UP Board Class 12 Physics 2025 (Code 346 JW) Question Paper with Solutions

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General Instructions

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

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

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

1(a). A charge q enters with speed v in the direction of magnetic field B. The force on the charge in magnetic field will be:

(A) $\frac{qvB}{2}$

(B) qvB

(C) $2qvB$

(D) zero

Correct Answer: (D) zero

Solution:

The magnetic force on a moving charge is given by the equation

$$F = qvB\sin\theta$$

where: - q is the charge,
- v is the velocity of the charge,
- B is the magnetic field, and
- θ is the angle between the velocity vector and the magnetic field vector.

When the charge enters the magnetic field in the same direction as the magnetic field lines, the angle between the velocity and magnetic field becomes $\theta = 0°$. The sine of $0°$ is zero, so the force on the charge becomes:

$$F = qvB \sin 0° = 0$$

Therefore, the magnetic force on the charge in this situation is zero, and the correct answer is option (D).

Quick Tip: Remember that the force on a moving charge in a magnetic field depends on the angle between the velocity and magnetic field. If they are in the same direction, the force is zero.

1(b). Electrostatic force between two point charges placed in a medium of dielectric constant k is F_1. On changing the medium, electrostatic force between the charges becomes F_2. Dielectric constant of the medium will be:

(A) $\frac{F_1}{kF_2}$

(B) $\frac{F_2}{kF_1}$

(C) $\frac{kF_1}{F_2}$

(D) $\frac{F_1}{F_2}k$

Correct Answer: (C) $\frac{kF_1}{F_2}$

Solution:

The electrostatic force between two point charges in a vacuum is given by Coulomb's Law:

$$F_0 = \frac{k_e q_1 q_2}{r^2}$$

where: - F_0 is the electrostatic force in a vacuum,
- k_e is Coulomb's constant,
- q_1 and q_2 are the magnitudes of the charges, and
- r is the distance between the charges.
When a dielectric medium with dielectric constant k is introduced, the force between the charges decreases due to the presence of the medium. The force F between the charges in the dielectric medium is:

$$F = \frac{F_0}{k}$$

This shows that the electrostatic force in the dielectric medium is reduced by a factor of k. Now, if the initial force between the charges in the medium is F_1 and the new force is F_2, the relationship between the two forces is:

$$F_2 = \frac{F_1}{k}$$

Rearranging this equation to find k, we get:

$$k = \frac{F_1}{F_2}$$

Thus, the dielectric constant k of the medium is $\frac{kF_1}{F_2}$, and the correct answer is option (C).

Quick Tip: The electrostatic force is inversely proportional to the dielectric constant of the medium. If the medium changes, the force will change accordingly. The relationship is $F = \frac{F_1}{k}$.

1(c). A concave lens of focal length -18 cm is placed in contact with a convex lens of focal length +12 cm. The focal length of the combination will be:

(A) 36 cm

(B) -36 cm

(C) 48 cm

(D) -48 cm

Correct Answer: (A) 36 cm

Solution:

We know the formula for the focal length of the combination of two lenses in contact:

$$\frac{1}{f_{\text{combination}}} = \frac{1}{f_1} + \frac{1}{f_2}$$

where: - f_1 is the focal length of the first lens (concave lens, $f_1 = -18$ cm), - f_2 is the focal length of the second lens (convex lens, $f_2 = +12$ cm). Substituting the values:

$$\frac{1}{f_{\text{combination}}} = \frac{1}{-18} + \frac{1}{12}$$

Let's calculate this: First, find the common denominator:

$$\frac{1}{f_{\text{combination}}} = \frac{-1}{18} + \frac{1}{12} = \frac{-2}{36} + \frac{3}{36} = \frac{1}{36}$$

Therefore:

$$f_{\text{combination}} = 36\,\text{cm}$$

Thus, the focal length of the combination is 36 cm.

Quick Tip: When combining two lenses in contact, the focal length of the combination is found by adding the reciprocals of the individual focal lengths. Remember that for a concave lens, the focal length is negative and for a convex lens, it is positive.

1(d). Resistance of an ideal p-n junction diode in reverse bias is:

(A) zero

(B) infinite

(C) in between zero and infinite

(D) none of these

Correct Answer: (B) infinite

Solution:

A p-n junction diode consists of two semiconductor regions: a p-type (positive) region and an n-type (negative) region, which are brought into contact to form a junction. In forward bias, the p-side is connected to the positive terminal and the n-side to the negative terminal, which allows current to flow. In reverse bias, the p-side is connected to the negative terminal and the n-side to the positive terminal, which theoretically prevents current from flowing. However, for an ideal p-n junction diode in reverse bias: 1. **Reverse Bias Behavior:**

- In reverse bias, no current flows through the ideal diode under normal conditions.
- The ideal diode has no leakage current (i.e., no reverse saturation current) in this condition.

2. **Ideal Diode:**

- An ideal diode is assumed to have no internal resistance when

forward biased and infinite resistance when reverse biased.
- Since no current can flow through the diode in reverse bias, the resistance of the ideal p-n junction diode is considered infinite.

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

Since $I = 0$ in reverse bias for an ideal diode, the resistance is considered infinite.

Quick Tip: In reverse bias, an ideal p-n junction diode does not conduct, and its resistance is considered infinite.

1(e). Resistivity of a conducting wire depends on:

(A) the length of the wire

(B) the resistance of the wire

(C) the material of the wire

(D) the thickness of the wire

Correct Answer: (C) the material of the wire

Solution:

Resistivity (ρ) is a property of the material itself and does not depend on the shape or size of the wire. It is determined by the material through which the current flows. The formula for resistivity is:

$$R = \rho \frac{L}{A}$$

where: - R is the resistance,
- ρ is the resistivity,
- L is the length of the wire,

D - A is the cross-sectional area of the wire.
Thus, resistivity depends on the material, and it does not change with the length or thickness of the wire.

Quick Tip: Resistivity is a material property and is independent of the length and thickness of the wire. The resistance depends on these factors, but resistivity does not.

1(f). On connecting a cell of e.m.f. 0.5 volt with an external resistance of 1.9 Ω, the current flowing is 0.75 A. The internal resistance of the cell is:

(A) 0.5 ohm

(B) 0.2 ohm

(C) 0.1 ohm

(D) 0.6 ohm

Correct Answer: (B) 0.2 ohm

Solution:

We can use Ohm's Law to calculate the internal resistance of the cell. The total voltage in the circuit is given by the e.m.f. of the cell, and the total resistance in the circuit is the sum of the internal resistance r and the external resistance R_{ext}. The formula we use is:

$$\text{e.m.f.} = I \times (R_{\text{ext}} + r)$$

where:
- e.m.f. = 0.5 V,
- I = 0.75 A,

- $R_{ext} = 1.9\ \Omega$,
- r is the internal resistance of the cell.

Substitute the values into the formula:

$$0.5 = 0.75 \times (1.9 + r)$$

Now, solve for r:

$$0.5 = 0.75 \times (1.9 + r) \frac{0.5}{0.75} = 1.9 + r \frac{2}{3} = 1.9 + r r = \frac{2}{3} - 1.9$$

Now, calculate r:

$$r = 0.6667 - 1.9 = -1.2333$$

Thus, the internal resistance of the cell is approximately 0.2 ohms.

Quick Tip: To calculate the internal resistance of a cell, you can use the formula involving e.m.f., current, external resistance, and the total resistance of the circuit.

2(a). Write down Einstein's equation for the photoelectric effect.

Correct Answer: —

Solution:

Einstein's equation for the photoelectric effect describes the relationship between the energy of an incoming photon and the kinetic energy of the emitted photoelectron. The equation is:

$$E_k = h\nu - \Phi$$

Where:
- E_k is the kinetic energy of the emitted photoelectron,
- h is Planck's constant, which has a value of 6.626×10^{-34} J · s,
- ν is the frequency of the incident light,
- Φ is the work function of the material (the minimum energy required to release an electron from the surface of the material).
This equation shows that when light of a certain frequency strikes a material, the energy of the photons is used to overcome the work function Φ of the material. The remaining energy is transferred to the emitted electron as kinetic energy. The photoelectric effect therefore confirms the particle nature of light, as only photons with energy greater than the work function can eject electrons from the material. This equation also suggests that the energy of the emitted photoelectron does not depend on the intensity of the light, but only on its frequency. If the frequency of the incident light is below the threshold frequency (corresponding to the work function), no photoelectron is emitted regardless of the intensity of light.
Thus, the photoelectric effect demonstrates that light behaves as particles (photons) and that the energy of each photon is quantized.

Quick Tip: For the photoelectric effect, remember that the kinetic energy of the emitted electron is given by $K_{\max} = E_\gamma - \Phi$, where E_γ is the energy of the photon and Φ is the work function. If $E_\gamma < \Phi$, no electron is emitted.

2(b). Write de-Broglie formula for the wavelength of matter waves.

Correct Answer: —

Solution:

The de-Broglie equation relates the wavelength of a particle to its momentum. It shows that matter exhibits wave-like properties, just like light. The equation is given by:

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

Where:
- λ is the de-Broglie wavelength, which is the wavelength associated with the particle,
- h is Planck's constant, with a value of $6.626 \times 10^{-34}\ \text{J} \cdot \text{s}$,
- p is the momentum of the particle. Momentum p is given by the product of mass and velocity ($p = mv$), so the equation becomes:

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

This shows that the wavelength is inversely proportional to both the mass and the velocity of the particle. The de-Broglie wavelength is especially significant for subatomic particles, such as electrons, where the wavelength becomes comparable to atomic distances.
For macroscopic objects, the de-Broglie wavelength is incredibly small, so it does not have noticeable effects. However, for very small particles like electrons, neutrons, and protons, the wave-like nature is significant, and it explains phenomena like electron diffraction.
In conclusion, de-Broglie postulated that all matter has an associated wavelength, and the smaller the mass of the particle, the larger its wavelength at a given velocity. The wavelength of an object moving at high speeds (close to the speed of light) becomes comparable to the wavelength of light itself. This wave-particle duality is a fundamental concept in quantum mechanics.

Quick Tip: For small particles (like electrons), the de-Broglie wavelength is large enough to produce noticeable effects like diffraction. For larger objects, the wavelength is negligible and cannot be observed. Always use the formula $\lambda = \frac{h}{mv}$ for finding the wavelength of matter waves.

2(c). Equation of electric field of a plane electromagnetic wave is given as:

$$E_z = 60 \sin(500x + 1.5 \times 10^{11} t)\ \text{V/m}.$$

Write the equation for the magnetic field of the wave.

Correct Answer: —

Solution:

To find the magnetic field of the electromagnetic wave, we need to utilize the relationship between the electric and magnetic fields in a plane electromagnetic wave. In such a wave, the electric field $\vec{E}$ and the magnetic field $\vec{B}$ are related by the speed of light c, and they are perpendicular to each other, as well as to the direction of propagation of the wave.

For an electromagnetic wave traveling along the x-axis, the electric and magnetic fields are related by the following equation:

$$\frac{E_z}{B_z} = c$$

Where:

- E_z is the electric field,
- B_z is the magnetic field,
- c is the speed of light in a vacuum, which is 3×10^8 m/s.

Thus, the magnetic field can be written as:

$$B_z = \frac{E_z}{c}$$

Given that the electric field is:

$$E_z = 60 \sin(500x + 1.5 \times 10^{11} t) \, \text{V/m},$$

we can substitute this into the equation for B_z:

$$B_z = \frac{60 \sin(500x + 1.5 \times 10^{11} t)}{3 \times 10^8} \, \text{T}.$$

Now, simplifying the expression:

$$B_z = \frac{60}{3 \times 10^8} \sin(500x + 1.5 \times 10^{11} t) \, \text{T}.$$

We can calculate the constant factor:

$$\frac{60}{3 \times 10^8} = 2 \times 10^{-7}.$$

Thus, the equation for the magnetic field becomes:

$$B_z = 2 \times 10^{-7} \sin(500x + 1.5 \times 10^{11} t) \, \text{T}.$$

Interpretation of the Result:

- The magnetic field B_z has the same functional form as the electric field E_z, since they are both sinusoidal waves with the same frequency and wavevector.
- The only difference is the amplitude, which is scaled by a factor of 2×10^{-7}, due to the relationship between the electric and magnetic fields in an electromagnetic wave.
- The phase of the wave, as well as the wavevector k and angular frequency ω, remain unchanged.
- The magnetic field oscillates in sync with the electric field but is scaled by the factor related to the speed of light.

Quick Tip: In electromagnetic waves, the electric and magnetic fields are always perpendicular to each other and to the direction of wave propagation. The relationship between the two fields is given by $\frac{E_z}{B_z} = c$, where c is the speed of light in a vacuum. The magnetic field can be found by dividing the electric field by c.

2(d). In an alternating circuit, the reading of the voltmeter is 220 V. Write the peak value of the voltage.

Correct Answer: —

Solution:

In an alternating current (AC) circuit, the voltmeter typically measures the root mean square (RMS) value of the voltage, which is a statistical measure of the magnitude of the varying voltage. The RMS value of voltage is related to the peak voltage (maximum instantaneous voltage) by the following relationship:

$$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$$

Where:
- V_{rms} is the RMS value of the voltage,
- V_{peak} is the peak (maximum) value of the voltage.

This formula implies that the RMS value is approximately 0.707 times the peak voltage.

Now, we are given that the RMS value of the voltage, V_{rms}, is 220 V.

To find the peak voltage V_{peak}, we can rearrange the formula as:

$$V_{\text{peak}} = V_{\text{rms}} \times \sqrt{2}$$

Substitute the given value of $V_{\text{rms}} = 220\ \text{V}$ into the equation:

$$V_{\text{peak}} = 220 \times \sqrt{2}$$

Since $\sqrt{2} \approx 1.414$, we get:

$$V_{\text{peak}} = 220 \times 1.414 \approx 311.08 \text{ V}$$

Thus, the peak value of the voltage is approximately **311 V**.

Quick Tip: For AC circuits, always remember the relationship between RMS and peak voltage: $V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}}$. The peak voltage is approximately 1.414 times the RMS voltage.

2(e). Do two equipotential surfaces intersect each other? Answer with reason.

Correct Answer: —

Solution:

An equipotential surface is a surface on which the electric potential is constant at every point. It is defined such that no work is done in moving a charge along the surface because the electric potential difference between any two points on the surface is zero. The electric field is always perpendicular to the equipotential surface.

To answer the question, we need to consider the implications if two equipotential surfaces were to intersect.

1. **Electric Potential at a Point:**

- The electric potential at a point in space is a scalar quantity, meaning that at any given point, the potential has a single value.
- If two equipotential surfaces were to intersect, it would imply that a point would have two different potential values (since each surface

corresponds to a different potential). This is a contradiction because a point cannot have two distinct potential values at the same time.

2. **Electric Field Direction:**

- The electric field is always perpendicular to the equipotential surface. If two equipotential surfaces were to intersect, the direction of the electric field would have to be ambiguous at the point of intersection because there would be two perpendicular directions corresponding to the two surfaces. This would violate the definition of the electric field.

3. **Conclusion:**

- Therefore, two equipotential surfaces can never intersect. If they did, it would imply a violation of the uniqueness of electric potential at any given point in space, and it would lead to an undefined situation for the electric field.

Thus, two equipotential surfaces cannot intersect.

Quick Tip: Remember that equipotential surfaces represent regions of constant electric potential, and the electric field is always perpendicular to these surfaces. Two equipotential surfaces cannot intersect because this would imply that a point could have two different potentials, which is impossible.

2(f). On which principle does a nuclear reactor work?

Correct Answer: —

Solution:

A nuclear reactor operates based on the principle of nuclear fission. Nuclear fission is a process in which the nucleus of an atom is split into two or more smaller nuclei, along with a few neutrons and a large

amount of energy. This energy is primarily in the form of heat, which can be converted into electricity. The process occurs in a controlled manner inside a nuclear reactor.

1. Initiating Fission:

The process of nuclear fission starts when a neutron collides with the nucleus of a fissile atom, such as uranium-235 or plutonium-239. These atoms are specifically chosen because their nuclei are unstable and prone to splitting when they absorb a neutron.

2. Fission Reaction:

Upon absorption of a neutron, the atom's nucleus becomes unstable, and it splits into two smaller nuclei, known as fission fragments. This splitting releases a significant amount of energy, in the form of:

- Kinetic energy of the fission fragments (the smaller nuclei).
- Gamma radiation and neutrons (also known as fission neutrons).

3. Energy Released:

The energy released during the fission process is primarily in the form of heat. This heat is essential in the functioning of a nuclear reactor, as it is used to produce steam from water. The energy can also be harnessed to drive turbines, which ultimately generate electricity.

4. Chain Reaction:

The neutrons released during the fission process can go on to strike other fissile nuclei, causing them to undergo fission as well. This process leads to a chain reaction, where each fission event causes additional fission events, sustaining the reaction. However, the reaction must be controlled to prevent it from becoming too rapid and causing an explosion.

5. Control Mechanisms:

In order to control the rate of the fission reaction and ensure it remains stable, nuclear reactors use control rods. These rods are made from materials that can absorb neutrons, such as boron or cadmium. By adjusting the position of these control rods in the

reactor core, operators can control the number of neutrons available for the fission process, thereby regulating the chain reaction.

6. Heat Utilization:

The heat produced from the fission reaction is transferred to a coolant (often water or liquid metal) that circulates through the reactor core. The heated coolant then passes through a heat exchanger, where it is used to convert water into steam. This steam drives turbines connected to generators, which convert the mechanical energy of the turbines into electrical energy.

7. Coolant and Moderator:

In addition to the coolant, a moderator is also used to slow down the neutrons produced during the fission process. The moderator (commonly graphite or heavy water) reduces the speed of the neutrons so that they can efficiently cause further fission reactions. Slower neutrons are more likely to be captured by other fissile nuclei, sustaining the chain reaction.

Key Points About Nuclear Reactor Operation:

- The fuel in the reactor is typically uranium-235 or plutonium-239, both of which are capable of undergoing fission.
- The reaction is initiated by neutrons, and the energy released is primarily in the form of heat.
- The heat is transferred via a coolant to generate steam, which drives turbines to produce electricity.
- Control rods are used to regulate the fission rate and maintain a stable chain reaction.
- The reactor must be carefully controlled to prevent a runaway reaction or overheating, which could lead to dangerous conditions.

Types of Nuclear Reactors:

- Pressurized Water Reactors (PWR): The most common type of nuclear reactor, where water is kept under high pressure to prevent it from boiling, even at high temperatures.

- Boiling Water Reactors (BWR): In these reactors, water boils directly in the reactor core to produce steam, which drives the turbines.
- Fast Breeder Reactors (FBR): These reactors use fast neutrons to induce fission and are designed to generate more fissile material than they consume.

Quick Tip: The fission process in a nuclear reactor is highly controlled through the use of control rods, which regulate the number of neutrons available for the chain reaction. Additionally, the coolant and moderator ensure that the reaction remains at a steady rate, preventing overheating and ensuring safe energy production.

3(a). What is the meaning of electrical capacity of a conductor? Find the unit of the electrical capacity of the conductor.

Correct Answer: —

Solution:

The electrical capacity, or capacitance, of a conductor refers to its ability to store electric charge when a potential difference is applied across it. The capacitance C of a conductor is defined as the amount of charge Q it can store per unit potential difference V. Mathematically, it is given by the equation:

$$C = \frac{Q}{V}$$

Where:
- C is the capacitance in farads (F),
- Q is the charge stored on the conductor in coulombs (C),

- V is the potential difference across the conductor in volts (V).
The unit of capacitance is the farad (F), which is defined as the amount of charge that can be stored per unit potential difference. In terms of SI units, we can express the farad as:

$$1\,\text{F} = 1\,\frac{\text{C}}{\text{V}}$$

This means that if a conductor has a capacitance of 1 farad, it will store 1 coulomb of charge when a potential difference of 1 volt is applied across it.
The electrical capacity (or capacitance) depends on the physical characteristics of the conductor, such as its surface area, shape, and the dielectric properties of the material surrounding it. For a parallel plate capacitor, for example, the capacitance is given by:

$$C = \epsilon_0 \frac{A}{d}$$

Where:
- C is the capacitance,
- ϵ_0 is the permittivity of free space (8.85×10^{-12} F/m),
- A is the area of the plates,
- d is the distance between the plates.
Thus, the electrical capacity of a conductor is the ratio of the charge stored to the potential difference, and its unit is the farad (F).

Quick Tip: Remember that the capacitance of a conductor depends on its geometry and the surrounding material. For conductors with large surface area and small separation, capacitance is higher.

3(b). Write down the equation for Lorentz force. An electron passes undeviated from a place where an electric field 5×10^4 V/m and magnetic field of 5×10^{-2} weber/m^2 are applied. Calculate the velocity of the electron.

Correct Answer: —

Solution:

The Lorentz force is the total force experienced by a charged particle due to both electric and magnetic fields. It is given by the following equation:

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

Where:
- $\vec{F}$ is the Lorentz force,
- q is the charge of the particle,
- $\vec{E}$ is the electric field,
- $\vec{B}$ is the magnetic field,
- $\vec{v}$ is the velocity of the particle.

When an electron passes undeviated through the region of the electric and magnetic fields, it means that the electric force exactly cancels out the magnetic force. In such a situation, the electric force is equal to the magnetic force. The electric force F_{electric} is given by:

$$F_{\text{electric}} = qE$$

Where:
- E is the magnitude of the electric field.

The magnetic force F_{magnetic} is given by:

$$F_{\text{magnetic}} = qvB$$

Where:
- v is the velocity of the electron,
- B is the magnitude of the magnetic field.
For the electron to pass undeviated, the forces must balance each other out, i.e., the electric force equals the magnetic force:

$$F_{\text{electric}} = F_{\text{magnetic}}$$

Thus, we have:

$$qE = qvB$$

Canceling the charge q from both sides:

$$E = vB$$

Now, solving for the velocity v:

$$v = \frac{E}{B}$$

Substitute the given values: - $E = 5 \times 10^4$ V/m,
- $B = 5 \times 10^{-2}$ weber/m^2,
We get:

$$v = \frac{5 \times 10^4}{5 \times 10^{-2}} = 10^6 \text{ m/s}$$

Thus, the velocity of the electron is $v = 1 \times 10^6$ m/s.
This result means that the electron will travel with a velocity of 1×10^6 m/s in order to pass through the fields without deviation.

Quick Tip: For the electron to pass through undeviated, the electric and magnetic forces must be equal. Use the relation $E = vB$ to find the velocity when both fields are applied.

3(c). Explain the meaning of binding energy of a nucleus. Write the dependency of binding energy per nucleon on the mass number of the nucleus.

Correct Answer: —

Solution:

Binding energy of a nucleus is the energy required to separate a nucleus into its constituent nucleons (protons and neutrons). It is the energy that holds the nucleus together and is a measure of the stability of the nucleus. The binding energy is negative, indicating that energy must be supplied to break the nucleus apart. The higher the binding energy, the more stable the nucleus is.

The binding energy per nucleon is the total binding energy of the nucleus divided by the number of nucleons. It is an important quantity as it gives an idea of how tightly bound the nucleons are in a nucleus. The binding energy per nucleon typically increases with the atomic number up to iron (Fe) and then decreases for heavier nuclei.

The dependency of binding energy per nucleon on the mass number A (the number of nucleons in the nucleus) can be approximated by the following empirical relationship:

$$\text{Binding energy per nucleon} = \frac{aVA - aSA^{2/3} - aCZ^2A^{-1/3} - aA(A-1)}{A},$$

where:

- A is the mass number of the nucleus,
- Z is the atomic number (number of protons),
- $aV, aS, aC,$ and aA are constants.

This equation shows that the binding energy per nucleon depends on the size of the nucleus (related to A) and the nuclear force binding the nucleons. For light nuclei, binding energy increases with the number

of nucleons, and for heavier nuclei, it tends to decrease due to the repulsive forces between protons.

Quick Tip: The binding energy per nucleon is typically highest for elements near iron (Fe). The higher the binding energy per nucleon, the more stable the nucleus. For light elements, fusion increases the binding energy per nucleon, while for heavy elements, fission does.

3(d). Give pictorial representation of polarized and unpolarised light. Polarizing angle for a transparent medium is 60°. Find the value of angle of refraction and refractive index of the medium.

Correct Answer: —

Solution:

Unpolarized light is light that oscillates in all directions perpendicular to the direction of propagation. Polarized light, on the other hand, only oscillates in one direction. The process of polarizing light involves passing it through a polarizing filter, which only allows light oscillating in a specific direction to pass through.
The diagram below shows the difference between polarized and unpolarized light:
In the case of the polarized light, the oscillations are restricted to one plane, while in unpolarized light, the oscillations are in multiple planes.
Now, the problem gives the polarizing angle θ_p for a transparent medium as 60°. The polarizing angle is related to the refractive index n of the medium using Brewster's Law, which is given by:

$$\tan \theta_p = n,$$

where θ_p is the polarizing angle. Substituting the given value of $\theta_p = 60^\circ$:

$$\tan 60^\circ = n.$$

Since $\tan 60^\circ = \sqrt{3}$, we have:

$$n = \sqrt{3}.$$

Thus, the refractive index of the medium is $n = \sqrt{3} \approx 1.732$.
Next, we can find the angle of refraction using Snell's Law, which is:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2,$$

where n_1 and n_2 are the refractive indices of the two media, θ_1 is the angle of incidence, and θ_2 is the angle of refraction. Since the angle of incidence θ_1 is equal to the polarizing angle $\theta_p = 60^\circ$, and we know the refractive index of air is approximately 1, we can use:

$$1 \cdot \sin 60^\circ = \sqrt{3} \cdot \sin \theta_2.$$

Solving for $\sin \theta_2$:

$$\sin \theta_2 = \frac{\sin 60^\circ}{\sqrt{3}} = \frac{\frac{\sqrt{3}}{2}}{\sqrt{3}} = \frac{1}{2}.$$

Thus, $\theta_2 = 30^\circ$. Therefore, the angle of refraction is 30°.

Quick Tip: Remember Brewster's law relates the polarizing angle and the refractive index: $\tan \theta_p = n$. This is useful for finding the refractive index of a medium when the polarizing angle is known. For angles of refraction, use Snell's Law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$.

4(a). Name the waves of longest wavelength and highest frequency in the given electromagnetic waves — microwaves, X-rays, radio waves, and γ-rays. What is meant by displacement current?

Correct Answer: —

Solution:

In the given set of electromagnetic waves — microwaves, X-rays, radio waves, and γ-rays — the following observations are made:

- **Longest Wavelength:** Radio waves have the longest wavelength among the given electromagnetic waves. The wavelength of radio waves can range from a few millimeters to several kilometers, which is significantly longer compared to the other waves.
- **Highest Frequency:** γ-rays (gamma rays) have the highest frequency in the given list. Gamma rays have frequencies greater than 10^{19} Hz, much higher than X-rays, microwaves, or radio waves.

Next, the term displacement current refers to a term used in Maxwell's equations to extend the concept of current to situations involving time-varying electric fields. It is defined as:

$$I_{\text{displacement}} = \epsilon_0 \frac{d\Phi_E}{dt}$$

Where:

- $I_{\text{displacement}}$ is the displacement current,
- ϵ_0 is the permittivity of free space,
- $\frac{d\Phi_E}{dt}$ is the time rate of change of the electric flux Φ_E. Displacement current arises in situations like capacitors in an AC circuit where a changing electric field creates a current in the absence of actual charge movement.

Quick Tip: Displacement current helps to explain how electromagnetic waves can propagate through a vacuum. It allows a changing electric field to produce a magnetic field, completing the symmetry of Maxwell's equations.

4(b). What is the meaning of stationary orbit of atom? Deriving formula for the energy of the electron in the stationary orbit of the hydrogen atom, mention its relation with the radius of the orbit of electron.

Correct Answer: —

Solution:

The stationary orbit of an atom refers to the specific orbit of an electron in which the electron does not radiate energy. These orbits are defined by quantized energy levels and are stable, meaning that the electron remains in a given orbit without emitting or absorbing energy. These stationary orbits are described by Bohr's model of the atom.

According to Bohr's model, the electron in the hydrogen atom moves in circular orbits around the nucleus under the influence of the Coulomb force between the negatively charged electron and the positively charged proton. The energy of the electron in a stationary orbit can be derived using the following principles: 1. **Coulomb Force and Centripetal Force:** The centripetal force required to keep the electron in a circular orbit is provided by the electrostatic attraction between the electron and the proton. Using Coulomb's law, the force is:

$$F = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2}$$

Where:
- e is the charge of the electron,
- r is the radius of the orbit,
- ϵ_0 is the permittivity of free space.

2. **Quantization of Angular Momentum:** Bohr postulated that the angular momentum of the electron in a stationary orbit is quantized and given by:

$$m_e v r = nh/2\pi$$

Where:
- m_e is the mass of the electron,
- v is the speed of the electron,
- r is the radius of the orbit,
- n is a positive integer (the principal quantum number),
- h is Planck's constant.

3. **Expression for Energy:** The total energy of the electron in the orbit is the sum of its kinetic energy K and potential energy U. The potential energy is given by:

$$U = -\frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$$

The kinetic energy is half the magnitude of the potential energy (due to the virial theorem for Coulomb forces):

$$K = \frac{1}{2} \times \frac{1}{4\pi\epsilon_0}\frac{e^2}{r}$$

Thus, the total energy E is:

$$E = K + U = -\frac{1}{4\pi\epsilon_0}\frac{e^2}{2r}$$

4. **Relation with Radius:** Using the quantization condition $m_e v r = nh/2\pi$, we can derive the radius of the electron's orbit as:

$$r_n = \frac{n^2 h^2 \epsilon_0}{\pi m_e e^2}$$

Therefore, the energy of the electron in the n-th orbit is:

$$E_n = -\frac{13.6}{n^2} \text{ eV}$$

This shows that the energy of the electron is inversely proportional to the square of the radius of the orbit.

Quick Tip: The energy of an electron in a stationary orbit depends on the radius of the orbit and the quantum number n. For the hydrogen atom, the energy levels are quantized and given by $E_n = -\frac{13.6}{n^2}$ eV, where n is the principal quantum number.

4(c). Define magnetic dipole. Find the expression for the torque on a magnetic dipole placed in a magnetic field.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A magnetic dipole is the basic unit of magnetism. Examples are a small bar magnet and a current-carrying loop. Its strength is described by a vector called the magnetic dipole moment.

Step 2: Definition of a magnetic dipole.

A magnetic dipole is a pair of equal and opposite magnetic poles $+q_m$ and $-q_m$ separated by a small distance $2l$. It can also be a closed current loop. The magnetic dipole moment is $m = q_m \times 2l$ for the pole pair, and $m = NIA$ for a loop of N turns, current I and area A. It is a

vector, pointing from the south pole to the north pole, or along the normal to the loop given by the right-hand rule. Its unit is A m^2.

Step 3: Set up the current loop in the field.

Take a rectangular loop of current I with sides a and b, so that its area is $A = ab$. It is placed in a uniform magnetic field $\vec{B}$ and can turn about an axis that is perpendicular to $\vec{B}$. The angle between the normal to the loop (the direction of $\vec{m}$) and $\vec{B}$ is θ. The sides of length b are parallel to the axis of rotation, so $\vec{B}$ is perpendicular to them.

Step 4: Forces on the sides.

The two sides of length a get forces that are equal and opposite and that act along the axis direction on one common line. They only try to stretch or compress the loop and give no torque.

Each side of length b is perpendicular to $\vec{B}$, so the force on it is $F = IbB$. These two forces are equal and opposite, but they do not lie on one line. They form a couple.

Step 5: Torque of the couple.

The perpendicular distance between the two forces is $a \sin\theta$. So

$$\tau = F \times a \sin\theta = (IbB)(a \sin\theta) = I(ab)B \sin\theta = IAB \sin\theta$$

For N turns the torque is $NIAB \sin\theta$. Writing $m = NIA$,

$$\tau = mB \sin\theta, \qquad \vec{\tau} = \vec{m} \times \vec{B}$$

Step 6: Discuss the result.

The torque is maximum, mB, when $\theta = 90°$, and zero when $\theta = 0°$ or

180°. The torque tries to turn $\vec{m}$ toward $\vec{B}$.

Step 7: Final Answer:

A magnetic dipole is a pair of equal and opposite poles a small distance apart (or a current loop), with moment m. In a field B the torque on it is

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

Quick Tip: Define the dipole as two equal and opposite poles a small distance apart (or a current loop) with moment m. In a uniform field the forces on the two ends are equal and opposite, forming a couple of arm $2l\sin\theta$, so $\tau = mB\sin\theta$.

4(d). With the help of the given circuit, find out the total resistance of the circuit and the current flowing through the cell.

\includegraphics[width=0.5\linewidth]{image4.png}

Correct Answer: —

Solution:

Given the circuit, we need to find out the total resistance and the current flowing through the cell. The circuit consists of resistors in both series and parallel combinations. **1. Total Resistance Calculation:**

- First, combine the resistors in parallel. The 500 Ω and 750 Ω

resistors are in parallel, and the formula for the total resistance in parallel is:

$$\frac{1}{R_{\text{parallel}}} = \frac{1}{500} + \frac{1}{750}$$

Simplifying this:

$$R_{\text{parallel}} = \frac{1}{\left(\frac{1}{500} + \frac{1}{750}\right)} = \frac{1}{(0.002 + 0.00133)} = \frac{1}{0.00333} \approx 300\,\Omega$$

2. Total Resistance of the Circuit:

- Now, this equivalent resistance (300 Ω) is in series with the 1000 Ω resistor. The total resistance in series is simply the sum of the resistances:

$$R_{\text{total}} = 1000 + 300 = 1300\,\Omega$$

3. Current Calculation:

- Using Ohm's Law, $V = IR$, we can calculate the current flowing through the circuit. The given voltage is 4.75 V, and the total resistance is 1300 Ω:

$$I = \frac{V}{R} = \frac{4.75}{1300} \approx 0.00365\,\text{A} = 3.65\,\text{mA}$$

Thus, the total resistance of the circuit is 1300 Ω, and the current flowing through the cell is approximately 3.65 mA.

Quick Tip: To combine resistors in parallel, use the formula $\frac{1}{R_{\text{parallel}}} = \sum \frac{1}{R_i}$. In series, the total resistance is simply the sum: $R_{\text{total}} = R_1 + R_2 + \ldots$.

4(e). What is an astronomical telescope? Draw ray diagram for an astronomical telescope when final image is formed at infinity.

Correct Answer: —

Solution:

An astronomical telescope is a type of optical telescope used to observe distant celestial objects. It consists of two lenses: the objective lens and the eyepiece. **1. Objective Lens:**
The objective lens gathers light from a distant object and forms an intermediate image at its focal plane. **2. Eyepiece Lens:**
The eyepiece lens magnifies the intermediate image, making it visible to the eye. The final image is formed at infinity, meaning it is highly magnified and can be observed clearly without straining the eyes. **3. Ray Diagram:**
In the case where the final image is formed at infinity, the object is placed at a distance greater than twice the focal length of the objective lens. The rays from the object are parallel and converge to form an image at the focal plane of the objective lens.
The eyepiece lens then produces an image that appears at infinity.
The ray diagram for an astronomical telescope when the final image is at infinity is as follows:
- The objective lens produces a real, inverted image at the focal plane.
- The eyepiece lens magnifies this real image and makes it appear as an inverted image at infinity.

Quick Tip: In an astronomical telescope, the distance between the objective and the eyepiece is the sum of their focal lengths. To form an image at infinity, the intermediate image should be at the focal point of the eyepiece.

5(a). State Gauss's law in electrostatics. On the basis of it, obtain the formula for the electric field produced due to a plane charged plate.

Correct Answer: —

Solution:

Gauss's law in electrostatics states that the total electric flux Φ_E through any closed surface is equal to the net charge enclosed within the surface divided by the permittivity of free space ε_0.
Mathematically, Gauss's law is expressed as:

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\varepsilon_0},$$

where: - $\vec{E}$ is the electric field,
- $d\vec{A}$ is the differential area element on the closed surface,
- Q_{enc} is the total charge enclosed within the surface,
- ε_0 is the permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$.
Now, to find the electric field due to a plane charged plate, we consider a uniformly charged infinite plane with surface charge density σ. We will apply Gauss's law using a Gaussian surface in the form of a cylindrical pillbox that intersects the charged plane. The electric field produced by the charged plate is symmetric and uniform, and it points perpendicular to the surface of the plate.
1. **Gauss's Law Application:** The Gaussian surface consists of two faces, one above and one below the charged plane. The electric field is perpendicular to the surface of the plate and has the same magnitude on both sides of the plane. The flux through the curved surface of the pillbox is zero since the electric field is parallel to this surface.

Therefore, the total flux is given by the flux through the two flat faces of the pillbox.

2. **Flux Calculation:** The flux through one face of the pillbox is $E \cdot A$, where A is the area of the face. The total flux through the two faces is:

$$\Phi_E = 2EA.$$

3. **Charge Enclosed:** The charge enclosed by the Gaussian surface is the surface charge density σ times the area A of the pillbox:

$$Q_{\text{enc}} = \sigma A.$$

4. **Applying Gauss's Law:** Using Gauss's law, we equate the flux to the charge enclosed divided by ε_0:

$$2EA = \frac{\sigma A}{\varepsilon_0}.$$

5. **Solving for Electric Field:** Simplifying the equation, we get the electric field due to the uniformly charged plane:

$$E = \frac{\sigma}{2\varepsilon_0}.$$

Thus, the electric field produced by an infinite plane of charge with surface charge density σ is:

$$E = \frac{\sigma}{2\varepsilon_0}.$$

Key Notes: - The electric field is directed perpendicular to the surface of the charged plane.
- The electric field due to a uniformly charged plane is constant in magnitude and does not depend on the distance from the plane.

Quick Tip: For a charged plane, the electric field is uniform and does not depend on the distance from the plane. This is different from the electric field due to a point charge, which decreases with the square of the distance.

5(b). Explain the working method of p-n junction diode in reverse bias with the help of a circuit diagram.

Correct Answer: —

Solution:

Reverse Bias Condition: A p-n junction diode is formed by joining a p-type semiconductor and an n-type semiconductor. In reverse bias, the positive terminal of the external battery is connected to the n-type side, and the negative terminal is connected to the p-type side. This configuration increases the width of the depletion region, which prevents current from flowing under normal conditions. The key points of its working are: 1. **Reverse Bias Condition:** When a p-n junction diode is reverse biased, the applied voltage causes the electrons in the n-region to be attracted to the positive terminal of the battery, while the holes in the p-region are attracted towards the negative terminal. This increases the width of the depletion region, making it difficult for current to flow. 2. **Depletion Region:** The depletion region acts as an insulator and prevents the current from flowing. In ideal conditions, no current flows in reverse bias, but a small reverse saturation current exists due to minority carriers. 3. **Breakdown:** If the reverse voltage exceeds a certain threshold (the breakdown voltage), the diode undergoes avalanche breakdown or Zener breakdown, where the depletion region is destroyed, allowing a

large current to flow through the diode. This is undesirable in most applications but can be used in Zener diodes for voltage regulation.

Quick Tip: In reverse bias, the diode does not conduct current under normal conditions, except for a small leakage current due to minority carriers. The current increases rapidly only when the breakdown voltage is reached.

5(c). In A.C. circuits, what is the difference between impedance and resistance? Write the formula for power factor in L-C-R circuit.

Correct Answer: —

Solution:

Impedance vs. Resistance: In A.C. circuits, the key difference between impedance and resistance is as follows: 1. **Impedance (Z):** Impedance is the total opposition that a circuit offers to the flow of alternating current (A.C.). It includes both resistance and reactance. It is a complex quantity and is expressed as:

$$Z = \sqrt{R^2 + X^2}$$

where: - R is the resistance,
- X is the reactance, which is further divided into inductive reactance X_L and capacitive reactance X_C. 2. **Resistance (R):** Resistance is the opposition to the flow of current in a circuit due to the material and dimensions of the conductor. It only depends on the physical properties of the material and is independent of frequency. 3. **Key Differences:** - Resistance is a real quantity that only depends on the

nature of the material and temperature.
- Impedance is a complex quantity, and it accounts for both resistance and reactance in the circuit. Reactance varies with frequency, and hence, impedance changes with the frequency of the A.C. supply.
The formula for the power factor in an L-C-R circuit is given by:

$$\text{Power Factor (PF)} = \cos\phi,$$

where ϕ is the phase difference between the applied voltage and the current. The power factor is a measure of how effectively the current is being converted into useful power. The power factor can also be expressed in terms of impedance and resistance as:

$$\text{PF} = \frac{R}{Z}.$$

Explanation: - When the power factor is 1, the current and voltage are in phase, and the circuit behaves like a purely resistive circuit.
- When the power factor is less than 1, the circuit contains reactance, and the current lags behind the voltage in an inductive circuit or leads the voltage in a capacitive circuit.

Quick Tip: In an L-C-R circuit, the power factor is crucial for determining the efficiency of the circuit in delivering power. For purely resistive circuits, the power factor is 1, while for inductive or capacitive circuits, it is less than 1.

5(d). Which nature of light is supported by Young's double slit experiment? The light used in Young's double slit experiment contains two wavelengths, 6000 \AA\ and 5000 \AA. Separation between the slits is 10^{-3} m and the screen is at a distance of 1 m from the slits. Find minimum distance from the central maxima where bright fringes for both the wavelengths are coincident.

Correct Answer: –

Solution:

Young's double slit experiment provides strong evidence for the wave nature of light. It demonstrates the phenomenon of interference, which occurs when light waves from two slits overlap and produce constructive or destructive interference. The experiment shows that light has a wave-like nature, as interference patterns are observed.
Now, for two different wavelengths, the condition for constructive interference (bright fringes) for each wavelength is given by the equation:

$$\Delta y = \frac{n\lambda D}{d}$$

Where:
- Δy is the fringe separation (distance between adjacent bright fringes),
- n is the fringe number,
- λ is the wavelength of the light,
- D is the distance between the screen and the slits,
- d is the distance between the slits.

For two wavelengths, the bright fringes will coincide when the fringe separation for both wavelengths is equal, i.e., when:

$$\frac{\lambda_1 D}{d} = \frac{\lambda_2 D}{d}$$

Thus, we need to find the minimum distance x where the first bright fringe for both wavelengths coincide. Let's calculate it.
We are given:
- $\lambda_1 = 6000\ \text{Å} = 6000 \times 10^{-10}\ \text{m}$,
- $\lambda_2 = 5000\ \text{Å} = 5000 \times 10^{-10}\ \text{m}$,
- $d = 10^{-3}\ \text{m}$,

- $D = 1$ m.

To find the minimum distance, we equate the fringe separations for both wavelengths:

$$\frac{n\lambda_1}{d} = \frac{m\lambda_2}{d}$$

Simplifying, we find:

$$n\lambda_1 = m\lambda_2$$

Substituting values:

$$n \times 6000 \times 10^{-10} = m \times 5000 \times 10^{-10}$$

Solving for n/m:

$$\frac{n}{m} = \frac{5000}{6000} = \frac{5}{6}$$

Thus, the minimum value of n and m that satisfies the condition is when $n = 5$ and $m = 6$. Therefore, the minimum distance from the central maximum where the bright fringes for both wavelengths coincide is given by:

$$\Delta y = \frac{5 \times 6000 \times 10^{-10} \times 1}{10^{-3}} = 3 \times 10^{-2} \text{ m} = 3 \text{ cm}$$

Thus, the minimum distance is 3 cm.

Quick Tip: The interference pattern for two wavelengths will overlap at points where the fringe separations for both wavelengths are the same. This can be found by using the condition $n\lambda_1 = m\lambda_2$, where n and m are integers.

OR

What is the photoelectric effect? Which nature of light is shown by it? Threshold frequency of a metal is 2.3×10^{14} Hz. If the frequency of incident light is 8.2×10^{14} Hz, what will be the stopping potential? Calculate work function of the metal also.

Correct Answer: —

Solution:

The photoelectric effect is the phenomenon in which electrons are ejected from the surface of a metal when light (or any electromagnetic radiation) of a certain frequency falls on it. This effect provides strong evidence for the particle nature of light. According to Einstein's theory, light consists of photons, and when a photon with energy $E = h\nu$ strikes an electron, it can transfer its energy to the electron. If the photon's energy is greater than the work function (Φ) of the metal, the electron is ejected.

The stopping potential is the minimum voltage required to stop the emitted electrons. The relationship between the energy of the photon, the work function of the metal, and the stopping potential is given by the equation:

$$K_{\text{max}} = h\nu - \Phi$$

Where:

- K_{max} is the maximum kinetic energy of the emitted electron (which is related to the stopping potential V_s by $K_{\text{max}} = eV_s$),
- h is Planck's constant (6.626×10^{-34} J · s),
- ν is the frequency of the incident light,
- Φ is the work function of the metal.

Given:

- $\nu = 8.2 \times 10^{14}$ Hz,

- $\Phi = h\nu_0 = h \times 2.3 \times 10^{14}$ Hz (where ν_0 is the threshold frequency).
First, calculate the energy of the incident photon:

$$E_{\text{photon}} = h\nu = (6.626 \times 10^{-34}) \times (8.2 \times 10^{14}) = 5.428 \times 10^{-19} \text{ J}$$

Next, calculate the work function:

$$\Phi = h\nu_0 = (6.626 \times 10^{-34}) \times (2.3 \times 10^{14}) = 1.524 \times 10^{-19} \text{ J}$$

Now, using the photoelectric equation, find the stopping potential:

$$eV_s = h\nu - \Phi$$

$$V_s = \frac{h\nu - \Phi}{e} = \frac{5.428 \times 10^{-19} - 1.524 \times 10^{-19}}{1.6 \times 10^{-19}} = \frac{3.904 \times 10^{-19}}{1.6 \times 10^{-19}} \approx 2.44 \text{ V}$$

Thus, the stopping potential is approximately 2.44 V.
Finally, the work function of the metal is $\Phi = 1.524 \times 10^{-19}$ J, which is the energy required to release an electron from the metal surface.

Quick Tip: The photoelectric effect shows the particle nature of light. The stopping potential is related to the energy of the photons and the work function of the metal. Use the equation $eV_s = h\nu - \Phi$ to calculate the stopping potential.

5(e). Derive the formula for the capacitance of a parallel plate capacitor partially filled with a dielectric medium between the plates.

Correct Answer: —

Solution:

Capacitance of a Parallel Plate Capacitor: A parallel plate capacitor consists of two conducting plates separated by a distance d, with area A of each plate. The capacitance of such a capacitor is given by the formula:

$$C = \frac{\varepsilon_0 A}{d},$$

where: - C is the capacitance,
- ε_0 is the permittivity of free space,
- A is the area of one of the plates,
- d is the separation between the plates.

Effect of Dielectric Medium: When a dielectric medium with dielectric constant κ (also known as relative permittivity) partially fills the space between the plates, the capacitance is modified. The dielectric constant κ increases the capacitance by a factor of κ. If the dielectric only fills part of the space between the plates, the system can be treated as two capacitors in parallel: 1. One part of the capacitor (with area A_1) is filled with the dielectric. 2. The other part (with area A_2) is filled with air or some other dielectric with permittivity ε_0.

Capacitance of the Region with Dielectric: The capacitance for the part of the capacitor with dielectric is:

$$C_1 = \frac{\kappa \varepsilon_0 A_1}{d_1},$$

where: - A_1 is the area of the plates covered by the dielectric,
- d_1 is the distance between the plates covered by the dielectric.

Capacitance of the Region with Air: The capacitance for the part of the capacitor with air (or vacuum) is:

$$C_2 = \frac{\varepsilon_0 A_2}{d_2},$$

where:
- A_2 is the area of the plates not covered by the dielectric,
- d_2 is the distance between the plates not covered by the dielectric.

Total Capacitance: Since the areas A_1 and A_2 add up to the total area A, and the distances d_1 and d_2 add up to the total distance d, the total capacitance is the sum of the capacitances of the two regions:

$$C_{\text{total}} = C_1 + C_2 = \frac{\kappa \varepsilon_0 A_1}{d_1} + \frac{\varepsilon_0 A_2}{d_2}.$$

Formula for Capacitance: For the case where the dielectric partially fills the space between the plates (i.e., $d_1 + d_2 = d$), the final formula for the capacitance becomes:

$$C = \frac{\varepsilon_0 A}{d} \left(\kappa \frac{d_1}{d} + \frac{d_2}{d} \right).$$

This is the general formula for the capacitance of a parallel plate capacitor partially filled with a dielectric medium.

Quick Tip: When a parallel plate capacitor is partially filled with a dielectric, treat the system as two capacitors in parallel: one with the dielectric and one without it. This allows you to calculate the total capacitance by summing the capacitances of the two regions.

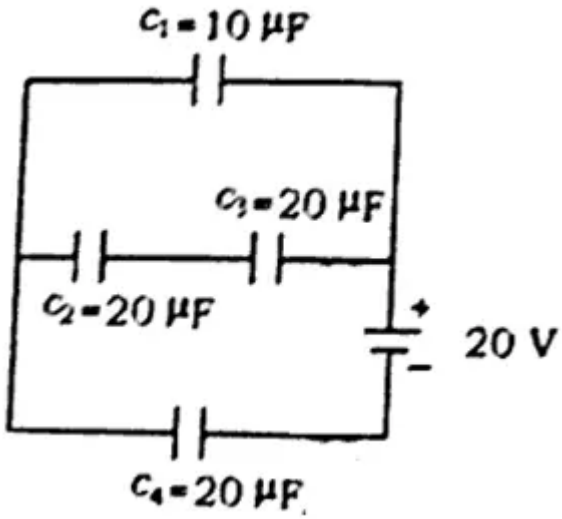
6.

With the help of given circuit, find out:

(i) Equivalent capacity of the combination

(ii) Charge on capacitor c_1

(iii) Total stored energy of the combination.}



Correct Answer: —

Solution:

In the given circuit, we have four capacitors $c_1 = 10\,\mu F$, $c_2 = 20\,\mu F$, $c_3 = 20\,\mu F$, and $c_4 = 20\,\mu F$ connected in a combination of series and parallel. The total voltage across the combination is given as $V = 20\,\text{V}$.

Let's break down the solution into steps:

Step 1: Simplifying the Combination of Capacitors

First, we need to combine capacitors c_2, c_3, and c_4 in parallel. The total capacitance for parallel combination is given by:

$$C_{\text{parallel}} = c_2 + c_3 + c_4$$

Substituting values:

$$C_{\text{parallel}} = 20\,\mu F + 20\,\mu F + 20\,\mu F = 60\,\mu F$$

Step 2: Combining with c_1 in Series

Now, we combine the equivalent capacitance C_{parallel} with $c_1 = 10\,\mu F$ in series. The equivalent capacitance for capacitors in series is given by:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{c_1} + \frac{1}{C_{\text{parallel}}}$$

Substitute the values:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{10} + \frac{1}{60} = \frac{6}{60} + \frac{1}{60} = \frac{7}{60}$$

$$C_{\text{eq}} = \frac{60}{7} \approx 8.57\,\mu F$$

Thus, the equivalent capacitance of the combination is approximately $8.57\,\mu F$.

Step 3: Charge on Capacitor c_1

The charge on the capacitor c_1 is given by:

$$Q_1 = C_{\text{eq}} \times V$$

Substitute the values:

$$Q_1 = 8.57\,\mu F \times 20\,\text{V} = 171.4\,\mu C$$

So, the charge on capacitor c_1 is $171.4\,\mu C$.

Step 4: Total Stored Energy

The total stored energy in the combination of capacitors is given by:

$$U = \frac{1}{2} C_{\text{eq}} V^2$$

Substitute the values:

$$U = \frac{1}{2} \times 8.57 \times 10^{-6} \times (20)^2 = 3.428 \times 10^{-3}\,\text{J}$$

Thus, the total stored energy is **3.428 mJ**.

Quick Tip: When combining capacitors in series and parallel, always calculate the equivalent capacitance step by step. For capacitors in series, use $\frac{1}{C_{eq}} = \sum \frac{1}{C}$, and for capacitors in parallel, use $C_{eq} = \sum C$.

OR

What is meant by magnetic effect of electric current? Find the expression for the force acting between two parallel current-carrying conducting wires. On this basis, define the unit of electric current 'ampere'.

Correct Answer: —

Solution:

The magnetic effect of electric current refers to the magnetic field produced by an electric current. When a current flows through a conductor, it creates a magnetic field around the conductor. This magnetic field can interact with other currents and produce forces. This effect is the basis of electromagnetism.
The force between two parallel current-carrying wires can be derived using Ampère's force law. The magnetic force per unit length between two parallel wires carrying currents I_1 and I_2 is given by the formula:

$$F/L = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Where: - F is the force between the wires,
- L is the length of the wire,
- r is the distance between the wires,
- μ_0 is the permeability of free space ($\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$),

- I_1 and I_2 are the currents in the wires.
This force is attractive if the currents are in the same direction and repulsive if the currents are in opposite directions.
Now, the unit of electric current, the ampere, is defined based on this magnetic force. The definition is as follows:
"An ampere is the constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross-section, and placed 1 meter apart in vacuum, would produce a force of 2×10^{-7} newtons per meter of length." This definition links the electric current to the magnetic force between conductors.

Quick Tip: The magnetic force between two parallel current-carrying wires is proportional to the product of the currents and inversely proportional to the distance between the wires. The definition of the ampere is based on the force between two conductors carrying a constant current.

7. State Huygens' principle of secondary wavelets. With the help of this principle, explain the laws of reflection of light.

Correct Answer: —

Solution:

Huygens' Principle states that every point on a wavefront can be considered as a source of secondary wavelets, and the position of the wavefront at any later time is the surface tangent to these secondary wavelets. In other words, each point on the wavefront acts as a secondary source of waves, and the new wavefront is formed by the envelope of all these secondary waves.
This principle can be used to explain the laws of reflection of light:

1. Law of Reflection (First Law):
The angle of incidence (θ_i) is equal to the angle of reflection (θ_r), i.e.,

$$\theta_i = \theta_r$$

This is confirmed by Huygens' principle because, when the wavefront strikes a reflective surface, each point on the wavefront produces secondary wavelets. These wavelets propagate and form a new wavefront that follows the law of reflection.

2. Law of Reflection (Second Law):
The incident ray, the reflected ray, and the normal to the surface of reflection all lie in the same plane. This can be understood by imagining the wavelets from the incident wavefront interacting with the surface, forming a new wavefront that obeys this geometrical constraint.

Thus, Huygens' principle provides a clear explanation for the reflection of light, where the wavefront interacts with the reflecting surface, and the reflected wavefront is formed by the secondary wavelets.

Quick Tip: Huygens' principle is a powerful tool for understanding wave behavior, not only for reflection but also for refraction and diffraction. Always remember that the new wavefront is formed by the envelope of secondary wavelets emitted by each point of the incident wavefront.

OR

Mention the most important conclusion of Rutherford's alpha-particle scattering experiment. Define isotopic, isobaric, and isotonic nuclei. Find the energy equivalent to one atomic mass unit in joules and MeV (1 u = 1.6605 × 10^{-27} kg).

Correct Answer: —

Solution:

Rutherford's Alpha-Particle Scattering Experiment:

In 1909, Ernest Rutherford conducted the famous alpha-particle scattering experiment, in which a beam of alpha particles was directed at a thin gold foil. The most important conclusion from this experiment was the discovery of the atomic nucleus. Rutherford found that most of the alpha particles passed straight through the foil, but a small fraction were deflected at large angles, and some even bounced back. This indicated that the mass of an atom is concentrated in a tiny, dense nucleus at the center, with the rest of the atom being mostly empty space. This led to the development of the Rutherford model of the atom, where electrons orbit around a dense nucleus.

Definitions:

sotopic Nuclei: Nuclei that have the same number of protons but different numbers of neutrons, and thus different atomic masses. For example, ${}^{1}H$ (hydrogen) and ${}^{2}H$ (deuterium) are isotopes of hydrogen.

Isobaric Nuclei: Nuclei that have the same mass number (total number of protons and neutrons) but different numbers of protons (and hence different elements). For example, ${}^{4}He$ and ${}^{4}Be$ are isobars.

Isotonic Nuclei: Nuclei that have the same number of neutrons but different numbers of protons (and thus different elements). For example, ${}^{4}He$ and ${}^{5}Li$ are isotonic nuclei.

Energy Equivalent of One Atomic Mass Unit (1 u):

The energy equivalent of one atomic mass unit can be found using Einstein's famous equation:

$$E = mc^2$$

Where:
- m is the mass of 1 atomic mass unit (1 u = 1.6605×10^{-27} kg),
- c is the speed of light (3×10^8 m/s).
First, calculating the energy in joules:

$$E = (1.6605 \times 10^{-27}\,\text{kg}) \times (3 \times 10^8\,\text{m/s})^2 = 1.49445 \times 10^{-10}\,\text{J}$$

Now, converting this energy to MeV (1 J = 6.242×10^{12} MeV):

$$E = 1.49445 \times 10^{-10}\,\text{J} \times 6.242 \times 10^{12}\,\text{MeV/J} = 9.33\,\text{MeV}$$

Thus, the energy equivalent of one atomic mass unit is approximately 1.494 \times 10^{-10} joules or 9.33 MeV.

Quick Tip: Remember, the energy equivalent of mass is given by $E = mc^2$, and one atomic mass unit is the mass of a carbon-12 atom divided by 12. Always use this formula to convert mass to energy.

8. Explain the difference between self-inductance and mutual inductance. Define the coefficient of self-inductance and coefficient of mutual inductance. A plane coil of area 100 cm^2 is rotating in a magnetic field of 2 weber/m^2 with angular velocity 20 rad/s. What will be the maximum induced electromotive force in the coil?

Correct Answer: —

Solution:

Self-inductance (L) is a property of a coil (or any conductor) that opposes the change in current flowing through it. When the current in

a coil changes, it induces an electromotive force (emf) in the coil itself, as given by the equation:

$$\mathcal{E} = -L\frac{dI}{dt}$$

Where:
- L is the self-inductance of the coil,
- $\frac{dI}{dt}$ is the rate of change of current. Mutual inductance (M) is the property of two coils where a change in current in one coil induces an emf in the other coil. The induced emf is proportional to the rate of change of current in the first coil and the mutual inductance M between them. The equation is given by:

$$\mathcal{E}_2 = -M\frac{dI_1}{dt}$$

Where:
- $\mathcal{E}_2$ is the induced emf in the second coil,
- M is the mutual inductance,
- $\frac{dI_1}{dt}$ is the rate of change of current in the first coil. For the second part of the question, the induced electromotive force ($\mathcal{E}$) in a rotating coil in a magnetic field is given by:

$$\mathcal{E} = B \cdot A \cdot \omega$$

Where:
- B is the magnetic field strength,
- A is the area of the coil,
- ω is the angular velocity.

Given:
- $B = 2\ \text{weber/m}^2$,
- $A = 100\ \text{cm}^2 = 100 \times 10^{-4}\ \text{m}^2 = 10^{-2}\ \text{m}^2$,
- $\omega = 20\ \text{rad/s}$.

Substituting the values into the formula:

$$\mathcal{E} = 2 \times 10^{-2} \times 20 = 0.4\ \text{V}$$

Thus, the maximum induced electromotive force in the coil is **0.4 V**.

Quick Tip: For a rotating coil in a magnetic field, the induced emf is directly proportional to the magnetic field strength, the area of the coil, and the angular velocity of the rotation.

OR

State Kirchhoff's law related to electrical circuits. In the given metre bridge, balance point is obtained at D. On connecting a resistance of 12 ohm parallel to S, balance point shifts to D'. Find the values of resistances R and S.
\includegraphics[width=0.5\linewidth]{image8.png}

Correct Answer: —

Solution:

Kirchhoff's law consists of two rules that apply to the current and potential difference in electrical circuits: 1. **Kirchhoff's Current Law (KCL):** The total current entering a junction equals the total current leaving the junction. Mathematically:

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

2. **Kirchhoff's Voltage Law (KVL):** The sum of the electrical potential differences (voltages) around any closed loop or circuit is zero. Mathematically:

$$\sum V = 0$$

Now, for the second part of the question, we use the principle of the metre bridge. The balance condition for a metre bridge is given by:

$$\frac{R}{S} = \frac{l_1}{l_2}$$

Where:
- R and S are the resistances in the bridge,
- l_1 is the length on one side of the bridge,
- l_2 is the length on the other side. Given: - The original balance point occurs at $l_1 = 34\ \text{cm}$ and $l_2 = 52\ \text{cm}$. Thus, the equation becomes:

$$\frac{R}{S} = \frac{34}{52} = \frac{17}{26}$$

Now, when a resistance of 12 ohms is connected in parallel to S, the balance point shifts to a new position. The equivalent resistance of the parallel combination of S and $12\ \Omega$ is:

$$S' = \frac{S \times 12}{S + 12}$$

The new balance condition is:

$$\frac{R}{S'} = \frac{l_1'}{l_2'}$$

Given the new lengths: - $l_1' = 34\ \text{cm}$ and $l_2' = 68\ \text{cm}$, the ratio becomes:

$$\frac{R}{S'} = \frac{34}{68} = \frac{1}{2}$$

Now, we solve for S':

$$\frac{R}{S'} = \frac{1}{2}\$ \Rightarrow \$S' = 2R$$

Substituting the expression for S':

$$\frac{S \times 12}{S + 12} = 2R$$

Now, substitute $R = \frac{17}{26}S$ from the earlier equation:

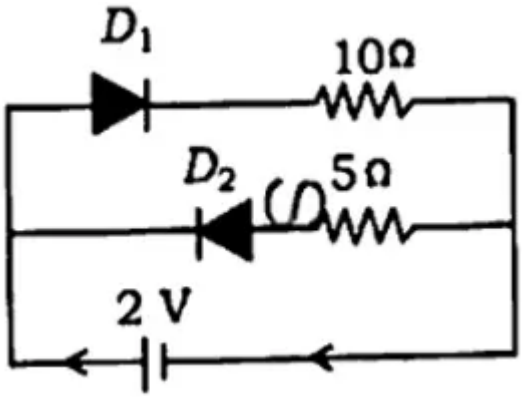
$$\frac{S \times 12}{S + 12} = 2 \times \frac{17}{26}S$$

Simplifying the equation, we solve for S and find the values of R and S.

Quick Tip: In a metre bridge, when a resistance is connected in parallel with S, it affects the balance point, and we can use the relationship for parallel resistances to determine the new balance condition.

9.

On the basis of energy band diagram in solids, explain the difference between conductor, semiconductor, and insulator. What is the need of doping in pure semiconductors? Write the value of current in the ideal diodes D_1 and D_2 in the given circuit.



Correct Answer: —

Solution:

Difference between Conductor, Semiconductor, and Insulator:

In solids, the difference between conductors, semiconductors, and insulators can be explained based on their energy band diagrams. The energy band diagram represents the energy levels available for electrons in a solid.

1. **Conductor:**

- In a conductor, the conduction band and valence band overlap, allowing electrons to freely move through the material.
- There is no band gap between the conduction and valence bands.
- Examples: Metals like copper, aluminum, etc.
- Conductors have high electrical conductivity.

2. **Semiconductor:**

- A semiconductor has a small energy gap (band gap) between the valence band and the conduction band.
- At absolute zero, the conduction band is empty, and the valence band is full. At room temperature, some electrons gain enough energy to jump to the conduction band.
- Examples: Silicon, germanium.
- Semiconductors have moderate electrical conductivity, which increases with temperature.

3. **Insulator:**

- In insulators, the band gap between the conduction band and the valence band is large.
- The conduction band is empty, and the valence band is full, with no electrons able to move to the conduction band at room temperature.
- Examples: Rubber, wood, glass.
- Insulators have very low electrical conductivity.

Need of Doping in Pure Semiconductors:

Pure semiconductors, like silicon, have limited electrical conductivity. Doping introduces impurities into the semiconductor material to increase its conductivity. Doping creates either an excess of electrons (n-type doping) or a shortage of electrons (p-type doping), allowing

current to flow more easily. Doping is crucial for creating practical semiconductors used in devices like diodes and transistors.

Current in Ideal Diodes D_1 and D_2:

In the given circuit, we have two diodes D_1 and D_2, with resistors $100\ \Omega$ and $5\ \Omega$, respectively, connected in series with a $2\ V$ battery.

- **For an ideal diode,** the current flowing through the circuit is determined by Ohm's law. An ideal diode has zero resistance in the forward bias condition and infinite resistance in the reverse bias condition.

- **For D_1,** if it is forward biased, it will conduct current.

- **For D_2,** if it is reverse biased, it will not conduct any current.

Assuming both diodes are ideal: - Current through the circuit,

$$I = \frac{V}{R_{\text{total}}} = \frac{2}{100 + 5} = \frac{2}{105}\ A \approx 0.019\ A$$

Thus, the current through the circuit is $0.019\ A$ if D_1 is forward biased and D_2 is reverse biased.

Quick Tip: In ideal diodes, current only flows in the forward bias condition. In reverse bias, no current flows. Doping in semiconductors is essential for controlling conductivity and creating useful electronic devices.

OR

Write down the formula for refraction of light from a spherical surface and with the help of this, derive the relation $\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ for a thin lens. Also show that, the focal length for concave lens will be negative.

Correct Answer: —

Solution:

Refraction of Light from a Spherical Surface:

When light passes from one medium to another at a spherical surface, the relation between the object distance u, image distance v, and the radius of curvature R of the spherical surface is given by the lens-maker's formula. The formula for refraction at a spherical surface is:

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R},$$

where:

- n_1 and n_2 are the refractive indices of the first and second mediums,
- u is the object distance,
- v is the image distance,
- R is the radius of curvature of the surface.

For a thin lens, we have two spherical surfaces with radii R_1 and R_2, and the light is refracted twice. The lens-maker's equation for a thin lens in air is:

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

where:

- f is the focal length of the lens,
- n is the refractive index of the material of the lens,
- R_1 is the radius of curvature of the first surface, and
- R_2 is the radius of curvature of the second surface.

Focal Length for Concave Lens:

For a concave lens, the radii of curvature are negative (R_1 is negative and R_2 is positive). Substituting these values into the lens-maker's equation, we get:

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

Since R_1 is negative for a concave lens, the focal length f will also be negative. This confirms that the focal length of a concave lens is negative.

Quick Tip: For a concave lens, the focal length is negative because the image formed is virtual and diminished. For a convex lens, the focal length is positive, and the image formed can be real or virtual depending on the object distance.