution:

Plane polarized light consists of waves oscillating in a single plane perpendicular to the direction of propagation.

Obtaining polarized light by refraction:

When unpolarized light is incident at Brewster's angle on a transparent medium, the reflected light becomes plane polarized.

Uses of polaroid:

- Reducing glare in sunglasses and cameras.
- Enhancing contrast in liquid crystal displays (LCDs).

Quick Tip: Polarization can occur by reflection, refraction, or scattering. Brewster's angle is key for obtaining plane polarized light.

5(d).

Obtain the formula for the internal resistance of a cell in terms of E, V, and R, where E, V, and R are the electromotive force of the cell, potential difference across the external resistance, and external resistance, respectively.

Correct Answer: —

Solution:

The total current in the circuit is:

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

where r is the internal resistance. The terminal voltage is given by:

$$V = IR = \frac{ER}{R+r}.$$

Rearranging:

$$r = R\left(\frac{E}{V} - 1\right).$$

Quick Tip: The internal resistance of a cell depends on the electromotive force E, terminal voltage V, and external resistance R.

5(e).

What do you mean by the current sensitivity of a moving coil galvanometer? Resistance of a galvanometer is $50\,\Omega$ and for full-scale deflection, the current is $0.05\,\text{A}$. What would be the required length of a wire to convert it into an ammeter of 5 A range? (Area of cross-section of wire = $2.7 \times 10^{-6}\,\text{m}^2$, specific resistance of the wire material = $5.0 \times 10^{-7}\,\Omega \cdot \text{m}$)

Correct Answer: —

Solution:

The shunt resistance is:

$$S = \frac{IG\,G}{I - IG}.$$

Substituting $G = 50\,\Omega, I = 5\,\text{A}, IG = 0.05\,\text{A}$:

$$S = \frac{0.05 \times 50}{5 - 0.05} = 0.5\,\Omega.$$

The length of the wire is:

$$R = \rho\frac{l}{A} \quad \Rightarrow \quad l = \frac{RA}{\rho}.$$

Substituting $R = 0.5, A = 2.7 \times 10^{-6}, \rho = 5.0 \times 10^{-7}$:

$$l = \frac{0.5 \times 2.7 \times 10^{-6}}{5.0 \times 10^{-7}} = 2.7\,\text{m}.$$

Quick Tip: The shunt resistance determines the range of an ammeter. Use the formula $S = \frac{IG\,G}{I - IG}$.

6. Explain the working of forward biased configuration of a *p-n* junction diode. Draw by making a graph between forward voltage and forward current, show the knee voltage.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A p-n junction diode is a p-type crystal joined to an n-type crystal. At the joint, electrons from the n side and holes from the p side diffuse across and cancel. This leaves a thin depletion layer with fixed ions, and a barrier potential V_0 (about 0.7 V for silicon and 0.3 V for germanium) that opposes further diffusion.

Step 2: Forward bias connection:

In forward bias the positive terminal of the battery is joined to the p side and the negative terminal to the n side, usually through a resistor that limits the current.

The battery voltage acts against the barrier potential. So the effective barrier becomes $V_0 - V$, where V is the applied voltage.

Step 3: What happens inside:

The depletion layer becomes narrow, because the battery pushes holes and electrons toward the junction.

Holes from the p side and electrons from the n side cross the lowered barrier. After crossing, they become minority carriers on the opposite side and recombine there.

The battery keeps supplying electrons to the n side and removing electrons from the p side, so a steady forward current flows in the circuit.

Step 4: Behaviour of the current with voltage:

For a small forward voltage the barrier is still large, so only a few carriers cross and the current is almost zero. The voltage at which the current starts to rise sharply is the knee voltage (about 0.7 V for Si, 0.3 V for Ge).

Beyond the knee voltage the barrier is mostly cancelled, and the current rises very fast, roughly as $I = I_0\left(e^{eV/kT} - 1\right)$. A small increase in voltage gives a large increase in current, so the series resistor is needed to protect the diode.

Step 5: The graph (described in words):

Plot forward voltage V in volts along the horizontal axis and forward current I in milliamperes along the vertical axis, in the first quadrant. The curve starts at the origin and stays almost flat and close to the voltage axis for small V. At the knee voltage V_k it bends upward and then climbs almost vertically. Mark the point on the voltage axis where this bend begins as the knee voltage V_k.

Final Answer:

In forward bias the applied voltage lowers the barrier and narrows the

depletion layer. Current is negligible below the knee voltage and rises steeply above it, as the I-V graph shows.

Forward bias: current rises sharply above knee voltage V_k

Quick Tip: Connect p to the positive terminal. The barrier falls, the depletion layer narrows, and majority carriers cross the junction.
The current is almost zero up to the knee voltage (0.7 V Si, 0.3 V Ge) and then rises steeply.

OR

Explain the working of reverse biased configuration of a *p-n* junction diode. Drawing a graph between reverse voltage and reverse current, show the breakdown voltage.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
A p-n junction has a depletion layer with a built-in barrier potential V_0 that stops majority carriers from crossing. Reverse bias means we connect the battery so that this barrier gets bigger.

Step 2: Reverse bias connection:
Join the p side to the negative terminal and the n side to the positive terminal of the battery. The applied voltage now adds to the barrier, so the total barrier becomes $V_0 + V$.

Step 3: What happens inside:
Holes in the p side are pulled away from the junction toward the

negative terminal. Electrons in the n side are pulled away toward the positive terminal. So the depletion layer widens.
No majority carrier can cross the higher barrier. But minority carriers (electrons in p, holes in n) are pushed across the junction by the same field.
This gives a very small current, the reverse saturation current. It is only a few microamperes (or less) because minority carriers are very few. It stays almost constant as the reverse voltage is raised, since it depends on how many minority carriers thermal energy makes, not on the voltage.

Step 4: Breakdown:
If the reverse voltage is raised high enough, the current suddenly shoots up at a voltage called the breakdown voltage V_{br}. There are two causes.
Zener breakdown: in a heavily doped junction the depletion layer is very thin, so even a small voltage creates a huge field (about 10^6 V/m) that pulls electrons straight out of the bonds.
Avalanche breakdown: in a lightly doped junction, fast minority carriers knock out more electrons by collision, and the process multiplies like an avalanche.

Step 5: The graph (described in words):
Plot reverse voltage along the negative horizontal axis, in volts, and reverse current along the negative vertical axis, in microamperes (third quadrant).
From the origin the curve is almost flat, running along the voltage axis, because the reverse saturation current is tiny and constant. At the breakdown voltage V_{br} the curve turns sharply downward, which means the reverse current rises very rapidly. Mark this point on the reverse voltage axis as the breakdown voltage.

Final Answer:

In reverse bias the barrier grows and the depletion layer widens, so only a tiny reverse saturation current flows. At the breakdown voltage the reverse current rises suddenly, as shown on the reverse I-V graph.

Reverse bias: tiny constant current until breakdown voltage V_{br}

Quick Tip: Connect p to the negative terminal. The barrier grows, the depletion layer widens, and only a tiny minority-carrier current flows.
At the breakdown voltage (Zener or avalanche) the reverse current rises very sharply.

7.

Show that the circumference of the orbit of an electron revolving in the n-th orbit is equal to $n\lambda$ with the help of Bohr's quantum theory. Also, show the emission and absorption spectral lines between energy levels $n = 1$ and $n = 3$ of hydrogen atom.

Correct Answer: —

Solution:

1. Bohr's Quantum Theory:
- Bohr's quantization condition states that the angular momentum mvr of an electron in the n-th orbit is given by:

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

Here, m is the mass of the electron, v is its velocity, r is the orbital radius, h is Planck's constant, and n is the quantum number. 2. Relation with De Broglie Wavelength:
- De Broglie wavelength of the electron is given by $\lambda = \frac{h}{mv}$.
- Substituting λ in the above expression:

$$2\pi r = n\lambda.$$

Thus, the circumference of the orbit is $n\lambda$. 3. Emission and Absorption Lines:
- The energy difference between two energy levels $E_n = -\frac{13.6}{n^2}$ eV is emitted or absorbed as a photon:

$$E = E_f - E_i = -\frac{13.6}{n_f^2} + \frac{13.6}{n_i^2}.$$

- For transitions between $n = 1$, $n = 2$, and $n = 3$, the emission and absorption lines correspond to the Lyman and Balmer series in the spectrum.

Quick Tip: The Bohr model combines classical circular orbits with quantum conditions. Emission corresponds to the release of energy, while absorption involves gaining energy.

OR

What do you mean by binding energy? Atomic mass of $^{16}_{8}\text{O} = 16.00000$ amu. Find out its binding energy per nucleon.
Given:
mass of electron = 0.00055 amu
mass of proton = 1.007593 amu
mass of neutron = 1.008982 amu
1 amu = 931 MeV

Correct Answer: –

Solution:

Step 1: Understanding the Concept:

The mass of a stable nucleus is always a little less than the sum of the masses of its separate protons and neutrons. This missing mass is called the mass defect. It has not vanished. It was released as energy when the nucleons joined, and Einstein's relation $E = \Delta m\, c^2$ connects the two.

Binding energy is the minimum energy that must be supplied to a nucleus to pull it apart into its separate free protons and neutrons. It is equal to the energy released when those nucleons come together to form the nucleus. A larger binding energy per nucleon means a more tightly held, more stable nucleus.

Step 2: Key Formula or Approach:

1. Mass defect: $\Delta m = Z\, m_p + (A - Z)\, m_n + Z\, m_e - M_{atom}$.
2. Binding energy: $BE = \Delta m \times 931$ MeV, with Δm in amu.
3. Binding energy per nucleon: BE/A.

The given mass of oxygen (16.00000 amu) is an atomic mass, so it already includes the 8 electrons of the atom. That is why the 8 electron masses are added on the other side, so that both sides count the same electrons.

Step 3: Count the particles:

For $^{16}_{8}\mathrm{O}$: $Z = 8$ protons, $A = 16$, so the number of neutrons is $A - Z = 16 - 8 = 8$. The atom also has 8 electrons.

Step 4: Find the mass defect:

Mass of 8 protons: $8 \times 1.007593 = 8.060744$ amu.

Mass of 8 neutrons: $8 \times 1.008982 = 8.071856$ amu.

Mass of 8 electrons: $8 \times 0.00055 = 0.00440$ amu.

Total mass of the separate particles: $8.060744 + 8.071856 + 0.00440 = 16.137000$ amu.

$$\Delta m = 16.137000 - 16.00000 = 0.137000 \text{ amu}$$

Step 5: Find the binding energy:

$$BE = 0.137 \times 931 = 127.547 \text{ MeV}$$

Step 6: Find the binding energy per nucleon:

There are 16 nucleons in the nucleus, so

$$\frac{BE}{A} = \frac{127.547}{16} = 7.97 \text{ MeV per nucleon}$$

Final Answer:

The total binding energy of ${}^{16}_{8}\text{O}$ is about 127.5 MeV, and the binding energy per nucleon is about 7.97 MeV.

$$\boxed{\frac{BE}{A} \approx 7.97 \text{ MeV/nucleon}}$$

Quick Tip: Find the mass defect from the masses of 8 protons, 8 neutrons and 8 electrons minus the atomic mass, then use $BE = \Delta m \times 931$ MeV and divide by 16.

8.

Differentiate between interference and diffraction of light. Explain qualitatively the diffraction phenomenon of light by a single slit. Light of 6000 Ã... wavelength is incident normally on a single slit of width 3×10^{-4} cm. Find out the angular width of the central maxima.

Correct Answer: —

Solution:

Difference Between Interference and Diffraction:

Pattern Origin and Superposition of waves from coherent sources and Light bends.

Fringes: All equally bright; spaced.

Central fringe brighter and wider; others diminish.

Cause: Interaction of more light beams

Single light wave- edges of aperture

Single-Slit Diffraction: - When light passes through a single slit, it bends and forms a pattern of alternating bright and dark fringes on a screen.

- The intensity distribution is maximum at the center (central maxima) and decreases for higher-order fringes. - At specific angles, destructive interference occurs due to the path difference, forming dark fringes.

$a \sin\theta = n\lambda$, where a is the slit width, λ is the wavelength, and $n = \pm 1, \pm 2, \ldots$

3. **Angular Width of Central Maximum:**

- Central maximum extends between $-\theta$ and $+\theta$. - The angular width $\Delta\theta$ is:

$$\Delta\theta = 2\sin^{-1}\left(\frac{\lambda}{a}\right).$$

Substituting $\lambda = 6000$ Ã... $= 6 \times 10^{-5}$ cm and $a = 3 \times 10^{-4}$ cm:

$$\sin\theta = \frac{\lambda}{a} = \frac{6 \times 10^{-5}}{3 \times 10^{-4}} = 0.2.$$

$$\Delta\theta = 2\sin^{-1}(0.2) \approx 2 \times 11.54^\circ = 23.08^\circ.$$

Final Answer:
The angular width of the central maxima is approximately 23.08°.

Quick Tip: Diffraction and interference demonstrate the wave nature of light. Diffraction is more evident with small apertures or obstacles.

OR

Draw a ray diagram of reflecting telescope. The magnifying power of an astronomical telescope is 5 and distance between the objective and eye-piece lenses is 36 cm. If the final image is formed at infinity, then find out focal lengths of the two lenses.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
A reflecting telescope uses a large curved mirror, instead of a lens, as its objective. Mirrors do not suffer from colour error and can be made very large and well supported from behind, so most big astronomical telescopes are of this type.
An astronomical (refracting) telescope has two convex lenses: the objective of large focal length f_o and the eyepiece of small focal length f_e. When the final image is at infinity, the telescope is in normal

adjustment.

Step 2: Ray diagram of a reflecting telescope (described in words):
The diagram is not printed in the paper, so here is how it is drawn (Cassegrain form).
1. Draw a large concave parabolic primary mirror on the right, with a small hole at its centre along the principal axis.
2. Draw parallel rays from a distant object coming from the left, travelling toward the primary mirror.
3. After reflection at the primary mirror, the rays travel back toward the left, converging toward its focus.
4. Place a small convex secondary mirror on the axis, just before this focus. It reflects the converging rays back to the right, through the hole in the primary mirror.
5. The rays meet at a point just behind the hole, where the real image is formed.
6. Draw the eyepiece lens just behind this point and an eye behind it. The eyepiece magnifies the image formed by the mirrors.
In the Newtonian form, a small plane mirror at 45 degrees on the axis sends the converging rays to the side, where the eyepiece is placed.

Step 3: Key Formula or Approach:
For an astronomical telescope in normal adjustment (final image at infinity):
1. Magnifying power $m = \frac{f_o}{f_e}$.
2. Tube length (distance between the lenses) $L = f_o + f_e$.

Step 4: Use the magnifying power:
Given $m = 5$, so $f_o = 5f_e$.
Given $L = 36$ cm, so $f_o + f_e = 36$.

Step 5: Solve the two equations:

Put $f_o = 5f_e$ into the second equation:

$$5f_e + f_e = 36$$

$$6f_e = 36 \Rightarrow f_e = 6 \text{ cm}$$

$$f_o = 5 \times 6 = 30 \text{ cm}$$

Check: $30 + 6 = 36$ cm and $30/6 = 5$. Both given conditions are satisfied.

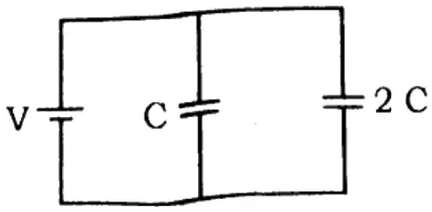
Final Answer:

The objective lens has focal length 30 cm and the eyepiece has focal length 6 cm.

$$\boxed{f_o = 30 \text{ cm},\ f_e = 6 \text{ cm}}$$

Quick Tip: For final image at infinity, $m = f_o/f_e = 5$ and $f_o + f_e = 36$ cm. This gives $f_e = 6$ cm and $f_o = 30$ cm.

9.



Two parallel plate capacitors of capacitances C and $2C$ are joined with a battery of voltage difference V as shown in the figure. If the battery is removed and the space between the plates of the capacitor of capacitance C is completely filled with a material of dielectric constant K, then find out:

i) total capacitance of the combination

ii) final voltage difference across the combination

iii) total energy stored in the combination.

Correct Answer: —

Solution:

Step 1: Read the circuit from the figure.

In the figure both capacitors are joined across the same two wires, and the battery is connected to those same two wires. So C and $2C$ are in PARALLEL, and each of them has the full battery voltage V across it. They are not in series.

Step 2: Charge on the combination before the battery is removed.

For capacitors in parallel the capacitances add.

$$C_i = C + 2C = 3C$$

The charge on each capacitor is its capacitance times the voltage

across it, so

$$Q_1 = CV, \qquad Q_2 = 2CV$$

$$Q = Q_1 + Q_2 = 3CV$$

Step 3: (i) Total capacitance after the dielectric is inserted.

Filling the space between the plates of C with a dielectric of constant K multiplies its capacitance by K. So the first capacitor becomes KC. The capacitor $2C$ is not changed. The two are still in parallel, so

$$C_f = KC + 2C = (K + 2)\,C$$

Step 4: (ii) Final voltage difference.

The battery has been removed, so the charge cannot leave the combination. The total charge stays $3CV$. The plates are still joined in parallel, so they settle to one common voltage V':

$$V' = \frac{Q}{C_f} = \frac{3CV}{(K+2)C}$$

$$V' = \frac{3V}{K+2}$$

Since $K > 1$, this is smaller than V. The voltage falls because the capacitance rose while the charge stayed fixed.

Step 5: (iii) Total energy stored.

Use $U = \frac{Q^2}{2C_f}$, because the charge is the quantity that is known and fixed.

$$U = \frac{(3CV)^2}{2(K+2)C} = \frac{9C^2V^2}{2(K+2)C}$$

$$U = \frac{9\,CV^2}{2(K+2)}$$

Before the dielectric the energy was $\frac{1}{2}(3C)V^2 = \frac{3}{2}CV^2$. The final energy is smaller by the factor $\frac{3}{K+2}$. The lost energy goes into pulling the dielectric slab into the capacitor.

Final Answer:

(i) total capacitance $(K+2)C$, (ii) final voltage $\frac{3V}{K+2}$, (iii) total energy $\frac{9CV^2}{2(K+2)}$.

$$\boxed{C_f = (K+2)C, \quad V' = \frac{3V}{K+2}, \quad U = \frac{9CV^2}{2(K+2)}}$$

Quick Tip: The figure shows **parallel** capacitors. Charge stays fixed at $3CV$ after the battery is removed. Use $C_f = (K+2)C$, $V' = Q/C_f$, $U = Q^2/2C_f$.

OR

Define electric flux and state its unit. Derive the formula for the intensity of electric field outside a uniformly charged thin spherical shell with the help of Gauss' law.

Correct Answer: –

Solution:

Step 1: Understanding the Concept:

Electric flux tells us how much electric field passes through a surface. Gauss' law then links the total flux through a closed surface to the charge inside it. When the charge has a symmetric shape, this law gives the field very quickly.

Step 2: Definition of electric flux and its unit:

The electric flux through a small area $d\vec{S}$ is $d\phi = \vec{E} \cdot d\vec{S} = E\,dS\cos\theta$, where θ is the angle between the field and the normal to the area. For a whole surface, add up all the small contributions:

$$\phi = \int \vec{E} \cdot d\vec{S}$$

In words, electric flux is the surface integral of the electric field over the surface, or the number of field lines passing normally through it. It is a scalar.

The SI unit is newton metre squared per coulomb (N m^2 C^{-1}), which is the same as volt metre (V m).

Step 3: Statement of Gauss' law:

The total electric flux through any closed surface equals $1/\varepsilon_0$ times the net charge enclosed by it:

$$\oint \vec{E} \cdot d\vec{S} = \frac{q_{enc}}{\varepsilon_0}$$

Step 4: Set up the problem:

Take a thin spherical shell of radius R carrying a uniform total charge q. We want the field at a point P at distance r from the centre O, with $r > R$, that is, outside the shell.

Because the charge is spread uniformly, the field has spherical symmetry. At every point it points radially outward (for positive q), and its size depends only on the distance r from the centre.

Step 5: Choose the Gaussian surface:

Imagine a concentric sphere of radius r passing through P. This is the Gaussian surface. It lies outside the shell, so it encloses the full charge q.

On this surface, $\vec{E}$ and $d\vec{S}$ both point radially outward at every point, so the angle between them is zero and $\cos 0 = 1$. The magnitude E is the same everywhere on it.

Step 6: Apply Gauss' law:

$$\oint \vec{E} \cdot d\vec{S} = E \oint dS = E \times 4\pi r^2$$

By Gauss' law this equals q/ε_0:

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

$$E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \quad (r \geq R)$$

Step 7: Interpret the result:

This is exactly the field of a point charge q placed at the centre of the shell. So, for points outside, a uniformly charged thin shell behaves as if all its charge were concentrated at its centre.

Final Answer:

Electric flux is $\phi = \oint \vec{E} \cdot d\vec{S}$ with unit N m^2/C. Outside a uniformly charged thin spherical shell the field is given below.

$$\boxed{E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}}$$

Quick Tip: Flux $\phi = \oint \vec{E} \cdot d\vec{S}$, unit N m^2/C. Take a concentric Gaussian sphere of radius $r > R$, so $E(4\pi r^2) = q/\varepsilon_0$.