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

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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). V/m and newton/coulomb both are the units of a physical quantity. The physical quantity is

(A) potential difference

(B) electric flux

(C) electric field intensity

(D) none of these

Correct Answer: (C) electric field intensity

Solution:

Step 1: Understanding the Concept:

Two different units are given and both must belong to one physical quantity. So we find the quantity whose definition produces both a volt per metre and a newton per coulomb.

Step 2: Key Formula or Approach:

The electric field at a point is the force per unit charge. It is also the rate at which potential falls with distance:

$$E = \frac{F}{q}, \qquad E = -\frac{dV}{dx}$$

Step 3: Detailed Explanation:

From $E = F/q$, the unit of force is the newton and the unit of charge is the coulomb. So the unit of E is N/C.

From $E = -dV/dx$, the unit of potential is the volt and the unit of distance is the metre. So the unit of E is V/m.

Both units describe electric field intensity. The two are equal: $1\ \text{V/m} = 1\ \text{N/C}$, because $1\ \text{V} = 1\ \text{J/C}$ and $1\ \text{J} = 1\ \text{N m}$.

Step 4: Check option (1):

Potential difference is measured in volt alone. A volt per metre is a potential difference divided by a length, so it is not a potential difference. Option (1) is wrong.

Step 5: Check option (2):

Electric flux is field times area, so its unit is V m or N m^2/C. This is not V/m. Option (2) is wrong.

Step 6: Check option (3):

Electric field intensity has both units V/m and N/C. Option (3) is right.

Step 7: Check option (4):

Since option (3) is correct, "none of these" is wrong.

Final Answer:

Both V/m and N/C are units of electric field intensity, which is option (3).

$\boxed{E}$

Quick Tip: Electric field is force per unit charge (N/C) and also potential gradient (V/m). So the quantity is electric field intensity.

1(b). In pure resistive alternating circuit, phase difference between voltage and current is

(A) π

(B) $\pi/2$

(C) $3\pi/2$

(D) 0

Correct Answer: (D) 0

Solution:

Step 1: Understanding the Concept:

In a purely resistive AC circuit only a resistor R is connected to the AC source. There is no inductor and no capacitor, so nothing stores energy and nothing delays the current.

Step 2: Key Formula or Approach:

Let the source voltage be $V = V_0 \sin \omega t$. By Ohm's law the current at every instant is $I = V/R$.

Step 3: Detailed Explanation:

Put the voltage in Ohm's law:

$$I = \frac{V_0 \sin \omega t}{R} = I_0 \sin \omega t, \qquad I_0 = \frac{V_0}{R}$$

The voltage and the current both contain $\sin \omega t$ with no extra angle added. They reach zero together and reach their peaks together. So the phase difference is $\phi = 0$.

Step 4: Check option (1):

A phase difference of π means the current is always opposite to the voltage. This does not happen in a resistor. Option (1) is wrong.

Step 5: Check options (2) and (3):

A phase difference of $\pi/2$ belongs to a pure inductor (voltage leads by $\pi/2$) or a pure capacitor (current leads by $\pi/2$). The value $3\pi/2$ is the same as a lead or lag of $\pi/2$ in the other direction. A resistor has none of this. Both options are wrong.

Step 6: Check option (4):

The phase difference is zero, so option (4) is right.

Final Answer:

In a pure resistor voltage and current are in phase, so the phase difference is zero. This is option (4).

$$\boxed{0}$$

Quick Tip: In a pure resistor $i = (V_0/R)\sin \omega t$, so current and voltage are in phase and the phase difference is 0.

1(c). p-terminal of a p-n diode is connected to earth. On applying -2.2 V voltage on the n-terminal of the diode, in the diode

(A) conduction will take place

(B) break down will occur

(C) conduction will not occur

(D) a feeble current will flow

Correct Answer: (A) conduction will take place

Solution:

Step 1: Understanding the Concept:

A p-n junction diode conducts when it is forward biased. This means the p side is at a higher potential than the n side. When the p side is at a lower potential, the diode is reverse biased.

Step 2: Key Formula or Approach:

Find the potential of each terminal and compare. Forward bias means $V_p - V_n > 0$, and the applied voltage must be above the small barrier voltage (about 0.3 V for germanium, 0.7 V for silicon).

Step 3: Detailed Explanation:

The p-terminal is connected to earth, so $V_p = 0$. The n-terminal is at $V_n = -2.2$ V. So

$$V_p - V_n = 0 - (-2.2) = +2.2 \text{ V}$$

The p side is 2.2 V above the n side, so the diode is forward biased. This voltage is larger than the barrier voltage, so the barrier is overcome and charge carriers cross the junction. Conduction takes place.

Step 4: Check options (2), (3) and (4):
Breakdown occurs only under a large reverse bias, so option (2) is wrong. Option (3) says no conduction, which is the reverse bias case, so it is wrong. A feeble current (reverse saturation current) flows only in reverse bias, so option (4) is wrong.

Final Answer:
The diode is forward biased by 2.2 V, so conduction takes place. This is option (1).

conduction will take place

Quick Tip: p is at 0 V and n is at -2.2 V, so p is at a higher potential than n. The diode is forward biased and conducts.

1(d). Two nuclei of masses m_1 and m_2 fuse to form a nucleus of mass m. Energy is also released in this process. The true relation in this reference is

(A) $m_1 + m_2 = m$

(B) $m_1 + m_2 > m$

(C) $m_1 + m_2 < m$

(D) none of these

Correct Answer: (B) $m_1 + m_2 > m$

Solution:

Step 1: Understanding the Concept:
In nuclear fusion two light nuclei join to form a heavier one. The

energy released comes from a small loss of mass, according to Einstein's mass-energy relation.

Step 2: Key Formula or Approach:

The energy released equals the mass lost times the square of the speed of light:

$$Q = \Delta m\, c^2 = (m_1 + m_2 - m)\, c^2$$

Step 3: Detailed Explanation:

The problem says energy is released, so $Q > 0$. Since c^2 is positive, the mass defect $\Delta m = m_1 + m_2 - m$ must also be positive. This gives

$$m_1 + m_2 > m$$

The fused nucleus is more tightly bound, so part of the original mass has left as energy.

Step 4: Check option (1):

If $m_1 + m_2 = m$, then $\Delta m = 0$ and no energy would be released. Option (1) is wrong.

Step 5: Check options (3) and (4):

If $m_1 + m_2 < m$, energy would have to be supplied to the process, not released. Option (3) is wrong. Option (4) is wrong because option (2) is true.

Final Answer:

The total mass of the two nuclei is more than the mass of the fused nucleus. This is option (2).

$$\boxed{m_1 + m_2 > m}$$

Quick Tip: Energy released means mass is lost: $Q = (m_1 + m_2 - m)c^2 > 0$, so $m_1 + m_2 > m$.

1(e). Formula for the dynamic mass of a photon is

(A) $\frac{h\nu}{\lambda}$

(B) $\frac{h\nu}{c}$

(C) $\frac{h}{\lambda}$

(D) $\frac{h}{c\lambda}$

Correct Answer: (D) $\frac{h}{c\lambda}$

Solution:

Step 1: Understanding the Concept:

A photon has zero rest mass, but it has energy and momentum. Its dynamic (moving) mass is the mass we get by treating its energy as mc^2.

Step 2: Key Formula or Approach:

Photon energy is $E = h\nu = hc/\lambda$. Einstein's relation is $E = mc^2$. Equate the two.

Step 3: Detailed Explanation:

Set $mc^2 = h\nu$. So

$$m = \frac{h\nu}{c^2}$$

Use $\nu = c/\lambda$:

$$m = \frac{h}{c\lambda}$$

This matches option (4).

Step 4: Check the other options:
Option (1) is $h\nu/\lambda$, which has the unit of energy per length, a force, not a mass. Option (2) is $h\nu/c$, which is the photon momentum, not mass. Option (3) is h/λ, which is also the momentum. So (1), (2) and (3) are wrong.

Final Answer:
The dynamic mass of a photon is $h/(c\lambda)$, option (4).

$$\boxed{m = \frac{h}{c\lambda}}$$

Quick Tip: Equate $mc^2 = h\nu = hc/\lambda$. This gives $m = h/(c\lambda)$.

1(f). Charge on a hollow metallic sphere is 10 coulomb. Radius of the sphere is 5 cm. Electric field inside the sphere will be

(A) zero

(B) 5 V/m

(C) equal to that at the surface of the sphere

(D) 12.4 V/m

Correct Answer: (A) zero

Solution:

Step 1: Understanding the Concept:

A hollow metallic sphere is a conductor. When the charge on a conductor stops moving, all the extra charge sits on its outer surface. The question asks for the electric field at points inside the hollow part, so we need to see how much charge lies inside.

Step 2: Key Formula or Approach:

Gauss's law says that the electric flux through any closed surface depends only on the charge enclosed by that surface.

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

Step 3: Apply Gauss's law inside the sphere:

Take a spherical Gaussian surface of radius r with $r < 5$ cm, concentric with the hollow sphere. This surface lies fully inside the cavity.

The 10 C of charge sits on the outer surface of the metal, so the Gaussian surface encloses no charge: $q_{enc} = 0$.

By symmetry the field has the same magnitude at every point of this surface and points along the radius. So the flux is $E \cdot 4\pi r^2$.

$$E(4\pi r^2) = 0 \Rightarrow E = 0$$

Step 4: Check option (1): zero:

This is what Gauss's law gave us. The charge value (10 C) and the radius (5 cm) do not matter inside a hollow conductor. So option (1) is

TRUE.

Step 5: Check option (2): 5 V/m:
A non-zero field inside would need enclosed charge or a charge nearby inside the cavity. Neither exists, so 5 V/m is FALSE.

Step 6: Check option (3): equal to the field at the surface:
At the surface the field is $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2} = \frac{9 \times 10^9 \times 10}{(0.05)^2} = 3.6 \times 10^{13}$ V/m. This is very large, while the field inside is zero. So option (3) is FALSE.

Step 7: Check option (4): 12.4 V/m:
This value does not come from any correct reasoning for the inside of a conducting shell. The field there is exactly zero, so option (4) is FALSE.

Final Answer:
The electric field at every point inside a charged hollow metallic sphere is zero. This is option (1).

$$\boxed{E = 0}$$

Quick Tip: Charge on a conductor sits on its outer surface, so a Gaussian surface inside the hollow encloses no charge and $E = 0$.

2(a). Write the name of mirror used in vehicles as rear view mirror.

Correct Answer: —

Solution:

Step 1: Understanding the Question:

A rear view mirror lets the driver see the traffic behind without turning around. We need the type of mirror that does this job best.

Step 2: What the driver needs:

The mirror must show a wide area of the road behind. The image must be erect (upright), so the driver does not confuse left and right or near and far. It is fine if the image is smaller, because a smaller image means more of the road fits in the mirror.

Step 3: Which mirror gives this:

A convex mirror always forms a virtual, erect and diminished image of an object placed in front of it, wherever the object is. Its outward curved surface spreads the reflected rays, so it covers a much larger field of view than a plane mirror of the same size.

A concave mirror gives an inverted real image for distant objects and a small field of view, so it is not suitable. A plane mirror has a narrow field of view.

Final Answer:

The mirror used as a rear view mirror in vehicles is a convex mirror.

Convex mirror

Quick Tip: The mirror must give an erect image and a wide field of view, so it is a convex mirror.

2(b). Explain the meaning of the work function of a photosensitive surface.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

In a metal, electrons move freely inside but are held in by the surface. To free an electron into the space outside, energy must be given to it. This is what happens in the photoelectric effect, when light falls on a photosensitive surface.

Step 2: Meaning of work function:

The work function of a surface is the minimum energy needed to pull the most loosely bound electron out of the surface into free space. It is denoted by ϕ_0 and depends only on the material of the surface. It is usually written in electron volts (eV), where $1\ \text{eV} = 1.6 \times 10^{-19}$ J.

Step 3: Link with the threshold frequency:

Light of frequency ν gives each electron a photon of energy $h\nu$. An electron comes out only if this energy is at least ϕ_0. The lowest such frequency is the threshold frequency ν_0:

$$\phi_0 = h\nu_0$$

Einstein's equation then reads $K_{max} = h\nu - \phi_0$. A metal with a smaller work function, like caesium, gives photoelectrons for lower frequencies of light.

Final Answer:

The work function is the minimum energy required to eject an electron from the surface of the metal, $\phi_0 = h\nu_0$.

$$\boxed{\phi_0 = h\nu_0}$$

Quick Tip: Work function ϕ_0 is the minimum energy needed to eject an electron from the surface, and $\phi_0 = h\nu_0$.

2(c). Write the relation between size of nucleus and mass number.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Scattering experiments show that the nucleus is almost a sphere and that its density is nearly the same for all nuclei. Because the density is constant, the volume must grow in proportion to the number of nucleons, that is, in proportion to the mass number A.

Step 2: Key Formula or Approach:

For a sphere of radius R, the volume is $\frac{4}{3}\pi R^3$. Constant density means:

$$\frac{4}{3}\pi R^3 \propto A$$

Step 3: Derive the relation:

Taking the cube root on both sides:

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

Writing the constant of proportionality as R_0:

$$R = R_0 A^{1/3}$$

Here R_0 is about 1.2×10^{-15} m (1.2 fermi). For example, for $A = 8$, $R = 1.2 \times 2 = 2.4$ fermi.

Final Answer:

The radius of a nucleus is proportional to the cube root of its mass number.

$$\boxed{R = R_0 A^{1/3}, \quad R_0 \approx 1.2 \times 10^{-15} \text{ m}}$$

Quick Tip: Nuclear density is constant, so $R = R_0 A^{1/3}$ with $R_0 = 1.2$ fermi.

2(d). Of which quantity is the unit kilowatt-hour ? How many joules are there in 1 kilowatt-hour ?

Correct Answer: —

Solution:

Step 1: Understanding the Question:

The question asks two things. First, which physical quantity is measured in kilowatt-hour. Second, the value of 1 kilowatt-hour in joules.

Step 2: Which quantity:

Electrical energy used is power multiplied by time. Kilowatt is a unit of power and hour is a unit of time, so their product is a unit of energy. Electricity companies bill households in this unit, which is why a meter reading is in kilowatt-hour (units). So kilowatt-hour is the unit of electrical energy.

Step 3: Convert to joules:

Use $1\ \text{kW} = 1000\ \text{W} = 1000\ \text{J/s}$ and $1\ \text{h} = 3600\ \text{s}$.

$$1\ \text{kWh} = 1000\ \text{J/s} \times 3600\ \text{s}$$

$$1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$$

Final Answer:

Kilowatt-hour is a unit of energy, and 1 kWh equals 3.6×10^6 joule.

$$\boxed{1\ \text{kWh} = 3.6 \times 10^6\ \text{J}}$$

Quick Tip: Power times time gives energy, and $1\ \text{kWh} = 1000 \times 3600 = 3.6 \times 10^6$ J.

2(e). An uncharged rod is placed near a charged rod. What will be the effect on the potential of the charged rod ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A conductor placed near a charged body gets polarised by electrostatic induction. Free electrons in the uncharged rod move under the field of the charged rod, so one end becomes positive and the other end becomes negative. The total charge on the uncharged rod stays zero.

Step 2: Key Formula or Approach:

The potential at any point is the sum of the potentials due to all charges around it. For a point charge, $V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$. So we add the potential of the induced charges to the potential the charged rod already had.

Step 3: Detailed Explanation:

Let the charged rod carry a positive charge $+Q$. Its field pulls electrons in the neutral rod towards the near end.

The near end becomes negative (charge $-q$) and the far end becomes positive (charge $+q$). The two induced charges are equal in size.

The negative charge $-q$ is closer to the charged rod than the positive charge $+q$. Potential falls with distance as $1/r$, so the nearer $-q$ lowers the potential more than the farther $+q$ raises it.

The extra potential at the charged rod is

$$\Delta V = \frac{1}{4\pi\epsilon_0}\left(\frac{-q}{r_1} + \frac{q}{r_2}\right) < 0 \quad (r_1 < r_2)$$

So the net potential of the charged rod decreases. The charge Q on the rod does not change, only its potential does.

If the rod were negatively charged, the same reasoning gives a smaller magnitude of potential, so the size of the potential falls in both cases.

Final Answer:

The potential of the charged rod decreases (its magnitude becomes smaller) because the induced opposite charge on the nearby end of the uncharged rod lies closer to it.

Potential of the charged rod decreases

Quick Tip: The neutral rod gets opposite charge induced on its near end, which lowers the potential of the charged rod.

2(f). Show the magnetic field lines produced by a straight current carrying wire.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A straight wire carrying current produces a magnetic field around it. Magnetic field lines are closed curves that show the direction of the field at every point. For a long straight wire the symmetry is circular, so the lines are circles.

Step 2: Key Formula or Approach:

1. The magnitude of the field at distance r from a long straight wire is $B = \frac{\mu_0 I}{2\pi r}$.
2. The direction is found from the right-hand thumb rule: point the thumb along the current, and the curled fingers show the direction of the field.

Step 3: Detailed Explanation:

Draw the wire as a point in the middle of the page, with the current coming out of the page towards you.

Draw several concentric circles around this point, all in the plane of the page and perpendicular to the wire. The wire passes through the common centre of the circles.

Put arrowheads on the circles. For current coming out of the page, the right-hand rule gives the anticlockwise direction. If the current goes into the page, the arrows are clockwise.

Draw the circles closer together near the wire and farther apart as you move away. This is because $B \propto 1/r$, so the field is strong near the wire and weak far from it.

The lines are closed loops with no beginning or end, and they never cross each other.

Final Answer:

The field lines of a straight current carrying wire are concentric circles in a plane perpendicular to the wire, centred on the wire, with the direction given by the right-hand thumb rule and the spacing wider at larger distance.

$$\boxed{\text{Concentric circles around the wire, } B = \frac{\mu_0 I}{2\pi r}}$$

Quick Tip: Draw concentric circles around the wire, closer near the wire, with direction from the right-hand thumb rule.

3(a). Define current sensitivity of a galvanometer. How can it be increased ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A moving coil galvanometer detects small currents. The coil turns through an angle when current flows. Current sensitivity tells us how much the coil turns for each unit of current.

Step 2: Definition:

Current sensitivity is the deflection produced in the galvanometer per unit current through its coil.

$$I_s = \frac{\theta}{I}$$

Its unit is radian per ampere (or division per ampere).

Step 3: Find the formula:

A coil of N turns, area A, carrying current I in a radial magnetic field B, feels a deflecting torque $\tau = NIAB$.

The suspension spring gives a restoring torque $k\theta$, where k is the torsional constant. At equilibrium the two torques are equal.

$$NIAB = k\theta$$

So

$$I_s = \frac{\theta}{I} = \frac{NAB}{k}$$

Step 4: How to increase it:

From $I_s = NAB/k$ we see what to change.

1. Increase the number of turns N of the coil.
2. Increase the area A of the coil.
3. Use a stronger magnetic field B, for example a strong permanent magnet.
4. Decrease the torsional constant k by using a thin phosphor-bronze or quartz suspension wire.

Increasing N or A also increases the coil resistance, so the voltage sensitivity may not rise in the same way. That is a separate point from current sensitivity.

Final Answer:

Current sensitivity is the deflection per unit current, $\theta/I = NAB/k$. It increases with more turns, bigger area, stronger field and a weaker suspension (smaller k).

$$\boxed{I_s = \frac{\theta}{I} = \frac{NAB}{k}}$$

Quick Tip: Current sensitivity is deflection per unit current, $\theta/I = NAB/k$. Raise N, A, B or lower k.

3(b). Explain the meaning of power factor and wattless current in alternating circuits.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

In an AC circuit, the voltage and the current may not reach their peaks at the same moment. The angle between them is called the phase difference ϕ. This angle decides how much real power the circuit uses.

Step 2: Key Formula or Approach:

1. Average power: $P = V_{rms} I_{rms} \cos\phi$.
2. For a series circuit, $\cos\phi = \frac{R}{Z}$, where R is the resistance and Z is the impedance.

Step 3: Meaning of power factor:

The factor $\cos\phi$ in the power formula is called the power factor.

$$\text{Power factor} = \cos\phi = \frac{P}{V_{rms} I_{rms}} = \frac{R}{Z}$$

It is the fraction of the apparent power $V_{rms} I_{rms}$ that is really used up in the circuit. Its value lies between 0 and 1. For a pure resistor $\phi = 0$, so the power factor is 1. For a pure inductor or capacitor $\phi = 90°$, so the power factor is 0.

Step 4: Meaning of wattless current:

Split the current into two parts. The part $I_{rms} \cos\phi$ is in phase with the voltage and does the real work. The other part $I_{rms} \sin\phi$ is at $90°$ to the voltage.

The average power due to the part at $90°$ over a full cycle is $V_{rms} I_{rms} \sin\phi \cos 90° = 0$. So this component draws no net power and is called the wattless current (or idle current).

In a pure inductor or capacitor the whole current is wattless, because $\phi = 90°$. Energy goes into the field and comes back every cycle, so the average power is zero.

Final Answer:

Power factor is $\cos\phi$, the fraction of the apparent power that does real work. Wattless current is the component of current at $90°$ to the voltage, which uses no average power.

$$\boxed{P = V_{rms} I_{rms} \cos\phi}$$

Quick Tip: Power factor is $\cos\phi$. Wattless current is the $I\sin\phi$ part, at 90 degrees to the voltage, with zero average power.

3(c). Electric field in an electromagnetic wave is $E_y = 3 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)$ V/m. Find the wavelength and equation for magnetic field of the wave.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A plane electromagnetic wave travelling along the x-axis has its electric field E and magnetic field B at right angles to each other and to the direction of travel. The two fields rise and fall together in phase, and their peak values are linked by the speed of light, $E_0 = cB_0$.

Step 2: Key Formula or Approach:

1. Compare with the standard form $E = E_0 \sin(kx \pm \omega t)$, where k

$= 2\pi/\lambda$.

2. Wavelength $\lambda = 2\pi/k$.

3. $B_0 = E_0/c$, with $c = 3 \times 10^8$ m/s.

Step 3: Find the wavelength:

Given: $E_y = 3 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t)$ V/m.

Comparing, $E_0 = 3 \times 10^{-7}$ V/m, $k = 0.5 \times 10^3 = 500$ rad/m and $\omega = 1.5 \times 10^{11}$ rad/s.

$$\lambda = \frac{2\pi}{k} = \frac{2 \times 3.14}{500} = 1.256 \times 10^{-2} \text{ m}$$

So $\lambda \approx 1.26$ cm.

Check of the speed: $\omega/k = 1.5 \times 10^{11}/500 = 3 \times 10^8$ m/s, which is the speed of light, so the data is consistent.

Step 4: Find the magnetic field equation:

Peak magnetic field:

$$B_0 = \frac{E_0}{c} = \frac{3 \times 10^{-7}}{3 \times 10^8} = 1 \times 10^{-15} \text{ T}$$

The sign of ωt is the same as the sign of kx, so the wave moves in the negative x direction.

E is along y and the wave travels along $-x$. The direction of $\vec{E} \times \vec{B}$ must be along the direction of travel. Since $\hat{y} \times (-\hat{z}) = -\hat{x}$, the magnetic field must point along $-z$.

$$\vec{B} = -1 \times 10^{-15} \sin\left(0.5 \times 10^3 x + 1.5 \times 10^{11} t\right) \hat{z} \text{ T}$$

That is, B_z has the same sine factor as E_y, with peak value 10^{-15} T, and

it lies along the z-axis.

Final Answer:

The wavelength is about 1.26×10^{-2} m, and the magnetic field has peak value 10^{-15} T along the z-axis, with the same phase as the electric field.

$$\boxed{\lambda = 1.26 \times 10^{-2}\ \text{m}, \quad B_z = -10^{-15} \sin\left(0.5 \times 10^3 x + 1.5 \times 10^{11} t\right)\ \text{T}}$$

Quick Tip: Compare with $E_0 \sin(kx + \omega t)$: $\lambda = 2\pi/k$ and $B_0 = E_0/c$.

3(d). Explain the difference between diamagnetic and paramagnetic substances.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Every substance reacts in some way when it is placed in a magnetic field. The reaction depends on whether its atoms carry a permanent magnetic moment of their own. Diamagnetic and paramagnetic substances are the two weakly magnetic classes, and they differ in exactly this respect.

Step 2: Key Formula or Approach:

The magnetisation M produced in a substance by a magnetising field H is written as $M = \chi H$, where χ is the magnetic susceptibility. The relative permeability is $\mu_r = 1 + \chi$. The sign and size of χ decide the class of the substance.

Step 3: Diamagnetic substances.

1. The atoms have no permanent magnetic moment, because the moments of their electrons cancel in pairs.
2. In an external field the orbital motion of the electrons changes a little (Lenz's law), and each atom gets a small moment opposite to the field.
3. So the substance is weakly repelled by a strong magnet and tends to move from a strong field to a weak field.
4. The susceptibility is small and negative, $\chi < 0$ (about -10^{-5}), and μ_r is slightly less than 1.
5. The field lines are pushed out of the material.
6. The property does not change with temperature.
7. Examples: bismuth, copper, gold, water, nitrogen.

Step 4: Paramagnetic substances.

1. The atoms or molecules have a permanent magnetic moment, because of unpaired electrons.
2. Without a field these small moments point in random directions, so the net moment is zero.
3. In an external field the moments turn partly along the field, so the substance gets a weak magnetisation in the direction of the field.
4. It is weakly attracted by a strong magnet and tends to move from a weak field to a strong field.
5. The susceptibility is small and positive, $\chi > 0$ (about 10^{-5} to 10^{-3}), and μ_r is slightly more than 1.
6. The field lines crowd into the material slightly.
7. The property falls as the temperature rises, following Curie's law $\chi = C/T$, because heat motion upsets the alignment.
8. Examples: aluminium, sodium, calcium, oxygen, platinum.

Step 5: Final Answer:

A diamagnetic substance has no permanent atomic moment, gets a weak opposite moment, is repelled by a magnet, has negative χ and does not depend on temperature. A paramagnetic substance has permanent atomic moments, gets a weak moment along the field, is attracted by a magnet, has small positive χ and depends on temperature as $1/T$.

Diamagnetic: $\chi < 0,\ \mu_r < 1$	Paramagnetic: $\chi > 0,\ \mu_r > 1$

Quick Tip: Compare the two classes on three points: whether the atom has a permanent magnetic moment, the sign of the susceptibility χ (negative for diamagnetic, small positive for paramagnetic), and the behaviour in a non-uniform field (repelled or attracted). Add one example of each.

4(a). Give a brief comment on the need of displacement current. Which physical quantity will be same for X-rays of wavelength 10^{-10} m, radio waves of wavelength 55 m and light waves of wavelength 6000 Å ?

Correct Answer: —

Solution:

Step 1: Understanding the Question:

The question has two parts. First, why Maxwell had to add a displacement current to Ampere's circuital law. Second, which property is the same for X-rays, radio waves and visible light, even though their wavelengths are very different.

Step 2: Why Ampere's law needs a correction:

Take a capacitor that is being charged by a current I. Draw a closed loop around the connecting wire, just outside the plates. Ampere's law says $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$, where I_{enc} is the current through any surface that has this loop as its edge.
Choose surface S_1 as a flat disc cut by the wire. The current I passes through it, so $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$.
Choose surface S_2 as a bulging bowl that passes between the capacitor plates. No conduction current goes through it, because charge does not cross the gap. So the same law gives $\oint \vec{B} \cdot d\vec{l} = 0$.
The same loop cannot have two different values of $\oint \vec{B} \cdot d\vec{l}$. So the law is incomplete for a changing electric field.

Step 3: Maxwell's fix:
Between the plates the electric flux Φ_E is changing. Maxwell said this changing flux acts like a current, called the displacement current:

$$I_d = \varepsilon_0 \frac{d\Phi_E}{dt}$$

The corrected law becomes

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_c + I_d)$$

Check with the capacitor: $\Phi_E = q/\varepsilon_0$, so $I_d = dq/dt = I$. Now surface S_2 also gives $\mu_0 I$, and the contradiction is gone.
This idea also led Maxwell to predict electromagnetic waves, since a changing electric field produces a magnetic field and a changing magnetic field produces an electric field.

Step 4: Compare the three waves:

X-rays, radio waves and light waves are all electromagnetic waves. Only their wavelengths differ. We convert $6000\ \text{Å} = 6000 \times 10^{-10}\ \text{m} = 6 \times 10^{-7}\ \text{m}$.

In vacuum every electromagnetic wave travels at the speed

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

The frequency $f = c/\lambda$ is not the same:

X-rays: $f = \dfrac{3 \times 10^8}{10^{-10}} = 3 \times 10^{18}\ \text{Hz}$

Radio waves: $f = \dfrac{3 \times 10^8}{55} \approx 5.5 \times 10^6\ \text{Hz}$

Light waves: $f = \dfrac{3 \times 10^8}{6 \times 10^{-7}} = 5 \times 10^{14}\ \text{Hz}$

Wavelength, frequency and photon energy all change, so they cannot be the common quantity. The speed in vacuum stays the same.

Final Answer:

Displacement current is needed so that Ampere's law holds for a changing electric field (for example inside a charging capacitor). The quantity that is the same for all three waves is their speed in vacuum, $3 \times 10^8\ \text{m/s}$.

$$\boxed{I_d = \varepsilon_0 \frac{d\Phi_E}{dt}, \quad c = 3 \times 10^8\ \text{m/s}}$$

Quick Tip: A changing electric flux acts like a current, $I_d = \varepsilon_0\, d\Phi_E/dt$, and fixes Ampere's law. All electromagnetic waves have the same speed c in vacuum.

4(b). State the difference between isotopic, isobaric and isotonic nuclei. Give example in support of your answer.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A nucleus is described by its atomic number Z (number of protons), its mass number A (protons plus neutrons) and its neutron number $N = A - Z$. Isotopes, isobars and isotones are three families of nuclei, each defined by which one of these numbers is kept the same.

Step 2: Isotopic nuclei (isotopes):

Isotopes have the same atomic number Z but different mass number A. They have the same number of protons, so they are the same element, but a different number of neutrons.

Example: hydrogen ${}_{1}^{1}\mathrm{H}$, deuterium ${}_{1}^{2}\mathrm{H}$ and tritium ${}_{1}^{3}\mathrm{H}$. All have $Z = 1$, while $A = 1, 2, 3$ and $N = 0, 1, 2$. Another example is ${}_{17}^{35}\mathrm{Cl}$ and ${}_{17}^{37}\mathrm{Cl}$.

Step 3: Isobaric nuclei (isobars):

Isobars have the same mass number A but different atomic number Z. They are different elements with different chemical properties, though the total count of nucleons is equal.

Example: ${}_{18}^{40}\mathrm{Ar}$ and ${}_{20}^{40}\mathrm{Ca}$. Both have $A = 40$, while $Z = 18$ and 20. Another example is ${}_{1}^{3}\mathrm{H}$ and ${}_{2}^{3}\mathrm{He}$.

Step 4: Isotonic nuclei (isotones):

Isotones have the same neutron number N but different Z and different A.

Example: ${}_{6}^{13}\mathrm{C}$ and ${}_{7}^{14}\mathrm{N}$. For carbon, $N = 13 - 6 = 7$. For nitrogen, $N = 14 - 7 = 7$. So both have 7 neutrons. Another pair is ${}_{1}^{3}\mathrm{H}$ and ${}_{2}^{4}\mathrm{He}$,

both with $N = 2$.

Step 5: Summary of the three:
Same Z, different A: isotopes.
Same A, different Z: isobars.
Same N, different Z: isotones.

Final Answer:
Isotopes share the proton number, isobars share the mass number and isotones share the neutron number.

$$\boxed{\text{Isotopes: same } Z;\ \text{Isobars: same } A;\ \text{Isotones: same } N}$$

Quick Tip: Isotopes: same Z. Isobars: same A. Isotones: same $N = A - Z$.

4(c). Explain the meanings of electric dipole and electric dipole moment. In an electric dipole charges of + 20 μC and − 20 μC are separated by a distance of 1.0 cm. Find the electric field intensity at an axial point at a distance of 1 m from the pole of the dipole.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
An electric dipole is a pair of equal and opposite point charges $+q$ and $-q$ separated by a small distance $2a$. The electric dipole moment $\vec{p}$ measures how strong the dipole is. Its magnitude is the charge times the separation, and its direction is from the negative charge to the positive charge.

$$p = q \times 2a$$

The SI unit is coulomb metre (C m). The dipole moment is a vector.

Step 2: Key Formula or Approach:

For a point on the axis of a short dipole, at distance r from its centre (the pole) with $r \gg a$, the field is along $\vec{p}$ and has magnitude

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

Step 3: Find the dipole moment:

Charge $q = 20\ \mu\text{C} = 20 \times 10^{-6}$ C. Separation $2a = 1.0$ cm $= 1.0 \times 10^{-2}$ m.

$$p = 20 \times 10^{-6} \times 1.0 \times 10^{-2} = 2 \times 10^{-7}\ \text{C m}$$

Step 4: Find the axial field:

Here $r = 1$ m, and the half-separation $a = 0.5$ cm is much smaller than r, so the short-dipole formula is valid. Use $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \text{N m}^2\text{C}^{-2}$.

$$E = \frac{9 \times 10^9 \times 2 \times 2 \times 10^{-7}}{(1)^3}$$

$$E = 3.6 \times 10^3\ \text{N/C}$$

The direction is along the dipole moment, that is, from the negative

charge towards the positive charge.

Final Answer:

The electric field at the axial point is **3600 N/C**, along the direction of the dipole moment.

$$\boxed{E = 3.6 \times 10^3 \text{ N C}^{-1}}$$

Quick Tip: $p = q(2a) = 2 \times 10^{-7}$ C m. Axial field $E = \frac{2kp}{r^3} = 3600$ N/C along $\vec{p}$.

4(d). Explain the difference between electromotive force (e.m.f.) and terminal potential difference of a cell. A cell of e.m.f. 2.0 V is connected to an external resistance of 3.9 ohm. Current flowing in the circuit is 0.5 ampere. What is the internal resistance of the cell ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Every cell has an internal resistance r, because the electrolyte and electrodes resist the flow of charge inside the cell. So the voltage across the cell terminals depends on whether the cell is giving current or not.

Step 2: Difference between e.m.f. and terminal potential difference:

E.m.f. (ε) is the potential difference between the two terminals when no current is drawn (open circuit). It is the work done by the cell per unit charge in moving charge through the whole circuit.

Terminal potential difference (V) is the potential difference across the terminals when the cell is delivering current. Because of the voltage drop Ir inside the cell, $V = \varepsilon - Ir$. So V is less than ε when the cell is discharging.

They are equal only when $I = 0$. Also, e.m.f. is not really a force, it is a potential difference, measured in volts.

Step 3: Key Formula or Approach:

For a cell of e.m.f. ε and internal resistance r connected to an external resistance R, the current is

$$I = \frac{\varepsilon}{R + r}$$

Step 4: Solve for the internal resistance:

Given $\varepsilon = 2.0$ V, $R = 3.9\ \Omega$ and $I = 0.5$ A. Rearrange:

$$R + r = \frac{\varepsilon}{I} = \frac{2.0}{0.5} = 4.0\ \Omega$$

$$r = 4.0 - 3.9 = 0.1\ \Omega$$

Final Answer:

The internal resistance of the cell is $0.1\ \Omega$.

$$\boxed{r = 0.1\ \Omega}$$

Quick Tip: Use $I = \frac{\varepsilon}{R + r}$. So $R + r = 2.0/0.5 = 4.0\ \Omega$ and $r = 0.1\ \Omega$.

4(e). Two thin convex lenses are placed in contact. Find the formula for the focal length of this combination. If one lens of this combination is replaced by a concave lens of focal length equal to that of the other remaining lens, what will be behaviour of the combination ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Two thin lenses in contact act like one lens. We find its focal length by letting the image of the first lens act as the object for the second lens. We take the lenses so thin that the distance between them is negligible and all distances are measured from the common centre.

Step 2: Derive the combined focal length:

Let the lenses have focal lengths f_1 and f_2. Place an object O at distance u from the first lens. It forms an image I_1 at distance v_1. The lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ gives

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \quad \cdots (1)$$

The image I_1 is the object for the second lens, at distance v_1 from it. The final image forms at distance v, so

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \quad \cdots (2)$$

Add (1) and (2). The term $1/v_1$ cancels:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$$

If the combination is replaced by a single lens of focal length F, then $\frac{1}{v} - \frac{1}{u} = \frac{1}{F}$. Comparing,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \quad \Rightarrow \quad F = \frac{f_1 f_2}{f_1 + f_2}$$

In terms of power, $P = P_1 + P_2$.

Step 3: Replace one lens with a concave lens:

Let the convex lens have focal length $+f$. The concave lens has the same magnitude, so its focal length is $-f$. Put these in the formula:

$$\frac{1}{F} = \frac{1}{f} + \frac{1}{(-f)} = 0$$

So $F \to \infty$ and the power of the combination is $P = P_1 + P_2 = +\frac{1}{f} - \frac{1}{f} = 0$.

Step 4: Behaviour of the combination:

A lens of infinite focal length and zero power neither converges nor diverges light. A parallel beam leaves as a parallel beam, so the combination behaves like a plane glass plate. It forms no real image and no magnification effect.

Final Answer:

The combined focal length of two thin lenses in contact is given by $\frac{1}{F}$

$= \frac{1}{f_1} + \frac{1}{f_2}$. With a convex and concave lens of equal focal length, the power is zero and the combination behaves like a plane glass plate.

$$\boxed{\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}; \quad F \to \infty \text{ (plane glass plate)}}$$

Quick Tip: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$. With $f_2 = -f_1$, $1/F = 0$, so the pair acts like a plane glass plate.

5(a). Write the conditions to obtain the interference between waves. What is meant by coherent source ?

Correct Answer: —

Solution:

Step 1: Understand what interference is:

Interference is the redistribution of light energy when two or more light waves overlap at a point. At some points the waves add up and the intensity is large (bright fringe). At other points they cancel and the intensity is small (dark fringe). For this pattern to stay steady and visible, some conditions must be met.

Step 2: Write the conditions for a steady interference pattern:

1. The two sources must be coherent, which means the phase difference between the waves they emit must stay constant with time.
2. The two waves must have the same frequency (same wavelength). If the frequencies differ, the phase difference changes with time and the fringes keep moving.
3. The amplitudes of the two waves should be equal or nearly equal.

Then the dark fringes are fully dark and the contrast between bright and dark fringes is best.
4. The two sources must be narrow and very close to each other, and the screen must be far away. Then the fringes are wide enough to see.
5. The light must be monochromatic (one colour). White light gives coloured, overlapping fringes.
6. The waves must be polarised in the same direction (or at least not at right angles), because waves vibrating at right angles do not interfere.

Step 3: Write the condition for bright and dark fringes:
If the path difference between the two waves at a point is Δx, then:

$$\Delta x = n\lambda \quad (n = 0, 1, 2, \ldots) \Rightarrow \text{constructive interference (bright)}$$

$$\Delta x = (2n - 1)\frac{\lambda}{2} \quad (n = 1, 2, 3, \ldots) \Rightarrow \text{destructive interference (dark)}$$

Step 4: Explain what a coherent source is:
Two sources are called coherent when they emit waves of the same frequency and the phase difference between the waves stays constant with time. Ordinary independent bulbs are not coherent, because their atoms emit light in random bursts of about 10^{-8} s, so the phase keeps changing. In practice, coherent sources are made by splitting light from one source into two parts, as in Young's double slit experiment, where the two slits act as coherent sources.

Final Answer:
Interference needs coherent sources of the same frequency, nearly

equal amplitudes, narrow close slits and monochromatic light. A coherent source emits waves with a constant phase difference.

Coherent sources : same frequency and constant phase difference

Quick Tip: The sources must be coherent, with the same frequency, a constant phase difference and nearly equal amplitudes.
Coherent sources keep a fixed phase relation.

5(b). Write the formula for the potential energy of a magnetic dipole placed in an external magnetic field. What will be the maximum and minimum values of potential energy ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
A bar magnet or any magnetic dipole has a magnetic dipole moment $\vec{m}$. When it is placed in a uniform magnetic field $\vec{B}$, the field exerts a torque on it, and the dipole has potential energy that depends on its orientation.

Step 2: Key Formula:
The work done in turning the dipole from an angle θ_1 to θ_2 is stored as potential energy. Taking zero potential energy at $\theta = 90°$ (dipole perpendicular to the field), the potential energy is

$$U = -mB\cos\theta = -\vec{m}\cdot\vec{B}$$

Here m is the magnetic moment, B is the field and θ is the angle between $\vec{m}$ and $\vec{B}$.

Step 3: Find the minimum value:
U is smallest when $\cos\theta$ is largest, that is $\theta = 0°$. The dipole then points along the field.

$$U_{min} = -mB\cos 0° = -mB$$

This is the stable equilibrium position.

Step 4: Find the maximum value:
U is largest when $\cos\theta = -1$, that is $\theta = 180°$. The dipole then points against the field.

$$U_{max} = -mB\cos 180° = +mB$$

This is the unstable equilibrium position.

Final Answer:
The potential energy is $U = -mB\cos\theta$. Its minimum value is $-mB$ at $\theta = 0°$ and its maximum value is $+mB$ at $\theta = 180°$.

$$\boxed{U = -mB\cos\theta, \quad U_{min} = -mB, \quad U_{max} = +mB}$$

Quick Tip: Use $U = -mB\cos\theta$.
Maximum is $+mB$ at $180°$ and minimum is $-mB$ at $0°$.

5(c). What is the meaning of polarization of light ? How are unpolarized and plane polarized light represented ? Which nature of light waves is proved by polarization of light ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
Light is an electromagnetic wave. In it, the electric field vector and the magnetic field vector vibrate at right angles to each other and both vibrate at right angles to the direction in which the wave travels. In ordinary light from a lamp or the Sun, the electric vector vibrates in all possible directions in the plane perpendicular to the direction of travel.

Step 2: Meaning of polarization:
The process of restricting the vibrations of the electric field vector of light to one single direction (one plane) is called polarization of light. Light whose vibrations are confined to a single plane is called plane polarized light. The plane that contains the vibrations is the plane of vibration.

Step 3: Represent unpolarized light:
The ray is drawn along the direction of travel. In unpolarized light, the vibrations are in all directions perpendicular to the ray. Some of these are in the plane of the paper and some are perpendicular to it. So we show it with both short double arrows (vibrations in the plane of the paper) and dots (vibrations perpendicular to the paper) along the ray, in equal numbers.

Step 4: Represent plane polarized light:

In plane polarized light, the vibrations are in only one direction. So we show only double arrows along the ray (vibrations in the plane of the paper), or only dots along the ray (vibrations perpendicular to the plane of the paper).

Step 5: Nature of light proved by polarization:
Only transverse waves can be polarized. Longitudinal waves such as sound vibrate along the direction of travel, so they have no sideways direction to restrict. Since light shows polarization, it proves that light waves are transverse in nature.

Final Answer:
Polarization means confining the vibrations of the electric vector to one plane. Unpolarized light is shown by arrows and dots, plane polarized light by only arrows or only dots. Polarization proves that light waves are transverse.

Polarization proves that light waves are transverse

Quick Tip: Polarization confines the electric vector to one plane. Unpolarized light is shown by dots and arrows, plane polarized by only one of them. It proves light is transverse.

OR

Show the difference between conductor, semiconductor and insulator by energy band diagram of solids.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

In an isolated atom, electrons occupy discrete energy levels. In a solid, the levels of the huge number of atoms come so close together that they form continuous bands. The highest band that is filled with electrons at 0 K is the valence band (VB). The band above it is the conduction band (CB). The gap between them is the forbidden energy gap E_g, where no electron can stay.

Step 2: Conductor (metal):

In a conductor, the valence band and the conduction band overlap, or the conduction band is partly filled. So $E_g = 0$. Electrons can move into empty states with almost no extra energy.

In the diagram, the VB and CB are drawn touching or overlapping, with no gap between them. Because many free electrons are available, the conductivity is very high. Examples are copper, silver and aluminium.

Step 3: Semiconductor:

In a semiconductor, the VB is full and the CB is empty at 0 K, and they are separated by a small gap, $E_g < 3$ eV. For germanium $E_g \approx 0.67$ eV and for silicon $E_g \approx 1.1$ eV.

In the diagram, a narrow gap is drawn between the VB and the CB. At room temperature, some electrons get enough thermal energy to jump to the CB, leaving holes in the VB. So the conductivity is moderate and it rises with temperature.

Step 4: Insulator:

In an insulator, the VB is full, the CB is empty and the gap is wide, $E_g > 3$ eV (for diamond it is about 5.4 eV).

In the diagram, a large gap is drawn between the VB and the CB. Electrons cannot cross it under normal conditions, so there are

almost no free charge carriers and the conductivity is nearly zero. Examples are glass, wood and diamond.

Step 5: Compare the three:

Conductor: $E_g = 0$, many free electrons, high conductivity.

Semiconductor: small E_g (about 1 eV), conductivity rises with temperature.

Insulator: large E_g (more than 3 eV), almost no conduction.

Final Answer:

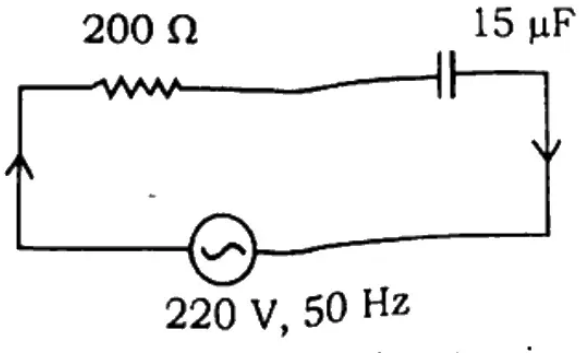
The size of the forbidden gap separates the three types of solids: zero for conductors, small for semiconductors and large for insulators.

$$\boxed{E_g(\text{conductor}) = 0,\ E_g(\text{semiconductor}) < 3\ \text{eV},\ E_g(\text{insulator}) > 3\ \text{eV}}$$

Quick Tip: Compare the forbidden gap between the valence band and the conduction band.

Conductor: zero gap. Semiconductor: about 1 eV. Insulator: more than 3 eV.

5(d).



Find the value of current flowing in the circuit given below. Compare the algebraic sum of the voltage across the terminals of the resistance and the capacitor with the voltage given to the circuit. Why is the difference obtained in them ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

The resistor R and the capacitor C are in series with an AC source. The current is the same in both. The capacitor does not offer plain resistance but capacitive reactance X_C. The voltage across the resistor is in phase with the current, while the voltage across the capacitor lags the current by $90°$.

Step 2: Key Formula:

1. $X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi f C}$
2. $Z = \sqrt{R^2 + X_C^2}$
3. $I_{rms} = \dfrac{V_{rms}}{Z}$

Given: $R = 200\ \Omega$, $C = 15\ \mu\text{F} = 15 \times 10^{-6}$ F, $V = 220$ V, $f = 50$ Hz.

Step 3: Find the capacitive reactance:

$$X_C = \frac{1}{2\pi \times 50 \times 15 \times 10^{-6}} = \frac{1}{4.712 \times 10^{-3}} \approx 212.2\ \Omega$$

Step 4: Find the impedance and the current:

$$Z = \sqrt{200^2 + 212.2^2} = \sqrt{40000 + 45033} = \sqrt{85033} \approx 291.6\ \Omega$$

$$I = \frac{V}{Z} = \frac{220}{291.6} \approx 0.754\ \text{A}$$

Step 5: Find the voltage across the resistor and the capacitor:

$$V_R = IR = 0.754 \times 200 \approx 150.9\ \text{V}$$

$$V_C = IX_C = 0.754 \times 212.2 \approx 160.1\ \text{V}$$

Step 6: Compare the algebraic sum with the source voltage:

$$V_R + V_C = 150.9 + 160.1 \approx 311\ \text{V}$$

This is much larger than the source voltage of 220 V. The difference is about $311 - 220 = 91$ V.

Step 7: Explain why there is a difference:

The two voltages are not in the same phase. V_R is in phase with the current, while V_C lags the current by 90°. So V_R and V_C are 90° apart and must be added as vectors (phasors), not as plain numbers.

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{150.9^2 + 160.1^2} \approx 220\ \text{V}$$

The vector sum equals the source voltage. The algebraic sum is larger only because the peaks of the two voltages do not occur at the same instant.

Final Answer:

The current in the circuit is about 0.75 A. The algebraic sum of the voltages across R and C is about 311 V, more than the 220 V of the source, because the two voltages differ in phase by 90° and add as vectors.

$$\boxed{I \approx 0.75\ \text{A};\ V_R + V_C \approx 311\ \text{V} > 220\ \text{V}}$$

Quick Tip: Find $X_C = 1/(2\pi fC) \approx 212\ \Omega$, then $Z = \sqrt{R^2 + X_C^2}$ and $I = V/Z$. The voltages across R and C are 90° out of phase, so they add as vectors.

5(e). Write down the postulates of Bohr atomic model.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Rutherford's model of the atom could not explain why an orbiting

electron does not spiral into the nucleus, and it could not explain the line spectrum of hydrogen. In 1913 Niels Bohr fixed these problems by adding three postulates for a hydrogen-like atom (a nucleus of charge $+Ze$ with one electron).

Step 2: Postulate 1, the electron moves in circular orbits.
The electron revolves around the nucleus in a circular orbit. The electrostatic pull of the nucleus gives the centripetal force. For an electron of mass m, speed v and orbit radius r:

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$$

Step 3: Postulate 2, only some orbits are allowed (quantum condition).
The electron can stay only in those orbits in which its angular momentum is a whole-number multiple of $h/2\pi$, where h is Planck's constant:

$$L = mvr = \frac{nh}{2\pi}, \qquad n = 1, 2, 3, \ldots$$

These orbits are called stationary orbits, and n is the principal quantum number. In a stationary orbit the electron does not radiate energy, even though it is accelerating. So the atom stays stable.

Step 4: Postulate 3, radiation comes only from a jump between orbits.
The electron emits or absorbs energy only when it jumps from one stationary orbit to another. If it falls from an orbit of energy E_i to a lower orbit of energy E_f, a photon is emitted with

$$h\nu = E_i - E_f$$

To go the other way, the atom must absorb a photon of exactly this energy.

Step 5: What the postulates give for hydrogen.
Using postulates 1 and 2 together, the radius of the nth orbit is $r_n \propto n^2$ and the energy is $E_n = -\frac{13.6}{n^2}$ eV. The ground state $n = 1$ has $E_1 = -13.6$ eV. Postulate 3 then gives the wavelengths of the observed spectral series.

Final Answer:
Bohr's three postulates are: circular orbits held by the Coulomb force, allowed orbits with $mvr = nh/2\pi$ in which the electron does not radiate, and emission or absorption of a photon of energy $h\nu = E_i - E_f$ in a jump.

$$\boxed{mvr = \frac{nh}{2\pi}, \qquad h\nu = E_i - E_f}$$

Quick Tip: Write the three postulates in order: Coulomb force gives the circular orbit, the angular momentum is quantised as $mvr = nh/2\pi$ in non-radiating stationary orbits, and a photon of energy $h\nu = E_i - E_f$ is emitted or absorbed in a jump.

6. What are dielectric materials ? Define electric susceptibility and relative permittivity of a medium. Deduce the relation between the two.

Correct Answer: —

Solution:

Step 1: What dielectric materials are:

Dielectric materials are insulators. They have almost no free charges, so they do not conduct, but they get polarised when placed in an electric field.

In a non-polar dielectric (like H_2 or O_2) the field pulls the centres of positive and negative charge apart and creates induced dipoles.

In a polar dielectric (like water) the permanent dipoles, which point randomly otherwise, line up partly along the field.

In both cases the material gets a net dipole moment along the field, and the field this produces inside the material is opposite to the applied field.

Step 2: Electric susceptibility:

The dipole moment per unit volume of the dielectric is called polarisation $\vec{P}$.

For weak fields, $\vec{P}$ is directly proportional to the net electric field $\vec{E}$ inside the dielectric:

$$\vec{P} = \varepsilon_0 \chi_e \vec{E}$$

The constant χ_e is the electric susceptibility of the medium. It has no unit and tells how easily the medium gets polarised. For vacuum $\chi_e = 0$.

Step 3: Relative permittivity:

If ε is the permittivity of the medium and ε_0 that of free space, the relative permittivity (dielectric constant) is

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = K$$

It is also the ratio E_0/E, where E_0 is the field without the dielectric and E is the field with it.

Step 4: Deduce the relation between them:
Take a parallel plate capacitor with free surface charge density σ on its plates. Without a dielectric the field between the plates is

$$E_0 = \frac{\sigma}{\varepsilon_0}$$

When a dielectric slab is put between the plates, its faces get bound charges of density σ_p, with magnitude equal to the polarisation P. These oppose the free charges, so the net field is

$$E = \frac{\sigma - P}{\varepsilon_0} \quad \Rightarrow \quad \varepsilon_0 E = \sigma - \varepsilon_0 \chi_e E$$

$$\varepsilon_0 E(1 + \chi_e) = \sigma \quad \Rightarrow \quad E = \frac{\sigma}{\varepsilon_0(1 + \chi_e)} = \frac{E_0}{1 + \chi_e}$$

By definition $K = E_0/E$. Comparing,

$$K = \varepsilon_r = 1 + \chi_e$$

So $\varepsilon = \varepsilon_0(1 + \chi_e)$ as well.

Final Answer:
Dielectrics are polarised insulators, $\vec{P} = \varepsilon_0 \chi_e \vec{E}$ defines the susceptibility, $\varepsilon_r = \varepsilon/\varepsilon_0$ defines the relative permittivity, and the two are related by

$$\boxed{\varepsilon_r = 1 + \chi_e}$$

Quick Tip: Use $P = \varepsilon_0 \chi_e E$ and the capacitor field $E = E_0/K$ (or $D = \varepsilon_0 E + P$) to reach $K = 1 + \chi_e$.

OR

Establish the relation between drift velocity of electrons and current flowing in a conductor. Length of a conducting wire is 3.0 m and free electron density in it is $8.5 \times 10^{28}\ \mathrm{m}^{-3}$. How much time will the electron take to drift from one end to other end of the wire ? Cross-section of the wire is $2.0 \times 10^{-6}\ \mathrm{m}^2$ and current flowing in the wire is 3.0 ampere.

Correct Answer: —

Solution:

Step 1: Understanding the setup:

Let a conductor of cross-section A carry current I. It has n free electrons per unit volume, each of charge e, and they drift with average speed v_d (the drift velocity).

Step 2: Charge crossing a section in time dt:

In a short time dt, every free electron within a distance $v_d\,dt$ of a cross-section crosses it. These electrons fill a volume $Av_d\,dt$.

Number of electrons crossing = $nAv_d\,dt$, so the charge crossing is

$$dq = neAv_d\,dt$$

Step 3: Relation between current and drift velocity:

Current is charge crossing per unit time, $I = dq/dt$:

$$I = neAv_d \quad \Rightarrow \quad v_d = \frac{I}{neA}$$

This also gives current density $J = I/A = nev_d$.

Step 4: Find the drift velocity in the wire:

Given: $n = 8.5 \times 10^{28}\ \text{m}^{-3}$, $A = 2.0 \times 10^{-6}\ \text{m}^2$, $I = 3.0\ \text{A}$, $L = 3.0\ \text{m}$, and $e = 1.6 \times 10^{-19}\ \text{C}$.

$$v_d = \frac{3.0}{(8.5 \times 10^{28})(1.6 \times 10^{-19})(2.0 \times 10^{-6})}$$

The denominator is $8.5 \times 1.6 \times 2.0 \times 10^{28-19-6} = 27.2 \times 10^3 = 2.72 \times 10^4$. So

$$v_d = \frac{3.0}{2.72 \times 10^4} \approx 1.1 \times 10^{-4}\ \text{m/s}$$

Step 5: Time to drift along the wire:

The electron moves at the steady speed v_d, so the time to cover the length L is

$$t = \frac{L}{v_d} = \frac{3.0}{1.103 \times 10^{-4}} \approx 2.72 \times 10^4\ \text{s}$$

This is about 7.6 hours. The drift is very slow, even though a bulb lights up at once, because the field travels through the wire almost at the speed of light and every electron starts moving together.

Final Answer:

The relation is $I = neAv_d$. The drift velocity is about 1.1×10^{-4} m/s and the electron takes about 2.7×10^4 s (nearly 7.6 hours) to go from one end to the other.

$$\boxed{I = neAv_d, \quad t \approx 2.72 \times 10^4 \text{ s}}$$

Quick Tip: Charge in length $v_d\,dt$ gives $I = neAv_d$. Then $t = L/v_d = LneA/I \approx 2.7 \times 10^4$ s.

7. Discuss the magnitude and direction of force acting on a charge moving in a uniform magnetic field. If charge moves along the direction of the magnetic field, what will be the magnitude of the force ? Comment on the work done by the magnetic field on the moving charge.

Correct Answer: —

Solution:

Step 1: Force on a moving charge:

A charge q moving with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ feels the magnetic (Lorentz) force

$$\vec{F} = q(\vec{v} \times \vec{B})$$

Step 2: Magnitude of the force:

If θ is the angle between $\vec{v}$ and $\vec{B}$, the cross product gives

$$F = qvB\sin\theta$$

The force is greatest, $F = qvB$, when the charge moves at right angles to the field ($\theta = 90°$). It is zero when $\theta = 0°$ or $180°$. It also needs $v \neq 0$, so a charge at rest feels no magnetic force.

Step 3: Direction of the force:
The force is perpendicular to both $\vec{v}$ and $\vec{B}$, that is, perpendicular to the plane containing them. For a positive charge, the direction follows the right-hand rule: turn the fingers from $\vec{v}$ towards $\vec{B}$ through the smaller angle and the thumb gives $\vec{F}$. For a negative charge, the force is in the opposite direction.

Step 4: Charge moving along the field:
When the charge moves along $\vec{B}$ (or opposite to it), $\theta = 0°$ or $180°$, so $\sin\theta = 0$.

$$F = qvB\sin 0° = 0$$

The magnitude of the force is zero and the charge keeps going straight at constant speed.

Step 5: Work done by the magnetic force:
Because $\vec{F}$ is always perpendicular to $\vec{v}$, the small displacement $d\vec{s} = \vec{v}\,dt$ is also perpendicular to $\vec{F}$.

$$dW = \vec{F} \cdot d\vec{s} = F\,ds\cos 90° = 0$$

So the magnetic field does no work on a moving charge. Its kinetic energy and speed stay the same. The field only changes the direction of the velocity, which is why a charge entering at right angles moves

in a circle of radius $r = mv/(qB)$.

Final Answer:

The force is $F = qvB\sin\theta$, perpendicular to both $\vec{v}$ and $\vec{B}$. It is zero when the charge moves along the field, and the magnetic force does no work on the charge.

$$\boxed{F = qvB\sin\theta, \quad F = 0 \text{ for } \theta = 0^\circ, \quad W = 0}$$

Quick Tip: Use $\vec{F} = q\vec{v} \times \vec{B}$. Along the field $\sin\theta = 0$, so $F = 0$. Force is perpendicular to velocity, so work done is zero.

OR

What is the meaning of electromagnetic induction ? Explain Faraday's laws of electromagnetic induction. Radius of a circular coil is 10 cm, resistance is 2 Ω and number of turns in it is 500. Plane of coil is perpendicular to a magnetic field of 3×10^{-5} tesla. Coil rotates 180° about its perpendicular axis in 0.25 s. Find the induced voltage and current in the coil.

Correct Answer: —

Solution:

Step 1: Meaning of electromagnetic induction:

Electromagnetic induction is the production of an emf (and a current, if the circuit is closed) in a coil whenever the magnetic flux linked with it changes. It was found by Faraday and Henry. Moving a magnet near a coil, or turning a coil in a field, are examples.

Step 2: Faraday's laws:

First law: whenever the magnetic flux linked with a circuit changes, an emf is induced in it. The emf lasts only as long as the flux keeps changing.
Second law: the magnitude of the induced emf equals the rate of change of magnetic flux linked with the circuit. For a coil of N turns,

$$\varepsilon = -N\frac{d\Phi}{dt}$$

The minus sign is Lenz's law: the induced current opposes the change that produces it. Flux is $\Phi = BA\cos\theta$, with θ the angle between $\vec{B}$ and the normal to the coil.

Step 3: Flux through the coil at the start and the end:
Radius $r = 10\text{ cm} = 0.10\text{ m}$, so the area is

$$A = \pi r^2 = 3.14 \times (0.10)^2 = 3.14 \times 10^{-2}\,\text{m}^2$$

At the start the plane of the coil is perpendicular to $\vec{B}$, so the normal is along $\vec{B}$ and $\theta = 0°$:

$$\Phi_1 = BA\cos 0° = (3 \times 10^{-5})(3.14 \times 10^{-2}) = 9.42 \times 10^{-7}\,\text{Wb}$$

After turning $180°$, the normal points opposite to $\vec{B}$, $\theta = 180°$, and $\Phi_2 = -9.42 \times 10^{-7}$ Wb.

Step 4: Induced emf (average value):
Change in flux through one turn: $\Delta\Phi = \Phi_2 - \Phi_1 = -1.884 \times 10^{-6}$ Wb.

$$|\varepsilon| = N\frac{|\Delta\Phi|}{\Delta t} = \frac{500 \times 1.884 \times 10^{-6}}{0.25} = \frac{9.42 \times 10^{-4}}{0.25}$$

$$|\varepsilon| = 3.77 \times 10^{-3}\,\text{V}$$

Step 5: Induced current:

Using Ohm's law with $R = 2\,\Omega$:

$$I = \frac{\varepsilon}{R} = \frac{3.77 \times 10^{-3}}{2} = 1.88 \times 10^{-3}\,\text{A}$$

Final Answer:

The average induced emf is about 3.8×10^{-3} V (3.8 mV) and the induced current is about 1.9×10^{-3} A (1.9 mA).

$$\boxed{\varepsilon \approx 3.77 \times 10^{-3}\,\text{V}, \quad I \approx 1.88 \times 10^{-3}\,\text{A}}$$

Quick Tip: Flux reverses sign, so $\Delta\Phi = 2NBA$. $\varepsilon = 2NBA/\Delta t \approx 3.77 \times 10^{-3}$ V and $I = \varepsilon/R \approx 1.88 \times 10^{-3}$ A.

8. Draw the diffraction pattern of light a single slit and write the formula for the width of central maximum. Mention the factors affecting the width of central maximum. What may be the maximum possible value of the angle of diffraction ?

Correct Answer: —

Solution:

Step 1: Diffraction pattern of a single slit:

When a parallel beam of monochromatic light of wavelength λ falls on a narrow slit of width a, the light spreads into the geometrical shadow and forms a pattern on a screen placed at distance D.

The pattern is a very bright, broad central maximum at the middle. On both sides there are dark minima and then weaker secondary maxima. The secondary maxima become fainter and are about half as wide as the central one. A graph of intensity against angle shows a tall central peak and small, quickly falling peaks on either side, with zero intensity at the minima.

Step 2: Condition for minima:

The minima are at angles θ given by $a\sin\theta = n\lambda$, with $n = \pm1, \pm2, \ldots$.

The first minimum on each side is at

$$\sin\theta_1 = \frac{\lambda}{a}$$

Step 3: Width of the central maximum:

The central maximum lies between the two first minima. For small angles $\sin\theta \approx \theta \approx \lambda/a$, so the angular width is $2\lambda/a$. The distance of the first minimum from the centre on the screen is $D\lambda/a$, so the linear width is

$$\beta_0 = \frac{2\lambda D}{a}$$

Step 4: Factors that change the width:

1. Wavelength: the width is proportional to λ, so red light gives a wider central maximum than blue light.

2. Slit width: the width is inversely proportional to a, so a narrower slit gives a wider central maximum.
3. Distance of screen: the width is proportional to D.

Step 5: Maximum angle of diffraction:
The relation $a \sin\theta = n\lambda$ needs $\sin\theta \leq 1$. The largest possible value of the angle is the one where $\sin\theta = 1$:

$$\theta_{max} = 90^\circ$$

This happens when the slit width becomes about equal to or less than the wavelength, so that the light spreads to 90 degrees on each side.

Final Answer:
The pattern has a wide central bright band with fainter side maxima. The central width is $2\lambda D/a$, which depends on λ, a and D. The largest angle of diffraction is 90°.

$$\boxed{\beta_0 = \frac{2\lambda D}{a}, \quad \theta_{max} = 90^\circ}$$

Quick Tip: Minima at $a \sin\theta = n\lambda$. Central width $= 2\lambda D/a$, so it depends on λ, a and D. Maximum angle is 90°.

OR

State the Huygens principle of secondary wavelets. On its basis verify the laws of refraction of light.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Christiaan Huygens explained how light travels by using the idea of a wavefront. A wavefront is the surface that joins all points of a medium which are in the same phase of vibration at the same moment.

The question has two parts. First we state the principle. Then we use it to prove the two laws of refraction.

Step 2: Huygens principle of secondary wavelets:

1. Every point on a given wavefront acts as a fresh source of a new disturbance. These new disturbances are called secondary wavelets. They spread out in all directions with the speed of light in that medium.

2. The new position of the wavefront after a time t is the forward envelope of these secondary wavelets. This means it is the surface that touches all the wavelets drawn with radius vt, where v is the speed of light in the medium.

3. The direction of travel of light (the ray) is always at right angles to the wavefront.

Step 3: Set up the refraction of a plane wave:

Let XY be a plane surface separating medium 1 (speed of light v_1) from medium 2 (speed of light v_2). Take $v_2 < v_1$, so medium 2 is optically denser.

A plane wavefront AB of a parallel beam is incident on XY. The incident rays make an angle i with the normal, so the wavefront AB makes the same angle i with the surface XY.

Point A of the wavefront touches the surface first. Point B is still in medium 1 and needs a time t to reach the surface at point C. So in this time the distance covered by light in medium 1 is

$$BC = v_1 t$$

Step 4: Draw the secondary wavelet from A:

During the same time t, the secondary wavelet from A spreads into medium 2 with speed v_2. Its radius is $AE = v_2 t$.

The tangent drawn from C to this hemispherical wavelet touches it at E. By Huygens principle, CE is the refracted wavefront. The refracted ray is perpendicular to CE and makes an angle r with the normal, so CE makes the angle r with the surface XY.

Step 5: Prove Snell's law:

In the right-angled triangle ABC, the angle at A is i. So

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$$

In the right-angled triangle AEC, the angle at C is r. So

$$\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$$

Divide the first equation by the second. The common length AC and the time t cancel:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

The speed of light in a medium of refractive index n is $v = c/n$. So $v_1/v_2 = n_2/n_1$, and

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

For two given media, v_1 and v_2 are fixed. So the ratio $\sin i / \sin r$ is a constant. This is the second law of refraction (Snell's law).

Step 6: Prove the first law:
The incident ray, the refracted ray and the normal are all perpendicular to wavefronts that lie in the same plane (the plane of the figure, which is perpendicular to the surface). So the incident ray, the refracted ray and the normal at the point of incidence lie in one plane. This is the first law of refraction.

Step 7: A useful check:
Light slows down on entering a denser medium ($v_2 < v_1$), so $\sin r < \sin i$. The ray bends towards the normal. This is exactly what we see in practice, for example when light goes from air to glass. The frequency of light does not change on refraction, so only the wavelength changes: $\lambda_2/\lambda_1 = v_2/v_1$.

Final Answer:
By Huygens principle, the ratio of the sines of the angles is equal to the ratio of the speeds of light in the two media, which gives Snell's law, and the coplanarity of rays gives the first law.

$$\boxed{\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{n_2}{n_1}}$$

Quick Tip: Draw plane wavefront AB meeting the surface at angle i. In the time B takes to reach C, the wavelet from A grows to radius v2 t. Use the two right triangles to get sin i / sin r = v1 / v2.

9. What are de Broglie matter waves? Mention its main properties. α-particle, proton and electron have the same kinetic energy. de Broglie wavelength associated with which particle will be maximum and why?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Light shows both wave and particle behaviour. In 1924 Louis de Broglie said that matter too has a dual nature. Every moving particle has a wave linked with it. These waves are called de Broglie waves or matter waves.

Step 2: Key Formula or Approach:

The wavelength of the matter wave of a particle of mass m moving with speed v is

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Here h is Planck's constant and p is the momentum. If the kinetic energy is K, then $p = \sqrt{2mK}$, so

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

Step 3: Main properties of matter waves:

1. The wavelength is inversely proportional to the momentum. A heavier or faster particle has a smaller wavelength.
2. Matter waves are not electromagnetic waves. They are not produced by oscillating charges. They are associated with every

moving particle, charged or neutral.
3. They are not seen for everyday objects because h is so small that the wavelength of a large body is far too short to detect.
4. The wave speed u of the matter wave is not the same as the particle speed v. It depends on the energy.
5. The waves are probability waves. The square of the wave amplitude at a place gives the chance of finding the particle there.
6. They show diffraction and interference. This was confirmed by the Davisson and Germer electron diffraction experiment.

Step 4: Compare the three particles:
All three particles have the same K and the same h. So from $\lambda = h/\sqrt{2mK}$ we get $\lambda \propto 1/\sqrt{m}$. The charge does not appear in the formula, so it plays no part here.
The masses are in the order $m_e < m_p < m_\alpha$. Approximately, $m_p = 1836\, m_e$ and $m_\alpha \approx 4\, m_p$. Then

$$\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}} = \sqrt{1836} \approx 43$$

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_p}} = \sqrt{4} = 2$$

So $\lambda_e : \lambda_p : \lambda_\alpha \approx 86 : 2 : 1$, which means $\lambda_e > \lambda_p > \lambda_\alpha$.

Step 5: Reason:
For a fixed kinetic energy, the lightest particle has the least momentum, and a smaller momentum gives a larger wavelength. The electron is the lightest of the three, so it has the longest de Broglie wavelength.

Final Answer:

Matter waves are the waves associated with moving particles, with wavelength $\lambda = h/p$. At equal kinetic energy the electron has the greatest wavelength because it has the smallest mass.

$$\boxed{\lambda_{\text{electron}} \text{ is maximum}, \quad \lambda = \frac{h}{\sqrt{2mK}}}$$

Quick Tip: Use $\lambda = h/\sqrt{2mK}$. For equal K, wavelength varies as $1/\sqrt{m}$, so the lightest particle (electron) has the longest wavelength.

OR

Explain the effect of forward and reverse biasing on depletion region and potential barrier of a *p*-*n* junction. Draw circuit diagram of a full-wave rectifier using junction diode. Depict the shape of input and output current.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A *p*-*n* junction is formed when a *p*-type and an *n*-type semiconductor are joined. Electrons from the *n*-side diffuse to the *p*-side, and holes diffuse the other way. Near the junction this leaves behind fixed positive donor ions on the *n*-side and fixed negative acceptor ions on the *p*-side.

This thin region, which has almost no free carriers, is the depletion region. The fixed ions create an electric field and a potential difference V_0 across it, called the potential barrier. It is about 0.7 V

for silicon and 0.3 V for germanium.

Step 2: Forward bias:

The p-side is joined to the positive terminal of the battery and the n-side to the negative terminal.

The battery field acts against the junction field. Holes on the p-side and electrons on the n-side are pushed towards the junction, and they neutralise some of the fixed ions.

So the depletion region becomes narrower, and the potential barrier falls to $V_0 - V$. Majority carriers can then cross the junction easily, and a large forward current (in mA) flows. The current rises quickly once the applied voltage passes the knee voltage.

Step 3: Reverse bias:

The p-side is joined to the negative terminal and the n-side to the positive terminal.

The battery field is now in the same direction as the junction field. It pulls holes and electrons away from the junction, so more fixed ions are uncovered.

So the depletion region becomes wider, and the potential barrier rises to $V_0 + V$. Majority carriers cannot cross. Only a very small leakage current (in μA) flows, due to minority carriers. This current stays almost constant until breakdown.

Step 4: Full-wave rectifier circuit:

A full-wave rectifier changes the full a.c. input into a pulsating d.c. output. It uses two junction diodes D_1 and D_2 and a centre-tapped transformer.

Circuit connections: The input a.c. is applied to the primary of the transformer. The two ends A and B of the secondary are joined to the p-sides (anodes) of D_1 and D_2. The n-sides (cathodes) of both diodes

are joined together. The load resistance R_L is connected between this common cathode point and the centre tap C of the secondary. The output is taken across R_L.

Step 5: Working and the shape of the currents:

In the first half cycle, end A is positive with respect to the centre tap and end B is negative. D_1 is forward biased and conducts. D_2 is reverse biased and does not conduct. The current goes through R_L from the cathode junction towards C.

In the next half cycle, end B becomes positive and A negative. D_2 conducts and D_1 is off. The current through R_L is again in the same direction.

Input: a continuous sine wave which is positive for half a cycle and negative for the next half cycle, with period T.

Output: a series of positive half-sine humps, one for every half cycle of the input, all above the zero line. So the output has no negative part, but it is not steady. It is pulsating d.c.

The output frequency is twice the input frequency (for a 50 Hz supply, the output ripple is 100 Hz). A filter such as a capacitor can then be used to smooth the output.

Final Answer:

Forward bias narrows the depletion region and lowers the barrier, so current flows. Reverse bias widens the region and raises the barrier, so almost no current flows. A centre-tap full-wave rectifier with two diodes gives an output current with positive pulses in both half cycles, at twice the input frequency.

$$\boxed{f_{\text{out}} = 2f_{\text{in}}}$$

Quick Tip: Forward bias: depletion region narrows and barrier falls to V_0 - V. Reverse bias: region widens and barrier rises to V_0 + V. Full-wave rectifier: two diodes, centre-tapped transformer, load between the cathode junction and the centre tap.