Maharashtra State Board
Physics
Sample Question Paper - 1
Academic Year: 2024-2025

General Instructions: The question paper is divided into four sections.

1. **Section A:** Q. No.1 contains Ten multiple-choice types of questions, carrying One mark each. Q. No.2 contains Eight very short answer type of questions carrying One mark each.
2. **Section B:** Q.No.3 to Q.No.14 contains Twelve short answer type of questions carrying Two marks each. (Attempt any Eight).
3. **Section C:** Q.No.15 to Q.No.26 contain Twelve short answer type questions carrying Three marks each. (Attempt any Eight).
4. **Section D:** Q.No.27 to Q.No.31 contain Five long answer type questions carrying Four marks each (Attempt any Three).
5. Use of the log table is allowed. Use of calculator is not allowed.
6. Figures to the right indicate full marks.
7. For each multiple-choice type question, it is mandatory to write the correct answer along with its alphabet, e.g., (a) ..../(b) .... /(c) ..../(d) ...., No marks(s) shall be given, if ONLY the correct answer or the alphabet of the correct answer is written. Only the first attempt will be considered for evaluation.
8. Physical Constants:
   (i) mass of electron $m = 9.1 \times 10^{-31}$ kg
   (ii) $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$
   (iii) $\pi = 3.142$
   (iv) charge on electron $e = 1.6 \times 10^{-19}C$
   (v) $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am
   (vi) $h = 6.63 \times 10^{-34}$ Js
   (vii) $C = 3 \times 10^{8}$ m/s

SECTION - A

Q1. Select and write the correct answers for the following multiple-choice type of questions:

1.1. A charged particle is in motion having initial velocity $\vec{v}$ when it enters into a region of uniform magnetic field perpendicular to $\vec{v}$. Because of the magnetic force the kinetic energy of the particle will ______.

1. remain unchanged
2. get reduced
3. increase
4. be reduced to zero

Solution

A charged particle is in motion having initial velocity v when it enters into a region of uniform magnetic field perpendicular to v. Because of the magnetic force the kinetic energy of the particle will remain unchanged.

Explanation:

The work done by the magnetic force is always zero because the direction of motion due to the magnetic force is always perpendicular to it. When the particle enters the field the magnitude of the velocity stays the same while the direction changes and while the kinetic energy remains the same. It can only lead to a change in the direction of motion and not the speed. Hence there is going to be no change in the kinetic energy of the particle.

1.2. The ratio of emissive power of perfect blackbody at 1327°C and 527°C is ______.

1. 4:1
2. 16:1
3. 2:1
4. 8:1

Solution

The ratio of emissive power of perfect blackbody at 1327°C and 527°C is 16:1.

Explanation:

The temperature of the black body is T’ = 1327°C.

The temperature of the black body is T” = 527°C.

Express the relation between emissive power and temperature.

$E_b = n^2\sigma T^4$

Here, E_b is emissive power, n is an index of refraction, σ is Stefan's constant, T is temperature.

Express the relation of emissive power at temperature 1327°C.

$E'_b = {''}n^2\sigma T''^4$ .....(i)

Here, E'_b is emissive power at temperature 1327°C.

Express the relation of emissive power at temperature 527°C

$E''_b = {'}n^2\sigma T'^4$ .....(ii)

Here, E''_b s emissive power at temperature 527°C

Convert temperatures T' and T'' from degree Celsius to kelvin.

T' = 1327°C + 273

T' = 1600 K

T'' = 527°C + 273

T'' = 800 K

Substitute 1600K for T' and 800 K for T'' in equation (i) and (ii) respectively to find emissive power.

$E'_b = n\sigma(1600)^4$

$E''_b = n\sigma(800)^4$

Divide E'_b by E''_b to find the relation between E'_b and E''_b.

$$\frac{E'_b}{E''_b} = \frac{n\sigma(1600)^4}{n\sigma(800)^4}$$

$$\frac{E'_b}{E''_b} = \left(\frac{1600}{800}\right)^4$$

$$\frac{E'_b}{E''_b} = (2)^4$$

$$\frac{E'_b}{E''_b} = \frac{16}{1}$$

1.3. An electron, a proton, an α-particle, and a hydrogen atom are moving with the same kinetic energy. The associated de Broglie wavelength will be longest for ______.

1. Electron
2. Proton
3. α-particle
4. Hydrogen atom

Solution

An electron, a proton, an α-particle, and a hydrogen atom are moving with the same kinetic energy. The associated de Broglie wavelength will be longest for **electron**.

Explanation:

The equation which relates Kinetic energy and De Broglie wavelength is

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

- According to the given condition, Kinetic Energy E is the same for all the given particles.
- So, the value of the De Broglie wavelength depends on the mass of the particle. If the mass of the particle is more, then De Broglie's wavelength is high and vice-versa.
- Among the given particles, the electron is having the lowest mass in the order 9.1×10-31kg.
- Therefore, the electron has the longest De Broglie wavelength.

1.4. Multiple Choice Question.

Two capillary tubes of radii 0.3 cm and 0.6 cm are dipped in the same liquid. The ratio of heights through which the liquid will rise in the tubes is

1. 1: 2
2. 2: 1
3. 1: 4
4. 4: 1

Solution

2: 1

Explanation:

The rise in the capillary tube is given by:

$$h = \frac{2T\cos(\theta)}{pgr}$$

Here, h is the height of capillary rise, T is the surface tension, θ is the contact angle, p is the density of the liquid, g is the acceleration due to gravity and is the radius of the tube.

Use the formula for the first tube and write the expression

$$h_1 = \frac{2T\cos(\theta)}{pgr_1} \text{ ......(i)}$$

Use the formula for the second tube and write the expression

$$h_2 = \frac{2T\cos(\theta)}{pgr_2} \text{ .....(ii)}$$

Divide (i) by (ii) and simplify the equation

$$h_1 \cdot h_2 = \frac{\frac{2T\cos(\theta)}{pgr_1}}{\frac{2T\cos(\theta)}{pgr_2}}$$

$$\frac{h_1}{h_2} = \frac{r_2}{r_1}$$

Substitute the value of r_1 = 0.3 cm and r_2 = 0.6 cm in $\frac{h_1}{h_2} = \frac{r_2}{r_1}$ to find the ratio of the height of capillary rise.

$$\frac{h_1}{h_2} = \frac{r_2}{r_1}$$

$$\frac{h_1}{h_2} = \frac{0.6}{0.3}$$

$$\frac{h_1}{h_2} = 2$$

1.5. Choose the correct option:

A parallel plate capacitor is charged and then isolated. The effect of increasing the plate separation on charge, potential, capacitance respectively are ______.

1. Constant, decreases, decreases
2. Increases, decreases, decreases
3. Constant, decreases, increases
4. Constant, increases, decreases

Solution

A parallel plate capacitor is charged and then isolated. The effect of increasing the plate separation on charge, potential, capacitance respectively are **Constant, increases, decreases**.

Explanation:

The charge on the capacitor stays constant because it is separated after charging.

Capacitance reduces as plate separation increases because $C = \frac{\varepsilon_0 A}{d}$, and as a result, potential rises because $V = \frac{q}{C}$.

1.6. A thin walled hollow cylinder is rolling down an incline, without slipping. At any instant, without slipping. At any instant, the ratio "Rotational K.E.: Translational K.E.: Total K.E." is ______.

1. 1 : 1 : 2
2. 1 : 2 : 3
3. 1 : 1 : 1
4. 2 : 1 : 3

Solution

A thin walled hollow cylinder is rolling down an incline, without slipping. At any instant, without slipping. At any instant, the ratio "Rotational K.E.: Translational K.E.: Total K.E." is 1 : 1 : 2.

Explanation:

We know,

Rotational kinetic energy $K_R = \frac{1}{2}mv^2\frac{K^2}{R^2}$ ...(1)

Translational K. E. $K_T = \frac{1}{2}mv^2$ ...(2)

Total kinetic energy $K.E_T = \frac{1}{2}mv^2\left(1+\frac{K^2}{R^2}\right)$ ...(3)

$I = mR^2$

$mK^2 = mR^2$

$\frac{K^2}{R^2} = 1$ ...(4)

$\therefore K_R : K_T : K.E_T = \frac{1}{2}mv^2\frac{K^2}{R^2} \;:\; \frac{1}{2}mv^2 \;:\; \frac{1}{2}mv^2\left(1+\frac{K^2}{R^2}\right)$

$\therefore K_R : K_T : K.E_T = \cancel{\frac{1}{2}mv^2}\frac{K^2}{R^2} \;:\; \cancel{\frac{1}{2}mv^2} \;:\; \cancel{\frac{1}{2}mv^2}\left(1+\frac{K^2}{R^2}\right)$

$\therefore K_R : K_T : K.E_T = \frac{K^2}{R^2} \;:\; 1 \;:\; \left(1+\frac{K^2}{R^2}\right)$

$K_R : K_T : K.E_T = 1 : 1 : (1 + 1)$ (From equation 4)

$K_R : K_T : K.E_T = 1 : 1 : 2$

1.7. In a series LCR circuit, the phase difference between the voltage and the current is 45°. Then the power factor will be ______.

1. 0.607
2. 0.707
3. 0.808
4. 1

Solution

In a series LCR circuit, the phase difference between the voltage and the current is 45°. Then the power factor will be **0.707**.

Explanation:

Let, Inductance = L

Conductance = C

Resistance = R

Frequency = f

Phase Difference between current and voltage = ϕ

As, in LCR circuit,

Power Factor = cosϕ

Substitute the given values from,

Φ = 45∘

cos 45∘ = $\frac{1}{\sqrt{2}}$

Therefore, P.F = 0.707

1.8. During refrigeration cycle, heat is rejected by the refrigerant in the ______.

1. Condenser
2. Cold chamber
3. Evaporator
4. Hot chamber

Solution

During refrigeration cycle, heat is rejected by the refrigerant in the **condenser**.

Explanation:

In the condenser, the heat is rejected by the refrigerant into the atmosphere, and then the refrigerant goes to the expansion valve. The condenser is made up of copper or aluminium coils since their conductivity is high to ensure the better transfer of heat from a hot region to the atmosphere. The condenser sometimes also contains some additional length to subcool the liquid below the saturation temperature.

1.9. Choose the correct option.

A conducting thick copper rod of length 1 m carries a current of 15A and is located on the Earth's equator. There the magnetic flux lines of Earth's magnetic field are horizontal, with the field of 1.3×10^{-4}T, south to north. The magnitude and direction of the force on the rod, when it is oriented so that current flows from west to east are

_______.

1. 14×10^{-4}N, downward
2. 20×10^{-4}N, downward
3. 14×10^{-4}N, upward
4. **20×10^{-4}N, upward**

Solution

A conducting thick copper rod of length 1 m carries a current of 15 A and is located on the Earth's equator. There the magnetic flux lines of Earth's magnetic field are horizontal, with the field of 1.3×10^{-4}T, south to north. The magnitude and direction of the force on the rod, when it is oriented so that current flows from west to east are **20×10^{-4}N, upward**.

Explanation:

Express the relation for the force acting on a current-carrying wire due to a perpendicular magnetic field.

$\vec{F} = i \cdot L \vec{\times} B$

Here, F is force, B is the perpendicular magnetic field, i is current and L is the length of the conductor.

Substitute 1.3×10^{-4}T for B, 1 m for L and 15A for I in the equation to find the magnitude of the force.

F = $\left(1.3 \times 10^{-4} T\right) \times (15A) \times (1m)$

F = $19.5 \times 10^{-4} N$

F ≈ $20 \times 10^{-4} N$

The direction of the force is found by using Fleming's left-hand rule where the current corresponds to the middle finger, the field corresponds to the pointing finger and the force corresponds to the thumb. Hence the force is upwards.

1.10. Choose the correct option.

In the spectrum of the hydrogen atom which transition will yield the longest wavelength?

1. n = 2 to n = 1
2. n = 5 to n = 4
3. n = 7 to n = 6
4. n = 8 to n = 7

Solution

n = 8 to n = 7

Explanation:

The eighth energy level, $E_8 = -0.2125$

The seventh energy level, $E_7 = -0.277$

$E_8 - E_7 = 0.06$

Q2. Answer the following questions:

2.1. What is Brewster's law? Derive the formula for Brewster angle.

Solution

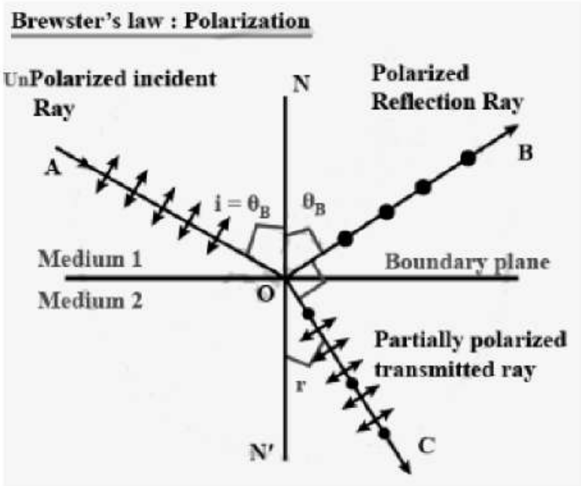
Brewster's law: The tangent of the polarising angle equals the refractive index of the reflecting medium in comparison to the surrounding medium (${}_1n_2$).

$$\text{If } \theta_B = {}_1n_2 = \frac{n_2}{n_1}$$

Here n_1 is the absolute refractive index of the surrounding and n_2 is that of the reflecting medium.

The angle θ_B is called the Brewster angle.

Consider a ray of unpolarized monochromatic light incident at an angle θ_B on a border between two transparent media, as illustrated in the figure below. Medium 1 has a lower refractive index (n_1) than Medium 2, which has a higher refractive index (n_2). Part of the incident light is refracted, and the rest.



The incident wave's electric field is perpendicular to the direction in which the incident light propagates. This electric field can be separated into two components: one parallel to the plane of the paper, represented by double arrows, and one perpendicular to the plane of the paper, represented by dots, both of equal magnitude. In general, reflected and refracted rays are partially polarised, which means that their magnitudes are not identical.

Sir David Brewster observed in 1812 that for a specific angle of incidence, θB, the reflected wave is totally plane-polarized, with its electric field perpendicular to the plane of the paper, but the refracted wave is partially polarised. This angle of incidence (θ_B) is known as the Brewster angle.

$\theta_B + \theta_r = 90°$ ....(1)

From snell's law of refraction,

$\therefore n_1 \sin\theta_B = n_2 \sin \theta_r$ ....(2)

From Eqs. (1) and (2), we have,

$n_1 \sin \theta_B = n_2 \sin (90° - \theta B)$

$= n_2 \cos \theta_B$

$$\therefore \frac{n_2}{n_1} = \frac{\sin\theta_B}{\cos\theta_B =} \tan\theta_B$$

$$\therefore \theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right) \quad ....(3)$$

This is called Brewster's law.

2.2. Do we need a banked road for a two-wheeler? Explain.

Solution

The force of friction produces the centripetal force when a two-wheeler makes a turn on an unbanked road. To counterbalance a torque that would cause it to tumble outward, the two-wheeler leans inward. For starters, friction alone cannot supply the required centripetal force in all road conditions. The friction, on the other hand, causes tyre wear and tear. Any vehicle can navigate a turn on a banked road without relying on friction or putting strain on the tyres.

So, the Banking of road provides the centripetal force at curved surface.

Hence, we need a banked road for a two-wheeler.

2.3. What do you understand by the term wave-particle duality? Where does it apply?

Solution

Electromagnetic radiation and material particles exhibit wave or particle nature depending on the experimental conditions or the structure of matter which is known as wave-particle duality.

It can be applied to any phenomenon. The wave nature and particle nature are liked by the de Broglie relation $\lambda = h/p$, where λ is the wavelength of matter waves, also called de Broglie waves/Schrodinger waves, p is the magnitude of the momentum of a particle or quantum of radiation and h is the universal constant called Planck's constant.

2.4. A star is emitting light at the wavelength of 5000 Å. Determine the limit of resolution of a telescope having an objective of a diameter of 200 inch.

Solution

Given: λ = 5000 Å = 5×10^{-7} m

D = 200 × 2.54 cm = 5.08 m

$$\theta = \frac{1.22\lambda}{D}$$

$$= \frac{1.22 \times 5 \times 10^{-7}}{5.08}$$

$= 1.2 \times 10^{-7}$ rad

2.5. Answer in brief:

A metal plate is introduced between the plates of a charged parallel plate capacitor. What is its effect on the capacitance of the capacitor?

Solution

Assume the parallel plate capacitor has capacitance C_0, area A plates, and a separation d. Suppose the introduced metal sheet has the same area A.

Case (1): Thickness t is finite. Free electrons in the sheet will travel to the positive plate of the capacitor. The metal sheet is subsequently drawn to the nearest capacitor plate and attached to it, giving it the same potential as that plate. When the gap between the capacitor plates is reduced to d - t, the capacitance increases.

Case (2): Thickness is negligible. The gap is divided into two thicknesses d_1 and d_2 of capacitances $C_1 = \varepsilon_0 A/d_1$ and $C_2 = \varepsilon_0 A/d_2$ in series by the thin metal sheet.

Their effective capacitance is

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{\varepsilon_0 A}{d_1 + d_2} = \frac{\varepsilon_0 A}{d} = C_0$$

In other words, the capacitance remains constant.

2.6. A voltmeter has a resistance of 30 Ω. What will be its reading, when it is connected across a cell of emf 2 V having internal resistance 10 Ω?

Solution

Data: E = 2V, r = 10 Ω, R = 30Ω

The voltmeter reading, V = IR

$$= \left(\frac{E}{R + r}\right)R$$

$$= \left(\frac{2}{30 + 10}\right)30$$

$$= \left(\frac{2}{40}\right)30$$

= 1.5 V

2.7. Explain why the inductance of two coils connected in parallel is less than the inductance of either coil.

Solution 1

i. For a parallel combination of two coils, the current through each parallel inductor is a fraction of the total current and the voltage across each parallel inductor is the same.

ii. As a result, a change in total current will result in less voltage dropped across the parallel array than for any one of the individual inductors.

iii. There will be less voltage drop across parallel inductors for a given rate of change in current than for any of the individual inductors.

iv. Less voltage for the same rate of change in current results in less inductance.

v. Thus, the total inductance of two coils is less than the inductance of either coil.

Solution 2

When two inductors with inductances L_1 and L_2 are connected in parallel, the equivalent inductance is given by

$$\frac{1}{L_{equivalent}} = \frac{1}{L_1} + \frac{1}{L_2}$$

which is less than the individual inductance value L_1 and L_2.

As a result, the inductance of two parallel coils is smaller than the inductance of either coil.

2.8. Answer in brief.

Why should a Carnot cycle have two isothermal two adiabatic processes?

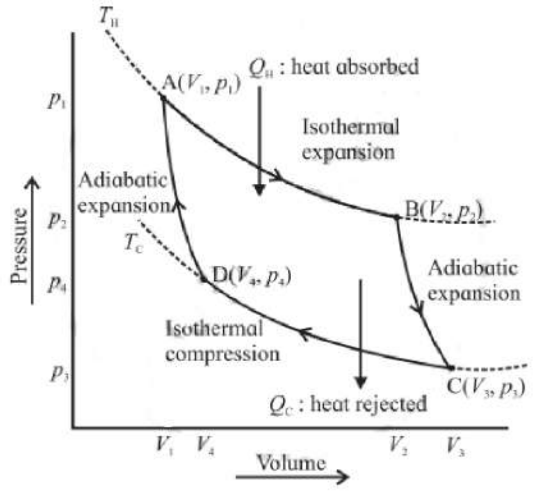
Solution

There are basically two processes:

1. Exchange of heat (steps A to B and C to D). For this to be reversible, the heat exchange must be isothermal. This is possible if the working substance is at the temperature T_H of the source while absorbing heat. The working substance should be at the temperature of the cold reservoir T_C while rejecting the heat.

2. Work done (steps B to C and D to A). For work done to be reversible, the process should be adiabatic.

   Thus, the cycle includes two isothermal and two adiabatic processes for maximum efficiency.



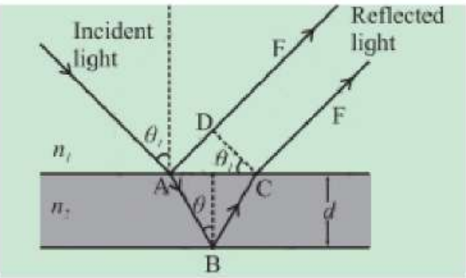
Carnot cycle

SECTION – B

Attempt any EIGHT questions of the following:

Q3. Why are multiple colours observed over a thin film of oil floating on water? Explain with the help of a diagram.

Solution



Interference due to a thin film:

The brilliant colours of soap bubbles and thin films on the surface of water are due to the interference of light waves reflected from the upper and lower surfaces of the film. The two rays have a path difference which depends on the point on the film that is being viewed. This is shown in above figure.

The incident wave gets partially reflected from upper surface as shown by ray AE. The rest of the light gets refracted and travels along AB. At B it again gets partially reflected and travels along BC. At Cit refracts into air and travels along CF. The parallel rays AE and CF have a phase difference due to their different path lengths in different media. As can be seen from the figure, the phase difference depends on the angle of incidence θ_1, i.e., the angle of incidence at the top surface which is the angle of viewing, and also on the wavelength of the light as the refractive index of the material of the thin film depends on it. The two waves propagating along AE and CF interfere producing maxima and minima for different colours at different angles of viewing. One sees different colours when the film is viewed at different angles.

As the reflection is from the denser boundary, there is an additional phase difference of π radians (or an additional path difference λ). This should be taken into account for mathematical analysis.

Q4. At what distance from the mean position is the speed of a particle performing S.H.M. half its maximum speed. Given the path length of S.H.M. = 10 cm.

Solution

Given: $v = \frac{1}{2}v_{max}$, $2A = 10$ cm

$\therefore a = 5$ cm

$v = \omega\sqrt{A^2 - x^2}$ and $v_{max} = \omega A$

since $c = \frac{1}{2}v_{max}$,

$\omega\sqrt{A^2 - x^2} = \frac{\omega A}{2}$

$\therefore A^2 - x^2 = \frac{A^2}{4}$

$\therefore x^2 = A^2 - \frac{A^2}{4} = \frac{3A^2}{4}$

$\therefore x = \pm\frac{\sqrt{3}}{2}A = \pm 0.866 \times 5 = \pm 4.33$ cm

This gives the required displacement.

Q5. If the effective current in a 50 cycle AC circuit is 5 A, what is the peak value of current? What is the current 1/600 after if was zero?

Solution

Data: f = 50 Hz, i_{rms} = 5 A, t = 1/600 s

The peak value of the current,

$$i_0 = i_{rms}\sqrt{2} = (5)(1.414) = 7.07\text{A}$$

$$i = i_0 \sin(2\pi ft)$$

$$= 7.07 \sin\left[2\pi(50)\left(\frac{1}{600}\right)\right]$$

$$= 7.07 \sin\left(\frac{\pi}{6}\right) = (7.07)(0.5)$$

= 3.535 A

Q6. Why is the surface tension of paints and lubricating oils kept low?

Solution

The surface tension of paints and lubricating oils is kept low so that they can spread over large areas easily and quickly.

Q7. A system releases 130 kJ of heat while 109 kJ of work is done on the system. Calculate the change in internal energy.

Solution

Data: Q = −130 kJ, W = −109 kJ

Find: ΔU = ?

Calculations:

ΔU = Q − W

ΔU = −130 − (−109)

ΔU = −130 + 109

ΔU = −21 kJ

∴ The change in internal energy is −21 kJ. This is the change (decrease) in the internal energy.

Q8. Answer in brief:

State the characteristics of stationary waves.

Solution

Stationary wave: When two identical waves travelling along the same path in opposite directions interfere with each other, resultant wave is called a stationary wave.

Characteristics of stationary waves:

1. Stationary waves are produced due to the superposition of two identical waves traveling through a medium along the same path in opposite directions.
2. A standing wave has an overall look of alternating intensity maximum (displacement antinode) and minimum (displacement node).
3. The distance between two consecutive nodes and antinodes is $\lambda/2$.
4. Nodes and antinodes are produced alternately. The distance between a node and an adjacent antinode is $\lambda/4$.
5. The amplitude of vibration varies periodically in space. All points vibrate with the same frequency.
6. Though all the particles (except those at the nodes) possess energy, there is no propagation of energy. The wave is localized and its velocity is zero. Therefore, we call it a stationary wave.
7. All the particles between adjacent nodes (i.e., in one loop) vibrate in phase. There is no progressive change of phase from one particle to another particle. All the particles in the same loop are in the same phase of oscillation, which reverses for the adjacent loop.

Q9. State the importance of Davisson and Germer experiment.

Solution

The Davisson and Germer experiment are probably one of the most important experiments ever since it substantiated de Broglie's hypothesis of wave-particle duality. It verified that De Broglie's "matter wave" hypothesis applied to matter (electrons) as well as light.

Q10. White light consists of wavelengths from 400 nm to 700 nm. What will be the wavelength range seen when white light is passed through a glass of refractive index 1.55?

Solution 1

Let λ_1 and λ_2 be the wavelengths of light in water for 400 nm and 700 nm (wavelengths in a vacuum) respectively. Let λ_a be the wavelength of light in vacuum.

$$\lambda_1 = \frac{\lambda_a}{n} = \frac{400 \times 10^{-9}\text{m}}{1.55} = 258.06 \times 10^{-9}\ \text{m}$$

$$\lambda_2 = \frac{\lambda_a}{n} = \frac{700 \times 10^{-9}\text{m}}{1.55} = 451.61 \times 10^{-9}\ \text{m}$$

The wavelength range seen when white light is passed through the glass would be 258.06 nm to 451.61 run.

Solution 2

Given: n = 1.55

Smallest wavelength = 400 nm,

Largest wavelength = 700 nm

To find: Range of wavelength of light when passed through the glass

Formula: $\lambda_{med} = \frac{\lambda_{vac}}{n}$

Calculation:

For the smallest wavelength (in glass),

From formula

$$\lambda_{med} = \frac{400}{1.55}$$

$= 2.5806 \times 10^2$ nm

= 258.06 nm

For largest wavelength

From formula,

$$\lambda_{med} = \frac{700}{1.55}$$

$= 4.5161 \times 10^2$ nm

= 451.61 nm

Q11. A voltmeter has a resistance of 30 Ω. What will be its reading, when it is connected across a cell of emf 2 V having internal resistance 10 Ω?

Solution

Data: E = 2V, r = 10 Ω, R = 30Ω

The voltmeter reading, V = IR

$$= \left(\frac{E}{R + r}\right)R$$

$$= \left(\frac{2}{30 + 10}\right)30$$

$$= \left(\frac{2}{40}\right)30$$

= 1.5 V

Q12. (a) What is electromagnetic induction?

Solution

The phenomenon of producing an induced e.m.f in a conductor or conducting coil due to changing magnetic flux is called electromagnetic induction.

Q12. (b) State Faraday's laws of electromagnetic induction.

Solution

Faraday's laws of electromagnetic induction:

1. **First law:** Whenever there is a change of magnetic flux in a closed circuit, an induced emf is produced in the circuit. This law is a qualitative law as it only indicates the characteristics of induced emf.
2. **Second law:** The magnitude of induced emf produced in the circuit is directly proportional to the rate of change of magnetic flux linked with the circuit. This law is known as quantitative law as it gives the magnitude of induced emf.

Q13. Calculate the value of the magnetic field at a distance of 2 cm from a very long straight wire carrying a current of 5 A (Given: $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am).

Solution

Given: I = 5A, x = 0.02 m,

The magnetic induction,

$$B = \frac{\mu_0 I}{2\pi x}$$

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

$$B = 10^{-7} \times \frac{2(5)}{2 \times 10^{-2}}$$

$$B = 5 \times 10^{-5} T$$

Q14. Mention the conditions under which a real gas obeys the ideal gas equation.

Solution

Conditions under which a real gas obeys ideal gas equation are:

Low density, low pressure or high temperature. In other words, a condition where gas molecules are far apart so that molecular interactions are negligible.

SECTION – C

Attempt any EIGHT questions of the following:

Q15. A gas contained in a cylinder fitted with a frictionless piston expands against a constant external pressure of 1 atm from a volume of 5 liters to a volume of 10 liters. In doing so it absorbs 400J of thermal energy from its surroundings. Determine the change in the internal energy of the system.

Solution

Given:

P = 1 atm = 1.013×10^5 Pa,
V_1 = 5 liters = 5×10^{-3} m^3,

V_2 = 10 liters = 10×10^{-3} m^3,
Q = 400 J

The work done by the system on its surroundings,

$W = P(V_2 - V_1)$

$= (1.013 \times 10^5)(10 \times 10^{-3} - 5 \times 10^{-3})$

$= 1.013 (5 \times 10^2)$

$= 5.065 \times 10^2$ J

The change in the internal energy of the system,

$\Delta U = Q - W = 400 - 506.5 = -106.5$ J

The negative sign shows that there is a decrease in the internal energy of the system.

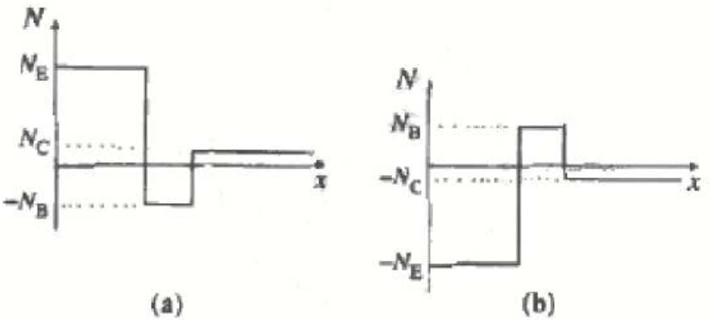
Q16. Why are the emitter, the base, and the collector of a BJT doped differently?

Solution

A BJT is a bipolar device, both electrons and holes participate in the conduction process. Under the forward-biased condition, the majority of carriers injected from the emitter into the base constitute the largest current component in a BJT. For these carriers to diffuse across the base region with negligible recombination and reach the collector junction, they must overwhelm the majority of carriers of the opposite charge in the base. The total emitter current has two components, due to majority carriers in the emitter and due to minority carriers diffusing from the base into the emitter. The ratio of the current component due to the injected majority carriers from the emitter to the total emitter current is a measure of the emitter efficiency. To improve the emitter efficiency and the common-base current gain (α), it can be shown that the emitter should be much more heavily doped than the base.

Also, the base width is a function of the base-collector voltage. A low doping level of the collector increases the size of the depletion region. This increases the maximum collector-base voltage and reduces the base width. Further, the large depletion region at the collector-base junction-extending mainly into the collector-corresponds to a smaller electric field and avoids avalanche breakdown of the reverse-biased collector-base junction.

[Note: Effective dopant concentrations of (a) npn transistor (b) pnp transistor are shown below.]



The base doping is less than the emitter doping but greater than the collector doping.

Q17. Discuss the interlink between translational, rotational and total kinetic energies of a rigid object rolls without slipping.

Solution

Consider an object of the moment of inertia I, rolling uniformly. If the frictional force on the body is large enough, the body rolls without slipping. Following quantities can be related,

v = Linear speed of the centre of mass

R = Radius of the body

ω = Angular speed of rotation of the body,

$\therefore \omega = \frac{v}{R}$ for any particle

M = Mass of the body

K = Radius of gyration of the body

$\therefore I = MK^2$

Total kinetic energy of rolling = Translational K.E. + Rotational K.E.

$$\therefore E = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$$

$$= \frac{1}{2}Mv^2 + \frac{1}{2}(MK^2)\left(\frac{v}{R}\right)^2$$

$$= \frac{1}{2}Mv^2\left(1 + \frac{K^2}{R^2}\right)$$

Q18. A 6 μF capacitor is charged by a 300 V supply. It is then disconnected from the supply and is connected to another uncharged 3 μF capacitor. How much electrostatic energy of the first capacitor is lost in the form of heat and electromagnetic radiation?

Solution

Data: $C = 6\ \mu F = 6 \times 10^{-6}\ F = C_1$, $V = 300\ V$, $C_2 = 3\ \mu F$

The capacitor's electrostatic energy

$$= \frac{1}{2} CV^2 = \frac{1}{2}(6 \times 10^{-6})(300)^2$$

= 3 × 10-6 × 9 × 104 = 0.27J

This capacitor has a charge on it.

Q = CV = (6 × 10-6) (300) = 1.8 mC

When two capacitors of capacitances C1 and C2 are connected in parallel, the equivalent capacitance C

= C1 + C2 = 6 + 3 = 9 μF

= 9 × 10-6 F

By conservation of charge, Q = 1.8 C.

$\therefore$ The energy of the system = $\frac{Q^2}{2C}$

$$= \frac{(1.8 \times 10^{-3})^2}{2(9 \times 10^{-6})} = \frac{18 \times 10^{-8}}{10^{-6}} = 0.18\ J$$

The energy lost = 0.27 -0.18 = 0.09 J

Q19. Obtain an expression for the orbital magnetic moment of an electron rotating about the nucleus in an atom.

Solution 1

In the Bohr model of a hydrogen atom, the electron of charge - e performs a uniform circular motion around the positively charged nucleus. Let r, v and T be the orbital radius, speed and period of motion of the electron. Then,

$$T = \frac{2\pi r}{v} \quad ...(1)$$

Therefore, the orbital magnetic moment associated with this orbital current loop has a magnitude,

$$I = \frac{e}{T} = \frac{ev}{2\pi r} \quad ...(2)$$

Therefore, the magnetic dipole moment associated with this electronic current loop has a magnitude

M_0 = current × area of the loop

$$= I\left(\pi r^2\right) = \frac{ev}{2\pi r} \times \pi r^2 = \frac{1}{2} evr \quad ....(3)$$

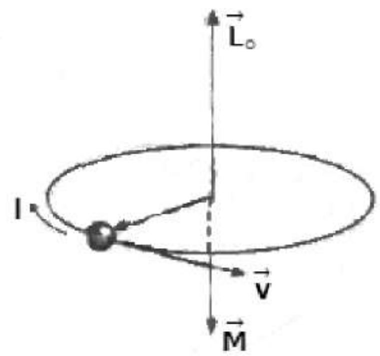
Multiplying and dividing the right-hand side of the above expression by the electron mass m_e,

$$M_0 = \frac{e}{2m_e}\left(m_e vr\right) = \frac{e}{2m_e} L_0 \quad ....(4)$$

where L_0 - $m_e vr$ is the magnitude of the orbital angular momentum of the electron. $\vec{M}_0$ is opposite to $\vec{L}_0$.

$$\therefore \vec{M}_0 = -\frac{e}{2m_e} \vec{L}_0 \quad ....(5)$$

which is the required expression. →



According to Bohr's second postulate of stationary orbits in his theory of hydrogen atom, the angular momentum of the electron in the nth stationary orbit is equal to n h/2π, where h is the Planck constant and n is a positive integer. Thus, for an orbital electron,

$$L_0 = m_e vr = \frac{nh}{2\pi} \quad ...(6)$$

Substituting for L_0 in Eq. (4),

$$M_0 = \frac{enh}{4\pi m_e}$$

For n = 1, $M_0 = \frac{eh}{4\pi m_e}$

The quantity $\frac{eh}{4\pi m_e}$ is a fundamental constant called the Bohr magneton,

$\therefore \mu_B \cdot \mu_B$

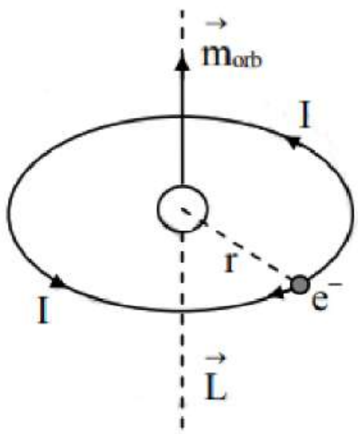
$= 9.274 \times 10^{-24}$ J/T (or Am^2)

= 5.788 x 10^{-5} eV/T.

Solution 2

Expression for magnetic dipole moment:

i. Consider an electron of mass me and charge e revolving in a circular orbit of radius r around the positive nucleus in a clockwise direction, leading to an anticlockwise current.



U.C.M of an electron around the nucleus

ii. If the electron travels a distance 2πr in time T then, its orbital speed v = 2πr/T

iii. The magnitude of circulating current is given by,

$$I = e\left(\frac{1}{T}\right)$$

But, $T = \frac{2\pi r}{v}$

$$\therefore I = e\left(\frac{1}{2\pi r/v}\right) = \frac{ev}{2\pi r}$$

iv. The orbital magnetic moment associated with the orbital current loop is given by,

$$m_{orb} = IA = \frac{ev}{2\pi r} \times \pi r^2 \; [\because \text{Area of current loop, } A = \pi r^2]$$

$$\therefore m_{orb} = \frac{evr}{2} \; ....(1)$$

v. The angular momentum of an electron due to its orbital motion is given by,
$L = m_e vr$

vi. Multiplying and dividing the R.H.S of equation (1) by m_e,

$$m_{orb} = \frac{e}{2m_e} \times m_e vr$$

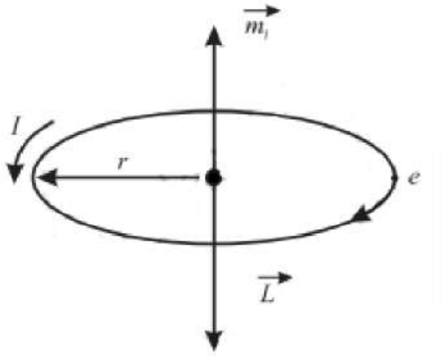
$$\therefore m_{orb} = \frac{eL}{2m_e}$$

vii. This equation shows that the orbital magnetic moment is proportional to the angular momentum. But as the electron bears a negative charge, the orbital magnetic moment and orbital angular momentum are in opposite directions and perpendicular to the plane of the orbit.

Using vector notation, $\vec{m}_{orb} = -\left(\frac{e}{2m_e}\right)\vec{L}$

Solution 3

Consider an electron moving with constant speed v in a circular orbit of radius r about the nucleus as shown in the figure.



If the electron travels a distance of 2πr (circumference) in time T, then its orbital speed,

$$v=\frac{2\pi r}{T}.$$

Thus, the current I associated with this orbiting electron of charge e is

$$I=\frac{e}{T}$$

$T=\frac{2\pi}{\omega}$ and $\omega=\frac{v}{r}$, the angular speed

$$I=\frac{e\omega}{2\pi}=\frac{ev}{2\pi r}$$

The orbital magnetic moment associated with orbital current loop is

$$m_{\text{orb}}=IA=\frac{ev}{2\pi r}\times\pi r^2$$

$$=\frac{1}{2}evr$$

Q20. A wave of frequency 500 Hz is traveling with a speed of 350 m/s. (a) What is the phase difference between two displacements at a certain point at times 1.0 ms apart? (b) what will be the smallest distance between two points which are 45° out of phase at an instant of time?

Solution

Given: n = 500 Hz, v = 350 m/s

v = n × λ

$\therefore \lambda=\frac{350}{500}$ = 0.7 m

(a) The path difference is the distance covered v × t = 350 × 0.001 = 0.35 m at t = 1.0 ms = 0.001 s.

$\therefore$ Phase difference = $\frac{2\pi}{\lambda}$ × Path difference

$= \frac{2\pi}{0.7} \times 0.35 = \pi$ rad

(b) Phase difference = 45° = $\frac{\pi}{4}$ rad

$\therefore$ Path difference = $\frac{\lambda}{2\pi}$ × Phase difference

$= \frac{0.7}{2\pi} \times \frac{\pi}{4} = 0.0875$ m

Q21. A 15.0 μF capacitor is connected to a 220 V, 50 Hz source. Find the capacitive reactance and the current (rms and peak) in the circuit. If the frequency is doubled, what will happen to the capacitive reactance and the current?

Solution

Data: C= 15 μF = 15 x 10^{-6} F, V_{rms} = 220 V, f = 50 Hz,

The capacitive reactance = $\frac{1}{2\pi fC}$

$$= \frac{1}{2(3.142)(50)\left(15 \times 10^{-6}\right)} = \frac{100 \times 100}{(3.142)(15)}$$

= 212.2 Ω

$$i_{rms} = \frac{V_{rms}}{\text{capacitive reactance}} = \frac{220}{212.2} = 1.037 \text{ A}$$

$$i_{peak} = i_{rms}\sqrt{2} = (1.037)(1.414) = 1.466 \text{A}$$

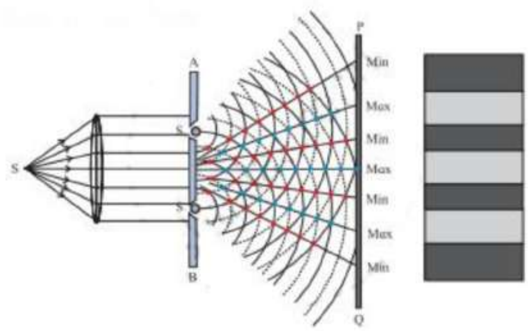
If the frequency is doubled, the capacitive reactance will be halved and the current will be doubled.

Q22. Describe Young's double-slit interference experiment and derive conditions for occurrence of dark and bright fringes on the screen. Define fringe width and derive a formula for it.

Solution

Description of Young's double-slit interference experiment:

1. a plane wavefront is made to fall on an opaque screen AB having two similar narrow slits S_1 and S_2.
2. The plane wavefront can be either obtained by placing a linear source S far away from the screen or by placing it at the focus of a convex lens kept close to AB.
3. The rays coming out of the lens will be parallel rays and the wavefront will be a plane wave front as shown in Figure.
4. The figure shows a cross-section of the experimental set up and the slits have their lengths perpendicular to the plane of the paper. For better results, the slits should be about 2-4 mm apart from each other. An observing screen PQ is placed behind of AB.
5. For simplicity, we assume that the slits S_1 and S_2 are equidistant from the S so that the wavefronts starting from S and reaching the S_1 and S_2 at every instant of time are in phase.

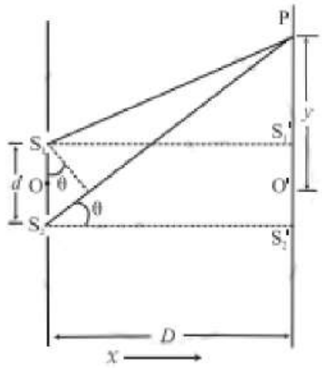


Young's double-slit experiment

6. S_1 and S_2 act as secondary sources. The crests/troughs of the secondary wavelets superpose and interfere constructively along straight lines joining the black dots shown in the above figure. The point where these lines meet the screen have high intensity and is bright.
7. Similarly, there are points shown with red dots where the crest of one wave coincides with the trough of the other. The corresponding points on the screen are dark due to destructive interference. These dark and bright regions are called fringes or bands and the whole pattern is called an interference pattern.

Conditions for the occurrence of dark and bright lunges on the screen:

Consider Young's double-slit experimental set up. Wavefront splitting produces two narrow coherent light sources as monochromatic light of wavelength emerges from two narrow and closely spaced, parallel slits S_1 and S_2 of equal widths. The separation $S_1 S_2 = d$ is very small. The interference pattern is observed on a screen placed parallel to the plane of S_1S_2 and at a considerable distance D (D >> d) from the slits. OO' is the perpendicular bisector of a segment S_1S_2.



Geometry of the double-slit experiment

Consider, a point P on the screen at a distance y from O' (y << 0). The two light waves from S_1 and S_2 reach P along paths S_1P and S_2P, respectively. If the path difference (Δl) between S_1P and S_2P is an integral multiple of λ, the two waves arriving there will interfere constructively producing a bright fringe at P. On the contrary, if the path difference between S_1P and S_2P is a half-integral multiple of λ, there will be destructive interference and a dark fringe will be produced at P.

From the above figure,

$(S_2P)^2 = (S_2S_2')^2 + (PS_2')^2$

$= (S_2S_2')^2 + (PO' + O'S_2')^2$

$$= D^2 + \left(y + \frac{d}{2}\right)^2 \quad .....(1)$$

and $(S_1P)^2 = (S_1S_1')^2 + (PS_1')^2$

$= (S_1S_1')^2 + (PQ' - Q'S_1)^2$

$$= D^2 + \left(y - \frac{d}{2}\right)^2 \quad .....(2)$$

$(S_2P)^2 - (S_1P)^2 = \left\{D^2 + \left(y + \frac{d}{2}\right)^2\right\} - \left\{D^2 + \left(y - \frac{d}{2}\right)^2\right\}$

$\therefore (S_2P + S_1P)(S_2P - S_1P)$

$$= \left[D^2 + y^2 + \frac{d^2}{4} + yd\right] - \left[D^2 + y^2 + \frac{d^2}{4} - yd\right] = 2yd$$

$\therefore S_2P + S_1P = \Delta l = 2yd/S_2P + S_1P$

In practice, D >> y and D >> d,

$\therefore S_2P + S_1P \cong 2D$

$\therefore$ Path difference,

$$\Delta l = S_2P + S_1P \cong 2\,\frac{yd}{2D} = y\frac{d}{D} \quad ....(3)$$

The expression for the fringe width (or band width):

The distance between consecutive bright (or dark) fringes is called the fringe width (or bandwidth) W. Point P will be bright (maximum intensity), if the

path difference,

$$\Delta l = y_n\,\frac{d}{D} = n\lambda \text{ where } n = 0, 1, 2, 3, ...$$

Point P will be dark (minimum intensity equal to zero), if

$$y_m\,\frac{d}{D} = (2m - 1)\frac{\lambda}{2}, \text{ where, } m = 1,2,3...,$$

Thus, for bright fringes (or bands),

$$y_n = 0, \lambda\frac{D}{d}, \frac{2\lambda D}{d} ...$$

and for dark fringes (or bands),

$$y_n = \frac{\lambda}{2}\frac{D}{d}, 3\frac{\lambda}{2}\frac{D}{d}, 5\frac{\lambda}{2}\frac{D}{d} ....$$

The bright and dark fringes (or bands) alternate and are evenly spaced in these situations. For Point O', the path difference (S_2O' - S_1O') = 0. Hence, point O' will be bright. It corresponds to the centre of the central bright fringe (or band). On both sides of O', the interference pattern consists of alternate dark and bright fringes (or band) parallel to the slit.

Let y_n and $y_n + 1$, be the distances of the nth and $(m + 1)^{th}$ bright fringes from the central bright fringe.

$$\therefore \frac{y_n d}{D} = n\lambda$$

$$\therefore y_n = \frac{n\lambda D}{d} \quad .....(4)$$

$$\text{and } \frac{y_{n+1} \; d}{D} = (n+1)\lambda$$

$$\therefore (y_{n+1}) = \frac{(n+1)\lambda D}{d} \quad .....(5)$$

The distance between consecutive bright fringes

$$= y_{n+1} - y_n = \frac{\lambda D}{d}[(n+1) - n] = \frac{\lambda D}{d} \quad ....(6)$$

Hence, the fringe width,

$$\therefore W = \triangle y = y_{n+1} - y_n = \frac{\lambda D}{d} \text{ (for bright fringes) ... (7)}$$

Alternately, let y_m and $y_m + 1$ be the distances of the m th and $(m + 1)^{th}$ dark fringes respectively from the central bright fringe.

$$\therefore \frac{y_m d}{D} = (2m - 1)\frac{\lambda}{2} \text{ and}$$

$$\frac{y_{m+1} \; d}{D} = [2(m+1) - 1]\frac{\lambda}{2} = (2m+1)\frac{\lambda}{2} \quad ....(8)$$

$$\therefore y_m = (2m - 1)\frac{\lambda D}{2d} \text{ and}$$

$$y_{m+1} = (2m+1)\frac{\lambda D}{2d} \quad .....(9)$$

$\therefore$ The distance between consecutive dark fringes,

$$y_{m+1} - y_m = \frac{\lambda D}{2d}[(2m+1) - (2m-1)] = \frac{\lambda D}{d} \quad ....(10)$$

$\therefore W = y_{m+1} - y_m$

$= \frac{\lambda D}{d}$ (for dark fringes) .....(11)

Eqs. (7) and (11) show that the fringe width is the same for bright and dark fringes.

Q23. Why two or more mercury drops form a single drop when brought in contact with each other?

Solution

A spherical shape has the smallest surface area to volume ratio of all geometric forms. When a number of droplets coalesce and form a drop, there is reduction in the total surface area. In this case, energy is released to the surrounding.

Let n droplets each of radius r coalesce to form a single drop of radius R. As the volume of the liquid remains constant,

volume of the drop = volume of n droplets

$$\therefore \frac{4}{3}\pi R^3 = n \times \frac{4}{3}\pi r^3$$

$$\therefore R^3 = nr^3$$

$$\therefore R = \sqrt[3]{n}r$$

Surface area of n droplets = $n \times 4\pi r^2$

Surface area of the drop = $4\pi R^2 = 4\pi(\sqrt[3]{n}r)^2 = n^{2/3} \times 4\pi r^2$

$\therefore$ The change in the surface area = surface area of drop - surface area of n droplets

$= (n^{2/3} \times 4\pi r^2) - (n \times 4\pi r^2) = 4\pi r^2 \times (n^{2/3} - n)$

Since $(n^{2/3} - n)$ will always be negative there is a decrease in surface area therefore there is a decrease in surface energy.

Since every system in the universe tries to attain a minimum state of energy, a single drop forms when two or more drops are brought in contact.

Q24. What is the difference between a nuclear reactor and a nuclear bomb?

Solution

- **Nuclear Reactor**

A nuclear reactor is a machine where electricity and heat energy are generated by utilizing the power of atoms. In this mechanism, nuclear chain reactions are produced, controlled, and contained releasing a tremendous amount of energy. This controlled energy is used in electricity generation and radioactive isotopes production. These isotopes are used in the treatment and research of cancer in the medical field. All operating nuclear reactors are "critical." When reactors are running at a constant power level, they are said to be in a "critical condition."

These reactors use heavy atoms as fuel instead of fossil fuels. Fast-moving electrons strike a radioactive nucleus such as Plutonium-239 or Uranium-235 causing the nucleus to split. This splitting process is known as fission. In the process of fission, a tremendous amount of energy, radiation, and free electrons are released. These free electrons that are released are guided to strike other nuclei and so on causing a chain reaction.

Neutron moderators and neutron poisons control these fast-moving electrons and slow them down while becoming absorbed in other nuclei, thus managing the output of electricity from a reactor. The moderators are heavy water, water, and solid graphite.

- **Nuclear Bomb**

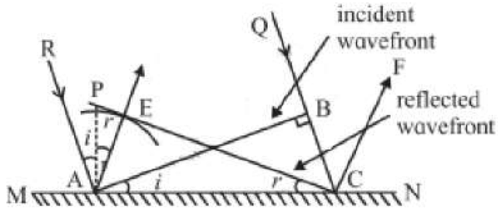
In a nuclear bomb, there is a nuclear device having massive destructive power coming from uncontrolled fusion and fission reactions. The fusion and fission processes generate a tremendous amount of energy with a small amount of matter. This matter is usually the unstable nuclei of Plutonium-239 and Uranium-235. An atom bomb is categorized as a fission bomb and a hydrogen bomb as a fusion bomb are both weapons of mass destruction. In World War II, Hiroshima and Nagasaki are recent examples of such mass destruction. In fusion bombs, nuclear fusion is the result of a huge amount of released energy while in the case of fission bombs the released energy is the result of fission reactions.

Q25. Derive the laws of reflection of light using Huygens' principle.

Explain reflection of light at a plane reflecting surface on the basis of Huygen's principle.

Solution

Reflection of a plane wavefront of light at a plane surface



Where MN: Plane mirror,
RA and QC: Incident rays,
AP: Normal to MN,
AB: Incident wavefront,
i: Angle of the incident,
CE: Reflected wavefront,
r: Angle of reflection

When wavefront AB is incident on the mirror, at first, point A becomes a secondary source and emits secondary waves in the same medium. If T is the time taken by the incident wavefront to travel from B to C, then BC = vT. During this time, the secondary wave originating at A covers the same distance, so that the secondary spherical wavelet has a radius vT at time T.

To construct the reflected wavefront, a hemisphere of radius vT is drawn from point A. Draw a tangent EC to the secondary wavelet.

The arrow AE shows the direction of propagation of the reflected wave.

AP is normal to MN at A.

∠RAP = i = angle of incidence and

∠PAE = r = angle of reflection

In ΔABC and ΔAEC,

AE = BC and ∠ABC = ∠AEC = 90°

∴ ΔABC and ΔAEC are congruent.

∴ ∠ACE = ∠BAC = i .....(1)

Also, as AE is perpendicular to CE and AP is perpendicular to AC,

∠ACE = ∠PAE = r .....(2)

∴ From Eqs (1) and (2),

i = r

Thus, the angle of incidence is equal to the angle of reflection. This is the first law of reflection. Also, it can be seen from the figure that the incident ray and reflected ray lie on the opposite sides of the normal to the reflecting surface at the point of incidence and all of them lie in the same plane. This is the second law of reflection. Thus, the laws of reflection of light can be deduced by Huygens' construction of a plane wavefront.

SECTION - D

Attempt any THREE questions of the following:

Q26.

26.1. Answer in brief.

State the postulates of Bohr's atomic model.

Solution

The postulates of Bohr's atomic model (for the hydrogen atom):

1. The electrons revolve around the nucleus in circular orbits. This is the same assumption as in Rutherford's model and the centripetal force necessary for the circular motion is provided by the electrostatic force of attraction between the electron and the nucleus.
2. The radius of the orbit of an electron can only take certain fixed values such that the angular momentum of the electron in these orbits is an integral multiple of $h/2\pi$, h being Planck's constant. Such orbits are called stable orbits or stable states of the electrons and electrons in these orbits do not emit radiation as is demanded by classical physics. Thus, different orbits have different and definite values of angular momentum and therefore, different values of energy.
3. An electron can make a transition from one of its orbits to another orbit having lower energy. In doing so, it emits a photon of energy equal to the difference in its energies in the two orbits.

26.2. A short bar magnet is placed in an external magnetic field of 700 gauss. When its axis makes an angle of 30° with the external magnetic field, it experiences a torque of 0.014 Nm. Find the magnetic moment of the magnet, and the work done in moving it from its most stable to the most unstable position.

Solution

Data: B = 700 gauss = 0.07 tesla, $\theta = 30°$, $\tau = 0.014$ Nm, $\tau = MB \sin\theta$

The magnetic moment of the magnet is

$$M = \frac{\tau}{B \sin\theta} = \frac{0.014}{(0.07)(\sin 30°)} = 0.4 \text{ A.m}^2$$

The most stable state of the bar magnet is for $\theta = 0°$. It is in the most unstable state when $\theta = 180°$. Thus, the work done in moving the bar magnet from 0° to 180° is

$W = MB (\cos \theta_0 - \cos \theta)$

$= MB (\cos 0° - \cos 180°)$

$= MB [1 - (- 1)]$

$= 2 MB$

$= (2)(0.4)(0.07)$

$= 0.056$ J

Q27. In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m^2 and the separation between the plates is 2 mm.

a. Calculate the capacitance of the capacitor.
b. If this capacitor is connected to 100 V supply, what would be the charge on each plate?
c. How would charge on the plates be affected if a 2 mm thick mica sheet of k = 6 is inserted between the plates while the voltage supply remains connected?

Solution

Data: k = 1 (air), $A = 6 \times 10^{-3}$ m^2, d = 2 mm = 2×10^{-3} m, V = 100 V, t = 2 mm = d, $k_1 = 6$, $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

a) The capacitance of the air capacitor,

$$C_0 = \frac{\varepsilon_0 A}{d}$$

$$= \frac{(8.85 \times 10^{-12})(6 \times 10^{-3})}{(2 \times 10^{-3})}$$

$= 26.55 \times 10^{-12}$ F

= 26.55 pF

b) $Q_0 = C_0V$

$= (26.55 \times 10^{-12})(100)$

$= 26.55 \times 10^{-10}$ C

= 2.655 nC

c) The relative permittivity dielectric k_1 entirely fills the space between the plates ($\because$ t = d), resulting in $C = k_1C_0$ as the new capacitance.

V remains the same while the supply is connected.

$\therefore Q = CV = kC_0V = kQ_0 = 6(2.655 \text{ nF}) = 15.93 \text{ nC}$

Therefore, the charge on the plates increases.

Q28.

28.1. On what factors do the degrees of freedom depend?

Solution

The degrees of freedom depends upon
(i) the number of atoms forming a molecule
(ii) the structure of the molecule
(iii) the temperature of the gas.

28.2. An aircraft of wing span of 50 m flies horizontally in the Earth's magnetic field of 6×10^{-5} T at a speed of 400 m/s. Calculate the emf generated between the tips of the wings of the aircraft.

Solution 1

Data: l = 50 m, $B = 6 \times 10^{-5}$ T, v = 400 m/s

The magnitude of the induced emf,

$|e| = Blv = (6 \times 10^{-5})(400)(50) = 1.2$ V

Solution 2

Induced emf between tips of wings,

$e = Blv$

$= 6 \times 10^{-5} \times 50 \times 400$

$= 1.2$ V

Q29. In a Faraday disc dynamo, a metal disc of radius R rotates with an angular velocity ω about an axis perpendicular to the plane of the disc and passing through its center. The disc is placed in a magnetic field B acting perpendicular to the plane of the disc. Determine the induced emf between the rim and the axis of the disc.

Solution

Assume a thin conducting disc with radius R is rotated anticlockwise around its axis in a plane perpendicular to a uniform magnetic field of induction $\vec{B}$ (see the figure in the above Note for reference). The arrow $\vec{B}$ points downward. Let the constant angular speed of the disc be ω.

Consider an infinitesimal element with radial thickness dr at r from the rotation axis. The area traced by the element in one rotation is dA = 2πrdr. Therefore, the time rate at which the element traces out the area is $\frac{dA}{dt}$ = frequency of rotation x dA = fdA

where $f = \frac{\omega}{2\pi}$ is the frequency of rotation.

$$\therefore \frac{dA}{dt} = \frac{\omega}{2\pi}(2\pi r dr) = \omega r dr$$

The total emf induced between the axle and the rim of the rotating disc is

$$|e| = \int B\frac{dA}{dt}$$

$$= \int_0^R B\omega r dr$$

$$= B\omega \int_0^R r dr$$

$$= B\omega \frac{R^2}{2}$$

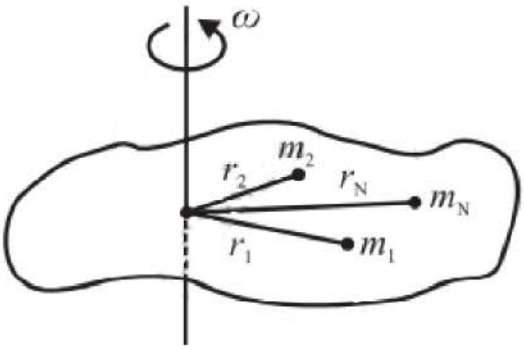
$$= \frac{1}{2}\left(B\omega R^2\right)$$

For anticlockwise rotation in $\vec{B}$ pointing down, the axle is at a higher potential.

Q30. Answer in brief:

Derive an expression which relates angular momentum with the angular velocity of a rigid body.

Solution



The figure above shows a rigid object rotating with a constant angular speed ω about an axis perpendicular to the plane of paper. For theoretical simplification let us consider the object to be consisting of N number of particles of masses m_1, m_2, ..., m_N at respective perpendicular distances r_1, r_2,..., r_N, respectively from the axis of rotation.

As the object rotates, all these particles perform UCM with same angular speed ω , but with different linear speeds

$$v_1 = r_1\omega,\ v_2 = r_2\omega,\ \ldots,\ v_N = r_N\omega.$$

Directions of individual velocities $\vec{v}_1, \vec{v}_2, \ldots, \vec{v}_N$ are along the tangents to their respective tracks.

Linear momentum of the first particle is of magnitude

$p_1 = m_1 v_1 = m_1 r_1 \omega$

Its angular momentum, defined by $\vec{L}_1 = \vec{p}_1 \times \vec{r}_1$, is thus of magnitude

$L_1 = p_1 r_1 = m_1 r_1 \omega r_1 = m_1 r_1^2 \omega$

Similarly, $L_2 = m_2 r_2^2 \omega$, $L_3 = m_3 r_3^2 \omega$, ..., $L_N = m_N r_N^2 \omega$

The angular momentum of the body about the given axis is

$L = L_1 + L_2 + ... + L_N$

$= m_1 r_1^2 \omega + m_2 r_2^2 \omega + ... + m_N r_N^2 \omega$

$= \left(m_1 r_1^2 + m_2 r_2^2 + ... + m_N r_N^2\right)\omega$

$\therefore L = I\omega$

where $I = \left(m_1 r_1^2 + m_2 r_2^2 + ... + m_N r_N^2\right)$ is the moment of inertia of the body about the given axis of rotation.

In vector form, $\vec{L} = I\vec{\omega}$

Thus, angular momentum = moment of inertia × angular velocity.