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

ZOLLEGE

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. A force of 80 newton acts between two point charges placed in air at a fixed distance. When the same charges are placed at the same distance in a dielectric medium, the force becomes 8 newton. The dielectric constant of the medium is:

(A) 10

(B) zero

(C) 0.1

(D) 8

Correct Answer: (A) 10

SOLUTION:

Step 1: Recall how a dielectric changes force.
Placing a dielectric of constant K between two charges reduces the electrostatic force by the factor K. In symbols, if F_0 is the force in vacuum/air, then in the medium $F = F_0/K$.

Step 2: Insert the numbers directly.
We are told $F_0 = 80$ N (air) and $F = 8$ N (medium). Therefore 8

$= 80/K$.

Step 3: Solve for K.

Rearranging, $K = 80/8$.

Step 4: Evaluate.

$K = 10$, a pure number (dielectric constant is dimensionless).

Step 5: Sanity check.

The medium made the force ten times smaller, which is exactly what a dielectric constant of 10 should do. This confirms the first choice.

$$\boxed{K = 10}$$

Quick Tip: In a medium the Coulomb force drops by the factor of the dielectric constant, so $K = F_{air}/F_{medium}$.

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2. In the resonance condition, the current drawn from the source by a parallel resonant (L-C) circuit is:

(A) infinite

(B) zero

(C) fixed

(D) none of these

Correct Answer: (B) zero

SOLUTION:

Step 1: Compare series and parallel resonance.
The key idea is that resonance makes reactances cancel, but the effect on line current is opposite for the two arrangements. In a parallel L-C tank the source sees a very high impedance.

Step 2: Think in terms of branch currents.
At resonance the capacitor branch current and inductor branch current are equal in size, $I_L = I_C$, but they are 180° out of phase. When they meet at the source node they add up to $I_L - I_C = 0$.

Step 3: Conclusion from cancellation.
Because the two branch currents cancel in the external line, no net current flows from the supply, even though a large current keeps oscillating inside the L-C loop.

Step 4: State the result.
Hence the current taken from the source is (ideally) zero, which is why the parallel resonant circuit is used as a rejector or band-stop element.

$$\boxed{I = 0}$$

Quick Tip: At parallel resonance the two branch currents are equal and opposite, so the impedance is maximum and the line current is minimum.

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3. In which region of the electromagnetic spectrum does the Lyman series of hydrogen lie?

(A) Infrared

(B) Visible

(C) X-rays

(D) Ultraviolet

Correct Answer: (D) Ultraviolet

SOLUTION:

Step 1: Recall the series-to-region map.
For hydrogen: Lyman (to $n = 1$) is ultraviolet, Balmer (to $n = 2$) is visible, and Paschen, Brackett, Pfund (to $n = 3, 4, 5$) are infrared. This memory rule alone settles the answer.

Step 2: Justify with energy.
Transitions ending on the ground state $n = 1$ release the most energy of any hydrogen series because the ground level is the deepest. Higher photon energy means shorter wavelength.

Step 3: Connect energy to region.
These high-energy photons (about 10 eV upward) have wavelengths shorter than violet visible light, placing them in the ultraviolet band.

Step 4: Final choice.
Therefore the Lyman series is found in the ultraviolet part of the electromagnetic spectrum.

$$\boxed{\text{Ultraviolet}}$$

Quick Tip: Lyman lines end on the ground state $n = 1$ and are the highest-energy hydrogen transitions, so they lie in the ultraviolet.

4. When a convex lens is dipped in water, its focal length and nature become:

(A) increased, convex lens

(B) decreased, convex lens

(C) increased, concave lens

(D) decreased, concave lens

Correct Answer: (A) increased, convex lens

SOLUTION:

Step 1: Focus on the refractive-index difference.
A lens bends light because of the difference between the lens index and the medium index. The larger this difference, the stronger the lens and the shorter its focal length.

Step 2: Move from air to water.
Water ($\mu \approx 1.33$) is optically closer to glass ($\mu \approx 1.5$) than air ($\mu = 1$) is. So immersing the lens in water shrinks the index difference from about 0.5 to about 0.17.

Step 3: Effect on strength and focal length.
A smaller index difference means a weaker lens. A weaker converging lens has a longer focal length, so f increases.

Step 4: Effect on nature.
Because glass is still denser than water, the lens continues to converge light. It does not turn into a diverging (concave-acting) lens; that reversal needs a medium denser than the lens.

Step 5: Answer.

Thus in water the convex lens keeps its converging (convex) character but with a larger focal length.

$$\boxed{f \text{ increases, lens stays convex}}$$

Quick Tip: Use the lens maker's formula: in water the factor $(\mu_g/\mu_w - 1)$ is smaller but still positive, so f grows while the lens stays converging.

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5. In a semiconductor, the energy gap between the valence band and the conduction band is nearly:

(A) 5 eV

(B) 1 eV

(C) 15 eV

(D) zero

Correct Answer: (B) 1 eV

SOLUTION:

Step 1: Ask what makes a semiconductor special.

A semiconductor conducts only a little at room temperature because a modest amount of thermal energy can push some electrons across the gap into the conduction band. This requires the gap to be small, but not zero.

Step 2: Estimate using thermal energy.

Room-temperature thermal energy is only about 0.025 eV, yet semiconductors show measurable conduction. A gap of roughly 1 eV is small enough that a few electrons cross it, matching observed behaviour.

Step 3: Contrast with the extremes.
If the gap were 0 eV the material would be a metal (always conducting); if it were 5 eV or more, almost no electrons could cross and it would be an insulator.

Step 4: Pick the value.
Therefore the characteristic semiconductor gap is about 1 eV (Si $\approx$ 1.1 eV, Ge $\approx$ 0.7 eV).

$$\boxed{E_g \approx 1\ \text{eV}}$$

Quick Tip: Semiconductors have a small forbidden gap near 1 eV; metals have zero and insulators have a large gap of several eV.

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6. The difference in the angular momenta of the electron between two successive orbits of a hydrogen atom is:

(A) h/π

(B) $h/2$

(C) $h/2\pi$

(D) $2h$

Correct Answer: (C) $h/2\pi$

SOLUTION:

Step 1: Recall the reduced Planck constant.

Bohr's model says the allowed angular momenta are integer multiples of $\hbar = h/2\pi$. That is, $L = n\hbar$ with n a whole number.

Step 2: Picture the ladder of values.

The permitted angular momenta form a ladder: $\hbar, 2\hbar, 3\hbar, \ldots$ The rung spacing is constant.

Step 3: Read off the spacing.

Going from one orbit to the very next always adds exactly one $\hbar$, so the gap between successive orbits is $\hbar = h/2\pi$, no matter which pair of neighbouring orbits you choose.

Step 4: Conclude.

Hence the difference in angular momentum between two consecutive Bohr orbits is $h/2\pi$.

$$\boxed{\Delta L = h/2\pi}$$

Quick Tip: Bohr's rule gives $L_n = nh/2\pi$; subtracting successive values leaves one quantum $h/2\pi$.

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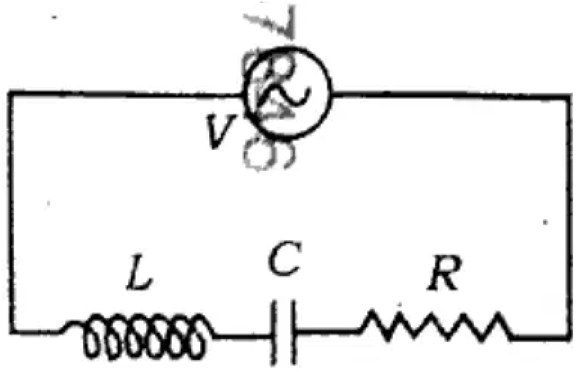
7.



An alternating current source is connected in the following figure (a series combination of an inductor L, a capacitor C and a resistor R across an AC source of rms voltage V). Determine the value of current flowing in the resistance R in the condition of resonance.

Correct Answer: —

SOLUTION:

Step 1: Recall what happens at series resonance.

In a series L-C-R circuit driven at its resonant (natural) frequency, the voltage across the inductor and the voltage across the capacitor are equal in magnitude but opposite in phase, so together they cancel out completely.

Step 2: Reduce the effective circuit.

Because the inductor and capacitor voltages cancel, the whole source voltage V appears across the resistor alone. The net phase angle between voltage and current becomes zero, meaning the circuit is purely resistive at this frequency.

Step 3: Express the resonant angular frequency (background).

The cancellation $X_L = X_C$ happens when $\omega L = \frac{1}{\omega C}$, i.e. at $\omega_0 = \frac{1}{\sqrt{LC}}$.

At this single frequency the reactive part vanishes.

Step 4: Compute the current directly.

With only R opposing the current, Ohm's law for the rms values gives

$$I = \frac{V}{R}$$

This is the largest possible current for the given source, which is why resonance is also called the condition of maximum current.

Result:

$$\boxed{I = \frac{V}{R}}$$

Quick Tip: At resonance $X_L = X_C$, so the impedance drops to just R. Apply $I = V/Z$.

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8. Calculate the de Broglie wavelength of a neutron of energy $12{\cdot}8$ MeV. (Given: mass of neutron $m_n = 1{\cdot}67 \times 10^{-27}$ kg, $h = 6{\cdot}6 \times 10^{-34}$ J s, 1 eV $= 1{\cdot}6 \times 10^{-19}$ J.)

Correct Answer: —

SOLUTION:

Step 1: Use the ready-made neutron formula.

Starting from $\lambda = \frac{h}{\sqrt{2m_nE}}$ and putting in the fixed constants h, m_n

and $1\,\text{eV} = 1.6 \times 10^{-19}$ J, the algebra collapses to a handy shortcut when the energy E is expressed in electron-volts:

$$\lambda = \frac{0.286}{\sqrt{E(\text{in eV})}}\ \text{Å}$$

This lets us skip repeated joule conversions.

Step 2: Put the energy in electron-volts.

$$E = 12.8\ \text{MeV} = 12.8 \times 10^6\ \text{eV} = 1.28 \times 10^7\ \text{eV}$$

Step 3: Take the square root of the energy.

$$\sqrt{1.28 \times 10^7} = 3.58 \times 10^3$$

Step 4: Evaluate the wavelength in angstrom.

$$\lambda = \frac{0.286}{3.58 \times 10^3} = 7.99 \times 10^{-5}\ \text{Å}$$

Step 5: Convert to metres.
Since $1\ \text{Å} = 10^{-10}$ m,

$$\lambda = 7.99 \times 10^{-5} \times 10^{-10}\ \text{m} = 7.99 \times 10^{-15}\ \text{m}$$

which agrees with the direct calculation.

Result:

$$\boxed{\lambda \approx 8.0 \times 10^{-15}\ \text{m}}$$

Quick Tip: Use $\lambda = h/\sqrt{2mE}$; first convert 12.8 MeV into joules.

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9. Write the definition of specific conductivity and its unit.

Correct Answer: —

SOLUTION:

Step 1: Start from the microscopic form of Ohm's law.
Ohm's law in point form links current density $\vec{J}$ to the electric field $\vec{E}$ inside a conductor by $\vec{J} = \sigma\vec{E}$. The constant of proportionality σ is exactly the specific conductivity.

Step 2: State the definition from this relation.
Rearranging, $\sigma = \frac{J}{E}$, so specific conductivity is the current density set up per unit electric field applied across the material. Equivalently, it is the conductance of a piece of the material having unit length and unit cross-sectional area.

Step 3: Obtain the unit from $\sigma = J/E$.
Current density J has unit ampere per square metre (A m^{-2}) and electric field E has unit volt per metre (V m^{-1}). Hence

$$[\sigma] = \frac{\text{A m}^{-2}}{\text{V m}^{-1}} = \frac{\text{A}}{\text{V m}} = \Omega^{-1}\text{m}^{-1}$$

using $\frac{\text{A}}{\text{V}} = \Omega^{-1}$ (siemens).

Result: Specific conductivity is the reciprocal of resistivity, with unit siemens per metre.

$$\boxed{\text{Unit} = \text{S m}^{-1} = \Omega^{-1}\text{m}^{-1}}$$

Quick Tip: It is the reciprocal of resistivity; think of the unit of $1/\rho$.

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10. What is the difference between paramagnetic and diamagnetic materials?

Correct Answer: —

SOLUTION:

Step 1: Contrast their origin at the atomic level.
The whole difference comes from electron arrangement. In a paramagnetic atom some electrons are unpaired, so the individual electronic magnetic moments do not cancel and the atom carries a net moment. In a diamagnetic atom every electron is paired, so the moments cancel and the atom has no net moment.

Step 2: Explain their response to an applied field.
When a field is switched on, a paramagnetic sample lets its existing atomic magnets partly line up with the field, so it is drawn into the field (attraction). A diamagnetic sample develops tiny induced moments that oppose the field (Lenz-law style), so it is pushed out of the field (repulsion).

Step 3: Tabulate the measurable differences.
• Susceptibility χ: paramagnetic → small and positive; diamagnetic → small and negative.
• Permeability μ_r: paramagnetic → just above 1; diamagnetic → just below 1.
• Temperature effect: paramagnetism weakens on heating (follows Curie's law $\chi \propto 1/T$); diamagnetism is essentially independent of temperature.
• Examples: paramagnetic → aluminium, platinum; diamagnetic → bismuth, copper.

Result: Paramagnetics are feebly attracted with positive χ and permanent atomic moments; diamagnetics are feebly repelled with negative χ and no permanent moment.

Quick Tip: Compare their behaviour in a magnetic field and the sign of their susceptibility χ.

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11. What is the phenomenon of radioactivity?

Correct Answer: —

SOLUTION:

Step 1: Describe why it happens.
Some nuclei have an unfavourable balance of protons and neutrons, which makes them unstable. To move towards a stable configuration, such a nucleus breaks up on its own and throws out energy in the form of nuclear radiation. This self-driven break-up is what we call

radioactivity.

Step 2: Name the process and its discoverer.
The effect was first observed by Becquerel with uranium salts and studied further by Marie and Pierre Curie. Because the emission comes from the nucleus itself, it is also called nuclear radioactivity.

Step 3: Summarise the emissions and their nature.
• α-decay: the nucleus emits a helium nucleus, so its mass number falls by 4 and charge by 2.
• β-decay: the nucleus emits an electron (with an antineutrino), and its atomic number changes by one.
• γ-emission: an excited nucleus releases surplus energy as a high-energy photon, without any change in mass or charge number.

Step 4: State the governing behaviour.
The decay is random for any single nucleus but, for a large sample, follows the exponential law $N = N_0 e^{-\lambda t}$, and it cannot be sped up or slowed down by ordinary physical or chemical means.

Result: Radioactivity is the spontaneous, temperature-independent disintegration of unstable heavy nuclei with emission of α, β or γ radiation.

Quick Tip: Think of the spontaneous break-up of an unstable heavy nucleus emitting alpha, beta and gamma rays.

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12. What will be the focal length of a combination of a convex and a concave lens of the same focal length (placed in contact)?

Correct Answer: —

SOLUTION:

Step 1: Argue using power instead of focal length.

The power of a lens is $P = \frac{1}{f}$ (with f in metres), and for lenses in contact the powers simply add: $P = P_1 + P_2$. This is often the quickest way to combine lenses.

Step 2: Write each power with its sign.

The convex lens has power $P_1 = +\frac{1}{f}$ and the concave lens, of equal focal-length magnitude, has power $P_2 = -\frac{1}{f}$.

Step 3: Add the powers.

$$P = P_1 + P_2 = +\frac{1}{f} - \frac{1}{f} = 0$$

Step 4: Convert back to focal length.

Since $P = \frac{1}{F} = 0$, the equivalent focal length is

$$F = \frac{1}{P} = \frac{1}{0} = \infty$$

A zero-power, infinite-focal-length system neither converges nor diverges the beam, so it acts just like a flat glass slab.

Result:

$$\boxed{P = 0,\ F = \infty}$$

Quick Tip: Use $1/F = 1/f_1 + 1/f_2$ with $f_1 = +f$ and $f_2 = -f$.

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13. Explain the meaning of power factor and wattless current in alternating current circuits.

Correct Answer: —

SOLUTION:

Step 1: Why a phase angle appears.
Inductors and capacitors store and return energy instead of dissipating it, so in an AC circuit containing them the current i leads or lags the applied voltage v by a phase angle ϕ. Only the resistance dissipates energy.

Step 2: Meaning of power factor.
Power factor is the number that tells us what fraction of the apparent (voltage × current) power is genuinely turned into useful work or heat. Writing it from the impedance triangle,

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

A high power factor (close to 1) means the circuit is mostly resistive and efficient; a low power factor means most of the current is being pushed back and forth uselessly.

Step 3: Wattless current by energy view.

Resolve the current into a part in step with the voltage, $I\cos\phi$, and a part quarter-cycle out of step, $I\sin\phi$. Over one full cycle the out-of-step part delivers positive energy in one quarter and takes exactly that much back in the next quarter, so its net energy transfer is zero. Because it carries current but transfers no watt, $I\sin\phi$ is named the wattless (idle) current.

Step 4: Limiting case.

In an ideal choke coil ($R = 0$) the phase angle is 90°; then $\cos\phi = 0$ and the entire current is wattless, which is why an ideal inductor controls current without heating up.

$$\boxed{\cos\phi = R/Z;\;\; I_{wattless} = I\sin\phi}$$

Quick Tip: Start from average AC power $P = V_{rms}I_{rms}\cos\phi$; the factor $\cos\phi = R/Z$ is the power factor, and the current component $I\sin\phi$ that transfers no net power is the wattless current.

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14. The area of each plate of a parallel plate condenser is 100 cm² and the intensity of the electric field between the two plates is 100 newton/coulomb. How much charge is there on each plate?
(Take $\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2/N{\cdot}m^2$.)

Correct Answer: —

SOLUTION:

Step 1: Find the surface charge density first.

The field between the plates depends only on how densely the charge is packed on a plate, through $E = \sigma/\varepsilon_0$. So begin by extracting the surface charge density σ:

$$\sigma = \varepsilon_0 E$$

Step 2: Put in the numbers.

$$\sigma = (8.85 \times 10^{-12}) \times (100) = 8.85 \times 10^{-10}\ \text{C/m}^2$$

Step 3: Convert the plate area.

$$A = 100\ \text{cm}^2 = 1 \times 10^{-2}\ \text{m}^2$$

Step 4: Charge = density × area.

Since $\sigma = Q/A$, the total charge on one plate is

$$Q = \sigma A = (8.85 \times 10^{-10}) \times (1 \times 10^{-2})$$

Step 5: Compute.

$$Q = 8.85 \times 10^{-12}\ \text{C}$$

The same value is obtained, confirming the result. Each plate holds equal and opposite charge of this magnitude.

$$\boxed{Q \approx 8.85 \times 10^{-12}\ \text{C}\ (8.85\ \text{pC})}$$

Quick Tip: Use $E = \sigma/\varepsilon_0 = Q/(A\varepsilon_0)$, so $Q = \varepsilon_0 EA$; remember to convert 100 cm² to 10^{-2} m^2.

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15. Write the difference between isotopic, isobaric and isotonic nuclei. Give an example of each.

Correct Answer: —

SOLUTION:

A quick way to remember these three families is to ask *which of the three numbers* Z (protons), A (mass number) or N (neutrons) is being held fixed.

Step 1: Fix the protons then isotopes.
If two nuclei share the same number of protons Z, they are the same element; only their neutron count (and hence A) changes. These are isotopes. For carbon, ${}^{12}_{6}C$ and ${}^{14}_{6}C$ both have $Z = 6$, so they are isotopes.

Step 2: Fix the mass number then isobars.
If instead the total nucleon count A is the same while Z differs, the nuclei weigh alike but are chemically different elements. These are isobars. For $A = 40$, ${}^{40}_{18}Ar$ and ${}^{40}_{20}Ca$ are isobars.

Step 3: Fix the neutrons then isotones.
If the neutron number $N = A - Z$ is the same while both Z and A differ, the nuclei are isotones. Silicon ${}^{30}_{14}Si$ ($N = 16$) and phosphorus ${}^{31}_{15}P$ ($N = 16$) are isotones.

Step 4: One-line contrast.
Isotopes match in protons, isobars match in total mass number, and isotones match in neutrons.

$$\boxed{Z \text{ same} \Rightarrow \text{isotopes};\ A \text{ same} \Rightarrow \text{isobars};\ N \text{ same} \Rightarrow \text{isotones}}$$

Quick Tip: Ask which quantity is equal: same atomic number Z means isotopes, same mass number A means isobars, same neutron number N = A - Z means isotones.

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16. Explain the energy bands in solids.

Correct Answer: —

SOLUTION:

Step 1: From single atom to crystal.
Picture bringing N identical atoms from far apart to the tight spacing of a crystal. When they are far away each has the same set of discrete levels. As they approach, the wavefunctions of the outer electrons overlap, and to keep every electron in a distinct quantum state (Pauli principle) each single level fans out into N finely separated levels. With $N \sim 10^{23}$ the spread is effectively continuous, giving a band of allowed energies.

Step 2: The two bands that matter.
Only the highest occupied band (the valence band) and the next empty band (the conduction band) decide electrical behaviour. Conduction requires empty nearby states for electrons to move into; a completely

full band cannot carry net current.

Step 3: Read the gap E_g.

The energy width separating these two bands, the forbidden gap E_g, is the key. It is the energy an electron must gain to jump from the filled valence band into the empty conduction band.

Step 4: Three outcomes.

If the bands overlap ($E_g = 0$) plenty of free states are always available and the solid is a metallic conductor. If E_g is large (several eV) thermal energy at room temperature (~ 0.025 eV) cannot lift electrons across, so the solid is an insulator. If E_g is only about 1 eV, a small but useful number of electrons are thermally promoted, making the solid a semiconductor whose conductivity rises with temperature.

$$\boxed{\text{Overlap} \to \text{metal}; \;\; E_g \sim 1\,\text{eV} \to \text{semiconductor}; \;\; E_g \text{ large} \to \text{insulator}}$$

Quick Tip: Discrete atomic levels split and merge into valence and conduction bands separated by a forbidden gap Eg; the size of Eg (0, about 1 eV, or large) classifies metals, semiconductors and insulators.

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17. What are electromagnetic waves? Explain two characteristics of these waves.

Correct Answer: —

SOLUTION:

Step 1: What they are, in Maxwell's picture.

Maxwell showed that an accelerating charge sets up a time-varying electric field, which by his equations creates a time-varying magnetic field, which in turn feeds back into an electric field. This self-supporting chain of oscillating fields spreading outward is an electromagnetic wave; no vibrating particles of a medium are involved, only the fields themselves.

Step 2: Characteristic 1, no medium and transverse nature.
Because the wave is built out of $\vec{E}$ and $\vec{B}$ that create each other, it does not rely on air, water or any material to travel and moves happily through vacuum. Both fields vibrate at right angles to the direction the wave moves and at right angles to each other, so the wave is transverse. This transverse character is what makes light capable of being polarised.

Step 3: Characteristic 2, universal speed and energy.
In vacuum every electromagnetic wave, from radio waves to gamma rays, travels at one fixed speed set only by the electric and magnetic constants of space:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \approx 3 \times 10^8 \text{ m/s}, \qquad \frac{E_0}{B_0} = c$$

The wave also transports energy shared equally between its electric and magnetic fields and exerts radiation pressure because it carries momentum.

Step 4: Conclusion.
Thus an electromagnetic wave is a medium-free, transverse wave of coupled electric and magnetic fields moving at the speed of light and carrying energy.

$$\vec{E} \perp \vec{B} \perp \text{propagation}; \quad c = 1/\sqrt{\mu_0 \varepsilon_0}$$

Quick Tip: Electromagnetic waves are mutually perpendicular oscillating E and B fields that regenerate each other; note they are transverse, need no medium, and travel at c = 1/sqrt(mu0 epsilon0) = 3e8 m/s.

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18. A convex lens of glass of focal length 15 cm is immersed in carbon disulphide. In this situation what will be the focal length and the nature of the lens? The refractive indices of glass and carbon disulphide (relative to air) are 3/2 and 5/3 respectively.

Correct Answer: —

SOLUTION:

Step 1: Use the ratio of the two lens equations.

The geometrical factor $\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ is common to the lens in air and in the liquid, so dividing the two lens maker equations eliminates it:

$$\frac{f_{med}}{f_{air}} = \frac{\left(\frac{n_g}{n_{air}} - 1\right)}{\left(\frac{n_g}{n_{med}} - 1\right)}$$

Step 2: Insert the refractive indices.

Glass in air: $\frac{n_g}{n_{air}} - 1 = \frac{3}{2} - 1 = \frac{1}{2}$.

Glass in carbon disulphide: $\frac{n_g}{n_{med}} - 1 = \frac{3/2}{5/3} - 1 = \frac{9}{10} - 1 = -\frac{1}{10}$.

Step 3: Form the ratio.

$$\frac{f_{med}}{f_{air}} = \frac{1/2}{-1/10} = \frac{1}{2} \times (-10) = -5$$

Step 4: Solve for the new focal length.

$$f_{med} = -5 \times f_{air} = -5 \times 15 = -75 \text{ cm}$$

Step 5: Nature of the lens.

The magnitude of the focal length increases from 15 cm to 75 cm and the sign turns negative. A negative focal length means the convex lens now diverges light, so in carbon disulphide it acts as a concave (diverging) lens, because the surrounding liquid is optically denser than the glass.

$$\boxed{f = -75 \text{ cm; diverging (concave) behaviour}}$$

Quick Tip: Apply the lens maker's formula in both media; the shape factor is common, so f_medium/f_air = (n_g - 1)/((n_g/n_CS2) - 1). Since carbon disulphide is denser than glass, the convex lens turns diverging.

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19. Explain the proton-neutron hypothesis in the structure of nucleus.

Correct Answer: —

SOLUTION:

Step 1: What the nucleus must account for.

Any correct nuclear model must reproduce three measured quantities of an atom ${}_Z^AX$: its charge $+Ze$, its mass number A, and its spin/magnetic behaviour. The proton-neutron hypothesis is judged by how well it does this.

Step 2: The two building blocks.
Only two particles are placed inside the nucleus:
Proton, charge $+e$, mass $\approx 1.67 \times 10^{-27}$ kg.
Neutron, charge 0, mass $\approx 1.67 \times 10^{-27}$ kg.
Both are called nucleons. No electron is placed inside the nucleus.

Step 3: Counting the particles.
To get a nuclear charge of $+Ze$ we need exactly Z protons. To make up the remaining mass we add neutrons. If the mass number is A, then
Neutron number $N = A - Z$.
So the nucleus holds Z protons and $A - Z$ neutrons.

Step 4: Checking the model.
Charge check: $Z(+e) + (A - Z)(0) = +Ze$, correct.
Mass check: A nucleons each of mass $\approx m_p$ give mass number A, correct.
Isotope check: atoms with the same Z but different N (hence different A) are naturally explained as isotopes, e.g. ${}_1^1H$, ${}_1^2H$, ${}_1^3H$.

Step 5: Why the electron model was dropped.
Placing an electron in a 10^{-15} m nucleus violates the uncertainty principle (it would need enormous energy) and gives wrong nuclear spin. The proton-neutron model has no such trouble, so it is accepted.

$$\boxed{{}_Z^AX : \ Z \text{ protons}, \ (A - Z) \text{ neutrons}}$$

Quick Tip: After Chadwick found the neutron (1932), Heisenberg said the nucleus holds only protons and neutrons: Z protons and $(A - Z)$ neutrons, no electrons.

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20. Explain the motion of a charged particle in a uniform magnetic field. Prove that the radius of the path of a charged particle moving perpendicular to a uniform magnetic field is proportional to the momentum of the particle.

Correct Answer: —

SOLUTION:

Step 1: Set up the geometry.
Let a particle of charge q, mass m and speed v enter a uniform field B at right angles to it. The field does not act along the motion, so the particle is deflected sideways continuously.

Step 2: Use the work-energy idea.
The Lorentz force $\vec{F} = q\vec{v} \times \vec{B}$ is perpendicular to $\vec{v}$, so $\vec{F} \cdot \vec{v} = 0$. Hence power delivered is zero and the kinetic energy (and speed v) never changes. Only the direction turns, which means uniform circular motion.

Step 3: Angular form of the balance.
For circular motion of radius r, centripetal force $= m\omega^2 r$ where $\omega = v/r$. The magnetic force qvB provides it:
$$qvB = m\frac{v^2}{r}.$$

Step 4: Solve for the radius.

$r = \dfrac{mv}{qB}$. Writing momentum $p = mv$ gives $r = \dfrac{p}{qB}$.

Step 5: Read off the proportionality.

With q and B fixed, r changes only through p, so doubling the momentum doubles the radius.

$$\boxed{r = \frac{p}{qB} \Rightarrow r \propto p}$$

Quick Tip: The magnetic force is perpendicular to velocity, giving circular motion. Set $qvB = mv^2/r$ and use $p = mv$.

• • •

21. Resistance of a wire is 16 ohm. By melting it, its length is stretched to half of its original length. What will be the resistance of the new wire?

Correct Answer: —

SOLUTION:

Step 1: Substitute the new dimensions directly.

Original resistance $R = \rho \dfrac{L}{A} = 16\,\Omega$. New wire has length $L' = L/2$ and, by volume conservation $LA = L'A'$, area $A' = 2A$.

Step 2: Plug into the resistance formula.

$R' = \rho \dfrac{L'}{A'} = \rho \dfrac{L/2}{2A} = \rho \dfrac{L}{4A}$.

Step 3: Relate to the original resistance.

Notice $\rho \dfrac{L}{4A} = \dfrac{1}{4}\left(\rho \dfrac{L}{A}\right) = \dfrac{R}{4}$.

Step 4: Insert the number.

$R' = \frac{16}{4} = 4\,\Omega.$

Step 5: Sanity check.

Shortening the wire lowers L and thickening it raises A; both changes reduce resistance, so a value below $16\,\Omega$ is expected, and $4\,\Omega$ fits.

$$\boxed{R' = 4\,\Omega}$$

Quick Tip: Volume stays constant, so $R \propto L^2$. Halving the length makes R' $= R/4$.

• • •

22. Write Ohm's law. Deduce Ohm's law on the basis of drift velocity of electron.

Correct Answer: —

SOLUTION:

Step 1: State Ohm's law.

For a conductor at constant temperature, $V = IR$, i.e. the current is proportional to the applied voltage. We now derive this from the microscopic motion of electrons.

Step 2: Start from current density.

Define current density $J = I/A$. In terms of drift velocity, $J = ne\,v_d$, where n is free-electron density and e the electronic charge.

Step 3: Insert the drift velocity.

An electron gains drift velocity $v_d = \frac{eE\tau}{m}$ under field E. Hence

$$J = ne \cdot \frac{eE\tau}{m} = \frac{ne^2\tau}{m} E = \sigma E,$$

where $\sigma = \dfrac{ne^2\tau}{m}$ is the conductivity. This is the microscopic form of Ohm's law, $J = \sigma E$.

Step 4: Move to the macroscopic form.

Put $J = I/A$ and $E = V/L$:

$$\frac{I}{A} = \sigma \frac{V}{L} \Rightarrow I = \frac{\sigma A}{L} V.$$

Step 5: Read off resistance.

Therefore $V = I \cdot \dfrac{L}{\sigma A} = IR$ with $R = \dfrac{L}{\sigma A} = \dfrac{mL}{ne^2\tau A}$, a constant for the conductor. Hence $V \propto I$.

$$\boxed{J = \sigma E \Rightarrow V = IR}$$

Quick Tip: Use $v_d = eE\tau/m$ and $I = neAv_d$ with $E = V/L$; collecting constants gives $V = IR$.

• • •

23. An equiconcave lens of crown glass has to be formed. What should be the radii of the surfaces of the lens so that the power of the lens is $-2.5\,\text{D}$? The refractive index of crown glass is 1.65.

Correct Answer: —

SOLUTION:

Step 1: Convert power to focal length.

Focal length $f = \dfrac{1}{P} = \dfrac{1}{-2.5} = -0.4\text{ m} = -40\text{ cm}$. The negative sign confirms a diverging (concave) lens.

Step 2: Write the lens maker's formula in f form.

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

Step 3: Use equal radii.

For an equiconcave lens $R_1 = -R$ and $R_2 = +R$, giving $\frac{1}{R_1} - \frac{1}{R_2} = -\frac{2}{R}$.

Step 4: Substitute numbers in centimetres.

$$\frac{1}{-40} = (1.65-1)\left(-\frac{2}{R}\right) = 0.65\left(-\frac{2}{R}\right) = -\frac{1.30}{R}.$$

Step 5: Solve.

$$-\frac{1}{40} = -\frac{1.30}{R} \Rightarrow R = 1.30 \times 40 = 52 \text{ cm}.$$

$$\boxed{R = 52 \text{ cm } (0.52 \text{ m})}$$

Quick Tip: Use $P = (n-1)(1/R_1 - 1/R_2)$ with $R_1 = -R$, $R_2 = +R$ so the bracket is $-2/R$; solve for R.

• • •

24. What do you mean by eddy current? How does it affect the energy losses? Write the uses of eddy current.

Correct Answer: —

SOLUTION:

Step 1: Origin of the current.

Consider a thick block of metal placed in a changing magnetic field. By

Faraday's law an emf is induced not just in a wire loop but throughout the volume of the block. Since the block has continuous conducting paths, closed circulating currents appear inside it, these are eddy currents.

Step 2: Direction and the energy question.
By Lenz's law each eddy current opposes the flux change, so mechanical or electrical work must be done against them. This work reappears as heat: power lost $= I^2R$ within the metal. In transformers and rotating machines this shows up as core heating and reduced efficiency.

Step 3: Controlling the loss.
The heat depends on how large the eddy loops can grow. Slicing the core into thin insulated laminations forces the currents into small loops of high resistance, cutting the loss sharply. Using high-resistivity alloys such as silicon steel helps further.

Step 4: Turning the effect to use.
The same heating and damping action is exploited deliberately in: induction furnaces (melting metal), electromagnetic brakes (smooth non-contact braking of trains), induction motors, dead-beat galvanometers (fast damping of the pointer), speedometers and household induction stoves.

$$\boxed{\text{Whirlpool induced currents} \rightarrow I^2R \text{ heat; minimised by lamination, used in furnaces, brakes, motors}}$$

Quick Tip: Eddy currents are induced circulating currents in bulk conductors due to changing flux; they cause I^2R heating (reduced by laminated cores) and are used in induction furnaces and electromagnetic braking.

• • •

25. The wavelength of first line of Balmer series of hydrogen atom is 6563 Å. Determine the wavelength of second line.

OR

What do you mean by polarization of light? How are unpolarized and plane polarized lights represented? Which nature of light waves is proved by polarization?

Correct Answer: —

SOLUTION:

Option 1: Second Balmer line by Balmer's empirical relation

Step 1: Balmer's original empirical formula writes each line of the series directly as

$$\lambda = B\,\frac{n^2}{n^2-4}, \quad n = 3, 4, 5, \ldots$$

where B is Balmer's constant and n labels the line ($n = 3$ first line, $n = 4$ second line).

Step 2: Fix B from the given first line. For $n = 3$: $\lambda_1 = B\frac{9}{9-4} = \frac{9B}{5}$.

Given $\lambda_1 = 6563$ Angstrom,

$$B = \frac{5}{9} \times 6563 = 3646 \text{ Angstrom.}$$

Step 3: For the second line $n = 4$:

$$\lambda_2 = B\,\frac{16}{16-4} = B\,\frac{16}{12} = \frac{4B}{3}.$$

Step 4: Substitute $B = 3646$ Angstrom:

$$\lambda_2 = \frac{4}{3} \times 3646 \approx 4861 \text{ Angstrom.}$$

The same value is reached without ever using the Rydberg constant.

$$\boxed{\lambda_2 \approx 4861 \text{ Angstrom}}$$

Option 2: Polarization explained through a polaroid experiment

Step 1: Think of an unpolarized beam as a mixture of transverse waves whose electric vibrations point randomly in every direction across the ray. No single direction is preferred, so the beam has no plane of vibration.
Step 2: Place a first polaroid (polarizer) in the path. It passes only the vibration component along its axis and absorbs the rest, so the transmitted beam now vibrates in one fixed plane. This one-plane beam is plane polarized light.
Step 3: Add a second polaroid (analyser) and rotate it. The transmitted intensity rises and falls, becoming zero when its axis is perpendicular to the first. A random (unpolarized) beam would show no such variation, proving the first polaroid produced polarized light.
Step 4 (Symbols): On a ray diagram, unpolarized light carries both dots (⊙) and arrows (↕) together; plane polarized light carries only arrows (↕) or only dots (⊙).
Step 5 (Conclusion): Because polarization is possible only for waves that vibrate across the direction of travel, it establishes that light is a transverse wave and not a longitudinal one.

$$\boxed{\text{Light is a transverse wave, confirmed by polarization.}}$$

Quick Tip: For the Balmer series use $\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{n^2}\right)$ with $n = 3$ for the first line and $n = 4$ for the second, then take the ratio. For the OR part, polarization confining vibrations to one plane proves light is transverse.

• • •

26. Deduce the formula of equivalent capacity of three condensers connected in parallel.

Correct Answer: —

SOLUTION:

Step 1 (Combine two first): Instead of adding all three at once, first replace C_1 and C_2 in parallel by a single capacitor. Both share the same voltage V, so their charges are $Q_1 = C_1V$ and $Q_2 = C_2V$, giving a combined charge $Q_1 + Q_2 = (C_1 + C_2)V$. Hence their equivalent value is

$$C_{12} = \frac{Q_1 + Q_2}{V} = C_1 + C_2.$$

Step 2 (Bring in the third): Now C_{12} and C_3 are themselves in parallel across the same V. Repeating the same reasoning,

$$C_p = C_{12} + C_3 = (C_1 + C_2) + C_3.$$

Step 3 (Result): Therefore

$$C_p = C_1 + C_2 + C_3.$$

Step 4 (Physical check): Capacitance measures charge stored per unit voltage. Putting plates side by side in parallel effectively enlarges the total plate area facing each other, and since $C \propto$ area, the capacitances simply add. This also explains why the parallel result exceeds every individual capacitor.

$$\boxed{C_p = C_1 + C_2 + C_3}$$

Quick Tip: In parallel the voltage across each capacitor is the same; add the charges $Q = C_1V + C_2V + C_3V$ and use $C_p = Q/V$.

• • •

27. Obtain the formula for the magnetic field inside a current carrying solenoid with the help of Ampere's circuital law.

OR

Obtain the formula for moment of couple acting on a magnetic dipole in a magnetic field. Define magnetic dipole moment with the help of this.

Correct Answer: —

SOLUTION:

Option 1: Solenoid field seen as a stack of circular loops

Step 1: A solenoid is nothing but a large number of identical circular current loops set side by side. Deep inside a very long solenoid the fields of neighbouring loops add along the axis and cancel sideways, giving a uniform axial field; outside, the return field spreads over a huge area and is practically zero.

Step 2 (Apply Ampere on a rectangle): Draw a rectangle of axial length L with one long side inside and one long side far outside. The circulation of $\vec{B}$ receives BL from the inner side; the outer side contributes nothing because $B \approx 0$ there, and the two end sides contribute nothing because $\vec{B}$ is perpendicular to them. So

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

Step 3 (Count the wires pierced): If the winding has n turns per metre, the rectangle of length L is pierced by nL wires, each carrying I; the enclosed current is nLI.
Step 4 (Ampere's law): Equating,

$$BL = \mu_0 (nL) I \;\Rightarrow\; B = \mu_0 nI.$$

Step 5: Writing $n = N/\ell$ (total turns N over length ℓ) gives the equivalent form $B = \mu_0 NI/\ell$. The result shows the field depends only on turns per unit length and current, not on the radius.

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

Option 2: Torque on a dipole through the current-loop model

Step 1: Model the magnetic dipole as a small plane current loop of area A carrying current i, so that its magnetic moment is $M = iA$ (equivalently $M = m \cdot 2l$ for a bar magnet). Place the loop in a uniform field $\vec{B}$ with its normal at angle θ to $\vec{B}$.
Step 2: The two opposite sides of the loop carry currents in opposite directions, so they feel equal and opposite forces $F = BiL_{\text{side}}$. These form a couple; the net force is zero.
Step 3: The moment arm of this couple is the projection of the loop width across the field, which introduces a factor $\sin\theta$. Working out the geometry gives torque $= (iA)B\sin\theta$.
Step 4: Since $M = iA$,

$$\tau = MB\sin\theta, \qquad \vec{\tau} = \vec{M} \times \vec{B}.$$

Step 5 (Definition): Setting $\theta = 90°$ and $B = 1$ makes $\tau = M$. So the magnetic dipole moment equals the maximum torque a dipole feels in a unit field, i.e. the torque when the dipole sits perpendicular to the field of unit strength.

$$\boxed{\tau = MB\sin\theta}$$

Quick Tip: For the solenoid apply $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$ on a rectangular loop with enclosed current nLI to get $B = \mu_0 nI$. For the dipole, the two pole forces form a couple giving $\tau = MB\sin\theta$ with $M = m \times 2l$.

• • •

28. How is the p-n junction diode used as a full wave rectifier? Explain its working process by making its simple circuit.

OR

What are de Broglie's matter-waves? The work function of potassium is 2 ·0 eV. When ultraviolet light of wavelength 3500 Å falls on the surface of potassium, calculate the maximum kinetic energy of the emitted photoelectrons in electron-volt.

Correct Answer: —

SOLUTION:

Option 1: Full wave rectification using a bridge of four diodes

Step 1 (Idea): Rectification means letting current pass in only one direction. A diode does exactly this because it conducts under forward bias and blocks under reverse bias. A full wave rectifier arranges diodes so that current reaches the load the same way during every half of the AC cycle.

Step 2 (Bridge circuit): Connect four diodes D_1, D_2, D_3, D_4 in a diamond (bridge). The AC secondary of the transformer feeds the two opposite corners of the diamond, and the load R_L is connected across the other two corners. No centre tap is needed.

Step 3 (First half cycle): When the upper input terminal is positive, diodes D_1 and D_3 become forward biased and conduct, while D_2 and D_4 stay off. Current runs from the source through D_1, down through R_L, and returns through D_3.

Step 4 (Second half cycle): When the polarity reverses, D_2 and D_4 conduct while D_1 and D_3 are off. Current now flows through D_2, again downward through R_L in the same direction as before, and returns through D_4.

Step 5 (Outcome): Because the load current keeps the same direction in both half cycles, the AC input is fully rectified into pulsating DC. Adding a capacitor filter smooths the ripples.

$$\boxed{\text{Bridge of 4 diodes} \Rightarrow \text{both half cycles rectified.}}$$

Option 2: Photoelectric energy via the $hc = 1240$ eV nm shortcut

Step 1 (Matter waves): de Broglie's hypothesis says a moving particle behaves like a wave of wavelength $\lambda = h/p$, where p is its momentum. So particles like electrons show diffraction, just as waves do; the heavier and faster the particle, the shorter its matter wavelength.

Step 2 (Photon energy shortcut): A handy form of $E = hc/\lambda$ is

$$E(\text{eV}) = \frac{1240}{\lambda(\text{nm})}.$$

Here $\lambda = 3500$ Angstrom $= 350$ nm, so

$$E = \frac{1240}{350} \approx 3.54 \text{ eV}.$$

Step 3 (Einstein's equation): The maximum kinetic energy of a photoelectron is the photon energy left over after paying the work function W_0:

$$KE_{\text{max}} = E - W_0.$$

Step 4 (Substitute): With $W_0 = 2.0$ eV,

$$KE_{\text{max}} = 3.54 - 2.0 = 1.54 \text{ eV}.$$

Step 5 (Check): The photon energy exceeds the work function, so emission does occur, and the surplus 1.54 eV appears as the fastest electrons' kinetic energy.

$$\boxed{KE_{\text{max}} \approx 1.54 \text{ eV}}$$

Quick Tip: For the rectifier, use that a diode conducts only in forward bias; two diodes with a centre-tapped transformer (or a 4-diode bridge) send current through the load the same way in both half cycles. For the OR part, use $KE_{max} = \frac{hc}{\lambda} - W_0$.

• • •

29. By drawing ray-diagram, explain the formation of image by a compound microscope. Establish the formula for its magnifying power.

OR

What is meant by binding energy of nucleus? Draw the graph of binding energy per nucleon with respect to the mass number. Discuss fission and fusion reactions with the help of this curve.

Correct Answer: —

SOLUTION:

OPTION 1: Compound Microscope

Step 1: Why two lenses. A single convex lens (simple microscope) cannot give a very high magnification because a short focal length is hard to grind. A compound microscope solves this by magnifying *twice*: first with a short-focus *objective* and again with the *eyepiece*. Both are converging lenses fitted in a tube of length L.

Step 2: Path of light. The specimen AB is fixed a little beyond the objective focus F_o. The objective throws a real, inverted, enlarged image $A'B'$ inside the tube. This image is deliberately made to lie just within the eyepiece focus, so that the eyepiece treats $A'B'$ as its object and creates a large virtual image $A''B''$ seen comfortably by the eye at the near point $D = 25$ cm.

Step 3: Magnification as a product. Since the object is magnified in two stages, the overall magnifying power is the product of the two stage magnifications:

$$M = m_o \, m_e$$

Step 4: First stage (objective). Using $m_o = v_o/u_o$ and taking the object almost at F_o (so $u_o \approx f_o$) with the image near the eyepiece end (so $v_o \approx L$):

$$m_o \approx \frac{L}{f_o}$$

Step 5: Second stage (eyepiece). The eyepiece is a simple magnifier. Its angular magnification for the image at the near point is

$$m_e = 1 + \frac{D}{f_e}$$

Step 6: Result. Combining the two stages,

$$M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

and for a relaxed eye (image at infinity) $M = \frac{LD}{f_o f_e}$. Keeping both focal lengths small makes M very large.

$$\boxed{M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)}$$

OPTION 2: Binding Energy of Nucleus

Step 1: Idea of binding. Protons repel each other electrically, yet nuclei hold together. The strong nuclear force binds the nucleons, and this binding shows up as a loss of mass. The energy tied up in holding the nucleus together is the binding energy.

Step 2: Mass defect and Einstein relation. The nucleons weigh more when free than when bound. The difference is

$$\Delta m = Zm_p + (A - Z)m_n - M_{nucleus}$$

and by $E = mc^2$ the binding energy is $B.E. = \Delta m\, c^2$. Per nucleon it is $B.E./A$, a direct measure of stability.

Step 3: Shape of the $B.E./A$ vs A graph. Starting from light nuclei the curve climbs quickly, flattens into a plateau around 8.5 to 8.8 MeV between mass numbers 30 and 120 (peak at iron, $A \approx 56$), and then droops gently to roughly 7.6 MeV for the heaviest nuclei. The top of the hump marks the most stable nuclei.

Step 4: Reading fission off the curve. Heavy nuclei sit on the right, below the peak. Splitting one into two mid-mass fragments moves the products up the curve to a higher $B.E./A$. Since the fragments are more tightly bound, the surplus energy (about 200 MeV) is liberated. This is nuclear fission.

Step 5: Reading fusion off the curve. Light nuclei sit on the far left, far below the peak. Joining them into a heavier nucleus climbs the steep left side of the curve to a much higher $B.E./A$, so a large amount of energy is released. This is nuclear fusion, the source of solar energy.

Both fission and fusion release energy precisely because each carries the system toward the peak of the binding-energy curve, where nucleons are bound most tightly.

$$\boxed{\text{Energy released} = (\text{final } B.E.) - (\text{initial } B.E.) > 0}$$

Quick Tip: Microscope: magnifying power is the product of objective magnification L/f_o and eyepiece magnification $(1 + D/f_e)$. Binding energy:

$B.E. = \Delta m\, c^2$; both fission and fusion move nuclei toward the peak of the $B.E./A$ curve, releasing energy.

• • •

30. Explain Biot-Savart law. Deduce the formula for magnetic field produced due to a straight current carrying conductor.
OR
An α-particle, accelerated with the potential difference of V volt strikes with a nucleus (atomic number = Z). If r be the nearest distance of closest approach to the nucleus then prove that r = 14·4 Z/V Å.

Correct Answer: —

SOLUTION:

OPTION 1: Biot-Savart Law and Straight Conductor

Step 1: What the law says. Biot-Savart law gives the magnetic contribution of one current element. For an element $I\, d\vec{l}$ at position $\vec{r}$ from an observation point, the field is

$$d\vec{B} = \frac{\mu_0}{4\pi}\,\frac{I\, d\vec{l} \times \hat{r}}{r^2}, \qquad dB = \frac{\mu_0}{4\pi}\,\frac{I\, dl \sin\theta}{r^2}$$

with θ the angle between $d\vec{l}$ and $\vec{r}$. The field is largest sideways to the element ($\theta = 90°$) and zero along its axis ($\theta = 0$).

Step 2: Choice of variable. Take the straight wire along a line and let P be at perpendicular distance a. Instead of ϕ, measure each element by the angle α that the line from the element to P makes with the wire itself. Then $\theta = \alpha$ and $\sin\theta = \sin\alpha$.

Step 3: Relations. With O the foot of the perpendicular and l the distance of the element from O, geometry gives $r = a/\sin\alpha$ and $l = -a\cot\alpha$, so $dl = a\ \csc^2\alpha\, d\alpha$.

Step 4: Substitute.

$$dB = \frac{\mu_0 I}{4\pi}\frac{(a\csc^2\alpha\, d\alpha)\sin\alpha}{(a/\sin\alpha)^2} = \frac{\mu_0 I}{4\pi a}\sin\alpha\, d\alpha$$

Step 5: Integrate between the end angles. If the two ends of the wire correspond to angles α_1 and α_2 measured from the wire,

$$B = \frac{\mu_0 I}{4\pi a}\int_{\alpha_1}^{\alpha_2}\sin\alpha\, d\alpha = \frac{\mu_0 I}{4\pi a}\left(\cos\alpha_1 - \cos\alpha_2\right)$$

This is the same result as before written with angles from the wire.

Step 6: Long wire limit. For an infinite wire the ends go to $\alpha_1 \to 0$ and $\alpha_2 \to 180°$, giving $\cos 0 - \cos 180° = 1 - (-1) = 2$. Hence

$$B = \frac{\mu_0 I}{4\pi a}\times 2 = \frac{\mu_0 I}{2\pi a}$$

the familiar field of a long straight wire, circling the conductor.

$$\boxed{B = \frac{\mu_0 I}{2\pi a}}$$

OPTION 2: Distance of Closest Approach of α-particle

Step 1: Work-energy view. The accelerating field does work $W = qV$ on the α-particle. Its charge is twice the electron charge, $q = 2e$, so it enters the target region with kinetic energy $K = 2eV$ joule. No energy is lost on the way in, so this is the energy budget for the head-on collision.

Step 2: Turning point. The nucleus of charge Ze repels the positive α-particle. The particle slows, stops at separation r, then returns. At that turning point its speed is zero, so kinetic energy has been fully traded for Coulomb potential energy:

$$U(r) = k\,\frac{(2e)(Ze)}{r}, \qquad k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$$

Step 3: Balance. Energy conservation $K = U$ gives

$$2eV = k\,\frac{2Ze^2}{r}$$

Dividing both sides by $2e$,

$$V = k\,\frac{Ze}{r} \;\Rightarrow\; r = \frac{kZe}{V}$$

Step 4: Numerical constant. Insert $k = 9 \times 10^9$ and $e = 1.6 \times 10^{-19}$ C:

$$r = \frac{(9 \times 10^9)(1.6 \times 10^{-19})Z}{V} = \frac{1.44 \times 10^{-9}\,Z}{V}\ \text{m}$$

Step 5: Angstrom form. Because 1.44×10^{-9} m equals 14.4×10^{-10} m and 10^{-10} m $=1$ Å,

$$r=\frac{14.4\,Z}{V}\ \text{Å}$$

Hence proved.

$$\boxed{r=\frac{14.4\,Z}{V}\ \text{Å}}$$

Quick Tip: Biot-Savart: $dB=\frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$; integrate along the wire to get $B=\frac{\mu_0 I}{2\pi a}$. Closest approach: set kinetic energy $2eV$ equal to Coulomb potential energy $\frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{r}$ and solve for r.