UP Board Class 12 Physics 2026 Set 346 DY Question Paper with Solutions

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General Instructions

(i) This booklet contains 30 questions, each provided with a complete, step-by-step solution.

(ii) It comprises 6 single-correct multiple-choice questions.

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

1. If the accelerating potential of a moving charged particle of λ de Broglie wavelength is increased by four times, then the de Broglie wavelength will be:

(A) $\lambda/4$

(B) $\lambda/2$

(C) 2λ

(D) 4λ

Correct Answer: (B) $\lambda/2$

Solution:

Step 1: Recall the de Broglie wavelength of a charged particle accelerated through a potential V. The particle gains kinetic energy $KE = qV$, so its momentum is $p = \sqrt{2mqV}$.

Step 2: The de Broglie wavelength is

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mqV}}.$$

This shows $\lambda \propto \frac{1}{\sqrt{V}}$.

Step 3: Let the new potential be $V' = 4V$. Then

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{V}{V'}} = \sqrt{\frac{V}{4V}} = \frac{1}{2}.$$

Step 4: Therefore $\lambda' = \frac{\lambda}{2}$, which is option 2. Options 3 and 4 wrongly assume λ grows with V; option 1 uses the square of the factor instead of the square root.

$$\boxed{\lambda' = \frac{\lambda}{2}}$$

Quick Tip: Use $\lambda = h/\sqrt{2mqV}$; the wavelength varies inversely with the square root of the accelerating potential.

2. In which of the following spherical mirrors is the magnification of the image always less than 1?

(A) Convex

(B) Plane

(C) Concave

(D) All of these

Correct Answer: (A) Convex

Solution:

Step 1: Magnification is $m = \dfrac{\text{image height}}{\text{object height}}$. If $|m| < 1$ the image is diminished (smaller than the object).

Step 2: A convex mirror always forms a virtual, erect and diminished image for any real object, no matter where the object is placed. So its magnification is always $|m| < 1$.

Step 3: A concave mirror can form magnified images (for example when the object lies between the focus and the pole, or between C and F), so $|m|$ can be greater than 1. A plane mirror always gives $|m| = 1$, an image equal in size, not less than 1.

Step 4: Only the convex mirror satisfies the condition, so option 1 is correct, and option 4 (all of these) is therefore wrong.

$$\boxed{\text{Convex mirror}}$$

Quick Tip: Which mirror always gives a virtual, erect and diminished image regardless of object position?

3. Coulomb's repulsive force of F newton acts between two point charges of $+3\,\mu C$ and $+8\,\mu C$. If $-5\,\mu C$ charge is given to both of them, then the force and its nature between them will be:

(A) $F/4$ newton, attractive

(B) $F/4$ newton, repulsive

(C) $3F/13$ newton, repulsive

(D) $4F$ newton, attractive

Correct Answer: (A) $F/4$ newton, attractive

Solution:

Step 1: Coulomb's law gives the force between two point charges as

$$F = \frac{1}{4\pi\varepsilon_0}\,\frac{q_1 q_2}{r^2}.$$

The separation r stays the same throughout.

Step 2: Initial charges are $q_1 = +3\,\mu C$ and $q_2 = +8\,\mu C$, so

$$F = \frac{1}{4\pi\varepsilon_0}\,\frac{(3)(8)}{r^2} = \frac{1}{4\pi\varepsilon_0}\,\frac{24}{r^2}\ \text{(in } \mu C \text{ units)}.$$

Step 3: Adding $-5\,\mu C$ to each charge:

$$q_1' = 3 + (-5) = -2\,\mu C, \qquad q_2' = 8 + (-5) = +3\,\mu C.$$

Step 4: New force magnitude

$$F' = \frac{1}{4\pi\varepsilon_0}\,\frac{|(-2)(3)|}{r^2} = \frac{1}{4\pi\varepsilon_0}\,\frac{6}{r^2}.$$

Step 5: Take the ratio

$$\frac{F'}{F} = \frac{6}{24} = \frac{1}{4} \Rightarrow F' = \frac{F}{4}.$$

The new charges have opposite signs ($-2\,\mu C$ and $+3\,\mu C$), so the force is attractive. Hence option 1.

$$\boxed{F' = \frac{F}{4}\text{, attractive}}$$

Quick Tip: Update each charge by adding $-5\,\mu C$; force scales as the product of charges, and opposite signs mean attraction.

4. In the given nuclear reaction, particle W is:

$$^{4}_{2}\text{He} + ^{A}_{Z}X \rightarrow ^{A+3}_{Z+2}Y + W$$

(A) Electron

(B) Proton

(C) Positron

(D) Neutron

Correct Answer: (D) Neutron

Solution:

Step 1: In every nuclear reaction the total mass number (top numbers) and the total atomic number (bottom numbers) are conserved on both sides.

Step 2: Balance the mass numbers. Left side: $4 + A$. Right side: $(A + 3) + A_W$. So

$$4 + A = (A + 3) + A_W \Rightarrow A_W = 4 + A - A - 3 = 1.$$

Step 3: Balance the atomic numbers. Left side: $2 + Z$. Right side: $(Z + 2) + Z_W$. So

$$2 + Z = (Z + 2) + Z_W \Rightarrow Z_W = 0.$$

Step 4: Particle W has mass number 1 and charge 0, i.e. ${}^{1}_{0}n$, which is a neutron. Hence option 4. A proton would have charge +1, an electron/positron mass number 0, so they are ruled out.

$$\boxed{W = {}^{1}_{0}n \text{ (neutron)}}$$

Quick Tip: Conserve mass number and atomic number separately; the missing particle has mass number 1 and charge 0.

5. A coil of one loop is formed by a wire of length L, and thereafter a coil of 3 loops is formed by the same wire. If the current remains the same in both cases, then the ratio of the magnetic fields at the centre will be:

(A) 1 : 3

(B) 3 : 1

(C) 1 : 9

(D) 9 : 1

Correct Answer: (C) 1 : 9

Solution:

Step 1: The magnetic field at the centre of a circular coil of N turns and radius r carrying current I is

$$B = \frac{\mu_0 N I}{2r}.$$

Step 2 (single loop): One turn uses the whole wire, so $2\pi r_1 = L \Rightarrow r_1 = \frac{L}{2\pi}$. With $N_1 = 1$,

$$B_1 = \frac{\mu_0 (1) I}{2r_1} = \frac{\mu_0 I}{2\,(L/2\pi)} = \frac{\mu_0 \pi I}{L}.$$

Step 3 (three loops): Three turns use the same wire, so $3(2\pi r_2) = L \Rightarrow r_2 = \frac{L}{6\pi}$. With $N_2 = 3$,

$$B_2 = \frac{\mu_0 (3) I}{2r_2} = \frac{3\mu_0 I}{2\,(L/6\pi)} = \frac{3\mu_0 I \cdot 6\pi}{2L} = \frac{9\mu_0 \pi I}{L}.$$

Step 4: Take the ratio

$$\frac{B_1}{B_2} = \frac{\mu_0 \pi I/L}{9\mu_0 \pi I/L} = \frac{1}{9}.$$

So $B_1 : B_2 = 1 : 9$, option 3.

$$\boxed{B_1 : B_2 = 1 : 9}$$

Quick Tip: For a fixed wire length, $B \propto N^2$ because more turns shrink the radius; compare $N = 1$ with $N = 3$.

6. Equivalent resistance R is obtained when n wires having the same length and same thickness of the same material are joined in parallel. The equivalent resistance on joining them in series will be:

(A) nR

(B) n^2R

(C) R/n

(D) R/n^2

Correct Answer: (B) n^2R

Solution:

Step 1: Since all n wires have the same length, thickness and material, they have the same resistance. Let each wire have resistance r.

Step 2 (parallel): For n equal resistances in parallel,

$$\frac{1}{R_{parallel}} = \frac{n}{r} \Rightarrow R_{parallel} = \frac{r}{n}.$$

We are told this equals R:

$$\frac{r}{n} = R \Rightarrow r = nR.$$

Step 3 (series): For n equal resistances in series,

$$R_{series} = n\,r.$$

Step 4: Substitute $r = nR$:

$$R_{series} = n \times (nR) = n^2R.$$

Hence option 2.

$$\boxed{R_{series} = n^2R}$$

Quick Tip: Let each wire be r; parallel gives $r/n = R$ so $r = nR$, and series gives nr.

7. Define and write the formula of mobility.

Correct Answer: —

Solution:

Step 1: Definition.

The **mobility** of a charge carrier is defined as the magnitude of the drift velocity acquired by the carrier per unit applied electric field. In other words, it tells us how easily a charge carrier (an electron in a metal) moves through the material under an external electric field.

Step 2: Formula.

If v_d is the drift velocity of the charge carrier and E is the applied electric field, then mobility μ is

$$\mu = \frac{v_d}{E}$$

Step 3: Alternative form and SI unit.

Since the drift velocity for electrons is $v_d = \dfrac{eE\tau}{m}$ (where e is the electronic charge, τ is the average relaxation time and m is the electron mass), substituting this gives

$$\mu = \frac{e\tau}{m}$$

The SI unit of mobility is $\mathrm{m^2\,V^{-1}\,s^{-1}}$ (metre squared per volt per second).

$$\boxed{\mu = \frac{v_d}{E} = \frac{e\tau}{m}}$$

Quick Tip: Mobility is drift velocity per unit electric field; recall $\mu = v_d/E$ $= e\tau/m$.

8. What are the uses of microwaves?

Correct Answer: —

Solution:

Step 1: What microwaves are.

Microwaves are electromagnetic waves whose frequency lies roughly in the range 10^9 Hz to 3×10^{11} Hz (wavelengths from about 1 mm to 30 cm). They are produced by special vacuum tubes such as klystrons and magnetrons.

Step 2: Main uses.

(i) **RADAR systems** for aircraft navigation and speed detection, because their short wavelength allows them to travel in straight lines and reflect from objects.

(ii) **Microwave ovens** for cooking, since microwaves are readily absorbed by water molecules in food and heat it.

(iii) **Telecommunication**, satellite communication and mobile phone networks for carrying signals.

$$\boxed{\text{RADAR, microwave ovens, and satellite/telecommunication}}$$

Quick Tip: Think of the very short wavelength: it makes microwaves ideal for RADAR, ovens and satellite communication.

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9. What is the difference between paramagnetic and diamagnetic substances?

Correct Answer: —

Solution:

Step 1: Paramagnetic substances.

These are substances that are **weakly attracted** by a magnet. When placed in an external magnetic field, they get feebly magnetised in the **same direction** as the field, so their relative permeability is slightly greater than 1 and their magnetic susceptibility χ is small and positive ($\chi > 0$). Their atoms have a net (permanent) magnetic moment. Example: aluminium, platinum, oxygen.

Step 2: Diamagnetic substances.

These are substances that are **weakly repelled** by a magnet. In an external field they get feebly magnetised in the **opposite direction** to the field, so their relative permeability is slightly less than 1 and their susceptibility is small and negative ($\chi < 0$). Their atoms have **no net** magnetic moment. Example: bismuth, copper, water.

$$\boxed{\text{Para: weak attraction, } \chi > 0; \quad \text{Dia: weak repulsion, } \chi < 0}$$

Quick Tip: Compare the sign of susceptibility and whether the atoms carry a permanent magnetic moment.

10. What is meant by the optical center of a lens?

Correct Answer: —

Solution:

Step 1: Definition.

The **optical center** of a lens is a fixed point on the principal axis of the lens through which any ray of light passes **undeviated** (without changing its direction).

Step 2: Explanation.

A ray directed toward the optical center enters and leaves the lens along parallel faces near the center, so it travels straight through and emerges without bending (there is only a negligible lateral shift). The optical center is usually the geometric center of a thin lens.

Step 3: Key property.
Because a ray through the optical center is undeviated, it is used as one of the standard construction rays when drawing ray diagrams for image formation by lenses.

$$\boxed{\text{Point on the axis through which a ray passes undeviated}}$$

Quick Tip: It is the point on the principal axis through which a ray passes without any deviation.

11. What are the charge carriers in p-type of semiconductors?

Correct Answer: —

Solution:

Step 1: How a p-type semiconductor is made.
A pure (intrinsic) semiconductor such as silicon or germanium is doped with a small amount of a **trivalent** impurity (an acceptor atom having 3 valence electrons, for example boron, aluminium or indium).

Step 2: What this creates.
Each trivalent atom forms only three covalent bonds with the neighbouring silicon atoms; the fourth bond is left incomplete, creating a vacancy called a **hole**. These holes are far more numerous than the electrons.

Step 3: The charge carriers.

Therefore, in a p-type semiconductor the **majority charge carriers are holes** (positive), while electrons are the minority carriers.

$$\boxed{\text{Majority carriers} = \text{holes (positive); minority} = \text{electrons}}$$

Quick Tip: Trivalent (acceptor) doping creates vacancies; recall which positive carrier dominates in p-type.

12. What is an equipotential surface?

Correct Answer: —

Solution:

Step 1: Definition.

An **equipotential surface** is a surface on which the **electric potential is the same at every point**.

Step 2: Key property (no work is done).

Since the potential is constant over the surface, the potential difference between any two points on it is zero. Hence the work done in moving a charge q from one point to another on the surface is

$$W = q(V_1 - V_2) = q \times 0 = 0$$

Step 3: Relation with electric field.

Because no work is done along the surface, the electric field $\vec{E}$ is always **perpendicular** to the equipotential surface at every point. For example, the equipotential surfaces around a point charge are concentric spheres.

$$\boxed{\text{Surface of constant potential; } \vec{E} \perp \text{surface, } W = 0}$$

Quick Tip: Constant potential everywhere means zero work along it and the electric field is perpendicular to the surface.

13. Work function of a metal surface is 3.2 eV. Find out the kinetic energy of the emitted photoelectrons in Joule, when a photon of 4.0 eV energy is incident on its surface.

Correct Answer: —

Solution:

Step 1: Write the governing law.
Einstein's photoelectric equation states that the incident photon energy is shared between the work function (energy needed to free the electron) and the maximum kinetic energy of the emitted electron:

$$KE_{max} = E - W_0$$

where E is the energy of the incident photon and W_0 is the work function of the metal.

Step 2: Substitute the given values (in eV).
$E = 4.0$ eV and $W_0 = 3.2$ eV, so

$$KE_{max} = 4.0\text{ eV} - 3.2\text{ eV} = 0.8\text{ eV}$$

Step 3: Convert the energy from eV to Joule.
Using 1 eV $= 1.6 \times 10^{-19}$ J,

$$KE_{max} = 0.8 \times 1.6 \times 10^{-19} \text{ J}$$

Step 4: Do the arithmetic.

$$KE_{max} = 1.28 \times 10^{-19} \text{ J}$$

$$\boxed{KE_{max} = 1.28 \times 10^{-19} \text{ J}}$$

Quick Tip: Use Einstein's photoelectric equation $KE_{max} = E - W_0$, then convert the answer from eV to Joule using 1 eV $= 1.6 \times 10^{-19}$ J.

14. What will be the effect on the drift velocity of electrons, when the current in a copper wire is passed in a wire, twice of its radius (the same current being maintained)?

Correct Answer: —

Solution:

Step 1: Write the relation between current and drift velocity.
The current in a conductor is related to the drift velocity of its free electrons by

$$I = neAv_d$$

where n = free-electron number density, e = electronic charge, A = cross-sectional area and v_d = drift velocity.

Step 2: Solve for drift velocity.

$$v_d = \frac{I}{n\,e\,A}$$

For the same wire material and the same current I, the quantities n, e and I are unchanged, so $v_d \propto \frac{1}{A}$.

Step 3: Bring in the area of a circular cross-section.
$A = \pi r^2$, therefore $v_d \propto \frac{1}{r^2}$.

Step 4: Double the radius.
If the radius becomes $r' = 2r$, the new area is

$$A' = \pi(2r)^2 = 4\pi r^2 = 4A$$

so the new drift velocity is

$$v'_d = \frac{I}{n\,e\,(4A)} = \frac{v_d}{4}$$

Conclusion: The drift velocity of the electrons falls to one-fourth of its original value.

$$\boxed{v'_d = \tfrac{1}{4}\,v_d}$$

Quick Tip: Use $v_d = I/(neA)$ with $A = \pi r^2$; at constant current $v_d \propto 1/r^2$, so doubling the radius quarters the drift velocity.

15. What is the phenomenon of radioactivity? How many types are there of radioactive decay?

Correct Answer: —

Solution:

Step 1: Define radioactivity.

Radioactivity is the phenomenon in which the unstable nucleus of a heavy atom disintegrates on its own (spontaneously) and emits radiation in the form of α-particles, β-particles or γ-rays, turning into a more stable nucleus. It was discovered by Henri Becquerel in 1896.

Step 2: State its key features.

It is a nuclear property (not affected by temperature, pressure or chemical state), and it is a random, spontaneous process that goes on until the nucleus becomes stable.

Step 3: List the types of radioactive decay.

There are **three** types:

1. **Alpha (α) decay:** the nucleus emits an α-particle (a helium nucleus ${}^4_2He$); mass number decreases by 4 and atomic number by 2.
2. **Beta (β) decay:** the nucleus emits a β-particle (an electron); atomic number changes by 1 while mass number stays the same.
3. **Gamma (γ) decay:** the excited nucleus releases energy as high-energy γ-ray photons; neither mass number nor atomic number changes.

$$\boxed{\text{Three types: } \alpha,\ \beta,\ \gamma \text{ decay}}$$

Quick Tip: Radioactivity is spontaneous emission of radiation from an unstable nucleus; the decay is of three kinds, alpha, beta and gamma.

16. Explain the difference between conductors and semiconductors on the basis of energy bands in solids.

Correct Answer: —

Solution:

Step 1: Recall the band picture of solids.
In a solid the closely packed atoms make the electron energy levels spread into bands. The highest band that is filled with valence electrons is the **valence band**, and the next higher band into which electrons must go to conduct is the **conduction band**. The gap between them is the **forbidden energy gap** E_g.

Step 2: Conductors (metals).
In a conductor the valence band and conduction band **overlap**, so $E_g \approx 0$. A very large number of free electrons is available in the conduction band even at room temperature, so a conductor conducts electricity easily.

Step 3: Semiconductors.
In a semiconductor the valence band is full and the conduction band is empty at 0 K, and they are separated by a **small** forbidden gap (about $E_g \approx 1$ eV, e.g. 1.1 eV for silicon and 0.7 eV for germanium). At 0 K it behaves like an insulator, but at room temperature some electrons gain enough thermal energy to jump the gap into the conduction band, so it conducts a little; its conductivity increases with temperature.

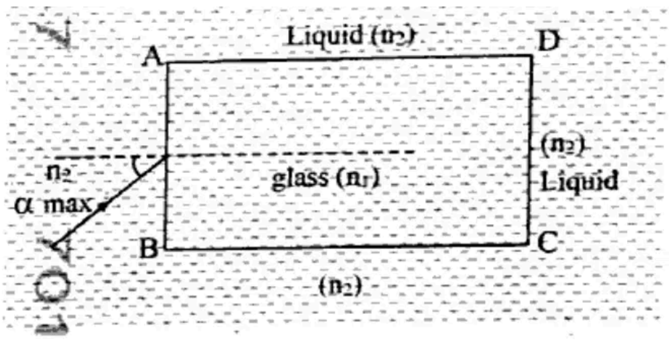
Step 4: State the key difference.

The distinction is the size of the forbidden gap and the availability of conduction electrons: a conductor has zero (overlapping bands) gap and plenty of free electrons, while a semiconductor has a small gap and only a few thermally excited electrons.

$$\boxed{\text{Conductor: } E_g \approx 0 \text{ (overlap)}; \quad \text{Semiconductor: } E_g \approx 1 \text{ eV (small gap)}}$$

Quick Tip: Compare the forbidden energy gap: conductors have overlapping valence and conduction bands (no gap), semiconductors have a small gap of about 1 eV.

17.



A rectangular glass slab ABCD of refractive index n_1 is placed in a liquid of refractive index n_2 ($n_1 > n_2$). A ray of light is incident at the surface AB of the slab as shown in the figure. Find out the maximum value of angle α, so that the ray comes out only from the other surface CD.

Correct Answer: —

Solution:

Step 1: Understand the required condition.

The ray enters face AB, bends inside the glass and travels towards the top (or bottom) side face. For the ray to leave *only* from the far face CD, it must undergo **total internal reflection (TIR)** at the side face it meets, instead of refracting out of it. The largest α corresponds to the ray striking that side face exactly at the critical angle.

Step 2: Apply Snell's law at face AB.

Light goes from the liquid (n_2) into the glass (n_1). If r is the angle of refraction inside the glass,

$$n_2 \sin\alpha = n_1 \sin r \quad \Rightarrow \quad \sin r = \frac{n_2}{n_1}\sin\alpha \qquad (1)$$

Step 3: Geometry at the side face.

The refracted ray then meets a side face whose normal is perpendicular to the normal of AB. So the angle of incidence at that face is $(90° - r)$.

Step 4: Critical-angle (TIR) condition at the side face.

The critical angle θ_c for the glass-liquid boundary satisfies $\sin\theta_c = \frac{n_2}{n_1}$.

For the maximum α, the ray strikes the side face exactly at θ_c:

$$90° - r = \theta_c \quad \Rightarrow \quad \sin(90° - r) = \sin\theta_c$$

$$\cos r = \frac{n_2}{n_1} \qquad (2)$$

Step 5: Find $\sin r$ from equation (2).

$$\sin r = \sqrt{1 - \cos^2 r} = \sqrt{1 - \frac{n_2^2}{n_1^2}} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \qquad (3)$$

Step 6: Combine (1) and (3).

$$\frac{n_2}{n_1}\sin\alpha_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$

$$\sin\alpha_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_2}$$

Step 7: Write the final answer.

$$\boxed{\alpha_{max} = \sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_2}\right)}$$

For any α up to this value, the ray totally reflects at the side face and emerges only from CD.

Quick Tip: Apply Snell's law at AB and impose total internal reflection at the side face, where the internal angle is $(90^\circ - r)$ and $\sin\theta_c = n_2/n_1$.

18. Find out the formula for the electric field at a point outside a uniformly charged spherical shell by using Gauss's theorem.

Correct Answer: —

Solution:

Step 1: State Gauss's theorem.

Gauss's theorem says the total electric flux through any closed surface equals the charge enclosed divided by ε_0:

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

Step 2: Describe the setup and choose a Gaussian surface.

Let a spherical shell of radius R carry a total charge q spread uniformly over it. To find the field at an external point P at distance r from the centre ($r > R$), imagine a concentric spherical *Gaussian surface* of radius r passing through P.

Step 3: Use symmetry.

By spherical symmetry, $\vec{E}$ has the same magnitude everywhere on this surface and points radially outward, parallel to $d\vec{S}$ at every point. Hence $\vec{E} \cdot d\vec{S} = E\,dS$.

Step 4: Evaluate the flux.

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

since the area of the Gaussian sphere is $4\pi r^2$.

Step 5: Find the enclosed charge.

The Gaussian surface (radius $r > R$) encloses the whole shell, so q_{enc} $= q$.

Step 6: Apply Gauss's theorem and solve for E.

$$E\,(4\pi r^2) = \frac{q}{\varepsilon_0}$$

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

Step 7: Interpret.

The field outside is exactly the same as if the entire charge q were concentrated at the centre of the shell.

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

Quick Tip: Take a concentric spherical Gaussian surface of radius r > R; flux $= E(4\pi r^2) = q/\varepsilon_0$ gives $E = q/(4\pi\varepsilon_0 r^2)$.

19. How a galvanometer is converted into an ammeter? The resistance of the coil of a galvanometer is 15 Ω and it gives full scale deflection by a current of 4 mA. How it can be converted into an ammeter in order to measure a current upto 6 A?

Correct Answer: —

Solution:

Concept: A galvanometer detects only very small currents. To turn it into an ammeter (which reads large currents), a small resistance called a **shunt** S is connected in parallel with the galvanometer coil. Most of the line current then passes through the shunt, and only the small full-scale current I_g passes through the coil.

Step 1 (Given): Galvanometer resistance $G = 15\ \Omega$; full-scale (maximum) coil current $I_g = 4\text{ mA} = 4 \times 10^{-3}$ A; total current to be measured $I = 6$ A.

Step 2 (Set up the parallel condition): Since S is in parallel with the coil, the potential difference across both is equal. Current through shunt $= I - I_g$. So:

$$I_g G = (I - I_g) S$$

Step 3 (Formula for shunt):

$$S = \frac{I_g G}{I - I_g}$$

Step 4 (Substitute values):

$$S = \frac{(4 \times 10^{-3})(15)}{6 - 4 \times 10^{-3}} = \frac{0.06}{5.996}$$

Step 5 (Arithmetic):

$$S = 0.01001\ \Omega \approx 0.01\ \Omega$$

Conclusion: Connecting a small shunt resistance of about $0.01\ \Omega$ in parallel with the galvanometer coil converts it into an ammeter capable of reading up to 6 A.

$$\boxed{S \approx 0.01\ \Omega\ \text{(shunt in parallel)}}$$

Quick Tip: Connect a small shunt in parallel so the coil voltage equals the shunt voltage: $I_g G = (I - I_g)S$. Solve for S.

20. The de Broglie wavelengths of a photon and a proton are λ_1 and λ_2 respectively. Both have same energy E. If mass of proton is m and speed of light is C, then prove that $\dfrac{\lambda_1}{\lambda_2} = C\sqrt{\dfrac{2m}{E}}$.

Correct Answer: —

Solution:

Concept: The de Broglie wavelength of any particle is $\lambda = h/p$, where p is its momentum. A photon and a proton relate energy to momentum differently, so we handle each separately and then take the ratio.

Step 1 (Photon wavelength λ_1): A photon of energy E has momentum $p_{ph} = E/C$ (since for a photon $E = pC$). Therefore

$$\lambda_1 = \frac{h}{p_{ph}} = \frac{h}{E/C} = \frac{hC}{E}$$

Step 2 (Proton wavelength λ_2): The proton is non-relativistic, so its kinetic energy E links to momentum by $E = \dfrac{p^2}{2m}$. Hence $p = \sqrt{2mE}$ and

$$\lambda_2 = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$$

Step 3 (Take the ratio):

$$\frac{\lambda_1}{\lambda_2} = \frac{hC/E}{h/\sqrt{2mE}} = \frac{hC}{E} \cdot \frac{\sqrt{2mE}}{h} = \frac{C\sqrt{2mE}}{E}$$

Step 4 (Simplify): Write $\frac{\sqrt{2mE}}{E} = \sqrt{\frac{2mE}{E^2}} = \sqrt{\frac{2m}{E}}$. Thus

$$\frac{\lambda_1}{\lambda_2} = C\sqrt{\frac{2m}{E}}$$

Conclusion: The required relation is proved.

$$\boxed{\frac{\lambda_1}{\lambda_2} = C\sqrt{\frac{2m}{E}}}$$

Quick Tip: Use $\lambda = h/p$. For the photon $p = E/C$; for the proton $p = \sqrt{2mE}$. Then divide.

21. What is meant by displacement current? What is the difference between displacement current and conduction current? Write down their formulae.

Correct Answer: —

Solution:

Step 1 (Meaning of displacement current): Maxwell noticed that Ampere's law failed in the gap of a charging capacitor, where no charges cross the gap yet a magnetic field still exists. He proposed that a **changing electric field** in that region acts like a current. This is the **displacement current** I_d. It is not a flow of charge; it is produced by a time-varying electric flux and, like a real current, it creates a magnetic field.

Step 2 (Formula for displacement current): If Φ_E is the electric flux through a surface,

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

where ε_0 is the permittivity of free space.

Step 3 (Meaning of conduction current): The **conduction current** I_c is the ordinary current caused by the actual motion (drift) of free charges, such as electrons in a metal wire.

Step 4 (Formula for conduction current):

$$I_c = \frac{dq}{dt}$$

the rate of flow of charge; equivalently $I_c = \frac{V}{R}$ in a resistive conductor.

Step 5 (Key differences):
• Conduction current needs a real flow of charges through a conductor; displacement current needs no charge flow, only a changing electric field.
• Conduction current dominates inside wires; displacement current

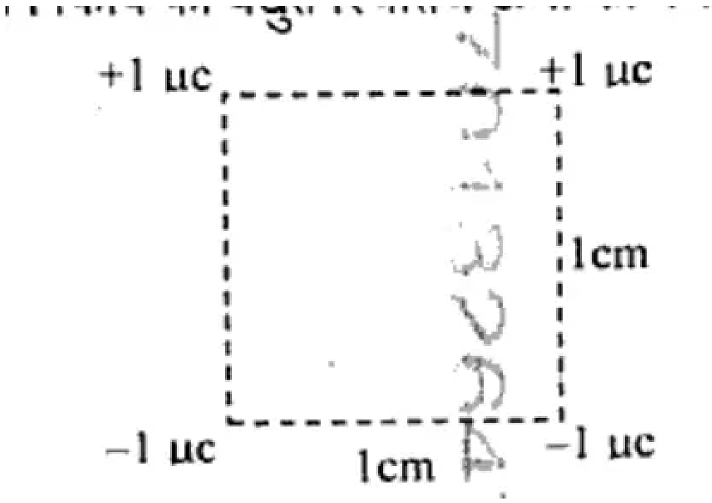
dominates in the gap of a capacitor or in free space (electromagnetic waves).

• Both produce magnetic fields, so the generalised Ampere-Maxwell law uses their sum: $I = I_c + I_d$.

$$\boxed{I_d = \varepsilon_0 \frac{d\Phi_E}{dt}, \qquad I_c = \frac{dq}{dt}}$$

Quick Tip: Displacement current comes from a changing electric flux, not moving charge: $I_d = \varepsilon_0\, d\Phi_E/dt$, while $I_c = dq/dt$.

22.



Compute the electric potential energy of the system with the help of the figure given above. The square has side 1 cm with charges $+1\ \mu C$ and $+1\ \mu C$ on the two top corners and $-1\ \mu C$ and $-1\ \mu C$ on the two bottom corners.

OR

The capacitance of a parallel plate capacitor is 20 pF and distance between the plates is 4 mm. It is charged by a battery of 100 volt and then battery is removed. Now a dielectric slab (K = 4) and 2 mm thickness is placed in between the plates. Find out: (i) the final charge on each plate (ii) the potential difference between the plates.

Correct Answer: —

Solution:

Option 1 (potential energy of the square array):

Step 1 (Formula): The potential energy of a system of point charges is the sum over every distinct pair:

$$U = \frac{1}{4\pi\varepsilon_0} \sum_{\text{pairs}} \frac{q_i q_j}{r_{ij}}$$

with $k = \dfrac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ \mathrm{N\,m^2/C^2}$.

Step 2 (Label and data): Side $a = 1\ \mathrm{cm} = 0.01\ \mathrm{m}$; each charge magnitude $q = 1\ \mu C = 10^{-6}\ \mathrm{C}$, so $q^2 = 10^{-12}\ \mathrm{C}^2$. Top corners $+q, +q$; bottom corners $-q, -q$. There are 6 pairs: 4 sides (length a) and 2 diagonals (length $a\sqrt{2}$).

Step 3 (Four side pairs): Products of charges along the sides are: top $(+q)(+q) = +q^2$; bottom $(-q)(-q) = +q^2$; left $(+q)(-q) = -q^2$; right $(+q)(-q) = -q^2$. Their sum $= +q^2 + q^2 - q^2 - q^2 = 0$. So the four sides contribute nothing:

$$U_{\text{sides}} = \frac{k}{a}(0) = 0$$

Step 4 (Two diagonal pairs): Each diagonal joins a $+q$ to a $-q$, giving product $-q^2$, at distance $a\sqrt{2}$:

$$U_{\text{diag}} = \frac{k}{a\sqrt{2}}(-q^2 - q^2) = \frac{-2kq^2}{a\sqrt{2}} = -\frac{\sqrt{2}\,kq^2}{a}$$

Step 5 (Numbers): $\dfrac{kq^2}{a} = \dfrac{9 \times 10^9 \times 10^{-12}}{0.01} = 0.9\ \mathrm{J}$. Hence

$$U = -\sqrt{2} \times 0.9 = -1.27\ \mathrm{J}$$

$$\boxed{U \approx -1.27\ \mathrm{J}}$$

The negative sign shows the system is bound (attractive overall).

Option 2 (capacitor with dielectric slab):

Step 1 (Charge stored, battery still on): $C_0 = 20\text{ pF} = 20 \times 10^{-12}\text{ F}$, $V = 100\text{ V}$.

$$Q = C_0 V = 20 \times 10^{-12} \times 100 = 2 \times 10^{-9}\text{ C} = 2\text{ nC}$$

Step 2 (Battery removed): With the battery disconnected the plates are isolated, so the charge cannot change. Therefore the **final charge is the same**:

$$\boxed{Q = 2 \times 10^{-9}\text{ C} = 2\text{ nC}}\ \text{(part i)}$$

Step 3 (New capacitance with the slab): For a slab of thickness t and dielectric constant K inside a gap d,

$$C = \frac{\varepsilon_0 A}{d - t + \dfrac{t}{K}}$$

From $C_0 = \varepsilon_0 A/d$, $\varepsilon_0 A = C_0 d = 20 \times 10^{-12} \times 4 \times 10^{-3} = 8 \times 10^{-14}$.

Step 4 (Effective gap): $d - t + t/K = 4 - 2 + \dfrac{2}{4} = 2.5\text{ mm} = 2.5 \times 10^{-3}\text{ m}$. So

$$C = \frac{8 \times 10^{-14}}{2.5 \times 10^{-3}} = 3.2 \times 10^{-11} \text{ F} = 32 \text{ pF}$$

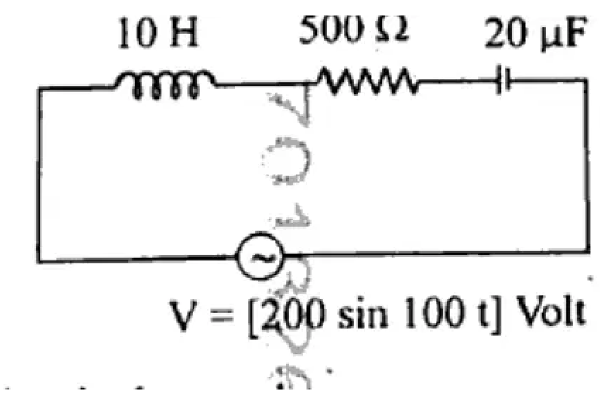
Step 5 (New potential difference):

$$V' = \frac{Q}{C} = \frac{2 \times 10^{-9}}{3.2 \times 10^{-11}} = 62.5 \text{ V}$$

$$\boxed{V' = 62.5 \text{ V}} \text{ (part ii)}$$

Quick Tip: Option 1: sum kq_iq_j/r over 6 pairs; the four edges cancel, only the two unlike diagonals remain. Option 2: charge is fixed after the battery is removed; use $C = \varepsilon_0 A/(d - t + t/K)$ then $V = Q/C$.

23.



Find out from the given circuit shown above: (i) Impedance (ii) power factor (iii) phase difference between current and voltage. The series circuit has $L = 10$ H, $R = 500\ \Omega$ and $C = 20\ \mu F$, driven by an AC source $V = [200 \sin 100t]$ Volt.

Correct Answer: —

Solution:

Step 1 (Read the source): Comparing $V = 200\sin 100t$ with $V = V_0 \sin\omega t$ gives peak voltage $V_0 = 200$ V and angular frequency $\omega = 100$ rad/s.

Step 2 (Inductive reactance):

$$X_L = \omega L = 100 \times 10 = 1000\ \Omega$$

Step 3 (Capacitive reactance): $C = 20\ \mu F = 20 \times 10^{-6}$ F.

$$X_C = \frac{1}{\omega C} = \frac{1}{100 \times 20 \times 10^{-6}} = \frac{1}{2 \times 10^{-3}} = 500\ \Omega$$

Step 4 (Net reactance):

$$X_L - X_C = 1000 - 500 = 500\ \Omega$$

Step 5 (i) Impedance:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{500^2 + 500^2} = 500\sqrt{2} \approx 707\ \Omega$$

Step 6 (ii) Power factor:

$$\cos\phi = \frac{R}{Z} = \frac{500}{500\sqrt{2}} = \frac{1}{\sqrt{2}} \approx 0.707$$

Step 7 (iii) Phase difference:

$$\tan\phi = \frac{X_L - X_C}{R} = \frac{500}{500} = 1 \Rightarrow \phi = 45^\circ$$

Since $X_L > X_C$ the circuit is inductive, so the voltage **leads** the current by 45°.

$$\boxed{Z \approx 707\ \Omega, \quad \cos\phi = 0.707, \quad \phi = 45^\circ}$$

Quick Tip: Read $\omega = 100$ from $200 \sin 100t$. Find $X_L = \omega L$, $X_C = 1/\omega C$, then $Z = \sqrt{R^2 + (X_L - X_C)^2}$, $\cos\phi = R/Z$, $\tan\phi = (X_L - X_C)/R$.

24. What is the law of Malus? A plane polarized light of intensity 16 watt/m², is incident on a polaroid in such a way that the vibration of its electric vector makes an angle of 30° from the transmission axis of the polaroid. Find out the intensity of the transmitted light from the polaroid. Write down any one use of polaroid.

Correct Answer: —

Solution:

Step 1 (Law of Malus): When completely plane-polarized light of intensity I_0 falls on a polaroid (analyser), the intensity of the transmitted light is proportional to the square of the cosine of the angle θ between the light's plane of vibration and the transmission axis of the polaroid:

$$I = I_0 \cos^2 \theta$$

Step 2 (Given data): $I_0 = 16\ \mathrm{W/m^2}$, $\theta = 30^\circ$.

Step 3 (Value of the cosine): $\cos 30^\circ = \dfrac{\sqrt{3}}{2}$, so $\cos^2 30^\circ = \dfrac{3}{4}$.

Step 4 (Substitute and compute):

$$I = 16 \times \frac{3}{4} = 12\ \mathrm{W/m^2}$$

$$\boxed{I = 12\ \mathrm{W/m^2}}$$

Step 5 (One use of polaroid): Polaroids are used in sunglasses to cut down glare from reflected light. (Other valid uses: to control light intensity in windows, in photographic filters, and in LCD screens.)

Quick Tip: Malus's law: $I = I_0 \cos^2 \theta$. Put $I_0 = 16$ and $\theta = 30^\circ$ with $\cos^2 30^\circ$ = 3/4.

25. Explain Ampere's circuital law. Obtain the expression for the magnetic field inside a current carrying solenoid with its help.

Correct Answer: —

Solution:

Step 1: State Ampere's circuital law.

It states that the line integral of the magnetic field $\vec{B}$ taken around any closed loop (Amperian loop) is equal to μ_0 times the total (net) current I_{enc} threading through that loop.

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

Here $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} is the permeability of free space.

Step 2: Describe the solenoid.

A solenoid is a long cylindrical coil of closely wound turns. Let it have n turns per unit length carrying current I. For a long (ideal) solenoid the field inside is uniform and directed along the axis, while the field outside is nearly zero.

Step 3: Choose an Amperian loop.

Take a rectangular loop $abcd$ with the side ab of length L lying inside the solenoid parallel to the axis, the side cd of the same length lying outside, and the two short sides bc and da perpendicular to the axis.

Step 4: Evaluate the line integral over each side.

Side ab (inside, along B): contribution $= BL$.

Sides bc and da: here $\vec{B} \perp d\vec{l}$ inside and $B = 0$ outside, so contribution $= 0$.

Side cd (outside): $B \approx 0$, so contribution $= 0$.

Therefore $\oint \vec{B} \cdot d\vec{l} = BL$.

Step 5: Find the enclosed current.

Number of turns enclosed by the loop $= nL$. Each carries current I, so $I_{enc} = nLI$.

Step 6: Apply Ampere's law and solve.

$$BL = \mu_0(nLI)$$

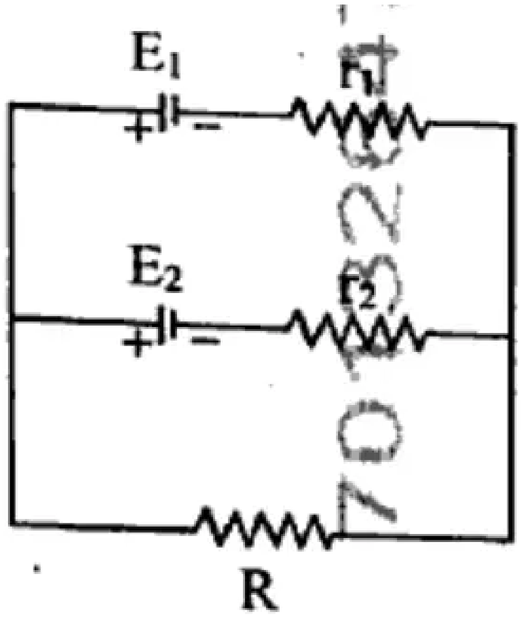
$$B = \mu_0 nI$$

This is the required uniform magnetic field inside a long current carrying solenoid.

$$\boxed{B = \mu_0 nI}$$

Quick Tip: Use $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$ with a rectangular loop having one long side inside the solenoid; only that side contributes, and the enclosed current is nLI.

26.



Obtain the formula for the current flowing in the resistor R, with the help of the circuit given above. (Two cells of e.m.f. E_1 and E_2 with internal resistances r_1 and r_2 are connected in parallel and feed a common external resistor R.)

Correct Answer: —

Solution:

Step 1: Label the circuit.

Let V be the common potential difference across the two parallel points to which R is connected. The current through R is I, and the currents supplied by the two cells are I_1 and I_2.

Step 2: Apply the junction (Kirchhoff's current) rule.

The two cell currents combine to give the current in R:

$$I = I_1 + I_2$$

Step 3: Write terminal voltage of each cell.

For a cell of e.m.f. E and internal resistance r delivering current i, the terminal voltage is $V = E - ir$, so $i = \dfrac{E - V}{r}$. Applying this to both cells:

$$I_1 = \frac{E_1 - V}{r_1}, \qquad I_2 = \frac{E_2 - V}{r_2}$$

Step 4: Add the currents.

$$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2} = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Step 5: Use the external resistor relation.

Across R, $V = IR$. Substitute $V = IR$:

$$I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - IR\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$I\left[1 + R\left(\frac{1}{r_1} + \frac{1}{r_2}\right)\right] = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

Step 6: Solve and simplify.

Multiply numerator and denominator by $r_1 r_2$:

$$I = \frac{E_1 r_2 + E_2 r_1}{r_1 r_2 + R(r_1 + r_2)}$$

This is the required current through R.

$$\boxed{I = \frac{E_1 r_2 + E_2 r_1}{r_1 r_2 + R(r_1 + r_2)}}$$

Quick Tip: Take a common terminal voltage V across R, write each cell current as $(E - V)/r$, add them for the R current, then put $V = IR$; or reduce the two parallel cells to one equivalent cell E_{eq}, r_{eq}.

27. Draw a circuit diagram of a p-n junction diode in reverse-biased condition and show a graph between the variation of current and voltage related with it. What is meant by avalanche breakdown?

OR

What is the difference between p-type and n-type semiconductors? A silicon diode and a load resistance of 500 Ω are joined in series with an alternating voltage source of 20 V. The forward resistance of the diode is 10 Ω and the barrier voltage is 0.7 V. Find out: (i) the peak current through the diode (ii) the peak voltage across the load.

Correct Answer: —

Solution:

Option 1

Step 1: Reverse-bias circuit.

Connect the p-side of the diode to the negative terminal and the n-side to the positive terminal of a battery, in series with a microammeter. (Circuit: battery negative → p-region, battery positive → n-region, so the diode symbol arrow points opposite to the conventional current the battery would drive.)

Step 2: What happens inside.
The applied voltage pulls holes and electrons away from the junction, so the depletion layer widens and its potential barrier increases. Majority carriers cannot cross, so only a very small reverse (leakage) current due to minority carriers flows, and it stays almost constant with voltage.

Step 3: I-V graph.
Plot current (y-axis) against voltage (x-axis). In the reverse (third) quadrant the curve runs almost flat and very close to the voltage axis (tiny current of the order of microamperes) until a particular voltage called the breakdown voltage V_{br} is reached. At V_{br} the reverse current suddenly shoots up steeply (the curve drops almost vertically).
Description of the graph: a nearly horizontal line just below the axis in the reverse region, then a sharp vertical fall at $V = V_{br}$.

Step 4: Avalanche breakdown.
When a lightly doped junction is strongly reverse biased, the minority carriers are accelerated by the strong field and gain enough kinetic energy to knock out more electrons from the atoms by collision (impact ionisation). These freshly released carriers again collide and free still more carriers, so the number of carriers multiplies rapidly like an avalanche. The reverse current therefore rises very sharply at the breakdown voltage. This is called **avalanche breakdown**.

$$\boxed{\text{Reverse current stays tiny, then rises sharply at } V_{br} \text{ (avalanche multiplication of carriers)}}$$

Option 2

Step 1: p-type vs n-type semiconductor.
p-type: formed by doping with a trivalent impurity (e.g. Al, B, In); it creates extra holes, so **holes are the majority carriers** and electrons the minority carriers. n-type: formed by doping with a pentavalent impurity (e.g. P, As, Sb); it supplies extra free electrons, so **electrons are the majority carriers** and holes the minority carriers. Both are electrically neutral as a whole.

Step 2: Given data.
Peak source voltage $V_0 = 20$ V, load $R_L = 500\ \Omega$, diode forward resistance $R_f = 10\ \Omega$, barrier voltage $V_b = 0.7$ V. (The stated 20 V is taken as the peak value of the a.c. source.)

Step 3: Peak current formula.
In the forward half cycle the diode conducts. The barrier voltage drops 0.7 V, and the rest is shared by R_f and R_L in series:

$$I_0 = \frac{V_0 - V_b}{R_f + R_L}$$

Step 4: Substitute and compute (i).

$$I_0 = \frac{20 - 0.7}{10 + 500} = \frac{19.3}{510} = 0.0378\ \text{A} \approx 37.8\ \text{mA}$$

Step 5: Peak voltage across the load (ii).

$$V_{L,0} = I_0\, R_L = 0.0378 \times 500 = 18.9\ \text{V}$$

$$\boxed{I_0 \approx 37.8\text{ mA}, \qquad V_{L,0} \approx 18.9\text{ V}}$$

Quick Tip: Reverse bias: p to battery negative, n to positive; reverse current is tiny until breakdown, then rises sharply by avalanche (impact-ionisation chain). For the diode: peak current $= (V_0 - V_b)/(R_f + R_L)$, then load peak voltage $= I_0 R_L$.

28. Derive the formula for the focal length of a thin lens.

OR

Explain the difference between diffraction and interference of light waves. Write down the formula for the fringe width in Young's double slit experiment. What will be the effect on the fringe width, when the separation between the slits is made one third and the distance between the slits and the screen is doubled? What will be the effect on the fringe width if the whole experiment is placed in water?

Correct Answer: —

Solution:

Option 1: Lens maker's (focal length) formula

Step 1: Setup.

Consider a thin lens of material refractive index n (with respect to the surrounding medium) bounded by two spherical surfaces of radii of curvature R_1 and R_2. Let an object O lie on the principal axis. We use the refraction-at-a-single-spherical-surface formula twice.

Step 2: Refraction at the first surface.

For refraction from medium 1 ($n_1 = 1$) into the lens ($n_2 = n$) at a surface of radius R_1, the image would form at v_1:

$$\frac{n}{v_1} - \frac{1}{u} = \frac{n-1}{R_1} \quad ...(1)$$

Step 3: Refraction at the second surface.

The image I_1 at v_1 acts as the object for the second surface (radius R_2), where light goes from the lens (n) back to the outside medium (1). For a thin lens the thickness is neglected, so the object distance is v_1:

$$\frac{1}{v} - \frac{n}{v_1} = \frac{1-n}{R_2} \quad ...(2)$$

Step 4: Add equations (1) and (2).

The n/v_1 terms cancel:

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

Step 5: Introduce focal length.

By definition, when the object is at infinity ($u \to \infty$) the image forms at the focus, $v = f$. Also for any object $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$. Hence:

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

This is the lens maker's formula giving the focal length of a thin lens.

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

Option 2: Diffraction vs interference and fringe width

Step 1: Difference between interference and diffraction.
(i) Interference is the superposition of light from two (or more) separate coherent sources; diffraction is the superposition of the secondary wavelets coming from different parts of the same wavefront (a single slit/obstacle).
(ii) In interference all bright fringes are of equal width and equal intensity; in diffraction the central maximum is the brightest and widest, and the intensity of side maxima falls off rapidly.
(iii) In interference the dark fringes are almost perfectly dark; in diffraction the minima are not perfectly dark.

Step 2: Fringe width formula (YDSE).

$$\beta = \frac{\lambda D}{d}$$

where λ is the wavelength, D the slit-to-screen distance and d the separation between the slits.

Step 3: Change the geometry.
New separation $d' = \frac{d}{3}$ and new distance $D' = 2D$. New fringe width:

$$\beta' = \frac{\lambda D'}{d'} = \frac{\lambda(2D)}{d/3} = 6\,\frac{\lambda D}{d} = 6\beta$$

So the fringe width becomes **six times** the original.

Step 4: Immerse the apparatus in water.
In a medium of refractive index n_w the wavelength becomes $\lambda' = \lambda/n_w$, so:

$$\beta'' = \frac{\lambda' D}{d} = \frac{\beta}{n_w}$$

With $n_w = 1.33$, the fringe width reduces to about $\beta/1.33 \approx 0.75\beta$, i.e. the fringes come closer together.

$$\boxed{\beta' = 6\beta; \qquad \beta_{water} = \beta/n_w \approx 0.75\beta}$$

Quick Tip: For the lens: apply the single spherical-surface refraction formula twice (air-glass then glass-air) and add to get $1/f = (n-1)(1/R_1 - 1/R_2)$. For YDSE: $\beta = \lambda D/d$; with $d \to d/3$, $D \to 2D$ the width becomes 6β, and in water it becomes β/n_w.

29. Enunciate the postulates of Bohr\'s model for the hydrogen atom. Show the spectral lines in the (i) emission and (ii) the absorption spectrum corresponding to the transition of hydrogen atom from $n = 1$ to $n = 3$ energy states.

OR

What is mass-energy conservation law? A neutron disintegrates into a proton, a β-particle and an antineutrino. The disintegration process is:

$$ {}_0n^1 \rightarrow {}_1H^1 + {}_{-1}\beta^0 + \bar{\nu} $$

Find out the energy produced in this process in MeV. (Mass of neutron $= 1.6747 \times 10^{-27}$ kg, Mass of proton $= 1.6725 \times 10^{-27}$ kg, Mass of electron $= 9.1 \times 10^{-31}$ kg.)

Correct Answer: —

Solution:

Option 1: Bohr postulates and the emission/absorption spectrum (n = 1 to n = 3)

Step 1 (Postulate of stationary orbits): In a hydrogen atom the electron revolves round the nucleus only in certain permitted circular orbits, called stationary orbits, without radiating energy. The electrostatic (Coulomb) attraction supplies the centripetal force:

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$$

Step 2 (Postulate of quantised angular momentum): Only those orbits are allowed for which the angular momentum of the electron is an integral multiple of $h/2\pi$:

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

Step 3 (Frequency / energy condition): The atom emits or absorbs energy only when the electron jumps from one stationary orbit of energy E_i to another of energy E_f. The photon frequency is given by

$$h\nu = E_i - E_f$$

Step 4 (Energy levels): The energy of the nth level is $E_n = -\frac{13.6}{n^2}$ eV. Hence $E_1 = -13.6$ eV, $E_2 = -3.4$ eV, $E_3 = -1.51$ eV.

Step 5 (Emission spectrum): In emission the electron falls from a higher level to a lower one, so within the levels n = 1, 2, 3 there are three downward transitions and hence **three bright emission lines**: 3 → 2, 2 → 1 and 3 → 1. The lines ending on n = 1 (Lyman series) lie in the ultraviolet, while 3 → 2 (Balmer, H_α) lies in the visible region.

Step 6 (Absorption spectrum): In absorption the atom is normally in the ground state (n = 1) and absorbs photons to jump up. From n = 1 only two upward jumps are possible, 1 → 2 and 1 → 3, so **two dark absorption lines** appear on the bright continuous background.

Step 7 (Diagram): Draw three horizontal energy levels (n = 1 lowest, then n = 2, then n = 3). For emission draw three downward arrows 3 → 2, 3 → 1, 2 → 1; for absorption draw two upward arrows 1 → 2, 1 → 3. Emission gives three lines, absorption gives two lines.

Option 2: Mass-energy conservation and energy released in neutron decay

Step 1 (Law): The mass-energy conservation law (Einstein) states that mass and energy are two forms of the same physical quantity and are interconvertible; the total mass-energy of an isolated system stays constant. A decrease in mass Δm appears as released energy through $E = \Delta m\, c^2$.

Step 2 (Mass defect - formula): The antineutrino is (practically) massless, so the mass lost is

$$\Delta m = m_n - (m_p + m_e)$$

Step 3 (Substitution): With $m_e = 9.1 \times 10^{-31} = 0.00091 \times 10^{-27}$ kg,

$$\Delta m = 1.6747 \times 10^{-27} - \left(1.6725 \times 10^{-27} + 0.00091 \times 10^{-27}\right)$$

Step 4 (Arithmetic): $\Delta m = (1.6747 - 1.67341) \times 10^{-27} = 0.00129 \times 10^{-27} = 1.29 \times 10^{-30}$ kg.

Step 5 (Energy - substitution): $E = \Delta m\, c^2 = 1.29 \times 10^{-30} \times (3 \times 10^8)^2 = 1.29 \times 10^{-30} \times 9 \times 10^{16}$.

Step 6 (Energy in joule): $E = 1.161 \times 10^{-13}$ J.

Step 7 (Convert to MeV): Since 1 MeV $= 1.6 \times 10^{-13}$ J,

$$E = \frac{1.161 \times 10^{-13}}{1.6 \times 10^{-13}} = 0.726 \text{ MeV}.$$

$$\boxed{E \approx 0.726 \text{ MeV}}$$

Quick Tip: Use Bohr\'s three postulates - non-radiating orbits, $mvr = nh/2\pi$, and $h\nu = E_i - E_f$ - and count 3 emission vs 2 absorption lines. For the OR part use $E = \Delta m\, c^2$ with $\Delta m = m_n - (m_p + m_e)$.

30. What are the Faraday\'s laws of electromagnetic induction? The magnetic flux linked with a coil of resistance 2 Ω is

$$\phi = (5t^3 - 100t + 300) \text{ Weber}$$

Find out: (i) induced e.m.f. produced in the coil at $t = 2$ seconds (ii) induced current in the coil.

OR

Explain the conditions required for the resonance in series LCR alternating circuit by the diagram. On which factors does the resonant frequency depend?

Correct Answer: —

Solution:

Option 1: Faraday\'s laws and the induced emf / current

Step 1 (Faraday\'s first law): Whenever the magnetic flux linked with a closed circuit changes, an e.m.f. is induced in it, and it lasts only as long as the flux keeps changing.

Step 2 (Faraday\'s second law): The magnitude of the induced e.m.f. equals the rate of change of magnetic flux linkage:

$$\varepsilon = -\frac{d\phi}{dt}$$

The minus sign is Lenz\'s law, showing the induced e.m.f. opposes the change producing it.

Step 3 (Differentiate the given flux): With $\phi = 5t^3 - 100t + 300$,

$$\varepsilon = -\frac{d}{dt}\left(5t^3 - 100t + 300\right) = -\left(15t^2 - 100\right) = 100 - 15t^2$$

Step 4 (Evaluate at t = 2 s): $\varepsilon = 100 - 15(2)^2 = 100 - 15 \times 4 = 100 - 60 = 40$ V.

Step 5 (Induced current): By Ohm\'s law $I = \frac{\varepsilon}{R} = \frac{40}{2} = 20$ A.

$$\boxed{\varepsilon = 40 \text{ V}, \qquad I = 20 \text{ A}}$$

Option 2: Resonance in a series LCR AC circuit

Step 1 (Reactances): In a series LCR circuit fed by $V = V_0 \sin \omega t$, the inductor offers inductive reactance $X_L = \omega L$ and the capacitor offers capacitive reactance $X_C = \frac{1}{\omega C}$.

Step 2 (Impedance): The total opposition is

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Step 3 (Condition for resonance): Resonance occurs when the inductive and capacitive reactances become equal, $X_L = X_C$. Then the net reactance is zero, so $Z = R$ is minimum, the current $I = V_0/Z$ is maximum, and the current is exactly in phase with the applied voltage (power factor = 1).

Step 4 (Resonant frequency): Putting $X_L = X_C$:

$$\omega L = \frac{1}{\omega C} \Rightarrow \omega^2 = \frac{1}{LC} \Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Step 5 (Diagram and dependence): A plot of current I against frequency f rises to a sharp peak at $f = f_0$ and falls off on both sides. The resonant frequency depends only on the inductance L and the capacitance C; it is independent of the resistance R (R only decides the sharpness/height of the peak).

$$\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ (depends on } L \text{ and } C \text{ only)}}$$

Quick Tip: Induced e.m.f. is $\varepsilon = -d\phi/dt = 100 - 15t^2$; put $t = 2$ then $I = \varepsilon/R$. For the OR part, resonance needs $X_L = X_C$, giving $f_0 = 1/(2\pi\sqrt{LC})$, which depends on L and C only.