Physics

TOP 100

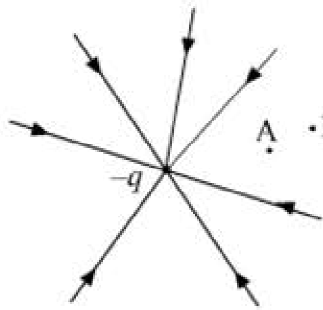
Questions & Solutions

Class 12

Meritnation Top 100 Questions
Grade - 12 (Physics)

Electric Charges and Fields

1. The field lines of a negative point charge are as shown in the figure. Does the kinetic energy of a small negative charge increase or decrease in going from B to A?



All India 2015

2. An electric dipole of length 4 cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $4\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has charge ±8 nC. **Delhi 2014**

3. An electric field exists in a region given by the equation:

$$\vec{E} = (a\hat{i} + b\hat{j}) \text{ N/C}$$

What is the electric flux through area $\vec{A}$, which lies in the xy plane?

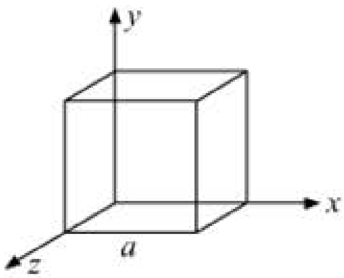
4. Four charges $+q$, $-q$, $+q$ and $-q$ are to be arranged respectively at the four corners of a square ABCD of side 'a'.

(a) Find the work required to put together this arrangement.
(b) A charge q_0 is brought to the centre of the square, the four charges being held fixed. How much extra work is needed to do this ? **Abroad 2015**

5. (a) An electric dipole of dipole moment $\vec{p}$ consists of point charges $+q$ and $-q$ separated by a distance $2a$ apart. Deduce the expression for the electric field $\vec{E}$ due to the dipole at a distance x from the centre of the dipole on its axial line in terms of the dipole moment $\vec{p}$.

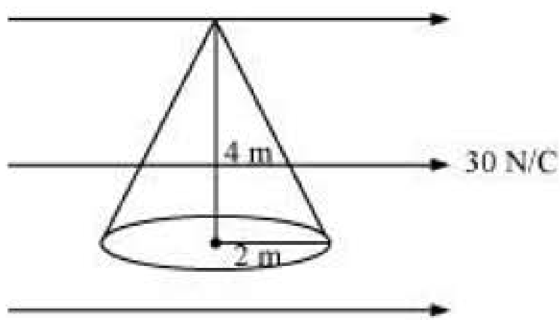
Hence show that in the limit $x >> a, \vec{E} \to 2\vec{p} / (4\pi \varepsilon_0 x^3)$.

(b) Given the electric field in the region $\vec{E} = 2x\hat{i}$, find the net electric flux through the cube and the charge enclosed by it.



Delhi 2015

6. A uniform electric field exists in a region (as shown below). In this region, a cone is placed such that its axis is perpendicular to the direction of the electric field.



7. (a) Deduce the expression for the torque acting on a dipole of dipole moment $\vec{P}$ in the presence of a uniform electric field $\vec{E}$.

(b) Consider two hollow concentric spheres, S_1 and S_2, enclosing charges 2Q and 4Q respectively as shown in the figure. (i) Find out the ratio of the electric flux through them. (ii) How will the electric flux through the sphere S_1 change if a medium of dielectric constant 'ε_r' is introduced in the space inside S_1 in place of air ? Deduce the necessary expression.

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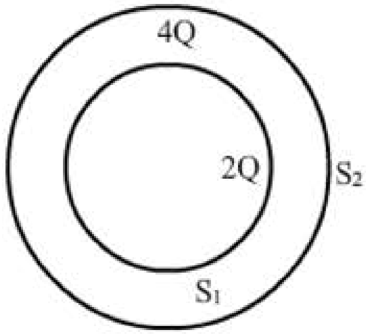

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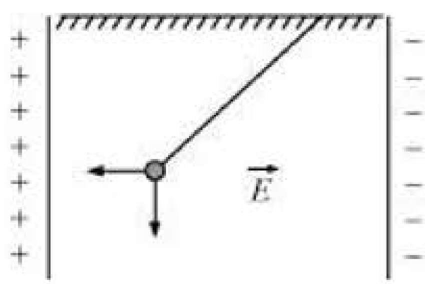

A bob of mass m with a charge $-q$ is set to oscillation. The time period recorded followed the equation:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Now, a uniform electric field E is applied (as shown in the given figure). Obtain a formula for calculating the time period in the above case.

Electrostatic Potential and Capacitance

9. A point charge $+Q$ is placed at point O, as shown in the figure. Is the potential difference $V_A - V_B$ positive, negative or zero? **Delhi 2016**

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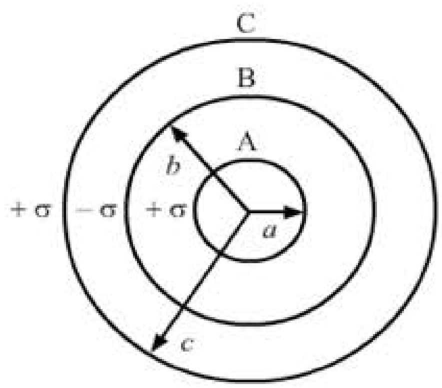
10. A capacitor of 150 pF is charged by a 200 V battery. The battery is then disconnected and the charge capacitor is connected to another uncharged capacitor of 50 pF. Calculate the difference between the final energy stored in the combined system and the initial energy stored in the single capacitor. **Abroad 2012**

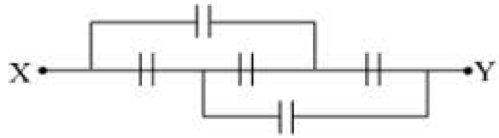
11. (a) An electron is 20 cm away from a fixed point charge, $Q = -0.250\ \mu C$. If it starts to move from rest, then how fast will it be moving when it is at a distance?
(b) How much work is done in bringing three electrons, which are initially a great distance apart, to form an equilateral triangle with sides 2×10^{-10} m?

12. Three concentric metallic shells A, B and C or radii a, b and c (a < b < c) have surface charge densities + σ, −σ and + σ, respectively as shown in the figure.



If shells A and C are at the same potential, then obtain the relation between the radii a, b and c. **Abroad 2014**

13. Find the equivalent capacitance of the network shown in the figure, when each capacitor is of 1 μF. When the ends X and Y are connected to a 6 V battery, find out (i) the charge and (ii) the energy stored in the network.



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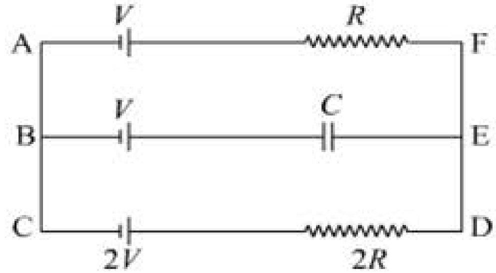
14. In the given circuit in the steady state, obtain the expressions for (a) the potential drop (b) the charge and (c) the energy stored in the capacitor, C.



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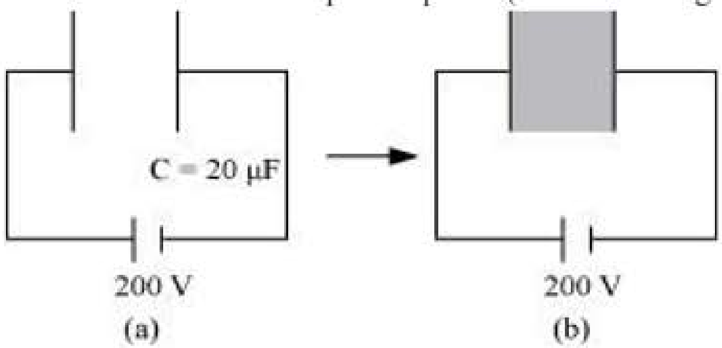
15. A capacitor was initially charged (as shown in figure *a*). Then, a dielectric of dielectric constant K = 4 was introduced between the capacitor plates (as shown in figure *b*).



(a) What is the new capacitance?
(b) How much charge is gained or lost by the capacitor after the dielectric is introduced?
(c) How much energy is gained or lost by the capacitor after the dielectric is introduced?

16. An electric field of 600 N/C is desired between the capacitor plates kept 2 mm apart. What value of potential difference must be applied across the plates?

Current Electricity

17. An ammeter of resistance 0.80 Ω can measure current up to 1.0 A.

(i) What must be the value of shunt resistance to enable the ammeter to measure current up to 5.0 A?
(ii) What is the combined resistance of the ammeter and the shunt?

Delhi 2013

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18. A cell of emf 'E' and internal resistance 'r' is connected across a variable resistor 'R'. Plot a graph showing variation of terminal voltage 'V' of the cell versus the current 'I'. Using the plot, show how the emf of the cell and its internal resistance can be determined.

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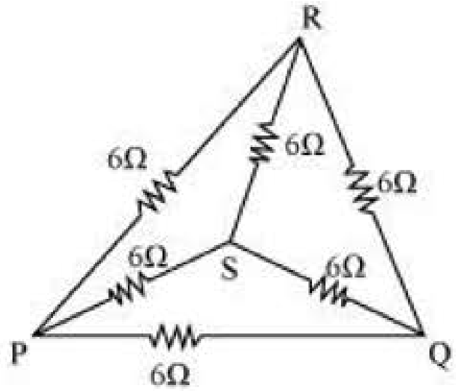
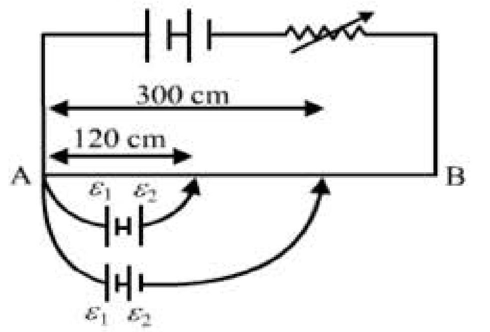


(a) What is the equivalent resistance between points **P** and **Q**?

(b) A balance point of 65 cm is obtained when a certain cell is connected to a potentiometer. With another cell (whose emf differs by 0.2 V), the balance point obtained is 60 cm. What is the emf of each cell?

20. (a) State the principle of a potentiometer. Define potential gradient. Obtain an expression for potential gradient in terms of resistivity of the potentiometer wire.

(b) Figure shows a long potentiometer wire AB having a constant potential gradient. The null points for the two primary cells of emfs ε_1 and ε_2 connected in the manner shown are obtained at a distance of $l_1 = 120$ cm and $l_2 = 300$ cm from the end A. Determine (i) $\varepsilon_1/\varepsilon_2$ and (ii) position of null point for the cell ε_1 only.

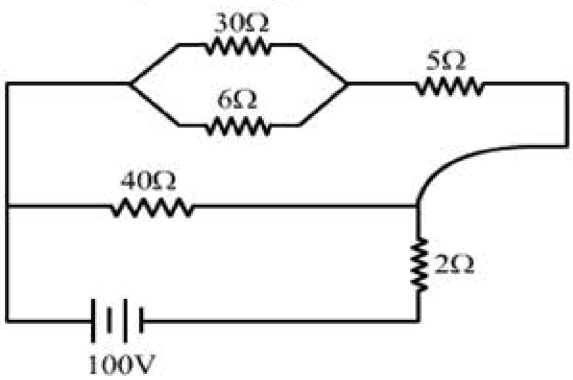


Abroad 2014

21. If it has direction , then why is current not classified as a vector quantity?

22. (a) Define the term 'drift velocity' of charge carriers in a conductor. Obtain the expression for the current density in terms of relaxation time.

(b) A 100 V battery is connected to the electric network as shown. If the power consumed in the 2 Ω resistor is 200 W, determine the power dissipated in the 5 Ω resistor.



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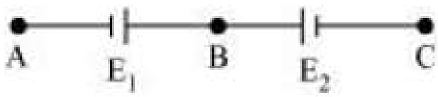
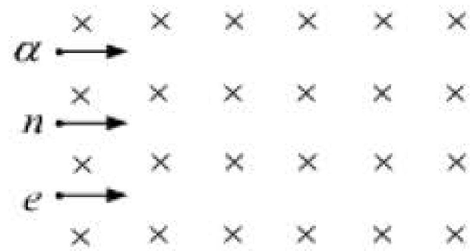


When a potentiometer is connected between points A and B, the balancing length is found to be 4 m. When the potentiometer is connected between points A and C, the balancing length is found to be 2 m. Calculate the ratio of E_1 and E_2.

Moving Charges and Magnetism

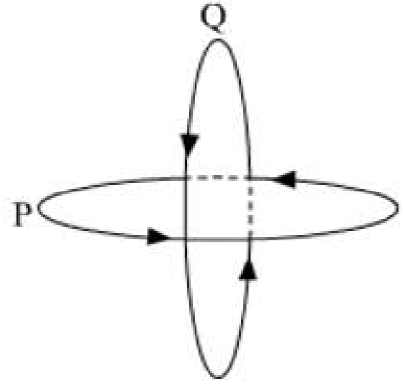
24. (a) Write the expression for the magnetic force acting on a charged particle moving with velocity v in the presence of magnetic field B.

(b) A neutron, an electron and an alpha particle, moving with equal velocities, enter a uniform magnetic field going into the plane of the paper, as shown. Trace their paths in the field and justify your answer.



Delhi 2016

25. Two identical coils P and Q each of radius R are lying in perpendicular planes such that they have a common centre. Find the magnitude and direction of the magnetic field at the common centre of the two coils, if they carry currents equal to I and $\sqrt{3}$ I respectively.



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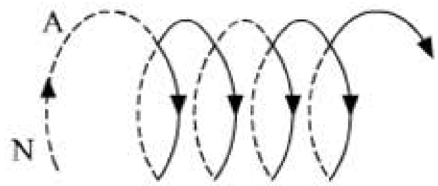
26. (a) State Ampere's circuital law. Use this law to obtain the expression for the magnetic field inside an air cored toroid of average radius 'r', having 'n' turns per unit length and carrying a steady current I.

(b) An observer to the left of a solenoid of N turns each of cross section area 'A' observes that a steady current I in it flows in the clockwise direction. Depict the magnetic field lines due to the solenoid specifying its polarity and show that it acts as a bar magnet of magnetic moment m = NIA.



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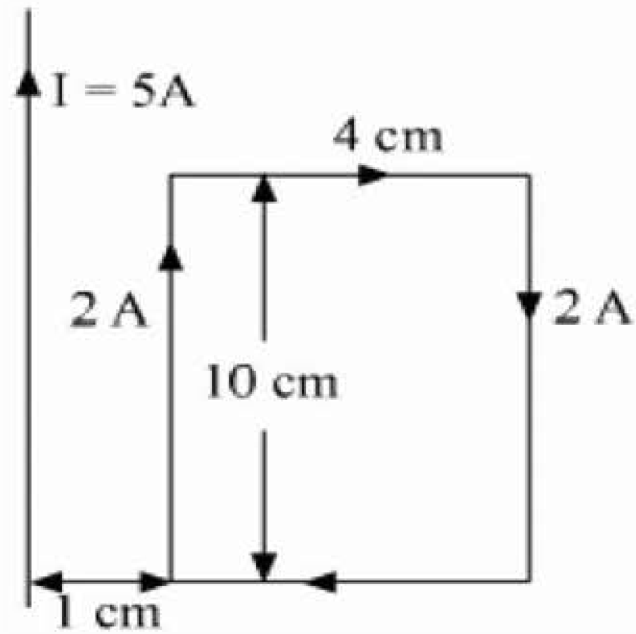
27. (a) Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(b) Answer the following:
(i) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer?
(ii) Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain, giving reason. **All India 2014**

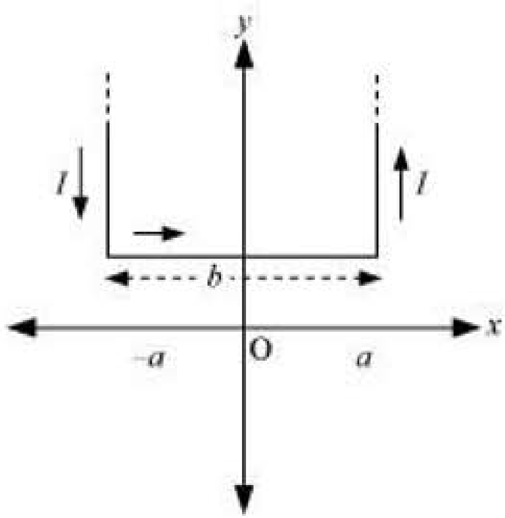
28. Electric field is defined as $\vec{E} = \frac{\vec{F}_E}{q}$, where $\vec{F}_E$ is the electric force exerted on a test particle q. Why cannot a similar approach be used for defining magnetic field? How is it defined instead?

29. A rectangular loop of wire of size 4 cm × 10 cm carries a steady current of 2 A. A straight long wire carrying 5 A current is kept near the loop as shown. If the loop and the wire are coplanar, find

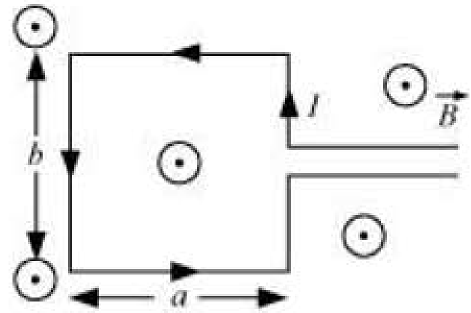


(i) the torque acting on the loop and
(ii) the magnitude and direction of the force on the loop due to the current carrying wire.

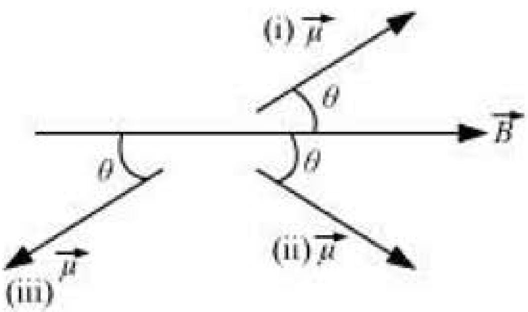
30. (a) What is the magnetic field (in terms of I, a and b) at the origin O because of the current loop shown in the figure?



(b) What is the torque on the given rectangular loop? The direction of magnetic field is outside the page, as shown by the dots.



31. The given figure shows three magnetic dipole moment $\vec{\mu}$ orientations. Rank the orientations according to



(a) The magnitude of the torque on the dipole

(b) The potential energy of the dipole

Magnetism and Matter

32. In what way is Gauss's law in magnetism different from that used in electrostatics? Explain briefly. The Earth's magnetic field at the Equator is approximately 0.4 G. Estimate the Earth's magnetic dipole moment. Given : Radius of the Earth = 6400 km. **All India 2015**

33. A magnetic needle with magnetic moment 3.6×10^{-2} A m^2 and moment of inertia 7.1×10^{-5} kg m^2 is placed in a magnetic field of strength 0.3 T. What is the frequency of its oscillations?

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34. Out of the two magnetic materials, 'A' has relative permeability slightly greater than unity while 'B' has less than unity. Identify the nature of the materials 'A' and 'B'. Will their susceptibilities be positive or negative? **Delhi 2014**

35. A short bar magnet of magnetic moment 0.9 J/T is placed with its axis at 30° to a uniform magnetic field. It experiences a torque of 0.063 J.

(i) Calculate the magnitude of the magnetic field.
(ii) In which orientation will the bar magnet be in stable equilibrium in the magnetic field?
Abroad 2012

36. (a) A solenoid of cross-sectional area 3×10^{-4} m^2 and 800 turns is placed with its axis at 45° in an external magnetic field of 900 G. It experiences a torque of 0.015 Nm.

i. What is the magnetic moment of the solenoid if a current of 1.5 A flows through it?

ii. What is the work done in moving it from its most stable to its most unstable position?

iii. The solenoid is replaced with a bar magnet of same magnetic moment. What is the torque experienced by it if it is placed at the same angle?

(b) If magnetic monopoles existed, then how would Gauss' law for magnetism be modified?

Electromagnetic Induction

37. Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why?

Delhi 2014

38. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the place is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased? **All India 2013**

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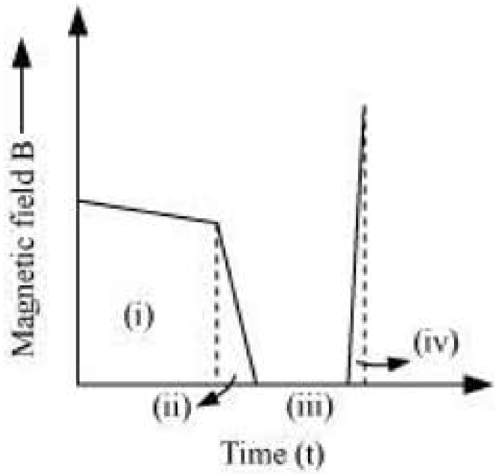
39.



A magnetic field exists inside a cylindrical conductor such that it is parallel to the length of the conductor. The variation of this magnetic field with time is indicated in the given figure. What is the order of magnitude of induced emf for regions (i), (ii), (iii), and (iv) in the above graph.

40. A circular coil of radius 10 cm, 500 turns and resistance 200 Ω is placed with its plane perpendicular to the horizontal component of the Earth's magnetic field. It is rotated about its vertical diameter through 180° in 0.25 s. Estimate the magnitude of the emf and current induced in the coil. (Horizontal component of the Earth's magnetic field at the place is 3.0×10^{-5} T)

Abroad 2016

41. Consider a straight conductor moving in a uniform time-independent magnetic field. The conductor PQ moves over the rectangular conductor TSRU with a constant speed 'v'. Assuming that there is no friction, the emf induced is $\varepsilon = -\dfrac{d\phi}{dt}$.

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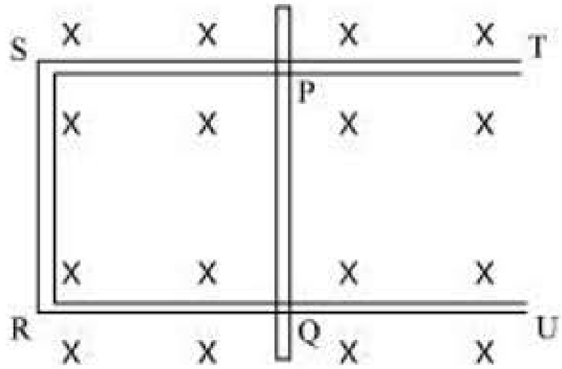
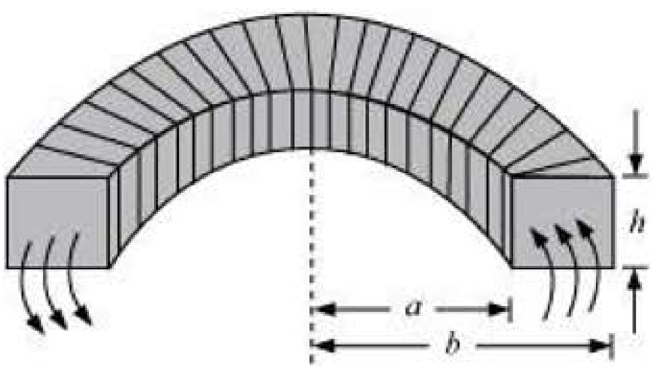


Now, suppose there is friction acting between conductor PQ and frame TSRU, and conductor PQ is still moving with the same speed 'v'. Determine whether the induced emf is different in this case. Give reasons.

42. The cross-section of a round toroid is shown in the given figure



Calculate the self-inductance of a toroid having N turns and a rectangular cross-section with inner radius a, outer radius b, and height h as shown.

43. A metallic rod of length 'l' is rotated with a frequency v with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius r, about an axis passing through the centre and perpendicular to the plane of the ring. A constant uniform magnetic field B parallel to the axis is present everywhere. Using Lorentz force, explain how emf is induced between the centre and the metallic ring and hence obtained the expression for it.

Delhi 2013

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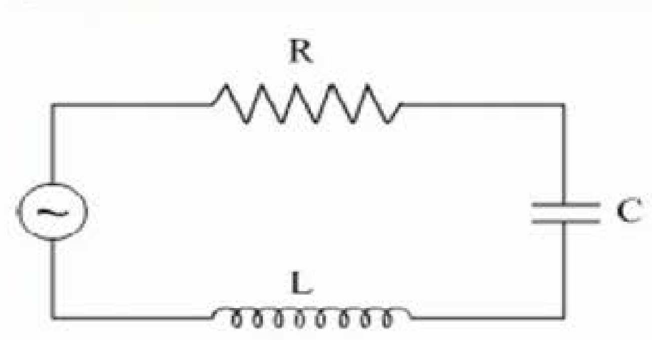
Alternating Current

44. The power factor of an a.c. circuit is 0.5. What is the phase difference between voltage and current in this circuit ? **Abroad 2015**

45. The figure shows a series LCR circuit with L = 10.0 H, C = 40 μF, R = 60 Ω connected to a variable frequency 240 V source, calculate

(i) the angular frequency of the source which drives the circuit at resonance,
(ii) the current at the resonating frequency,
(iii) the rms potential drop across the inductor at resonance. **Delhi 2012**



46. (i) Write the function of a transformer. State its principle of working with the help of a diagram. Mention various energy losses in this device.

(ii) The primary coil of an ideal step-up transformer has 100 turns and the transformation ratio is also 100. The input voltage and power are 220 V and 1100 W, respectively. Calculate the

(a) number of turns in secondary

(b) current in primary

(c) voltage across secondary

(d) current in secondary **Delhi 2016**

47. A 2 μF capacitor, 100 Ω resistor and 8 H inductor are connected in series with an AC source.

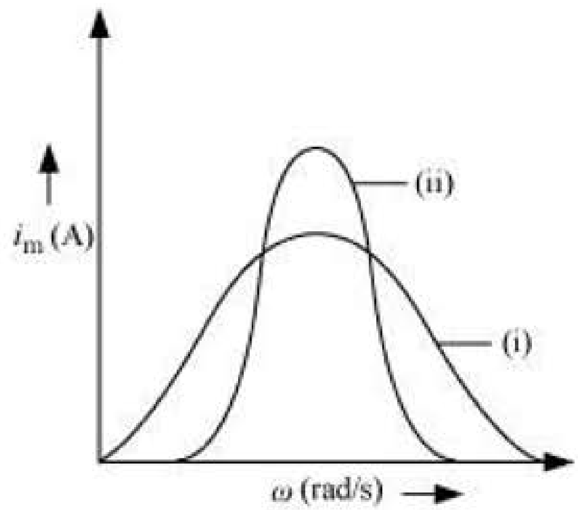
(i) What should be the frequency of the source such that current drawn in the circuit is maximum? What is this frequency called?

(ii) If the peak value of e.m.f. of the source is 200 V, find the maximum current.

(iii) Draw a graph showing variation of amplitude of circuit current with changing frequency of applied voltage in a series LRC circuit for two different values of resistance R_1 and R_2 ($R_1 > R_2$).

(iv) Define the term 'Sharpness of Resonance'. Under what condition, does a circuit become more selective?
Abroad 2016

48.



The current vs. frequency plots of two circuits having the same inductance and capacitance, but different resistance is shown above. Which of the two circuits will have a higher resistance?

49. (a) What is meant by 'reflected resistance' of a transformer?

(b) How can the loss of energy, due to leakage of magnetic flux, in a pair of transformer coils be minimized?

(c) A transformer operates at V_p = 8.5 kV and V_s= 120 V (both are r.m.s. values). Assuming an ideal transformer with 100% efficiency, determine the following:

i. Turns ratio of the transformer.

ii. Rms currents in the primary and secondary of the transformer, if the rate of energy consumption in the areas served by the transformer is 78 kW.

50. Show that the net energy stored in a capacitor and inductor in a freely oscillating LC circuit is constant with time. Plot the energies on an energy vs. time graph.

Electromagnetic Waves

51. (a) An em wave is travelling in a medium with a velocity $\vec{v} = v\,\hat{i}$. Draw a sketch showing the propagation of the em wave, indicating the direction of the oscillating electric and magnetic fields.

(b) How are the magnitudes of the electric and magnetic fields related to velocity of the em wave? **Delhi 2013**

52. Answer the following:

(a) Name the em waves which are suitable for radar systems used in aircraft navigation. Write the range of frequency of these waves.
(b) If the earth did not have atmosphere, would its average surface temperature be higher or lower than what it is now? Explain.
(c) An em wave exerts pressure on the surface on which it is incident. Justify. **Delhi 2014**

53. A capacitor, made of two parallel plates each of plate area A and separation d, is being charged by an external ac source. Show that the displacement current inside the capacitor is the same as the current charging the capacitor. **All India 2013**

54. The amount of light energy that continuously falls on a surface for one minute is 3.52×10^5 J. What is the magnitude of force exerted on the surface?

55. The expression for electric field associated with a plane electromagnetic wave is

$$\vec{E}(z,t) = E_0 \cos(kz - \omega t)\hat{i}$$

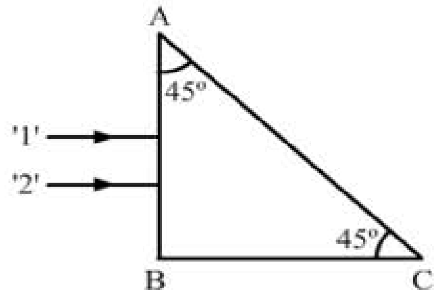
(a) What is the direction of propagation of the wave?

(b) What is the amplitude of magnetic field in terms of E_0. What is the corresponding expression for magnetic field $\vec{B}$?

Ray Optics and Optical Instruments

56. How does focal length of a lens change when red light incident on it is replaced by violet light? Give reason for your answer. **Abroad 2012**

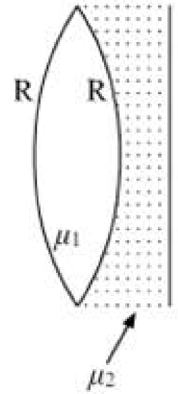
57. Two monochromatic rays of light are incident normally on the face AB of an isosceles right-angled prism ABC. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.35 and 1.45. Trace the path of these rays after entering the prism.



All India 2014

58. A convex lens of focal length 20 cm is placed coaxially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm apart. A point object lies 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed. **All India 2014**

59. A biconvex lens with its two faces of equal radius of curvature R is made of a transparent medium of refractive index μ_1. It is kept in contact with a medium of refractive index μ_2 as shown in the figure.

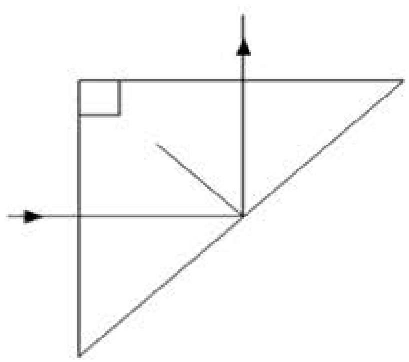


(a) Find the equivalent focal length of the combination.
(b) Obtain the condition when this combination acts as a diverging lens.
(c) Draw the ray diagram for the case $\mu_1 > (\mu_2 + 1) / 2$, when the object is kept far away from the lens. Point out the nature of the image formed by the system. **All India 2015**

60. (i) Plot a graph to show variation of the angle of deviation as a function of angle of incidence for light passing through a prism. Derive an expression for refractive index of the prism in terms of angle of minimum deviation and angle of prism.

(ii) What is dispersion of light? What is its cause?

(iii) A ray of light incident normally on one face of a right isosceles prism is totally reflected, as shown in fig. What must be the minimum value of refractive index of glass? Give relevant calculations.



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61. An equiconvex lens of focal length 12 cm is vertically cut into halves of equal thickness. What is the focal length of each half?

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62. An air bubble trapped inside a glass sphere of radius 0.01 m appears to be 0.005 m below the surface, when observed along a diameter containing the bubble. Find the real depth of the bubble inside the sphere along the line of sight. ($\mu = 1.54$)

63. (a) A combination of a flint glass prism $(\mu_v' = 1.688, \mu_r' = 1.650)$ and a crown glass prism ($\mu_v = 1.523$, $\mu_r = 1.515$) produces dispersion of light without deviation. The angle of prism of the crown glass prism is 6°. What should be the angle of prism in the flint glass prism?

(b) What is meant by the dispersive power of a prism? Which of the two prisms (of the same material) of angles A_1 and A_2 ($A_1 > A_2$) has a greater dispersive power?

Wave Optics

64. (a) Show, with the help of a diagram, how unpolarised sunlight gets polarised due to scattering.

(b) Two polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. An unpolarised light of intensity I_o is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its pass axis makes an angle of 45° with that of P_1. Determine the intensity of light transmitted through P_1, P_2 and P_3. **All India 2014**

65. Answer the following questions :

(a) In a double slit experiment using light of wavelength 600 nm, the angular width of the fringe formed on a distant screen is 0.1°. Find the spacing between the two slits.

(b) Light of wavelength 5000 Å propagating in air gets partly reflected from the surface of water. How will the wavelengths and frequencies of the reflected and refracted light be affected?

66. (a) Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

(b) Two wavelengths of sodium light of 590 nm and 596 nm are used in turn to study the diffraction taking place at a single slit of aperture 2×10^{-6} m. The distance between the slit and the screen is 1·5 m. Calculate the separation between the positions of first maxima of the diffraction pattern obtained in the two cases. **All India 2014**

Meritnation Top 100 Questions
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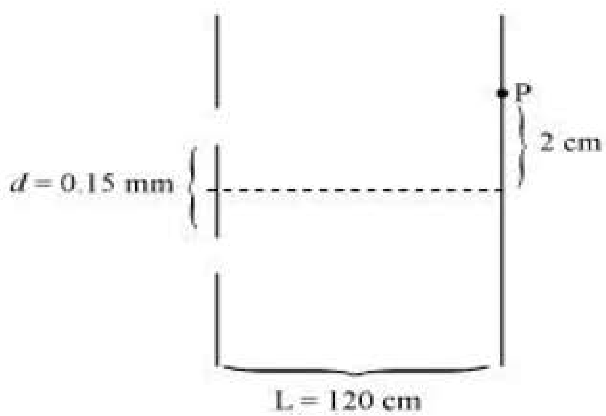
67. (a) Use Huygens' principle to show the propagation of a plane wavefront from a denser medium to a rarer medium. Hence find the ratio of the speeds of wavefronts in the two media.

(b) (i) Why does an unpolarised light incident on a polaroid get linearly polarised ?
(ii) Derive the expression of Brewster's law when unpolarised light passing from a rarer to a denser medium gets polarised on reflection at the interface.

68. Explain why two incoherent sources of light do not produce observable interference patterns?

69. Consider the double slit arrangement given below:



(a) A light of wavelength $\lambda = 833$ nm is made incident on the slits.

(i) What is the path difference δ for the rays from the two slits arriving at point P?

(ii) Express this path difference in terms of λ.

(iii) Does point P correspond to a maximum, minimum, or intermediate situation?

(b) The spectral line of an element present in a star is shifted towards the longer wavelength side. The star moves away from the Earth with a speed of 6.5×10^5 m/s. What is the red shift percentage of the given star?

70. (a) To obtain a pure interference pattern, why are the slits taken (for a double slit experiment) kept very small?

(b) Graphically, represent the intensity of a single slit diffraction as function of θ for $a = \lambda$ and for $a = 2\lambda$.

(c) A monochromatic light is incident on a single slit of width 0.800 mm and a diffraction pattern is formed on a screen 0.8 m away. The second order bright fringe is at a distance of 1.6 mm from the centre of the central maximum. What is the wavelength of the incident light?

Dual Nature of Matter and Radiation

71. (i) Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface.

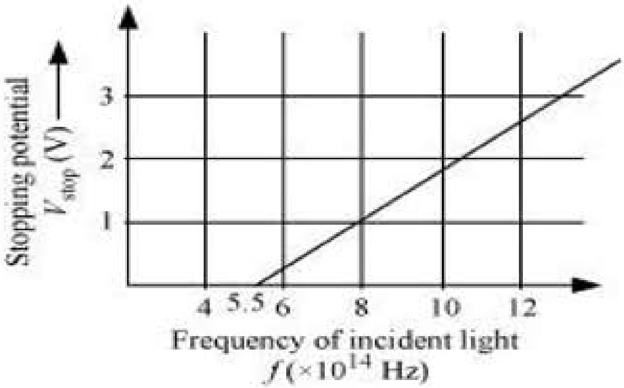
72. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain.

Abroad 2014

73. Define the term "cut off frequency" in photoelectric emission. The threshold frequency of a metal is f. When the light of frequency 2f is incident on the metal plate, the maximum velocity of photo-electrons is v_1. When the frequency of the incident radiation is increased to 5f, the maximum velocity of phto-electrons is v_2. Find the ratio $v_1 : v_2$. **Abroad 2016**

74. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc. to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which used yellow light? **All India 2014**

75.



An experiment was performed to plot the variation of stopping potential with the frequency of incident light (as shown in the given figure). Use the given graph to obtain the value of Planck's constant *h*.

76. (a) For a given photosensitive surface, yellow light does not eject any photoelectrons while green light does. Determine which light- red or violet will emit photoelectrons from it?

(b) Read the statement below:

The minimum energy required to eject an electron from metallic sodium is 2.28 eV.

Now, answer the following questions:

i. Does red light cause photoelectric emission when it is incident on it?

(Wavelength of red light = 680 nm)

ii. What is the cut-off wavelength for photoelectric emission from sodium?

iii. What colour does it correspond to?

Atoms

77. (i) State Bohr postulate of hydrogen atom that gives the relationship for the frequency of emitted photon in a transition.

(ii) An electron jumps from fourth to first orbit in an atom. How many maximum number of spectral lines can be emitted by the atom? To which series these lines correspond? **Abroad 2016**

Meritnation Top 100 Questions
Grade - 12 (Physics)

78. A 12.3 eV electron beam is used to bombard gaseous hydrogen at room temperature. Upto which energy level the hydrogen atoms would be excited?

Calculate the wavelengths of the second member of Lyman series and second member of Balmer series. **Delhi 2014**

79. How does one explain, using de Broglie hypothesis, Bohr's second postulate of quantization of orbital angular momentum? **All India 2015**

80. Define ionization energy.

How would the ionization energy change when electron in hydrogen atom is replaced by a particle of mass 200 times that of electron but having the same charge ? **All India 2016**

81. The relation between impact parameter 'b' and scattering angle 'θ' is

$$b = \frac{Ze^2 \cot\frac{\theta}{2}}{4\pi \epsilon_0 \left(\frac{mv^2}{2}\right)}$$

$v \rightarrow$ Velocity of the projectile (α-particle)

$m \rightarrow$ Mass of the projectile (α-particle)

(a) What is the scattering angle of a α-particle if its impact parameter is zero?

(b) Two α-particles having the same impact parameter, but one having greater energy than the other, bombard a gold foil. Which of them will exhibit a greater scattering angle?

(c) What is the impact parameter of an α-particle if its energy is 20 MeV and scattering angle is 90° for a gold nucleus?

82. Verify Bohr's Second postulate using de Broglie wavelength of an electron.

Nuclei

Meritnation Top 100 Questions
Grade - 12 (Physics)

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83. Distinguish between nuclear fission and fusion. Show how in both these processes energy is released.

Calculate the energy release in MeV in the deuterium-tritium fusion reaction :

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + n$$

Using the data :

$m(^{2}_{1}H) = 2.014102\ u$

$m(^{3}_{1}H) = 3.016049\ u$

$m(^{4}_{2}He) = 4.002603\ u$

$m_n = 1.008665\ u$

$1u = 931.5\ MeV/c^2$ **Delhi 2015**

84. Obtain the relation between the decay constant and half life of a radioactive sample.

The half life of a certain radioactive material against α-decay is 100 days. After how much time, will the undecayed fraction of the material be 6.25%? **All India 2015**

85. (a) Write the basic nuclear process involved in the emission of β^+ in a symbolic form, by a radioactive nucleus.

(b) In the reactions given below:

(i) $^{11}_{6}C \rightarrow ^{z}_{y}B + x + \nu$

(ii) $^{12}_{6}C + ^{12}_{6}C \rightarrow ^{20}_{a}Ne + ^{c}_{b}He$

Find the values of *x*, *y*, and *z* and *a*, *b* and *c*. **All India 2016**

Meritnation Top 100 Questions
Grade - 12 (Physics)

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86. (a) In a typical nuclear reaction, e.g.

$$^2_1H + ^2_1H \longrightarrow ^3_2He + n + 3.27\ MeV$$

,

although number of nucleons is conserved, yet energy is released. How? Explain.
(b) Show that nuclear density in a given nucleus is independent of mass number A.

87. Why is the mass of a nucleus always less than the sum of the masses of its constituent protons and neutrons?

88. (b) A sample has an average life of 2 days. What is its disintegration constant?

(b) The half-life of 16 g of a sample of pure radioactive element is 4 days. How much of the sample will be disintegrated after 16 days?

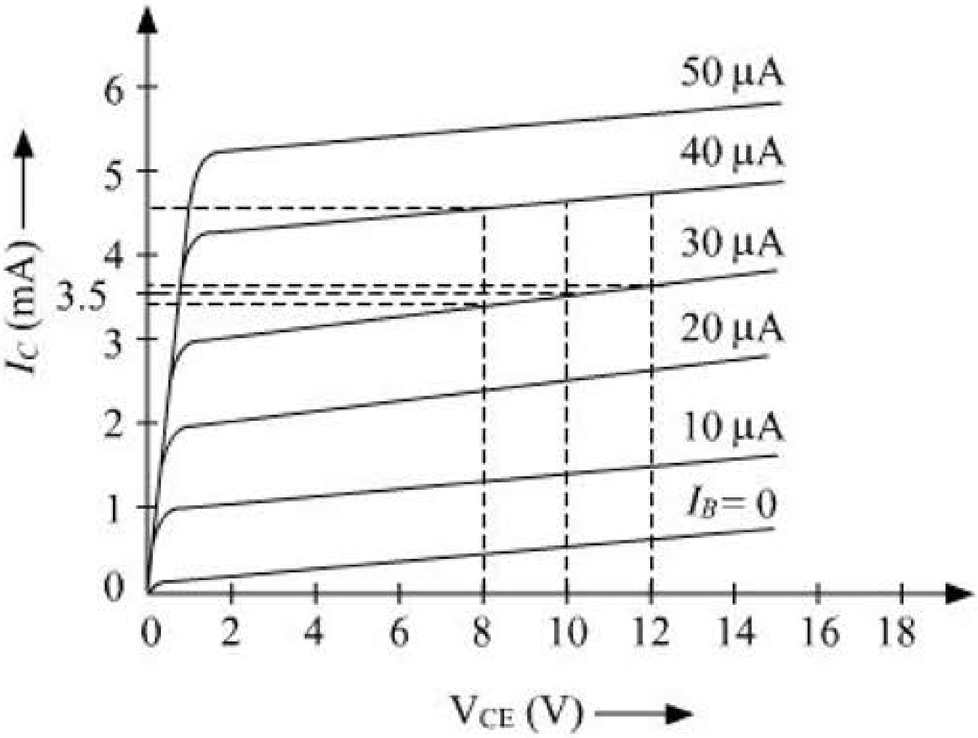
(c) What is difference between half-life and average life of a sample?

Semiconductor Electronics: Materials, Devices and Simple Circuits

89. For a CE-transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 2 V. Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 kΩ. **All India 2016**

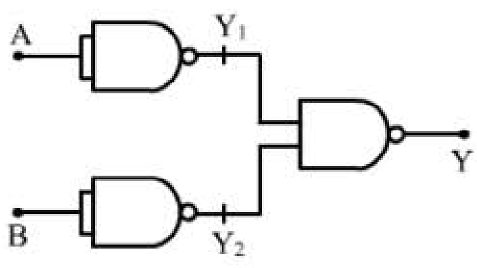
90. Output characteristics of an n-p-n transistor in CE configuration is shown in the figure.

Determine:
(i) dynamic output resistance
(ii) dc current gain and
(iii) ac current gain at an operating point $V_{CE} = 10$ V, when $I_B = 30\ \mu A$.



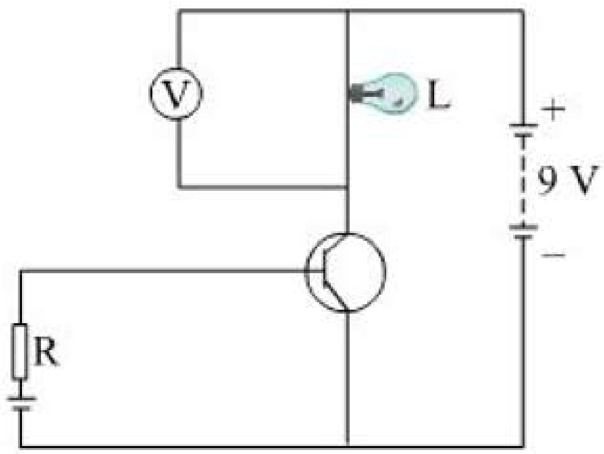
Delhi 2013

91. Identify the equivalent gate represented by the circuit shown in the figure. Draw its logic symbol and write the truth table.



Abroad 2014

92. In the given circuit diagram a voltmeter 'V' is connected across a lamp 'L'. How would (i) the brightness of the lamp and (ii) voltmeter reading 'V' be affected, if the value of resistance 'R' is decreased? Justify your answer.



Delhi 2013

93. A pure silicon crystal has 5×10^{28} atoms/m^3. It is converted into an n-type semiconductor by doping it with 2×10^{21} atoms of arsenic. What is the concentration of holes in the silicon crystal?

($n_i = 1.5 \times 10^{16}$ m^{-3})

94. (a) Draw the circuit diagram used for constructing an AND gate using p−n junction diodes.

(b) Draw a logic circuit for the Boolean expression $\left[(A.\overline{B}) + \overline{C}\right].\overline{A}$.

(c) Form a truth table for the same Boolean expression.

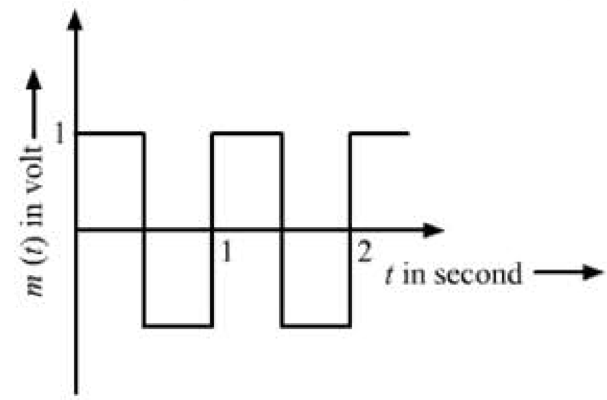
Communication System

95. The carrier wave is given by

C(t) = 2sin($8\pi t$) volt.

The modulating signal is a square wave as shown. Find modulation index.

Meritnation Top 100 Questions
Grade - 12 (Physics)



Delhi 2014

96. Name the type of waves which are used for line of sight (LOS) communication. What is the range of their frequencies?

A transmitting antenna at the top of a tower has a height of 20 m and the height of the receiving antenna is 45 m. Calculate the maximum distance between them for satisfactory communication in LOS mode. (Radius of the Earth = 6.4×10^6m) **All India 2013**

97. Distinguish between 'sky waves' and 'space waves' modes of propagation in communication system.

(a) Why is sky wave mode propagation restricted to frequencies upto 40 MHz?
(b) Give two examples where space wave mode of propagation is used. **Delhi 2013**

98. (i) Which mode of propagation is used by shortwave broadcast services having frequency range from a few MHz upto 30 MHz? Explain diagrammatically how long distance communication can be achieved by this mode.

(ii) Why is there an upper limit to frequency of waves used in this mode? **All India 2016**

99. (a) An antenna of height 100 m transmits TV signals. What should be the height of the receiving antenna in a town 50 km away to successfully receive the TV signals?

(b) What should be the minimum antenna length for the transmission of a modulated wave of frequency 20 MHz?

(c) How does the effective power radiated by an antenna change with the frequency of the radiated signal?

100. Draw a block diagram representing the production of an AM wave.

Solutions

Meritnation Top 100 Questions
(Solutions)
Grade - 12 (Physics)

Electric Charges and Fields

1. From the given field lines, we can say that the electric field present due to the given point charge will be directed towards the centre. Since we know that a negative charge always experiences a force in the direction opposite to that of the external electric field present, the negative charge will experience the force away from the centre. This will cause its motion to retard while moving from B to A. Hence, its kinetic energy will decrease in going from B to A.

2. Torque, $\tau = PEsin\theta = (Ql)Esin\theta$ ...(1)

Here, l is the length of the dipole, Q is the charge and E is the electric field.
Potential energy, $U = -PEcos\theta = -(Ql)Ecos\theta$ ...(2)
Dividing (2) by (1):

$$\frac{\tau}{U} = \frac{(Ql)E\sin\theta}{-(Ql)E\cos\theta} = -\tan\theta$$

$$\Rightarrow U = -\frac{\tau}{\tan\theta}$$

$$\Rightarrow U = -\frac{\tau}{\tan 60^o}$$

$$\Rightarrow U = -\frac{4\sqrt{3}}{\sqrt{3}}$$

$$\Rightarrow U = -4\text{ J}$$

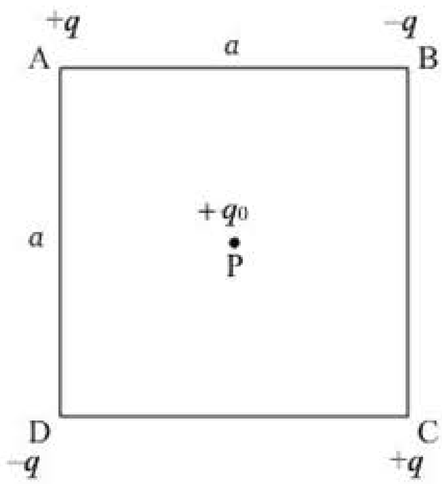
3. We know that electric flux is given by,

$$\Phi_E = \vec{E}.\vec{A}$$

$$\vec{E} = a\hat{i} + b\hat{j}$$
$$\vec{A} = A\hat{k}$$
$$\phi_E = (a\hat{i} + b\hat{j}).A\hat{k}$$
$$= 0$$

Hence, there is zero electric flux through area $\vec{A}$.

4.



Here,
AB = BC = CD = DA = a
And,
$AC = BD = a\sqrt{2}$
Now,

Total work done (W) = Potential energy of the system of four charges

$$W = \frac{(-q)(+q)}{4\pi\varepsilon_0 a} + \frac{(+q)(-q)}{4\pi\varepsilon_0 a} + \frac{(-q)(+q)}{4\pi\varepsilon_0 a} + \frac{(+q)(-q)}{4\pi\varepsilon_0 a} + \frac{1}{4\pi\varepsilon_0}\frac{((-q)(-q))}{a\sqrt{2}} + \frac{1}{4\pi\varepsilon_0}\frac{((+q)(+q))}{a\sqrt{2}}$$

$$= \frac{-4q^2}{4\pi\varepsilon_0 a} + \frac{2q^2}{4\pi\varepsilon_0 a\sqrt{2}} = \frac{-q^2}{4\pi\varepsilon_0 a}(4-\sqrt{2})$$

(b)

Extra work needed, $W_P = q_0 \times V_P$

Here,

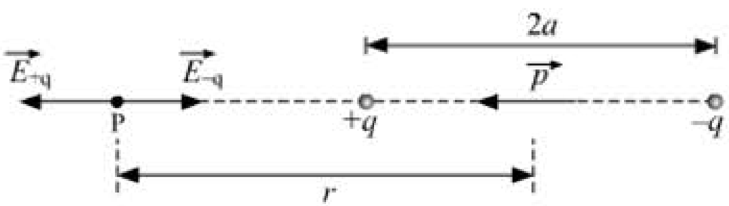
V_P = Potential at point P

Now,

$$\text{Potential at point P} = \frac{q}{4\pi\varepsilon_0\frac{a\sqrt{2}}{2}} + \frac{(-q)}{4\pi\varepsilon_0\frac{a\sqrt{2}}{2}} + \frac{q}{4\pi\varepsilon_0\frac{a\sqrt{2}}{2}} + \frac{(-q)}{4\pi\varepsilon_0\frac{a\sqrt{2}}{2}} = 0$$

$\Rightarrow W = 0$

5. (a) Electric Field on Axial Line of an Electric Dipole



Let P be at distance r from the centre of the dipole on the side of charge $-q$.
Then, the electric field at point P due to charge $-q$ of the dipole is given by

$$\vec{E}_{-q} = -\frac{q}{4\pi\varepsilon_0(r+a)^2}\hat{p}$$

Where $\hat{p}$ is the unit vector along the dipole axis (from $-q$ to q).

Also, the electric field at point P due to charge $+q$ of the dipole is given by

$$\vec{E}_{+q} = \frac{q}{4\pi\varepsilon_o (r-a)^2}\hat{p}$$

The total field at P is

$$\vec{E} = \vec{E}_{+q} + \vec{E}_{-q} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{p}$$

$$\Rightarrow \vec{E} = \frac{q}{4\pi\varepsilon_0}\frac{4ar}{(r^2-a^2)^2}\hat{p}$$

Given:

$r = x$

$$\vec{E} = \frac{q}{4\pi\varepsilon_0}\frac{4ax}{(x^2-a^2)^2}\hat{p}$$

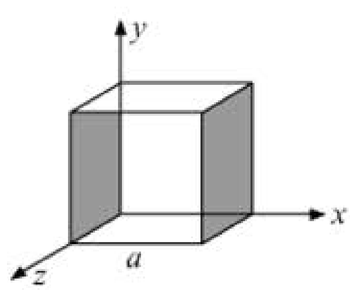
For $x >> a$,

$$\vec{E} = \frac{4qa}{4\pi\varepsilon_0 x^3}\hat{p}$$

$$\vec{E} = \frac{2\vec{p}}{4\pi\varepsilon_0 x^3} \quad [\because \vec{p} = (q \times 2a)\hat{p}]$$

(b)

Since the electric field has only x component, for faces normal to x direction, the angle between E and ΔS is $\pm \pi/2$. Therefore, the flux is separately zero for each face of the cube except the two shaded ones.



The magnitude of the electric field at the left face is

$E_L = 0$ (As $x = 0$ at the left face)

The magnitude of the electric field at the right face is
$E_R = 2a$ (As x = a at the right face)

The corresponding fluxes are

$$\phi_L = \vec{E}_L . \Delta\vec{S} = 0$$

$$\phi_R = \vec{E}_R . \Delta\vec{S} = E_R \Delta S\cos\theta = E_R \Delta S \quad (\because \theta = 0°)$$

$$\Rightarrow \phi_R = E_R a^2$$

Net flux (Φ) through the cube = $\phi_L + \phi_R = 0 + E_R a^2 = E_R a^2$

$$\phi = 2a(a)^2 = 2a^3$$

We can use Gauss's law to find the total charge q inside the cube.

$$\phi = \frac{q}{\varepsilon_0}$$

$$q = \phi\varepsilon_0 = 2a^3\varepsilon_0$$

6. Curved surface area(A) of the cone is πrl

l, the slant height = $\sqrt{r^2+h^2} = \sqrt{4+16} = 2\sqrt{5}$ m

Let θ be the base angle of the cone

$$\tan\theta = \frac{4}{2} = 2$$

Angle between electric field and unit vector normal to the curved surface of the cone is $90^o - \theta$

Flux(φ) = E A cos $(90^o - \theta)$

$\varphi = EA \sin\theta$

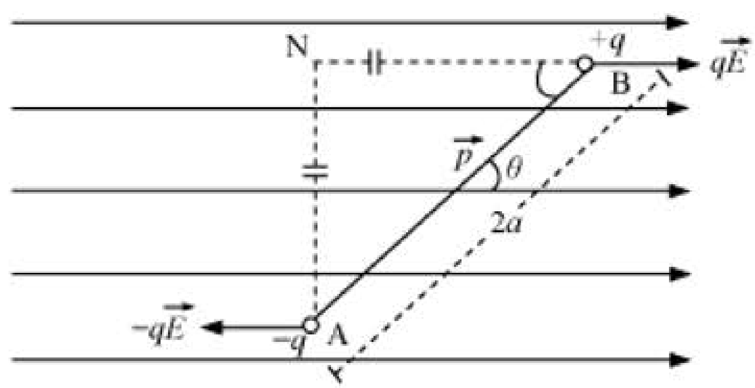
$if \tan\theta = 2$

$\text{then } \sin\theta = \dfrac{2}{\sqrt{5}}$

$\varphi = 30 \times 3.14 \times 2 \times 2\sqrt{5} \times \dfrac{2}{\sqrt{5}}$

$\varphi = 753.6 \text{ Wb}$

7. (a) Dipole in a Uniform External Field



Consider an electric dipole consisting of charges $-q$ and $+q$ and of length $2a$ placed in a uniform electric field $\vec{E}$ making an angle θ with electric field.

Force on charge $-q$ at $A = -q\vec{E}$ (opposite to $\vec{E}$)

Force on charge $+q$ at $B = q\vec{E}$ (along $\vec{E}$)

Electric dipole is under the action of two equal and unlike parallel forces, which give rise to a torque on the dipole.

τ = Force × Perpendicular distance between the two forces

$\tau = qE\,(AN) = qE\,(2a \sin\theta)$

$\tau = q(2a)\,E \sin\theta$

$\tau = pE \sin\theta$

$\therefore \vec{\tau} = \vec{p} \times \vec{E}$

(b) (i) Charge enclosed by sphere $S_1 = 2Q$

By Gauss law, electric flux through sphere S_1 is

$$\phi_1 = \frac{2Q}{\varepsilon_0}$$

Charge enclosed by sphere $S_2 = 2Q + 4Q = 6Q$

$$\therefore \phi_2 = \frac{6Q}{\varepsilon_0}$$

The ratio of the electric flux is

$$\frac{\phi_1}{\phi_2} = \frac{\frac{2Q}{\epsilon_0}}{\frac{6Q}{\epsilon_0}} = \frac{2}{6} = \frac{1}{3}$$

(ii) For sphere S_1, the electric flux is

$$\phi' = \frac{2Q}{\varepsilon_r}$$

$$\therefore \frac{\phi'}{\phi_1} = \frac{\varepsilon_0}{\varepsilon_r}$$

$$\Rightarrow \phi' = \phi_1 . \frac{\varepsilon_0}{\varepsilon_r}$$

$\because \varepsilon_r > \varepsilon_0$

$\therefore \phi' < \phi_1$

Therefore, the electric flux through the sphere S_1 decreases with the introduction of the dielectric inside it.

Meritnation Top 100 Questions
(Solutions)
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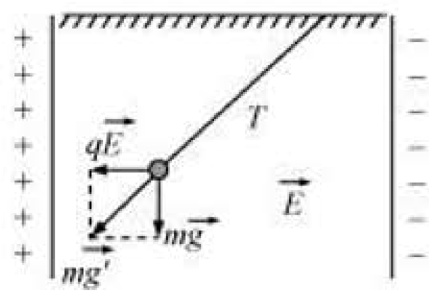
8.



On applying a uniform electric field, the apparent weight of the bob is owing to the gravitational force (mg) and the electric force (qE) (as shown in the figure).

Then, the apparent weight :

$$(mg') = \sqrt{(mg)^2 + (qE)^2}$$

$$m^2g'^2 = m^2g^2 + (qE)^2$$

$$g' = \sqrt{g^2 + \left(\frac{qE}{m}\right)^2}$$

Therefore, time period (T):

$$= 2\pi\sqrt{\frac{l}{g'}}$$

$$= 2\pi\sqrt{\frac{l}{\sqrt{g^2 + \left(\frac{qE}{m}\right)^2}}}$$

Meritnation Top 100 Questions
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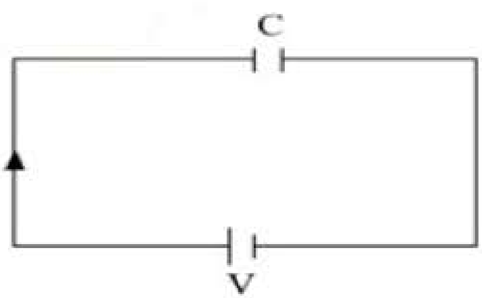
Electrostatic Potential and Capacitance

9. According to the question, $V_A - V_B$ is positive, which leads to the conclusion that $V_A > V_B$, since potential inversely proportional to distance from the charge ($V \propto \frac{1}{r}$). Thus, charge at O is positive.

10. Given that,
$V = 200$ V
$C = 150$ pF
$= 150 \times 10^{-12}$ F



$$U_i = \frac{1}{2}CV^2$$
$$= \frac{1}{2}\left(150\times10^{-12}\right)\left(200\right)^2$$
$$= \frac{1}{2}\times15\times10^{-11}\times4\times10^4$$
$$= \frac{1}{2}\times60\times10^{-7}$$
$$= 3\times10^{-6}\,\mathrm{J}$$

Charge on capacitor C, given by
$Q = CV = (150 \times 10^{-12})\,(200)$
$= 30000 \times 10^{-12}$
$= 30 \times 10^{-9} c$
$= 30$ nC
Now, charged capacitor is connected with the other capacitor C' (= 50 pF). Then, charge on the capacitors is distributed.

Meritnation Top 100 Questions
(Solutions)
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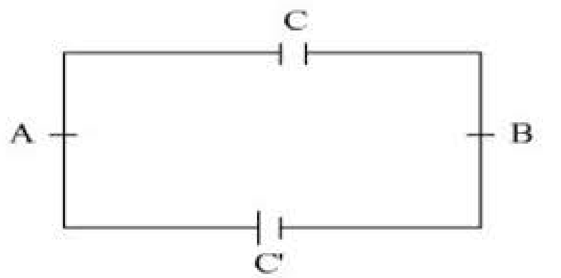


Suppose charge on C and C' are q and q' respectively.
According to charge conservation principle,
Q = $q + q'$ ……….. (1)
Also, Potential between the points A and B should be same.

$$\text{So,} \frac{q}{C} = \frac{q'}{C'}$$

$$\Rightarrow \frac{q}{150} = \frac{q'}{50}$$

$$\Rightarrow \frac{q}{3} = q'$$

$$\Rightarrow \boxed{q = 3q'} \quad \ldots \quad (2)$$

From equation (1) & (2)

$$Q = 3q' + q' = 4q'$$

$$\Rightarrow q' = \frac{Q}{4} = \left(\frac{30nC}{4}\right)$$

$$\boxed{q' = 7.5nC}$$

$$q = (3\times 7.5)nC$$
$$= 22.5nC$$

$$U_f = \frac{q^2}{2C} + \frac{q'^2}{2C'}$$
$$= \frac{1}{2}\times\frac{(22.5\times 10^{-9})^2}{150\times 10^{-12}} + \frac{(7.5\times 10^{-9})^2}{2\times 50\times 10^{-12}}$$
$$= \left(\frac{22.5\times 22.5}{2\times 150} + \frac{7.5\times 7.5}{2\times 50}\right)\times 10^{-6}$$
$$= (1.69 + 0.56)\times 10^{-6}$$
$$= 2.25\times 10^{-6}\,J$$

Difference of energy

$$\Delta U = |U_f - U_i|$$
$$= |2.25\times 10^{-6} - 3\times 10^{-6}|$$
$$\Delta U = 0.75\times 10^{-6}\,J$$

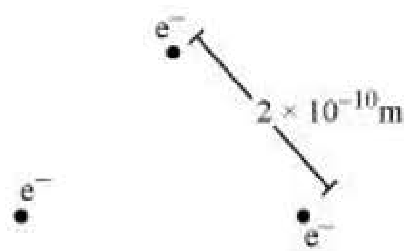
11. (a) The potential energy of an electron from a fixed point charge system is:

$$U = \frac{KQe}{r}$$
$$= \frac{9\times10^{9}\times(-0.25\times10^{-6})\times(-1.6\times10^{-19})}{(0.2)^{2}}$$
$$= \frac{9\times10^{9}\times0.25\times10^{-6}\times1.6\times10^{-19}}{0.04}$$
$$= 9\times10^{-15}\ \text{J}$$

This energy will get completely converted into kinetic energy of the electron when it is at a distance from the fixed point charge.
Hence,

$$\frac{1}{2}m_e v^2 = 9\times10^{-15}$$
$$v^2 = \frac{18\times10^{-15}}{m_e}$$
$$v^2 = \frac{18\times10^{-15}}{9.1\times10^{-31}}$$
$$v = 1.41\times10^{5}\ \text{m/s}$$

(b)



The potential energy of two electrons kept $2\times10^{-10}\ \text{m}$ apart is:

$$U = \frac{Ke^2}{r}$$
$$= \frac{9\times10^9 \times (1.6\times10^{-19})^2}{2\times10^{-10}}$$
$$= 1.152\times10^{-18}\ \text{J}$$

Here, the three electrons form three separate pairs.
Hence,

$$U = 3\times(1.152\times10^{-18})$$
$$= 3.456\times10^{-18}\ \text{J}$$

12. If q_A, q_B and q_C are the charges of the respective shells, then we have:

$$q_A = 4\pi a^2\sigma$$

$$q_B = -4\pi b^2\sigma$$

$$q_C = 4\pi c^2\sigma$$

Let V_A and V_C be the potentials of shells A and C.
A point on the surface of shell A lies inside the shells B and C.

$$\therefore V_A = \frac{1}{4\pi\varepsilon_0}.\frac{q_A}{a} + \frac{1}{4\pi\varepsilon_0}.\frac{q_B}{b} + \frac{1}{4\pi\varepsilon_0}.\frac{q_C}{c}$$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{4\pi a^2\sigma}{a} - \frac{4\pi b^2\sigma}{b} + \frac{4\pi c^2\sigma}{c}\right)$$

$$\Rightarrow V_A = \frac{\sigma}{\varepsilon_0}(a-b+c)$$

A point on shell C lies outside both A and B.

$$\therefore V_C = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_A}{c} + \frac{q_B}{c} + \frac{q_C}{c}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{4\pi a^2\sigma}{c} - \frac{4\pi b^2\sigma}{c} + \frac{4\pi c^2\sigma}{c}\right)$$

$$\Rightarrow V_C = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2 - b^2}{c} + c\right)$$

If the shells A and C are at the same potential, then $V_A = V_C$.

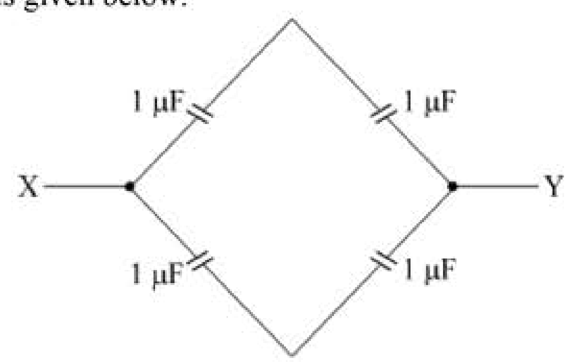
$$\text{i.e.,} \frac{\sigma}{\varepsilon_0}(a - b + c) = \frac{\sigma}{\varepsilon_0}\left(\frac{a^2 - b^2}{c} + c\right)$$

$$\Rightarrow (a - b + c) = \frac{a^2 - b^2}{c} + c$$

$$\Rightarrow c(a - b) = a^2 - b^2$$

$$\Rightarrow c = a + b$$

13. The equivalent circuit is given below.



There are two capacitors in one branch in series. So, the equivalent capacitance of one branch will be

$$\frac{1}{1} + \frac{1}{1} = 2\mu\text{F}$$

The arrangement will be further reduced to the form given below.

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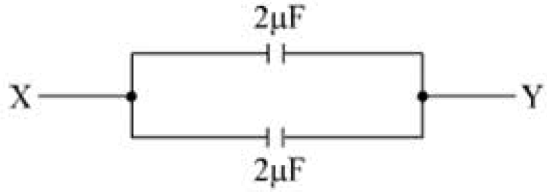

Now, both the capacitors are in parallel, so the equivalent capacitance will be
$2+2=4\mu F$

Therefore, the equivalent capacitance is 4 μF.

(i) Voltage, $V = 6$ V
The charge in the network is given by

$q = CV$

Here, C is the equivalent capacitance.

Now,

$$q = 4\times 10^{-6}\times 6$$
$$= 24\times 10^{-6}\ \text{C} = 24\ \mu\text{C}$$

(ii) The energy stored in the network is given by

$$E = \frac{1}{2}CV^2$$
$$= \frac{1}{2}\times 4\times 10^{-6}\times (6)^2$$
$$= \frac{1}{2}\times 4\times 36\times 10^{-6}$$
$$= 72\times 10^{-6}\ \text{J} = 72\ \mu\text{J}$$

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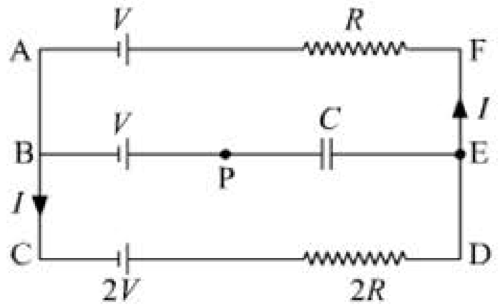
14. (a)



In the steady state, the capacitor behaves as an open circuit. When the steady state is reached, there is no current through arm BE. The potential difference across the two plates of the capacitor is equal to the potential difference across EF.

Applying Kirchhoff's voltage law in the loop ACDF

$$-2V + 2RI + RI + V = 0$$

$$V = 3RI$$

$$\Rightarrow I = \frac{V}{3R}$$

Hence, the potential difference across E and B is

$$V_E - V_B = 2V - \left(\frac{V}{3R}\right) \times 2R = \frac{4V}{3}$$

Since there is no current through the battery in branch BE, therefore, $V_P - V_B = V$

Now,

$$V_E - V_B = \left(V_E - V_P\right) + \left(V_P - V_B\right)$$

$$\frac{4V}{3} = V_E - V_P + V$$

$$\Rightarrow V_E - V_P = \frac{V}{3}$$

(b) The charge stored in the capacitor, $Q = CV = \frac{CV}{3}$

(c) The energy stored in the capacitor, $E = \frac{1}{2}C\left(V_E - V_P\right)^2 = \frac{1}{2}C\left(\frac{V}{3}\right)^2 = \frac{1}{18}CV^2$

15. (a)

Capacitance after introduction of the dielectric, $C' = KC$

$$= 4 \times 20\mu\text{ F}$$
$$= 80\mu\text{F}$$

(b) Originally:

$$Q = CV$$
$$= 20\mu\text{F} \times 200\text{ V}$$
$$= 4000\mu\text{C}$$

Finally:

$$Q' = C'V$$
$$= 80\mu\text{F} \times 200\text{ V}$$
$$= 16000\mu\text{C}$$

Therefore, charge gained $= 16000 - 4000$

$= 12000\mu\text{C}$

(c) Originally:

$$E = \frac{1}{2}CV^2$$
$$= \frac{1}{2} \times 20 \times 10^{-6} \times (200)^2$$
$$= 0.04\text{ J}$$

Finally:

$$E' = \frac{1}{2} \times C'V^2$$
$$= \frac{1}{2} \times 80 \times 10^{-6} \times (200)^2$$
$$= 0.16 \text{ J}$$

Therefore, increase in energy = (0.16 − 0.04) J = 0.12 J

16.

$$\text{Electric field, } E = \frac{-dv}{dr}$$
$$dv = -Edr$$

Here, E is nearly uniform between capacitor plates.
Hence,

$$V = Ed$$
$$= 600 \text{ N/C} \times 2 \text{ mm}$$
$$= 600 \text{ N/C} \times 2 \times 10^{-3} \text{ m}$$
$$= 1200 \times 10^{-3} \text{ V}$$
$$= 1.2 \text{ V}$$

Current Electricity

17. We have, resistance of ammeter, R_A = 0.80 ohm and maximum current across ammeter, I_A = 1.0 A.

So, voltage across ammeter, V = $\text{IR} = 1.0 \times 0.80 = 0.8 \text{ V}$.
Let the value of shunt be *x*.

(i) Resistance of ammeter with shunt, $\text{R} = \frac{\text{R}_\text{A} x}{\text{R}_\text{A} + x} = \frac{0.8x}{0.8 + x}$.
Current through ammeter, I = 5 A.

$$\therefore\left(\frac{0.8x}{0.8+x}\right)\times 5 = 0.8 \Rightarrow 0.8x\times 5 = 0.8(0.8+x) \Rightarrow 4x = 0.64 + 0.8x$$

$$\therefore x = \frac{0.64}{3.2} = 0.2$$

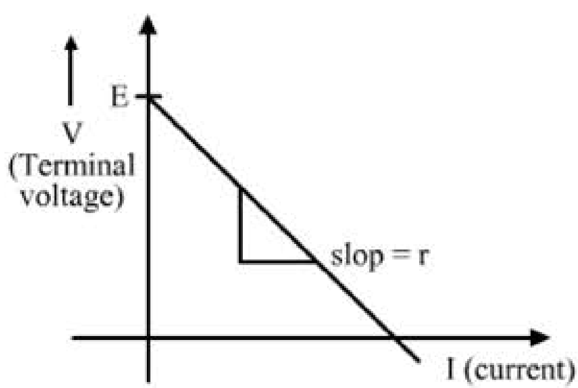
Thus, the shunt resistance is 0.2 ohm.
(ii) Combined resistance of the ammeter and the shunt,

$$R = \frac{0.8x}{0.8+x} = \frac{0.8\times 0.2}{0.8+0.2} = \frac{0.16}{1} = 0.16 \text{ ohm}$$

18. Terminal voltage 'V' of the cell is $V = E - Ir$
E is the emf of the cell, r is the internal resistance of the cell and I is the current through the circuit.

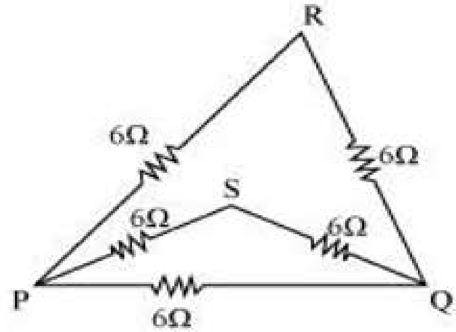
So, $V = -Ir + E$
Comparing with the equation of a straight line $y = mx + c$, we get:
$y = V$; $x = I$; $m = -r$; $c = E$

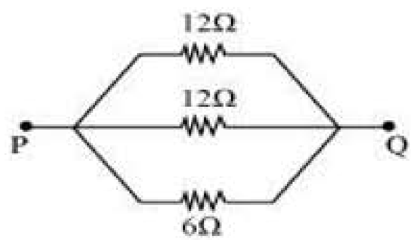
Graph showing variation of terminal voltage 'V' of the cell versus the current 'I' is



Emf of the cell = Intercept on V axis
Internal resistance = slop of line

19. (a) The mesh **PRQS** forms a balanced Wheatstone bridge. Thus, the resistance between **R** and **S** may be neglected.
Then,





$$\frac{1}{R_{eq}} = \frac{1}{12} + \frac{1}{12} + \frac{1}{6}$$

$$\frac{1}{R_{eq}} = \frac{4}{12}$$

$$R_{eq} = \frac{12}{4} = 3\ \Omega$$

(b) Let the emf of the first cell be ε.

$\varepsilon \propto l$ (balance length of the potentiometer)

Thus, $\dfrac{\varepsilon}{\varepsilon - 0.2} = \dfrac{l_1}{l_2}$

$$\frac{\varepsilon}{\varepsilon - 0.2} = \frac{65}{60}$$

$$12\varepsilon = 13(\varepsilon - 0.2)$$

$$\varepsilon = 2.6\ \text{V}$$

Therefore, Emf of the other cell $= (2.6 - 0.2)\ \text{V}$

$= 2.4\ \text{V}$

20. (a) Principle

When a constant current is passed through a wire of uniform area of cross-section, the potential drop across any portion of the wire is directly proportional to the length of that portion.

Let *V* be the potential difference across certain portion of the wire, whose resistance is R. If I is the current through the wire, then

$$V = IR$$

We know that $R = \rho \frac{l}{A}$, where *l*, A and ρ are length, area of cross-section and resistivity of the material of the wire, respectively.

$$\therefore V = I\rho \frac{l}{A}$$

$$\Rightarrow \frac{V}{l} = \frac{I\rho}{A}$$

(b)

(i) Let x be the resistance per unit length of the potentiometer wire and I be the constant current flowing through it. Then from the figure, we have:

$$\varepsilon_1 - \varepsilon_2 = (120x)I \quad \ldots(1)$$

and

$$\varepsilon_1 + \varepsilon_2 = (300x)I \quad \ldots(2)$$

Dividing both equations, we get:

$$\frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + \varepsilon_2} = \frac{120}{300}$$

$$\Rightarrow 180\varepsilon_1 = 420\varepsilon_2$$

$$\Rightarrow \frac{\varepsilon_1}{\varepsilon_2} = \frac{7}{3}$$

(ii) Now adding equations (1) and (2), we get:

$2\varepsilon_1 = (420x)I$

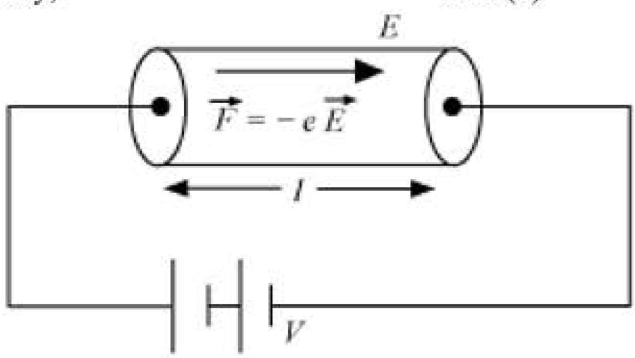
$\Rightarrow \varepsilon_1 = (210x)I$

Comparing with $\varepsilon = (Lx)I$, we get:
length of balancing point, L = 210 cm for cell 1

21. Current has direction. But, it does not follow the rules of vector addition and product. Instead, it follows the rules of scalar addition and product. Therefore, it is classified as a scalar and not a vector quantity.

22. (a) Drift velocity: It is the velocity with which free electrons get drifted towards the positive terminal under the effect of the applied electric field.
Free electrons are in continuous random motion. They undergo change in direction at each collision and the thermal velocities are randomly distributed in all directions.

∴ Average thermal velocity, $u = \dfrac{u_1 + u_2 + ... + u_n}{n} = 0$ … (1)



The electric field E exerts an electrostatic force $-Ee$.

Acceleration of each electron, $\vec{a} = \dfrac{-e\vec{E}}{m}$ ...(2)
where,
m = mass of an electron
e = charge on an electron

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$$\vec{v}_d = \frac{\vec{v}_1 + \vec{v}_2 + \ldots\ldots\ldots\ldots + \vec{v}_n}{n}$$

$$\vec{v}_d = \frac{(\vec{u}_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \ldots\ldots\ldots\ldots + (\vec{u}_n + \vec{a}\tau_n)}{n}$$

where,

$\vec{u}_1, \vec{u}_2 \rightarrow$ thermal velocities of the electrons

$\vec{a}\tau_1, \vec{a}\tau_2 \rightarrow$ velocity acquired by electrons

τ_1, $\tau_2 \rightarrow$ time elapsed after the collision

$$\vec{v}_d = \frac{(\vec{u}_1 + \vec{u}_2 + \ldots + \vec{u}_n)}{n} + \frac{\vec{a}(\tau_1 + \tau_2 + \ldots + \tau_n)}{n}$$

Since $\frac{\vec{u}_1 + \vec{u}_2 + \ldots + \vec{u}_n}{n} = 0$, we get:

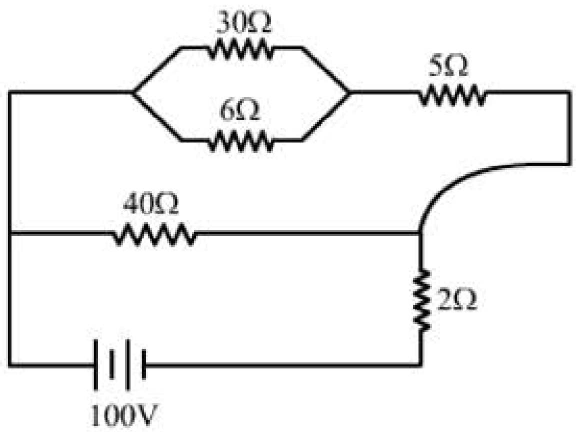
$\therefore v_d = a\,\tau$, where, $\tau = \frac{\tau_1 + \tau_2 + \tau_3 + \ldots\ldots\ldots + \tau_n}{n}$ is the average time elapsed.

Substituting the value of a from equation (2), we have:

$$\vec{v}_d = \frac{-e\vec{E}}{m}\tau \qquad \ldots(4)$$

(b) Total current, $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{200}{2}} = 10\text{A}$

Equivalent circuit:



Potential difference across AB = potential difference across CD

$\Rightarrow I_1R_1 = I_2R_2$

$\Rightarrow 10I_1 - 40I_2 = 0$

$\Rightarrow I_1 - 4I_2 = 0 \quad \ldots(1)$

$\Rightarrow I_1 + I_2 = I$

$\Rightarrow I_1 + I_2 = 10 \quad \ldots(2)$

$\Rightarrow I_1 = 8\text{A}$

Power dissipated in the 5 Ω resistor = 5 $\times$ (current through 5 Ω resistor)^2

$\therefore$ P = 320 W

23.

The potential $E \propto$ length of the potentiometer wire, which balances it.

When connected between A and B:

$E_1 \propto 4$

When connected between A and C:

$(E_1 - E_2) \propto 2$

$$\frac{E_1}{E_1 - E_2} = \frac{4}{2}$$

$$\frac{1}{1 - \frac{E_2}{E_1}} = \frac{2}{1}$$

$$1 - \frac{E_2}{E_1} = \frac{1}{2}$$

$$\frac{E_2}{E_1} = \frac{1}{2}$$

$$E_1 : E_2 = 2 : 1$$

Moving Charges and Magnetism

24. (a) The force due to the magnetic field (B) acting on the charged particle moving with the velocity v is given by

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

The direction of this force is given by the right-hand rule and it is perpendicular to the plane containing v and B.
the velocity of particle. The radius of the circular path will be given by

$$\frac{mv^2}{r} = Bqv$$

$$r = \frac{mv}{Bq}$$

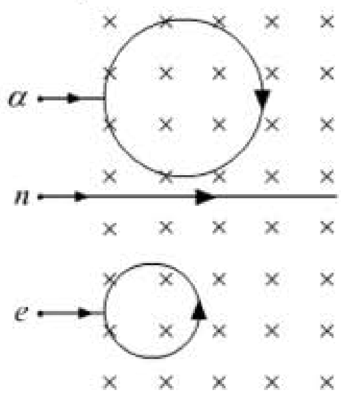
As B and v are constant, we can write

$$r \propto \frac{m}{q}$$

The neutron will move along the straight line as it has no charge.

The electron will inscribe a circle of radius smaller than that of the alpha particle as the mass to charge ratio of the alpha particle is more than that of the electron.

So, the alpha particle will move in the clockwise direction and the electron will move in anticlockwise direction according to the right-hand rule.



25. Magnetic field at the centre of the coils due to coil P, having current I is

$$B_P = \frac{\mu_0 I}{2R}$$

And magnetic field due to coil Q having current $\sqrt{3}I$ is

$$B_Q = \frac{\mu_0 \sqrt{3} I}{2R}$$

Since both coils are inclined to each other at an angle of 90°, the magnitude of their resultant magnetic field at the common centre will be

$$B = \sqrt{B_P^2 + B_Q^2} = \frac{\mu_0 I}{2R}\sqrt{1+3} = \frac{\mu_0 I}{R}$$

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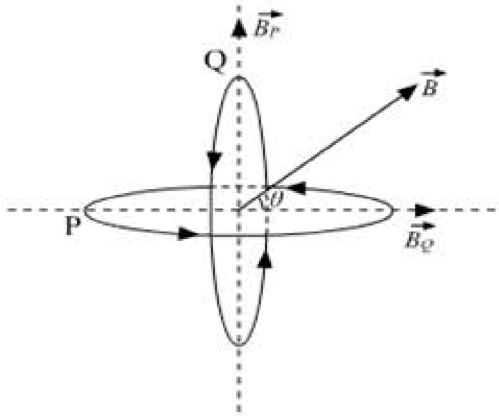

The directions of B_P and B_Q are as indicated in the figure. The direction of the resultant field is at an angle θ given by

$$\theta = \tan^{-1}\left(\frac{B_P}{B_Q}\right) = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = 30°$$

Hence, the direction of the magnetic field will be at an angle 30° to the plane of loop P.

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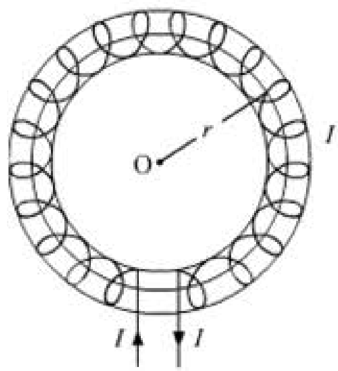
26. (a) Ampere's circuital law states that the line integral of magnetic field induction $\vec{B}$ around a closed path in vacuum is equal to μ_0 times the total current I passing through the surface, i.e.

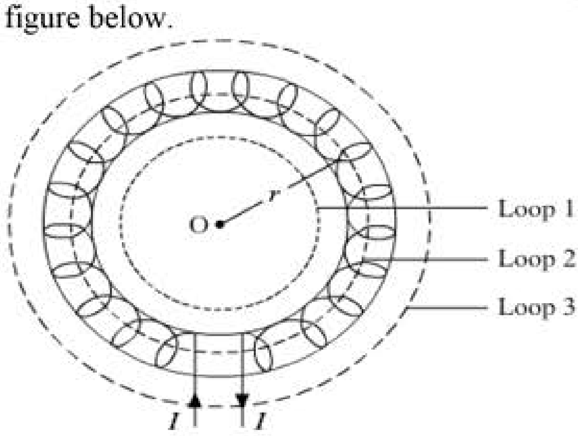
$$\oint \vec{B}.\vec{dl} = \mu_0 I$$



A toroid is a hollow circular ring on which a large number of turns of a wire are closely wound. Consider an air-cored toroid (as shown above) with centre O.

Given:
r = Average radius of the toroid
I = Current through the solenoid
n = Number of turns per unit length

To determine the magnetic field inside the toroid, we consider three amperian loops (loop 1, loop 2 and loop 3) as show in the figure below.



For loop 1:

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According to Ampere's circuital law, we have

$$\oint \vec{B}.\vec{dl} = \mu_0(\text{Total current})$$

Total current for loop 1 is zero because no current is passing through this loop.

So, for loop 1

$$\oint \vec{B}.\vec{dl} = 0$$

For loop 3:

According to Ampere's circuital law, we have

$$\oint \vec{B}.\vec{dl} = \mu_0(\text{Total current})$$

Total current for loop 3 is zero because net current coming out of this loop is equal to the net current going inside the loop.

For loop 2:

The total current flowing through the toroid is *NI,* where *N* is the total number of turns.

$$\oint \vec{B}.\vec{dl} = \mu_0(NI)$$

Now, $\vec{B}$ and $\vec{dl}$ are in the same direction

$$\oint \vec{B}.\vec{dl} = B\oint dl$$

$$\Rightarrow \oint \vec{B}.\vec{dl} = B(2\pi r) \quad .....(ii)$$

Comparing (i) and (ii), we get

$B(2\pi r) = \mu_0 NI$

$$\Rightarrow B = \frac{\mu_0 NI}{2\pi r}$$

Number of turns per unit length is given by

$$n = \frac{N}{2\pi r}$$

$\therefore B = \mu_0 nI$

This is the expression for magnetic field inside air-cored toroid.

(b) Given that the current flows in the clockwise direction for an observer on the left side of the solenoid. This means that left face of the solenoid acts as south pole and right face acts as north pole. Inside a bar magnet, the magnetic field lines are directed from south to north. Therefore, the magnetic field lines are directed from left to right in the solenoid.

Magnetic moment of single current carrying loop is given by

$m' = IA$

where

I = Current flowing through the loop

A = area of the loop

So, magnetic moment of the whole solenoid is given by

$m = Nm' = N(IA)$

27. (a) **Principle:** Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a torque.

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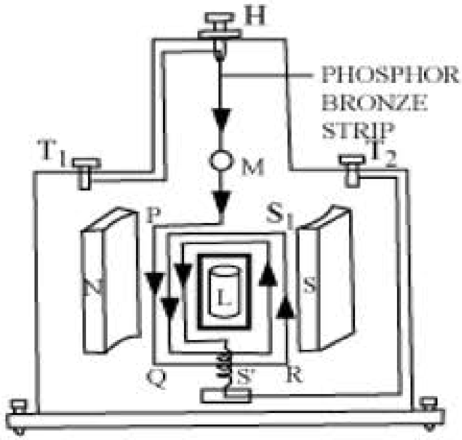

Working:

Suppose the coil *PQRS* is suspended freely in the magnetic field.
Let l = length *PQ* or *RS* of the coil
b = breadth *QR* or *SP* of the coil
n = number of turns in the coil
Area of each turn of the coil, $A = l \times b$
Let B = strength of the magnetic field in which the coil is suspended
I = current passing through the coil in the direction *PQRS*
At any instant, let α be the angle that the normal drawn on the plane of the coil makes with the direction of magnetic field.
The rectangular coil carrying current, when placed in the magnetic field, experiences a torque whose magnitude is given by:
$\tau = nIBA \sin\alpha$
Due to the deflecting torque, the coil rotates and the suspension wire gets twisted. A restoring torque is set up in the suspension wire.
Let θ be the twist produced in the phosphor bronze strip due to the rotation of the coil and K be the restoring torque per unit twist of the phosphor bronze strip. Then, we have:
Total restoring torque produced = $k\theta$
In equilibrium position of the coil, we have:
Deflecting torque = Restoring torque
$\therefore NIBA = k\theta$

or $$I = \frac{k}{NBA}\theta \text{ or } G\theta$$

Here, $\frac{k}{NBA} = \text{G} = a$ [constant for a galvanometer]
It is known as galvanometer constant.

(b) (i) The cylindrical soft iron core, when placed inside the coil of a galvanometer, makes the magnetic field stronger and radial in the space between it and pole pieces, such that whatever the position of the rotation of the coil is the magnetic field is always parallel to its plane.

(ii) The current sensitivity of a moving coil galvanometer is given by $\frac{nBA}{k}$, where n is the number of turns , A is the area of the coil , B is the magnetic field strength of the poles and k is the spring's constant of the suspension wire.

Similarly, voltage sensitivity is given by $\frac{nBA}{kR}$, where R is the resistance of the wire.
From the above two expressions, we get:
Voltage sensitivity = Current sensitivity/R
Thus, on increasing the current sensitivity, voltage sensitivity may or may not increase because of similar changes in the resistance of the coil, which may also increase due to increase in temperature.

28. Magnetic field cannot be defined as the magnetic force experienced per unit magnetic monopole simply because a magnetic monopole does not exist in nature.

It is defined instead as $B = \frac{F_{\text{B}}}{|q|v}$, where F_{B} is the magnitude of magnetic force and v is the magnitude of velocity of the charged particle moving perpendicular to the magnetic field.

29.

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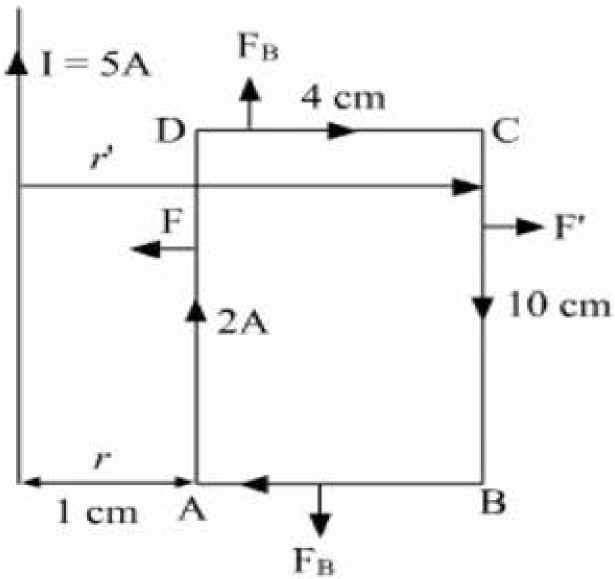

$$\text{(i) } \vec{\tau} = \vec{M} \times \vec{B} = MB\sin\theta$$

Here M and B have the same direction
$\theta = 0°$

$$|\vec{\tau}| = MB\sin\theta = 0$$

$$\text{(ii) We know } \vec{F}_B = i\vec{l} \times \vec{B}$$

On line AB, and CD magnetic forces are equal and opposite. So they cancel out each other.
Magnetic force on line AD.

$$\vec{F} = i\vec{l} \times \vec{B} \qquad [\text{Attractive}]$$

$$= ilB \qquad \left[\begin{array}{l} l = 10\,\text{cm} \\ = 0.1\,\text{cm} \end{array}\right.$$

$$\because B = \frac{\mu_0 I}{2\pi r}$$

$$|\vec{F}| = \frac{\mu i I l}{2\pi r} \qquad (\text{Attractive})$$

Magnetic force on line CB.

$$\vec{F} = i\vec{l} \times \vec{B} \qquad [\text{Repulsive}]$$

$$\Rightarrow F = |\vec{F}| = il\,B'$$

$$\because B' = \frac{\mu_0 I}{2\pi r'}$$

$$F = \frac{\mu_0 iIl}{2\pi r'} \qquad (\text{Repulsive})$$

So, net force

$$F_n = F - F'$$

$$= \frac{\mu_0 iIl}{2\pi r} \quad \left[\frac{1}{r} - \frac{1}{r'}\right]$$

Given $i = 5\text{A}$

$I = 2$ A

$r = 1$ cm $= 0.01$ m

$r' = (1 + 4)$ cm $= 5$ cm

$= 0.05$ m

$l = 10$ cm $= 0.1$ m

Plugging in the values in above equation

$$F_n = \left(2\times10^{-7}\right)(5)(2)(0.1)\left[\frac{1}{0.01} - \frac{1}{0.05}\right]$$

$$= 2\times10\times10^{-7}\times10\left[\frac{1}{1} - \frac{1}{5}\right]$$

$$= 200\times10^{-7}\left[\frac{5-1}{5}\right]$$

$$= 200\times10^{-7}\times\frac{4}{5}$$

$$= 160\times10^{-7}\,\text{N}$$

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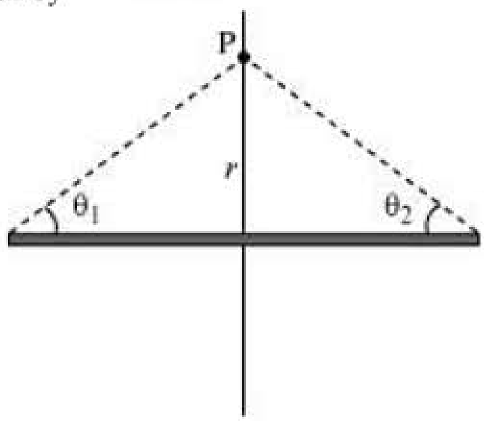
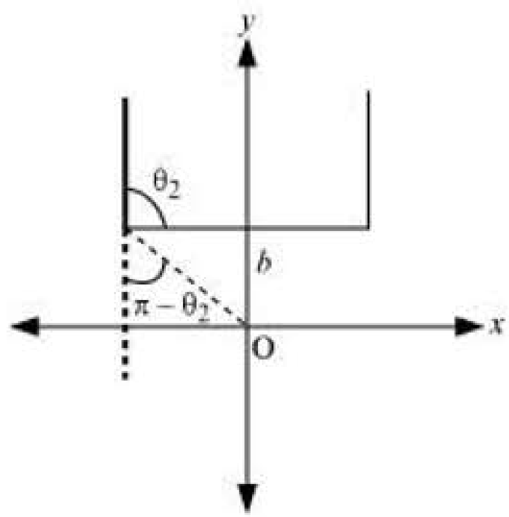
30. (a) For a finite wire carrying a current I, the magnitude of the magnetic field at a perpendicular distance r from the wire is given by $B = \frac{\mu_0 I}{4\pi r}(\cos\theta_1 + \cos\theta_2)$.



Consider the left segment of the wire, which extends from $(x, y) = (-a \text{ to } \infty)$ to $(-a, b)$.
Thus, the corresponding angles:

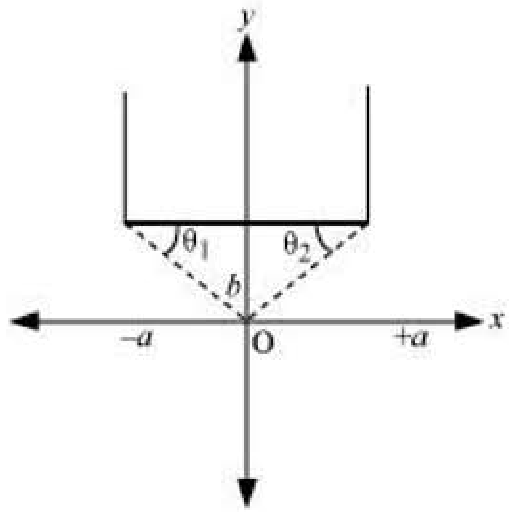
$$\cos\theta_1 = 1(\theta_1 = 0°)$$

$$\cos\theta_2 = -\frac{b}{\sqrt{b^2 + a^2}}$$



Thus, $$B_1 = \frac{\mu_0 I}{4\pi a}(\cos\theta_1 + \cos\theta_2) = \frac{\mu_0 I}{4\pi a}\left(1 - \frac{b}{\sqrt{b^2 + a^2}}\right)$$

The direction of $\vec{B}$ is $\widehat{K}$ (out of the page).
Consider the segment of the wire that extends from $(x, y) = (-a, b)$ to (a, b).



$$\cos\theta_1 = \frac{a}{\sqrt{a^2 + b^2}}$$

$$\cos\theta_2 = \cos\theta_1 = -\frac{a}{\sqrt{a^2 + b^2}}$$

Thus, $$B_2 = \frac{\mu_0 I}{4\pi b}\left(\frac{2a}{\sqrt{a^2 + b^2}}\right)$$

$$= \frac{\mu_0 I_a}{2\pi b\sqrt{a^2 + b^2}}$$

The direction of $\vec{B}_2$ is $\widehat{K}$ (into the page).
Consider the segment that extends from $(x, y) = (a, b)$ to (a, ∞).

By similar argument as the first segment, we have $B_3 = B_1 = \dfrac{\mu_0 I}{4\pi a}\left(1 - \dfrac{b}{\sqrt{b^2 + a^2}}\right)$

The direction of $\vec{B}_3$ is $\hat{K}$ (out of the page).

Net field at O, $\vec{B} = \vec{B_1} + \vec{B_3} - \vec{B_2}$

$$= 2\vec{B_1} - \vec{B_2}$$

$$= \frac{\mu_0 I}{2\pi a}\left(1 - \frac{b}{\sqrt{a^2 + b^2}}\right)\hat{K} - \frac{\mu_0 I a}{2\pi b\sqrt{a^2 + b^2}}\hat{K}$$

$$= \frac{\mu_0 I}{2\pi ab\sqrt{a^2 + b^2}}(b\sqrt{a^2 + b^2} - b^2 - a^2)\hat{K}$$

(b) The magnetic moment $\vec{\mu}$ of the loop is perpendicular to the plane surface bound by the loop.

The magnetic field, $\vec{B}$, is also perpendicular to this surface. Since the angle between them is zero, torque

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$
$$= \mu B \sin\theta \ (\theta = 90°)$$
$$= 0$$

31. (a) Torque on a magnetic dipole is given by $\tau = \vec{\mu} \times \vec{B} = \mu B \sin\theta$

i. $\tau = \mu B \sin\theta$

ii. $\tau = \mu B \sin(-\theta) = -\mu B \sin\theta$

iii. $\tau = \mu B \sin(\pi + \theta) = -\mu B \sin\theta$

Thus, **(i) > (ii) = (iii)**

(b) Potential energy of a magnetic dipole is given by $U = -\vec{\mu}.\vec{B} = -\mu B \cos\theta$

i. $U = -\mu B \cos\theta$

ii. $U = -\mu B \cos(-\theta) = -\mu B \theta \cos$

iii. $U = -\mu B \cos(\pi + \theta) = +\mu B \cos\theta$

Thus, **(iii) > (i) = (ii)**

Magnetism and Matter

32. (i) Gauss's law for magnetism states that net magnetic flux Φ_B through any closed surface is zero.

$$\phi_B = \oint \vec{B}.\vec{ds} = 0$$

On the other hand, Gauss's law for electrostatics states that electric flux through a closed surface S is given by

$$\phi_E = \oint \vec{E}.\vec{ds} = \frac{q}{\varepsilon_0}$$

where

q = Electric charge enclosed by closed surface

ε_0 = Permittivity of free space

So, if an electric dipole is enclosed by surface, electric flux will be zero. But the fact that Φ_B is zero indicates that in magnetism there is no counterpart of isolated charge as in electricity. So, by this, we can say that isolated magnetic poles or monopoles do not exist.

(ii) Assuming that Earth's magnetic field is due to a bar magnet at the centre of the Earth, held along the polar axis of Earth, the equatorial magnetic field of Earth is given by

$$B = \frac{\mu_0 M}{4\pi d^3}$$

where

$d = R =$ Radius of the Earth

$\mu_0 =$ Absolute magnetic permeability of free space

M = Earth's dipole moment

Given:

$B = 0.4\ \text{G} = 0.4 \times 10^{-4}\ \text{T}$

$\frac{\mu_0}{4\pi} = 10^{-7}\ \text{Wb A}^{-1}\ \text{m}^{-1}$

$d = 6400\ \text{km} = 6400000\ \text{m} = 6.4 \times 10^6\ \text{m}$

$$\therefore M = \frac{Bd^3}{10^{-7}}$$

$$\Rightarrow M = \frac{(0.4 \times 10^{-4})(6.4 \times 10^6)^3}{10^{-7}}$$

$$\Rightarrow M = 1.05 \times 10^{23}\ \text{A m}^2$$

33. We know that $B = \frac{4\pi^2 I}{mT^2}$

Where B = Magnetic field strength
I = Moment of inertia
m = Magnetic moment
T = Time period of oscillation

Thus, $T = \sqrt{\frac{4\pi^2 I}{mB}}$

$$= 2\pi\sqrt{\frac{7.1\times10^{-5}}{3.6\times10^{-2}\times0.3}}$$
$$= 0.509 \text{ s}$$

Frequency, $(f) = \frac{1}{T} = \frac{1}{0.509} = 1.965 \text{ Hz}$

34. For a paramagnetic material, the relative permeability lies between $1 < \mu_r < 1 + \varepsilon$ and its susceptibility lies between $0 < \chi < \varepsilon$.

Hence, 'A' is a paramagnetic material and its susceptibility is positive. This is because its relative permeability is slightly greater than unity.

For a diamagnetic material, the relative permeability lies between $0 \le \mu_r < 1$ and its susceptibility lies between $-1 < \chi < 0$.

Hence, 'B' is a diamagnetic material and its susceptibility is negative. This is because its relative permeability is less than unity.

Here, μ_r and χ refer to the relative permeability and susceptibility.

35. (i) Magnetic moment M = 0.9 J/T
$\tau = 0.063$ J, $\theta = 30°$
We know $\tau = M \times B$
$= MB \sin\theta$
$0.063 = 0.9 \times B \times \sin 30°$

$$B = \frac{2\times0.063}{0.9} = 0.14\text{T}$$

(ii) Stable equilibrium is position of minimum energy. Since $U = -\vec{M}.\vec{B}$
$U = -MB\cos\theta$
Where, U is the energy stored or P.E. of the magnet inside magnetic field B.
So, when $\theta = 0$, $U = -MB$ is the minimum energy.

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Thus, when $\vec{M}$ and $\vec{B}$ are parallel to each other bar magnet is in stable equilibrium.

36. (a) **i.** Magnetic moment of a solenoid, $m = NIA$
Where N = Number of turns = 800
I = Current = 1.5 A
A = Cross-sectional area = 3×10^{-4} m^2
$m = 800 \times 1.5 \times 3 \times 10^{-4} = 3600 \times 10^{-4} = 3.6 \times 10^{-1}$ A m^2
ii. Most stable position occurs when $\theta = 0°$.
Most unstable position occurs when $\theta = 180°$.
Work done = $U_m (\theta = 180°) - U_m (\theta = 0°)$
$= 2\ mB$
$= 2 \times 3.6 \times 10^{-1} \times 900 \times 10^{-4}$
$= 18 \times 3.6 \times 10^{-3}$
$= 6.48 \times 10^{-2}$ J
iii. Torque, $\tau = mB \sin\theta$
$= 3.6 \times 10^{-1} \times 900 \times 10^{-4} \times 0.707$
$= 2.291 \times 10^{-2}$ Am^2
(b) Let us assume that magnetic monopoles do exist.
Let the magnitude of magnetic charge be q_m.
Analogous to Gauss' law to electrostatics, net flux through any Gaussian surface would be

$$\int_s \vec{B}.d\vec{S} = \mu_0 q_m$$

Electromagnetic Induction

37. A glass bob is non-conducting, while a metallic bob is conducting. Due to the non-conducting nature of the glass bob, it will only experience the Earth's gravitational pull. So, the glass bob will reach the ground earlier.
Because of its conducting nature, Eddy current is induced in the metallic bob as it falls through the magnetic field of the Earth.
By Lenz's law, the current induced is such that it opposes the motion of the metallic bob. So, the metallic bob will experience a force in the upward direction. This will slow down the metallic bob by some extent. Hence, it will reach the Earth after the glass bob.

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38. $\because H = B\cos I = 0.4\cos 60^o = 0.2\ \text{G} = 0.2\times10^{-4}\ \text{T}$

This component is parallel to the plane of the wheel. Thus, the emf induced is given as,

$$E = \frac{1}{2}Bl^2\omega, \text{ where } \omega = \frac{2\pi N}{t}.$$

$$\therefore E = \frac{1}{2}\times0.2\times10^{-4}\times0.5^2\times\frac{2\times3.14\times120}{60} = 3.14\times10^{-5}\ \text{V}$$

The value of emf induced is independent of the number of spokes as the emf's across the spokes are in parallel. So, the emf will be unaffected with the increase in spokes.

39. Magnitude of induced emf

$$\propto \frac{d\phi}{dt} \propto \frac{d(\text{BA})}{dt} \propto A\frac{d(\text{B})}{dt} (A \rightarrow \text{Area of cross-section of the wire})$$

Thus, greatest magnitude of induced emf is obtained in the region experiencing greatest change in magnetic field in the shortest amount of time. This is determined by observing the slope of the given graph. The greater the slope, the greater is the induced emf.

From the above graph, we can see that the order of increasing induced emf is iii < i < ii < iv.

40. Horizontal component of the Earth's magnetic field, $B = 3 \times 10^{-5}$ T
Radius of the coil, $r = 10$ cm = 0.1 m
Number of turns, $N = 500$
Resistance of the coil, $R = 200\ \Omega$

Angular speed of rotation of coil,

$$\omega = \frac{d\theta}{dt} = \frac{\pi}{0.25}$$

$$\Rightarrow \omega = \frac{3.14}{0.25} = 12.56\ \text{rad/s}$$

Area of the coil,

$$A = \pi r^2$$

$$\Rightarrow A = 3.14\times(0.1)^2 = 0.0314\ \text{m}^2$$

The Emf induced in the coil is a function of time and is given by

$e = NAB\omega \sin\omega t$

Maximum emf induced in the coil is given as,

$e = NAB\omega$

$\Rightarrow e = 500 \times 0.0314 \times 3 \times 10^{-5} \times 12.56$

$\Rightarrow e = 5.91 \times 10^{-3}$ V

Maximum induced current in the coil is given as,

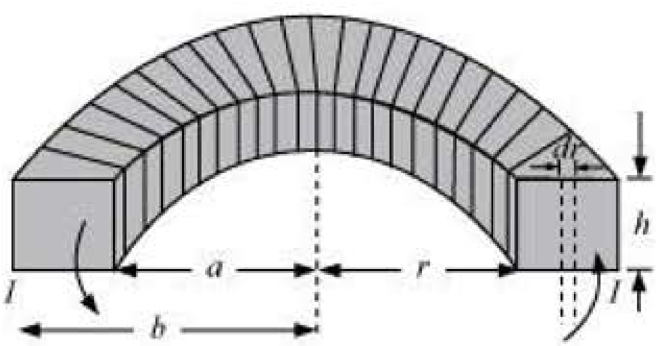
$i = \dfrac{e}{R}$

$\Rightarrow i = \dfrac{5.91 \times 10^{-3}}{200} = 2.95 \times 10^{-5}$ A

Disclaimer: As it is not mentioned in the question, that whether instantaneous or maximum value of the induced emf and current in the coil are to be calculated. Thus, the maximum values of induced emf and current are calculated. The instantaneous values of the induced emf and current are zero for the given instant.

41. No, the induced emf will not be different. This is because the rod still moves with the same speed. As a result, the rate of change of flux remains the same. Therefore, the emf remains unchanged.

42. (a)



According to Ampere's law,

The magnetic field $\vec{B}$ is related to the current I as $\oint \vec{B}.d\vec{s} = \mu_0 NI$.

Or, $\oint Bds = B\oint ds = B(2\pi r) = \mu_0 NI$

Or, $B = \dfrac{\mu_0 NI}{2\pi r}$

Let us now consider infinitesimally small area elements $dA = hdr$ and integrate the magnetic flux through each to obtain the magnetic flux, Φ_B.

$$\phi_B = \int \vec{B}.d\vec{A} = \int_a^b \left(\frac{\mu_0 NI}{2\pi r}\right) hdr$$
$$= \frac{\mu_0 NIh}{2\pi} \ln\left(\frac{b}{a}\right)$$

The total magnetic flux linked with N number of coils is $N\Phi_B$.

Hence, self-inductance is $L = \dfrac{N\phi_B}{I} = \dfrac{\mu_0 N^2 h}{2\pi} \ln\left(\dfrac{b}{a}\right)$.

(b) Under the limit $a >> b - a$, we have:

$$\ln\left(\frac{b}{a}\right) = \ln\left(1 + \frac{b-a}{a}\right) \approx \frac{b-a}{a}$$

Then, self-inductance L becomes $\approx \dfrac{\mu_0 N^2 h}{2\pi} \dfrac{b-a}{a}$

$$= \frac{\mu_0 N^2 A}{2\pi a}$$
$$= \frac{\mu_0 N^2 A}{l}$$

43. Suppose the length of the rod is greater than the radius of the circle and rod rotates anticlockwise and suppose the direction of electrons in the rod at any instant be along +y-direction.

Suppose the direction of the magnetic field is along +z-direction.
Then, using Lorentz law, we get the following:

$$\vec{F} = -e\left(\vec{v} \times \vec{B}\right)$$

$$\Rightarrow \vec{F} = -e\left(v\hat{j} \times B\hat{k}\right)$$

$$\Rightarrow \vec{F} = -evB\hat{i}$$

Thus, the direction of force on the electrons is along $-x$ axis.
Thus, the electrons will move towards the center i.e., the fixed end of the rod. This movement of electrons will result in current and hence it will produce emf in the rod between the fixed end and the point touching the ring.
Let θ be the angle between the rod and radius of the circle at any time t.

Then, area swept by the rod inside the circle $= \frac{1}{2}\pi r^2\theta$

$$\text{Induced emf} = B \times \frac{d}{dt}\left(\frac{1}{2}\pi r^2\theta\right) = \frac{1}{2}\pi r^2 B\frac{d\theta}{dt} = \frac{1}{2}\pi r^2 B\omega = \frac{1}{2}\pi r^2 B\left(2\pi\nu\right) = \pi^2 r^2 B\nu$$

NOTE: There will be an induced emf between the two ends of the rods also.

Alternating Current

44.

Power factor of an a.c. circuit $= \cos\varphi = 0.5$

where

φ = Phase difference between voltage and current

$\therefore\ \varphi = \cos^{-1}(0.5) = 45°$

45. (i) Resonant angular frequency

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10\times 40\times 10^{6}}}$$
$$= \frac{1}{\sqrt{400\times 10^{-6}}} = \frac{1}{20\times 10^{-3}}$$
$$= \frac{1000}{20}$$
$$= 50 \text{ rads}^{-1}$$

(ii) At resonant frequency, we know that the inductive reactance cancels out the capacitive reactance.
The impedance = Z = 60Ω the value of resistance
The current amplitude at resonant frequency

$$I_0 = \frac{E_0}{Z} = \frac{\sqrt{2}E_v}{R} = \frac{\sqrt{2}\times 240}{60}$$
$$= \frac{339.36}{60} = 5.66\text{A}$$

(iii) The R.M.S. value of current

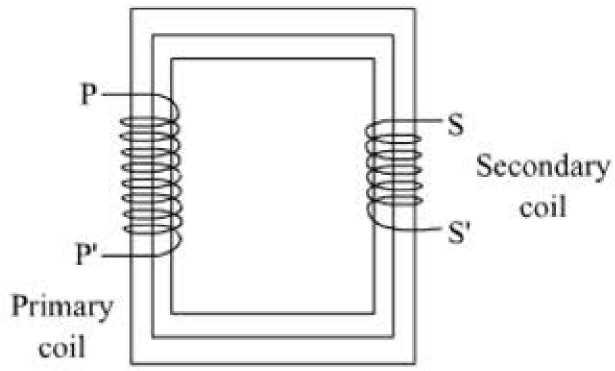
$$I_V = \frac{I_0}{\sqrt{2}} = \frac{5.66}{\sqrt{2}} = 4\text{A}$$

For R.M.S potential drop across inductor

$$V_L = I_V X_L$$
$$= I_V \times \omega L$$
$$= 4\times 50\times 10$$
$$= 200\times 10$$
$$= 2000\,\text{V}$$

46. (i)
A transformer is a device that changes or transforms a low alternating voltage into a high

alternating voltage or vice versa.
It works on the principle of mutual induction. Here, a changing alternating current in primary coil produces a changing magnetic field, which, in turn, induces a changing alternating current in secondary coil.



Energy losses:

- Flux leakage, due to poor design of the core and air gaps in the core
- Resistance of the windings, which leads to loss of energy due to heat produced
- Eddy currents, due to alternating magnetic flux in the iron core, which leads to loss due to heating
- Hysteresis, frequent and periodic magnetisation and demagnetisation of the core, leading to loss of energy due to heat

(ii)
(a) Number of turns in secondary coil is given by

$$\frac{N_S}{N_P} = n$$

$$\Rightarrow \frac{N_S}{100} = 100$$

$$\Rightarrow N_S = 10{,}000$$

(b) Current in primary is given by

$I_P V_P = P$

$$\Rightarrow I_P = \frac{1100}{220} = 5\text{ A}$$

(c) Voltage across secondary is given by

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = n$$

$$\Rightarrow V_S = 100 \times 220 = 22{,}000\text{ V}$$

(d) Current in secondary is given by
$V_S I_S = P$

$$\Rightarrow I_S = \frac{P}{V_S} = \frac{1100}{22000} = 0.05\text{ A}$$

(e) Power in secondary is power in primary in an ideal transformer.

= 1,100 W

47. (i) To draw maximum current from a series *LCR* circuit, the circuit must be at resonance. For resonance, we know at particular frequency $X_L = X_C$.

The frequency of the source will be

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

$$= \frac{1}{2 \times 3.14 \times \sqrt{8 \times 2 \times 10^{-6}}}$$

$$= 39.80\text{ Hz}$$

This frequency is known as the series resonance frequency.

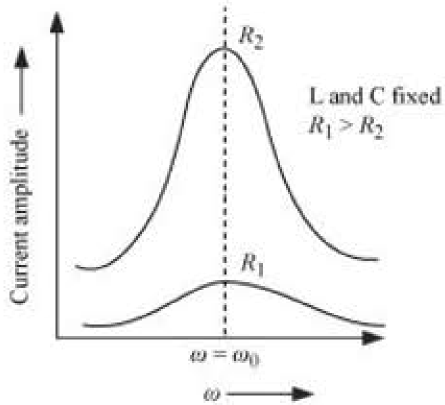
(ii) The maximum current will be given by

$$I_0 = \frac{E_0}{R}$$

$$= \frac{200}{100}$$

$$= 2\ \text{A}$$

(iii)



(iv) Sharpness of Resonance : It is defined as the ratio of the voltage developed across the inductance (L) or capacitance (C) at resonance to the voltage developed across the resistance (R).

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

It may also be defined as the ratio of resonance angular frequency to bandwidth of the circuit.

$$Q = \frac{\omega_r}{2\Delta\omega}$$

Circuit become more selective if the resonance is more sharp, maximum current is more, the circuit is close to resonance for smaller range of (2 $\Delta\omega$) of frequencies. Thus, the tuning of the circuit will be good.

48.
Sharpness is given by the equation:

$$Q=\frac{\omega_0 L}{R}$$

It can be observed from the given graph that (ii) is sharper than (i).
Hence, the resistance of the circuit implied by curve (ii) is lesser than that implied by curve (i).

49. (a) 'Reflected resistance' of a transformer is the resistance value that appears to exist across the primary of a transformer when a resistive load is across the secondary.
(b) The geometrical design as well as the material of the core may be optimized to ensure minimum leakage of magnetic flux.
(c)

i. Ratio, $\dfrac{N_s}{N_p}=\dfrac{V_s}{V_p}=\dfrac{120}{8.5\times10^3}\approx 0.014$

ii. I_p = r.m.s. current in primary coil $=\dfrac{P_{avg}}{V_p}$

$$=\frac{78\times10^3}{8.5\times10^3}$$
$$=9.2\text{ A}$$

$I_s=\dfrac{P_{avg}}{V_s}=$ r.m.s. current in secondary coil $=\dfrac{78\times10^3}{120}=650\text{ A}$

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50. Let the instantaneous charge be $q = q_0 \cos \omega t$.

Thus, instantaneous current, $I = \frac{dq}{dt} = -q_0 \omega \sin \omega t$.

Energy stored in capacitor at time t, $U_C = \frac{q^2}{2C}$

$$= \frac{q_0^2}{2C} \cos^2 \omega t$$

Where,
q = Instantaneous charge
q_0 = Maximum charge corresponding to peak current I_0

Energy stored in inductor at the same time $t, U_L = \frac{1}{2} L I^2$

$$= \frac{1}{2} L \left[-q_0 \omega \sin \omega t \right]^2$$

$$= \frac{q_0^2 L}{2} \omega^2 \sin^2 \omega t$$

$$= \frac{q_0^2 L}{2LC} \sin^2 \omega t$$

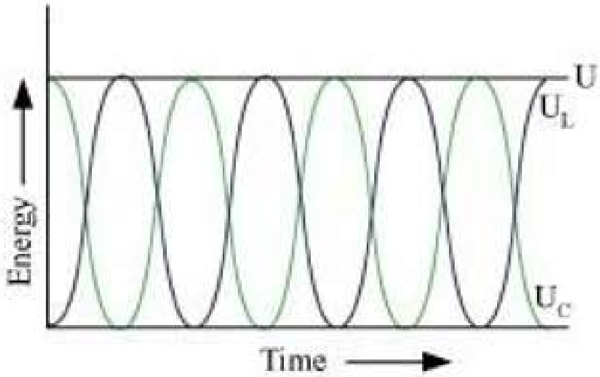
$$= \frac{q_0^2}{2C} \sin^2 \omega t$$

Thus, total energy at time t, $U = U_C + U_L$

$$= \frac{q_0^2}{2C}\left(\sin^2 \omega t + \cos^2 \omega t\right)$$

$$= \frac{q_0^2}{2C} = \text{ Constant with time}$$

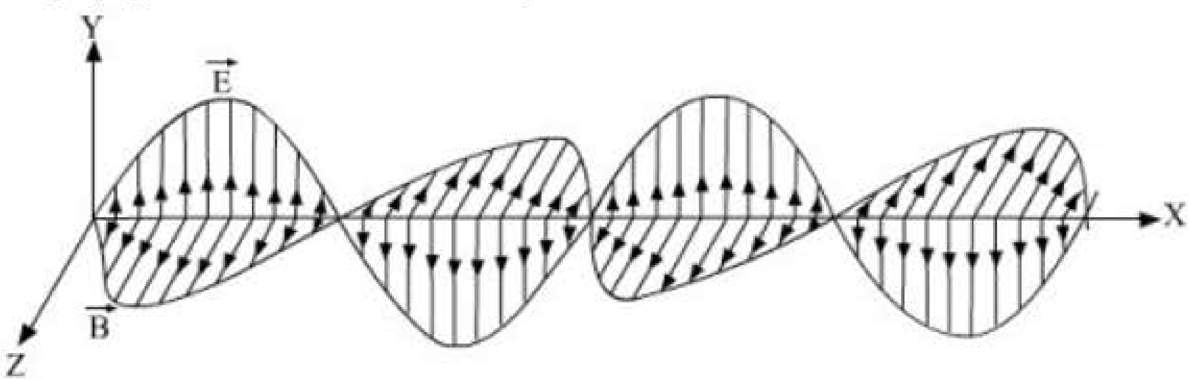
Energy vs. time graph of an LC oscillator:



Electromagnetic Waves

51. (a) Given that velocity, **V** = v î and electric field, **E** along X-axis and magnetic field, **B** along Z-axis.

The propagation of EM wave is following:



(b) Speed of EM wave can be given as the ratio of magnitude of electric field (E_0) to the magnitude of magnetic field (B_0), $c = \frac{E_0}{B_0}$

52. (a) Microwaves are suitable for radar systems used in aircraft navigation. The range of frequency for these waves is 10^9 Hz to 10^{12} Hz.

(b) In the absence of atmosphere, there would be no greenhouse effect on the surface of the Earth. As a result, the temperature of the Earth would decrease rapidly, making it difficult for human survival.

(c) An em wave carries a linear momentum with it. The linear momentum carried by a portion of wave having energy U is given by $p = \frac{U}{c}$.
Thus, if the wave incident on a material surface is completely absorbed, it delivers energy U and momentum $p = \frac{U}{c}$ to the surface. If the wave is totally reflected, the momentum delivered is $p = \frac{2U}{c}$ because the momentum of the wave changes from p to $-p$. Therefore, it follows that an em waves incident on a surface exert a force and hence a pressure on the surface.

53. Let the alternating emf charging the plates of capacitor be $E = E_o \sin \omega t$
Charge on the capacitor, $q = EC = CE_o \sin \omega t$
Instantaneous Current is I.

$$I = \frac{dq}{dt} = \frac{d}{dt}\left(CE_o \sin \omega t\right) = \omega CE_o \cos\omega t = I_o \cos\omega t\left(\text{where } I_o = \omega CE_o\right)$$

$$\text{Displacement current, } I_D = \varepsilon_o \frac{d\varphi_E}{dt} = \varepsilon_o A \frac{d(E)}{dt} = \varepsilon_o A \frac{d}{dt}\left(\frac{q}{\varepsilon_o A}\right) = \varepsilon_o A \frac{d}{dt}\left(\frac{CE_o \sin \omega t}{\varepsilon_o A}\right)$$

$$= \frac{d}{dt}(CE_o \sin \omega t) = \omega CE_o \cos \omega t = I_o \cos \omega t$$

Thus, the displacement current inside the capacitor is the same as the current charging the capacitor.

54. Energy of a light radiated from a source, $E = 3.52 \times 10^5$ J
Time for which light falls on a surface, $t = 1$ min $= 60$ s

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Momentum of light = p
Speed of light in vacuum, $c = 3 \times 10^8$ m/s
Energy of a radiation is related to its momentum by the relation $E = pc$.

$$\therefore p = \frac{E}{c} = \frac{3.52 \times 10^5}{3 \times 10^8} = 1.17 \times 10^{-3} \text{ kg m/s}$$

Hence, force exerted on a surface can be calculated as

$$F = \frac{p}{t}$$
$$= \frac{1.17 \times 10^{-3}}{60} = 1.95 \times 10^{-5} \text{ N} = 1.95 \text{ dynes}$$

Hence, the magnitude of force exerted on the surface is 1.95 dynes.

55. (a) $\vec{E}(z,t) = E_0 \cos(kz - \omega t)\hat{i}$

$= E_0 \cos k(z - ct)\hat{i}$ (Where $\omega = ck$)
Thus, the wave is travelling in the + z-direction.
(b) The amplitude of magnetic field is

$$B_0 = \frac{E_0}{c}$$

We know that $\vec{E}$ and $\vec{B}$ are perpendicular to each other. They are also in phase with each other.

Thus, $\vec{B}(z,t) = B_0 \cos(kz - \omega t)\hat{j}$

We also know that $\frac{E_0}{B_0} = c$

Or, $B_0 = \frac{E_0}{c}$

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Thus, magnetic field is given by $\vec{B}(z,t) = \frac{E_0}{c}\cos(kz - \omega t)\,\hat{j}$

Ray Optics and Optical Instruments

56. The refractive index of the material of a lens increases with the decrease in wavelength of the incident light. So, focal length will decrease with decrease in wavelength according to formula.

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

Thus, when we replace red light with a violet wavelength decrease and hence the focal length of the lens also decrease.

57. Critical angle of ray 1:

$$\sin(c_1) = \frac{1}{\mu_1} = \frac{1}{1.35}$$

$$\Rightarrow c_1 = \sin^{-1}\left(\frac{1}{1.35}\right) = 47.73^\circ$$

Similarly, critical angle of ray 2:

$$\sin(c_2) = \frac{1}{\mu_2} = \frac{1}{1.45}$$

$$\Rightarrow c_2 = \sin^{-1}\left(\frac{1}{1.45}\right) = 43.6^\circ$$

Both the rays will fall on the side AC with angle of incidence *(i)* equal to 45°. Critical angle of ray 1 is greater than that of *i*. Hence, it will emerge from the prism, as shown in the figure. Critical angle of ray 2 is less than that of *i*. Hence, it will be internally reflected, as shown in the figure.

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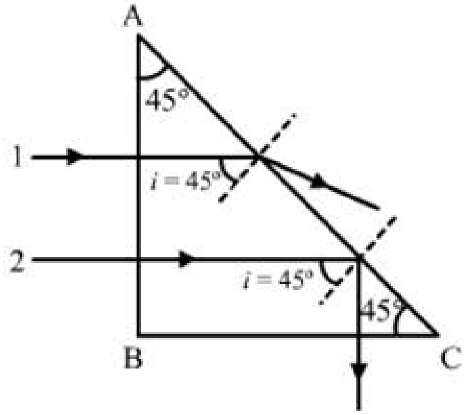

58. Let us first locate the image of the point object S formed by the convex lens.
Here:
u = -60 cm
and f = 20 cm
From the lens formula, we have:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{f} + \frac{1}{u}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{20} + \frac{1}{(-60)}$$

$$\Rightarrow \frac{1}{v} = \frac{3-1}{60} = \frac{2}{60}$$

$$\Rightarrow v = 30 \text{ cm}$$

The positive sign shows that the image is formed to the right of the lens, as shown in the following figure.

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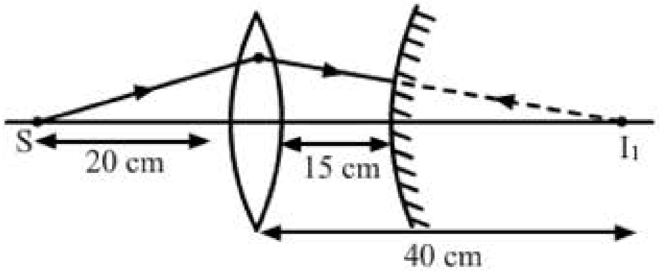


The image I_1 is formed behind the mirror and hence, acts as a virtual source for the mirror. The convex mirror forms the image I_2, whose distance from the mirror can be calculated as:

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

Here:

$u=15$ cm

And, $f=\dfrac{R}{2}=10$ cm

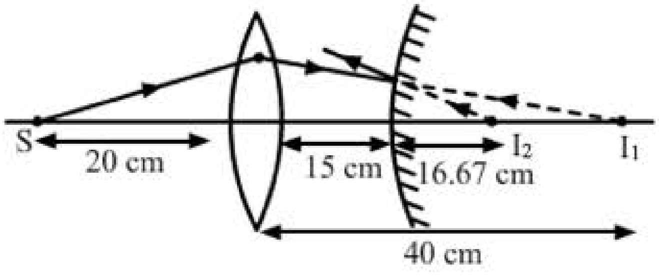
$$\Rightarrow \frac{1}{v}=\frac{1}{f}-\frac{1}{u}$$

$$\Rightarrow \frac{1}{v}=\frac{1}{10}-\frac{1}{15}$$

$$\Rightarrow \frac{1}{v}=\frac{3-2}{30}=\frac{1}{30}$$

$$\Rightarrow v=30 \text{ cm}$$

Hence, the final virtual image is formed at a distance of 30 cm from the convex mirror, as shown in the figure below.



59. From the lens maker formula, we have

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

where

f = Focal length the lens

μ = Refractive index of material

R_1 = Radius of curvature of first face

R_2 = Radius of curvature of second face

Let f_1 and f_2 be the focal lengths of the two mediums. Then,

$$\frac{1}{f_1}=\left(u_1-1\right)\left[\frac{1}{R}-\left(-\frac{1}{R}\right)\right]$$

$$\Rightarrow \frac{1}{f}=\left(u_1-1\right)\left(\frac{2}{R}\right)$$

$$\frac{1}{f_2}=\left(u_2-1\right)\left[\left(-\frac{1}{R}\right)-\frac{1}{\infty}\right]$$

$$\Rightarrow \frac{1}{f_2}=\left(u_2-1\right)\left(-\frac{1}{R}\right)$$

(a) If f_{eq} is the equivalent focal length of the combination, then

$$\frac{1}{f_{eq}} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\Rightarrow \frac{1}{f_{eq}} = \frac{2(\mu_1 - 1)}{R} - \frac{(\mu_2 - 1)}{R}$$

$$\Rightarrow \frac{1}{f_{eq}} = \frac{2\mu_1 - \mu_2 - 1}{R}$$

$$\Rightarrow f_{eq} = \frac{R}{2\mu_1 - \mu_2 - 1}$$

(b) For the combination to behave as a diverging lens, $f_{eq} < 0$

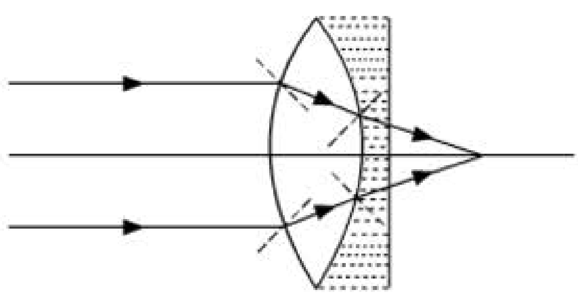
$$\Rightarrow \frac{R}{2\mu_1 - \mu_2 - 1} < 0$$

$$\Rightarrow 2\mu_1 - \mu_2 - 1 < 0$$

$$\Rightarrow \mu_1 < \frac{(\mu_2 + 1)}{2}$$

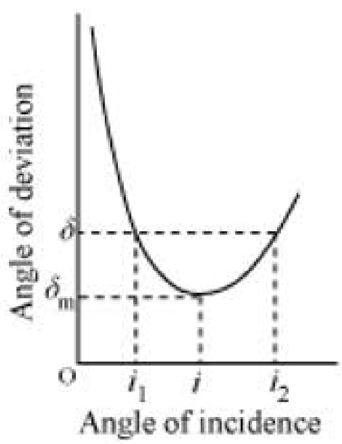
which is the required condition

(c) For $\mu_1 > (\mu_2 + 1)/2$, the combination will behave as the converging lens. So, an object placed far away from the lens will form image at the focus of the lens.



The image so formed will be real and diminished in nature.

60. (i)



If the angle of incidence is increased gradually, then the angle of deviation first decreases, attains a minimum value (δ_m) and then again starts increasing.
When angle of deviation is minimum, the prism is said to be placed in the minimum deviation position.
There is only one angle of incidence for which the angle of deviation is minimum.
When $\delta = \delta_m$ [prism in minimum deviation position],
$e = i$ and $r_2 = r_1 = r$ .....(i)
$\because\ r_1 + r_2 = A$
From (i), we get

$r + r = A$
$$r = \frac{A}{2}$$
Also, we have
$A + \delta = i + e$
Substituting $\delta = \delta_m$ and $e = i$,
$A + \delta_m = i + i$

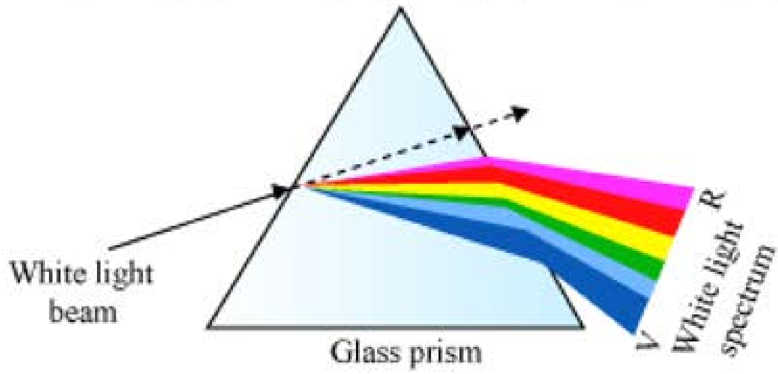
$$i = \frac{\left(A + \delta_m\right)}{2}$$

$$\because \mu = \frac{\sin i}{\sin r}$$

$$\therefore \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

(ii)

Dispersion of light is the phenomenon of splitting of light into its component colours.
When a narrow beam of sunlight is incident on a glass prism, the emergent light splits into seven colours, namely, violet (V), indigo (I), blue (B), green (G), yellow (Y), orange (O) and red (R).



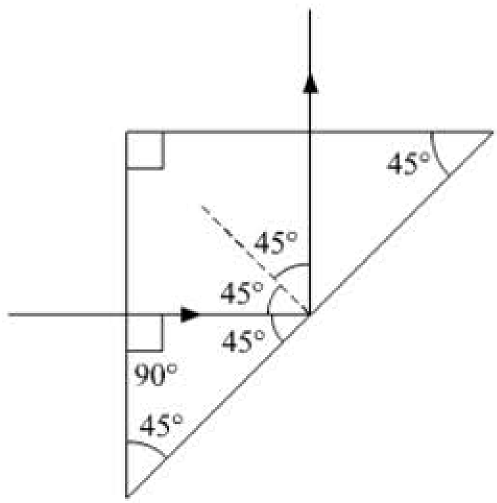
Cause of dispersion: Different colours of white light have different wavelengths. The wavelength of violet light is smaller than that of red light. The refractive index of a material in terms of the wavelength of the light is given by Cauchy's expression.

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

Here, *a, b* and *c* are constants for the material.

Thus, a material offers different refractive indices to lights of different wavelengths. This is the cause of dispersion of light.

(iii)



We know that light incident normally on one face of a right isosceles prism is totally reflected.

$\mu = \dfrac{1}{\sin C}$ (Total internal reflection)

C is the critical angle, which is 45º.

$$\mu = \frac{1}{\sin 45}$$

$$\mu = \sqrt{2} = 1.41$$

Thus, the minimum value of the refractive index of the glass is 1.41.

61. We know that $\dfrac{1}{f} = (\mu - 1)\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$.

Let $R_1 = R$ and $R_2 = -R$.

Thus, $\dfrac{1}{12}=(\mu-1)\left(\dfrac{2}{R}\right)$.

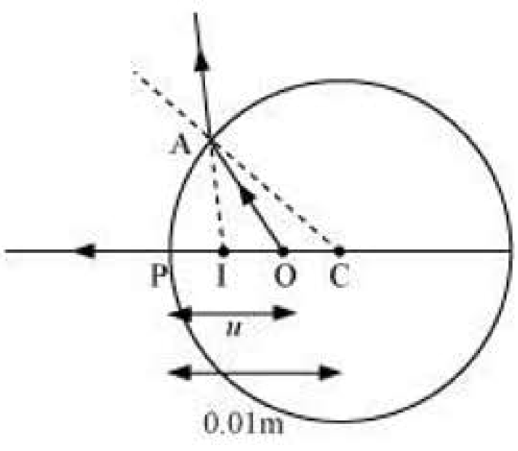
For each half of the lens, $R_1 = R$ and $R_2 = \infty$.

Thus,

$$\frac{1}{f'}=(\mu-1)\left(\frac{1}{R}-\frac{1}{\infty}\right)$$
$$=(\mu-1)\frac{1}{R}$$
$$=\frac{1}{24}$$

Hence, the new focal length of each half is 24 cm.

62.



C → Centre of sphere

O → Actual position of bubble

I → Image of bubble

Here,

$R = -0.01$

m = − 1 cm

μ = 1.54

$v = -0.005$

m = − 0.5 cm

For refraction at a spherical surface, we have:

$$-\frac{\mu}{u}+\frac{1}{v}=\frac{1-\mu}{R}$$

$$\text{or, } \frac{-1.54}{u}-\frac{1}{0.5}=\frac{1-1.54}{-1}$$

$$-\frac{1.54}{u}=-0.54+\frac{1}{0.5}$$

$$u=-\frac{1.54}{1.46}=-1.05\text{ cm}$$

Hence, the actual depth of the bubble from the surface is 1.05 cm.

63. (a) In order for no deviation to be produced, (Deviation by flint glass) = − (Deviation by crown glass).

$$A'(\mu'-1)=-A(\mu-1)$$

$$\text{or, } A' = -A\frac{(\mu-1)}{(\mu'-1)}$$

$$\text{Now, } \mu = \frac{\mu_v + \mu_r}{2} = \frac{1.523+1.515}{2} = 1.519$$

$$\text{and } \quad \mu' = \frac{\mu_v' + \mu_r'}{2} = \frac{1.688+1.650}{2} = 1.669$$

$$\text{Thus, } A' = -6\left(\frac{1.519-1}{1.669-1}\right)$$

$$= \frac{-6\times 0.519}{0.669}$$

$$= -4.65°$$

The negative sign indicates that the two prisms must be oriented oppositely.

(b) **Dispersive power:**

The dispersive power of a prism is the ratio of the angular dispersion to the mean deviation produced by the prism.

Dispersive power depends only on the nature of the material of the prism and not on the angle of the prism. According to the given condition, it can be said that both prisms have the same dispersive power.

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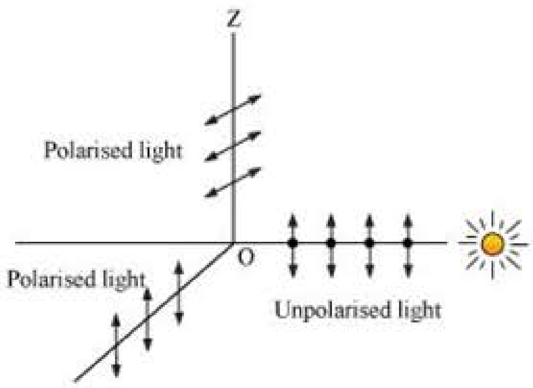
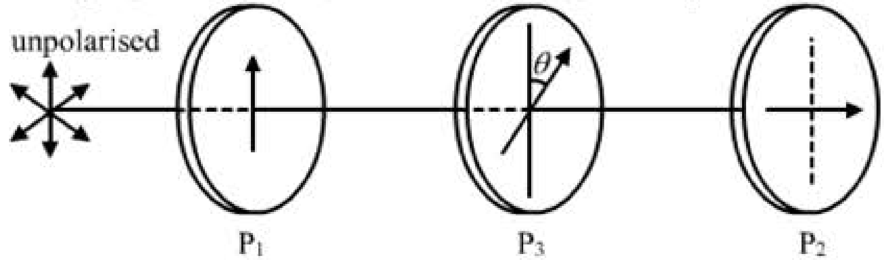
Wave Optics

64. (a) Unpolarized light scattering from air molecules shakes their electrons perpendicular to the direction of the original ray. The scattered light therefore has a polarisation perpendicular to the original direction and none parallel to the original direction.



(b) As given in the question, the polaroids P_1 and P_2 are placed with their pass axes perpendicular to each other. Also, P_3 is placed at an angle of $45°$ with respect to P_1.



Now, we have:

Intensity of light after falling on P_1, $I' = \frac{I_0}{2}$

Intensity of light after falling on P_3, $I'' = I'\cos^2(\theta) = \frac{I_0}{2}\cos^2(45°) = \frac{I_0}{4}$

Therefore, a light of intensity $\frac{I_0}{4}$ will pass through P_3 and the angle between P_3 and P_2 will be $45°$ because of the condition given in the question.

Intensity of light after falling on P_2, $I''' = I''\cos^2(\theta) = \frac{I_0}{4}\cos^2(45°) = \frac{I_0}{8}$

65. (a)
Angular width (θ) of fringe in double-slit experiment is given by

$$\theta = \frac{\lambda}{d}$$

Where
d = Spacing between the slits

Given:

Wavelength of light, λ = 600 nm

Angular width of fringe, $\theta = 0.1° = \frac{\pi}{1800} = 0.0018$ rad

$$\therefore\ d = \frac{\lambda}{\theta}$$

$$\Rightarrow d = \frac{600\times10^{-9}}{18\times10^{-4}}$$

$$\Rightarrow d = 0.33\times10^{-3}\text{ m}$$

(b) The frequency and wavelength of reflected wave will not change.

The refracted wave will have same frequency.

The velocity of light in water is given by

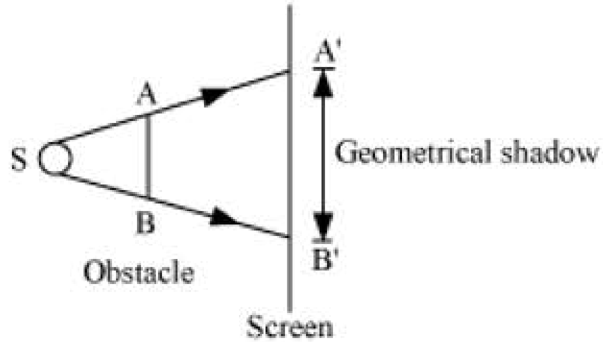
$$v = \lambda f$$

where
v = Velocity of light
f = Frequency of light

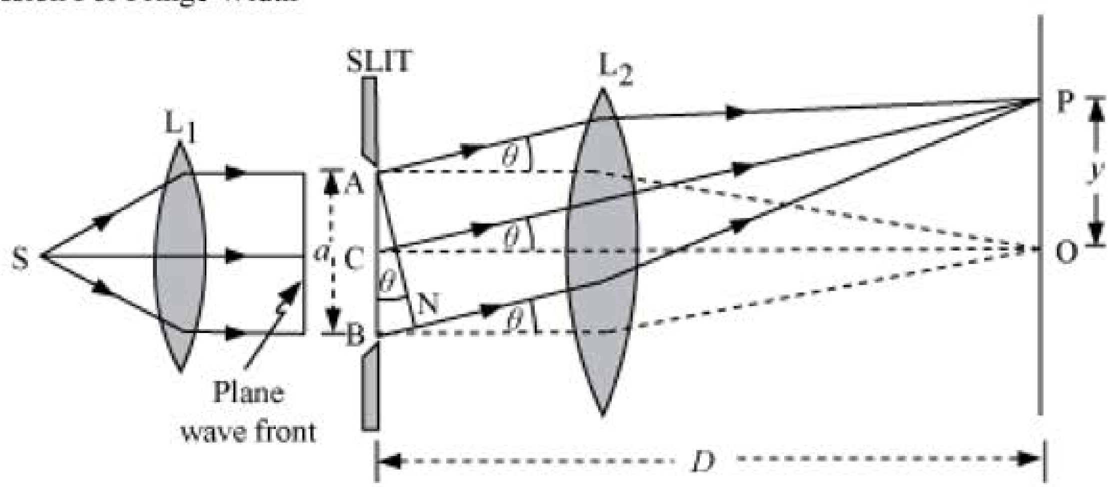
λ = Wavelength of light

If velocity will decrease, wavelength (λ) will also decrease.

66. (a) The phenomenon of bending of light round the sharp corners of an obstacle and spreading into the regions of the geometrical shadow is called diffraction.



Expression For Fringe Width



Consider a parallel beam of light from a lens falling on a slit AB. As diffraction occurs, the pattern is focused on the screen XY with the help of lens L_2. We will obtain a diffraction pattern that is a central maximum at the centre O flanked by a number of dark and bright fringes called secondary maxima and minima.

Central Maximum − Each point on the plane wave front AB sends out secondary wavelets in all directions. The waves from points equidistant from the centre C lying on the upper and lower half reach point O with zero path difference and hence, reinforce each other, producing maximum intensity at point O.

Positions and Widths of Secondary Maxima and Minima

Consider a point P on the screen at which wavelets travelling in a direction making angle θ with

CO are brought to focus by the lens. The wavelets from points A and B will have a path difference equal to BN.

From the right-angled ΔANB, we have:

BN = AB sinθ

BN = a sinθ …(i)

Suppose BN = λ and $\theta = \theta_1$

Then, the above equation gives

$\lambda = a \sin \theta_1$

$$\boxed{\sin \theta_1 = \frac{\lambda}{a}} \qquad \text{...(ii)}$$

Such a point on the screen will be the position of first secondary minimum.

If BN = 2λ and $\theta = \theta_2$, then

2λ = a sin θ_2

$$\sin \theta_2 = \frac{2\lambda}{a} \qquad \text{...(iii)}$$

Such a point on the screen will be the position of second secondary minimum.

In general, for n^{th} minimum at point P,

$$\sin \theta_n = \frac{n\lambda}{a} \qquad \text{...(iv)}$$

If y_n is the distance of the n^{th} minimum from the centre of the screen, from right-angled ΔCOP, we have:

$$\tan \theta_n = \frac{\text{OP}}{\text{CO}}$$

$$\tan \theta_n = \frac{y_n}{D} \qquad \text{...(v)}$$

In case θ_n is small, sin $\theta_n \approx$ tan θ_n

∴ Equations (iv) and (v) give

$$\frac{y_n}{D} = \frac{n\lambda}{a}$$

$$y_n = \frac{nD\lambda}{a}$$

Width of the secondary maximum,

$$\beta = y_n - y_{n-1} = \frac{nD\lambda}{a} - \frac{(n-1)D\lambda}{a}$$

$$\beta = \frac{D\lambda}{a} \qquad ...(vi)$$

$\because \beta$ is independent of n, all the secondary maxima are of the same width β.

If $\mathrm{BN} = \frac{3\lambda}{2}$ and $\theta = \theta'_1$, from equation (i), we have:

$$\sin\theta'_1 = \frac{3\lambda}{2a}$$

Such a point on the screen will be the position of the first secondary maximum.
Corresponding to path difference,

$\mathrm{BN} = \frac{5\lambda}{2}$ and $\theta = \theta'_2$, the second secondary maximum is produced
In general, for the n^{th} maximum at point P,

$$\sin\theta'_n = \frac{(2n+1)\lambda}{2a} \qquad (vii)$$

If y'_n is the distance of n^{th} maximum from the centre of the screen, then the angular position of the n^{th} maximum is given by

$$\tan\theta'_n = \frac{y'_n}{D} \qquad (viii)$$

In case θ'_n is small,

$$\sin\theta'_n \approx \tan\theta'_n$$

$$\therefore y'_n = \frac{(2n+1)D\lambda}{2a}$$

Width of the secondary minimum,

$$\beta' = y'_n - y'_{n-1} = \frac{nD\lambda}{a} - \frac{(n-1)D\lambda}{a}$$

$$\boxed{\beta' = \frac{D\lambda}{a}} \qquad \text{(ix)}$$

Since β' is independent of n, all the secondary minima are of the same width β'.

(b) For first maxima of the diffraction pattern we know $\sin\theta = \frac{3\lambda}{2a}$
where a is aperture of slit.

For small values of θ, $\sin\theta \approx \tan\theta = \frac{y}{D}$
Where y is the distance of first minima from central line and D is the distance between the slit and the screen.

So, $y = \frac{3\lambda}{2a}D$
For 590 nm,

$$y_1 = \frac{3 \times 590 \times 10^{-9}}{2 \times 2 \times 10^{-6}} \times 1.5$$

$$y_1 = 0.66375 \text{ m}$$

For 596 nm,

$$y_2 = \frac{3 \times 596 \times 10^{-9}}{2 \times 2 \times 10^{-6}} \times 1.5$$

$$y_2 = 0.6705 \text{ m}$$

Separation between the positions of first maxima = $y_2 - y_1$ = 0.00675 m

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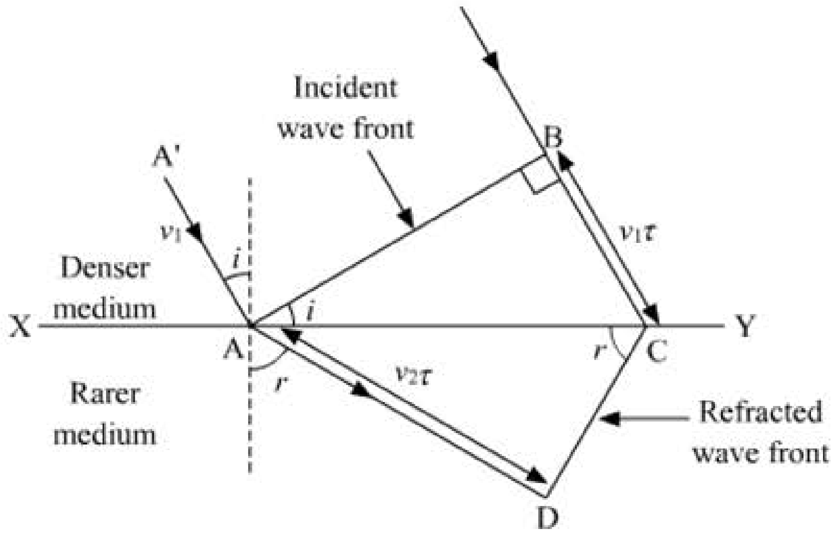
67. (a)



Let XY be the surface separating the denser medium and the rarer medium.
Let:
v_1 = Speed of light wave in the denser medium
v_2 = Speed of light wave in the rarer medium
Let us consider a plane wavefront AB propagating in the direction AA'. Let this wavefront incident on the interface at an angle of incidence i with the normal to the interface.
Let τ be the time taken by the wavefront to travel the distance BC in denser medium.

$$\Rightarrow BC = v_1\tau$$

To determine the shape of refracted wavefront, we will draw a sphere of radius $v_2\tau$ from point A in the rarer medium. Let CD represent a tangent plane drawn from point C onto the sphere.
Now,
$$AD = v_2\tau$$

Here, CD would represent the refracted wavefront. Considering the triangles ABC and ADC, we get

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

$$\sin r = \frac{AD}{AC} = \frac{v_2 \tau}{AC}$$

$$\Rightarrow \frac{\sin i}{\sin r} = \frac{v_1}{v_2} \quad .....(1)$$

where
i = Angle of incidence
r = Angle of refraction

Since $r > i$ (rays bend away from the normal on travelling from denser to rarer medium), the speed of light in the rarer medium (v_2) will be greater than the speed of light in the denser medium (v_1). If c represents the speed of light in vacuum, then

$$\mu_1 = \frac{c}{v_1}$$

$$\mu_2 = \frac{c}{v_2}$$

where
μ_1 = Refractive index of denser medium
μ_2 = Refractive index of rarer medium

Further, (1) can be written as
$\mu_1 \sin i = \mu_2 \sin r$

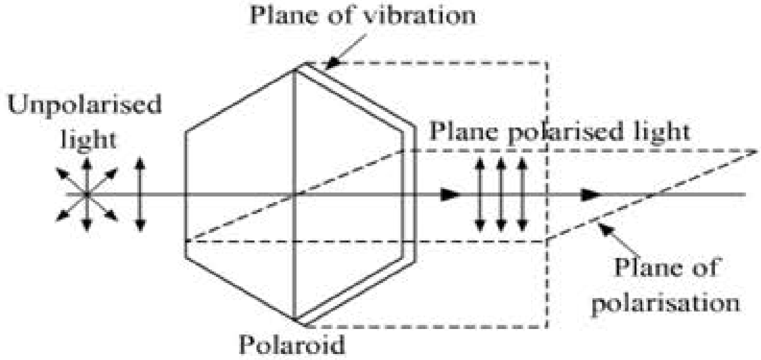
This is the Snell's law of refraction.

Now, if λ_1 and λ_2 represent the wavelengths of light in the denser medium and rarer medium, respectively, and if the distance BC is λ_1, then the distance AD will be λ_2. So, we have

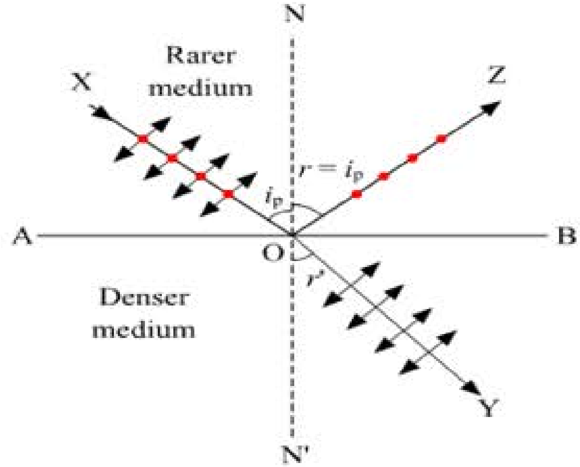
$$\frac{\lambda_1}{\lambda_2} = \frac{BC}{AD} = \frac{v_1}{v_2}$$

$$\Rightarrow \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

(b)
(i) When unpolarised light is passed through a polaroid crystal, only those vibrations of light pass through the crystal that are parallel to the axis of the crystal. All other vibrations will be absorbed by the crystal. In this way, the unpolarised light incident on a polaroid gets linearly polarised.



(ii)



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Let us consider that an unpolarised light is incident along XO at an angle i_p (angle of polarisation) on the interface AB, separating air, a rarer medium, from a denser medium of refractive index μ. It has been experimentally observed that when unpolarised light is incident at polarising angle, the reflected components along OZ and OY are mutually perpendicular to each other. So, from the above figure, we have

$$\angle ZOB + \angle BOY = 90°$$

$$\Rightarrow (90° - i_p) + (90° - r') = 90°$$

where r' is the angle of refraction

$$\Rightarrow 90° - i_p = r'$$

According to Snell's law,

$$\mu = \frac{\sin i}{\sin r}$$

Here,

$$i = i_p$$

$$r = r' = (90° - i_p)$$

$$\therefore \mu = \frac{\sin i_p}{\sin(90° - i_p)}$$

$$\Rightarrow \mu = \frac{\sin i_p}{\cos i_p} = \tan i_p$$

This gives us the required expression for Brewster's law.

68. Let the two waves emitted by light sources have a phase difference Φ.

Displacement produced by one wave, $y_1 = a\cos\omega t$

Displacement produced by second wave, $y_2 = a\cos(\omega t + \phi)$

On interference, net displacement, $y = y_1 + y_2$

$= a\left[\cos \omega t + \cos(\omega t + \phi)\right]$

$= 2a \cos \frac{\phi}{2} \cos \frac{\omega t + \phi}{2}$

Thus, Amplitude $= 2a \cos \frac{\phi}{2}$

And, Intensity, $I = 4a^2 \cos^2 \frac{\phi}{2}.$

Now, for incoherent sources, Φ is not a constant with time.
Then, average intensity should be calculated as:

$< I > = 4I_0 < \cos^2 \frac{\phi}{2} >$

We know that the time average of $\cos^2 \frac{\phi}{2}$ is $\frac{1}{2}$.
Thus, resultant intensity, $I = 2I_0$.
Therefore, resultant intensity is the sum of intensities of the two waves.
Hence, we do not observe any interference pattern between the two incoherent sources of light.

69. (a)
(i) Path difference,

$\delta = d \sin \theta$

When $L \gg y,$ as in the given situation, θ is small.

Thus, $\sin \theta \approx \tan \theta = \frac{y}{L}$.
($y = 2$ cm)

Thus, $\delta = d\left(\frac{y}{L}\right)$

$$= (1.5\times10^{-4})\left(\frac{2\times10^{-2}}{1.20}\right)$$

$$= 2.5\times10^{-6}\ \text{m}$$

(ii) In terms of λ, we can express δ as:

$$\delta = n\lambda$$

$$n = \frac{\delta}{\lambda}$$

$$= \frac{2.5\times10^{-6}}{833\times10^{-9}}$$

$$\approx 3$$

Or, $\delta = 3\lambda$

(iii) Since the path difference is an integer multiple of the wavelength, the intensity at P is the maximum.

(b) Shift of a distant star towards the longer wavelength $= \dfrac{\Delta\lambda}{\lambda}$

Speed with which the star is receding, $v = 6.5 \times 10^5$ m/s

Speed of light in vacuum, $c = 3 \times 10^8$ m/s

The red shift of a star is related to receding velocity as:

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

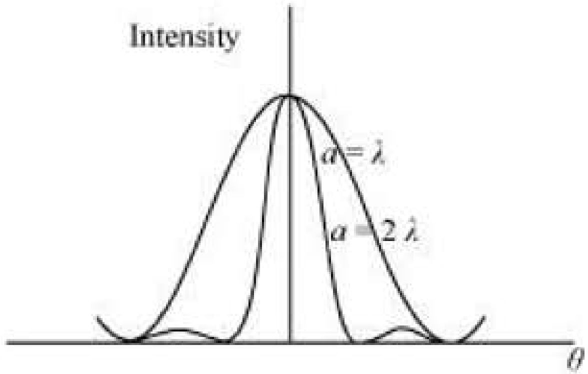
$$= \frac{6.5\times10^5}{3\times10^8} = 2.17\times10^{-3}$$

$$= 2.17\times10^{-3}\times100 \approx 0.22\%$$

Hence, the red shift percentage of the given star is 0.22 %.

70. (a) In case of a double slit experiment, the slits taken are very small so that they can be considered as single light sources. This is done to ensure that there is no interference of waves within the slit itself. As a result, no diffraction takes place and the interference obtained is a pure interference pattern.

(b)



(c) The general condition for destructive interference is:

$$\sin\theta = \mathrm{m}\frac{\lambda}{a} \approx \frac{y_{\mathrm{m}}}{L}\,(\text{making small angle approximation})$$

Where,

y = Distance of m$^{\text{th}}$ order fringe from the centre of the central fringe

L = Distance between slit and screen

Thus, $y_m = \mathrm{m}\frac{\lambda}{a}L$

Let the second bright fringe be located midway between the second and third dark fringes

i.e., $y_{2\text{bright}} = \frac{1}{2}(y_2 + y_3)$.

$$= \frac{1}{2}(2+3)\frac{\lambda}{a}L$$

$$= \frac{5}{2}\frac{\lambda L}{a}$$

Given,

$$y_{2\text{bright}} = 1.60\ \text{mm}$$

$=1.6\times10^{-3}$ m

$L=0.8\ m$

$a=0.8$ mm

$=0.8\times10^{-3}$ m

Thus, $\lambda=\dfrac{2ay_{2\text{bright}}}{5L}$

$$=\frac{2\times0.8\times10^{-3}\times1.6\times10^{-3}}{5\times0.8}=6.4\times10^{-7}\text{ m.}$$

Dual Nature of Matter and Radiation

71. (i) Energy = hν

On an average, number of photons emitted per second = $\dfrac{\text{Power}}{\text{Energy of one photon}}$

On putting the values, we get:

$$=\frac{2\times10^{-3}}{6.63\times10^{-34}\times6\times10^{14}}$$

On an average, number of photons emitted per second $=5.03\times10^{15}$

(ii)

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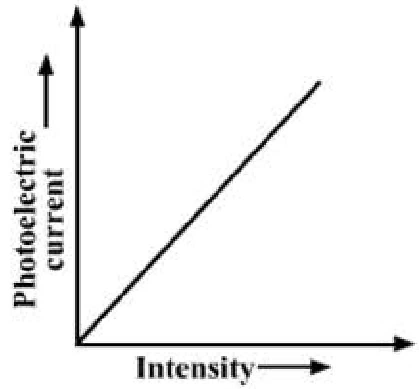

72. Photoelectric effect is a one photon-one electron phenomenon. Therefore, when the intensity of radiation incident on the surface increases, the number of photons per unit area per unit time increases (since intensity of incident radiation ∝ no. of photons). Hence, the photoelectrons ejected will be large, which, in turn, will contribute to the increase in photoelectric current.

73. That particular frequency of incident radiation for which the minimum negative potential V_0 given to a plate for photo-electric current becomes zero is called the cut-off frequency.

Given that threshold frequency of metal is *f*. For light of frequency 2*f*, using Einstein's equation for photoelectric effect, we can write

$$h(2f-f)=\frac{1}{2}mv_1^{\,2} \quad .....(1)$$

Similarly, for light having frequency 5*f*, we have

$$h(5f-f)=\frac{1}{2}mv_2^{\,2} \quad .....(2)$$

Using (1) and (2), we find

$$\frac{f}{4f}=\frac{v_1^{\,2}}{v_2^{\,2}} \Rightarrow \frac{v_1}{v_2}=\sqrt{\frac{1}{4}}$$

$$\Rightarrow \frac{v_1}{v_2}=\frac{1}{2}$$

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74. The de-Broglie wavelength of the electrons is given by:

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

Here:
m = mass of the electron = 9.1×10^{-31} kg
e = charge on the electron = 1.6×10^{-19} C
V = accelerating potential = 50 kV
h = Planck's constant = 6.626×10^{-34} Js

$$\Rightarrow \lambda = \frac{6.626\times10^{-34}}{\sqrt{2(9.1\times10^{-31})(1.6\times10^{-19})(50\times10^{3})}}$$

$$\Rightarrow \lambda = 0.0549\ \text{Å}$$

Resolving power of a microscope, $R = \dfrac{2\mu\sin\theta}{\lambda}$

This formula suggests that to improve resolution, we have to use shorter wavelength and media with large indices of refraction. For an electron microscope, μ is equal to 1(vacuum).
For an electron microscope, the electrons are accelerated through a 60,000 V potential difference. Thus the wavelength of electrons is found to be,

$$\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{60000}} = 0.05\ \text{Å}$$

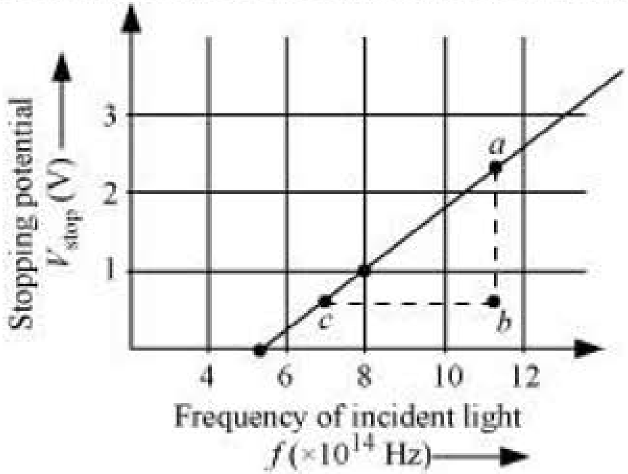
As, λ is very small (approximately 10^{-5} times smaller) for electron microscope than an optical microscope which uses yellow light of wavelength (5700 Å to 5900 Å). Hence, the resolving power of an electron microscope is much greater than that of optical microscope.

75.

$$V_{\text{stop}} = \left(\frac{\text{h}}{\text{e}}\right)f - \frac{\phi}{\text{e}}$$

This is the equation of a straight line with slope $\left(\dfrac{\text{h}}{\text{e}}\right)$ and y-intercept $\dfrac{\phi}{\text{e}}$.

From the given graph, we obtain the slope for the segment of line as shown.



Slope $= \frac{h}{e}$

Or, $h = e \times \text{slope}$

$= 1.6 \times 10^{-19} \times 4.1 \times 10^{-15}$

$= 6.6 \times 10^{-34}$ Js.

76. (a) It is known that the energy associated with a particular wave frequency is hf. Now, red light does not cause photoelectric emission from the surface because its frequency is less than that of yellow light.

Violet light, on the other hand, causes photoelectric emission from the surface as its frequency is greater than that of green light.

(b)

i. Work function of sodium, $\Phi = 2.28$ eV

$= 2.28 \times 1.6 \times 10^{-19}$ J

$= 3.65 \times 10^{-19}$ J

The energy associated with red light is $E = \frac{hc}{\lambda}$.

Then,

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{680 \times 10^{-9}}$$
$$= 2.925 \times 10^{-19} \text{ J}$$

Hence, red light will not cause photoemission in sodium as $E < \Phi$.

ii. At cut-off wavelength,

$E = \Phi$

$$\frac{hc}{\lambda} = \phi$$

Or, $\lambda = \frac{hc}{\phi}$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{3.65 \times 10^{-19}}$$
$$= 5.45 \times 10^{-7} \text{ m}$$
$$= 545 \text{ nm}$$

iii. From wavelength 545 nm, we can infer that it corresponds to green light.

Atoms

77. (i) According to Bohr's postulate: electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final state.

$h\nu = E_i - E_f$

(ii) When an electron passes from n = 4 energy level to n = 1 level, the number of maximum spectral lines emitted by the atom will be 6 because maximum number of photons emitted are 6, corresponding to 6 transitions. These lines will correspond to Balmer series.

78. Let the hydrogen atoms be excited to n^{th} energy level.

$$12.3 = 13.6\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$$

$$\Rightarrow 12.3 = 13.6 - \frac{13.6}{n^2}$$

$$\Rightarrow \frac{13.6}{n^2} = 13.6 - 12.3 = 1.3$$

$$\Rightarrow n^2 = \frac{13.6}{1.3}$$

$$\Rightarrow n \approx 3$$

The formula for calculating the wavelength of Lyman series is given below:

$$\frac{1}{\lambda} = R\left(1 - \frac{1}{n^2}\right)$$

For the second member of Lyman series:
$n = 3$

$$\therefore \frac{1}{\lambda} = R\left(1 - \frac{1}{3^2}\right)$$

$$\Rightarrow \frac{1}{\lambda} = \left(1.09737 \times 10^7\right)\left(\frac{8}{9}\right)$$

$$\Rightarrow \lambda = 1025\ \mathring{A}$$

The formula for calculating the wavelength of Balmer series is given below:

$$\frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{n^2}\right)$$

For second member of Balmer series:
$n = 4$

$$\therefore \frac{1}{\lambda} = R\left(\frac{1}{4} - \frac{1}{4^2}\right)$$

$$\Rightarrow \frac{1}{\lambda} = \left(1.09737 \times 10^7\right)\left(\frac{3}{16}\right)$$

$$\Rightarrow \lambda = 4861 \text{ Å}$$

79. According to de-Broglie hypothesis, a stationary orbit is the one that contains an integral number of de-Broglie waves associated with the revolving electron.
For an electron revolving in nth circular orbit of radius r_n,
Total distance covered by electron = Circumference of the orbit = $2\pi r_n$
For the permissible orbit, we have

$$2\pi r_n = n\lambda$$

, where λ is the wavelength.

According to de-Broglie, wavelength of matter waves is given by

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

where

h = Planck's constant

m = mass of electron

v_n = speed of electron in nth orbit

$$\therefore 2\pi r_n = \frac{n\mathrm{h}}{mv_n}$$

$$\Rightarrow mv_n r_n = \frac{n\mathrm{h}}{2\pi}$$

This is Bohr's second postulate of quantisation of orbital angular momentum.

80. Ionization energy: The minimum amount of energy required to remove an electron from the outermost orbit of a neutral atom in its ground state is known as the ionization energy of that atom.

The ionization energy of Hydrogen atom is

$E_H \propto m_e \quad .....(1)$

When mass of electron is replaced by a particle having mass $= 200m_e$, then

$E_H' \propto 200m_e \quad .....(2)$

From (1) and (2), we have

$E_H' = 200E_H = 200 \times (-13.6) = -2720 \text{ eV} \quad (\because E_H = -13.6 \text{ eV})$

81. (a) $b = 0$

Implies:

$$\cot\frac{\theta}{2} = 0$$

$$\tan\frac{\theta}{2} = \infty$$

Thus, $\frac{\theta}{2} = 90°$

Or, $\theta = 180°$

Hence, the scattering angle is 180°.

(b)

$$b = \frac{Ze^2}{4\pi \in_0} \frac{\cot\frac{\theta}{2}}{\left(\frac{1}{2}mv^2\right)}$$

$$\text{Or, } b = \frac{Ze^2}{4\pi \in_0} \frac{\cot\frac{\theta}{2}}{E}$$

(Where, E is the energy of the α-particle for a particular impact parameter)

If E increases, then $\cot\frac{\theta}{2}$ also increases for a particular impact parameter.

Also, $\cot\frac{\theta}{2}$ increases when θ decreases.

Hence, the angle of scattering decreases in this case.

(c)

$$b = \frac{Ze^2 \cot\frac{\theta}{2}}{4\pi \in_0 \left(\frac{mv^2}{2}\right)}$$

For gold, $Z = 79$.

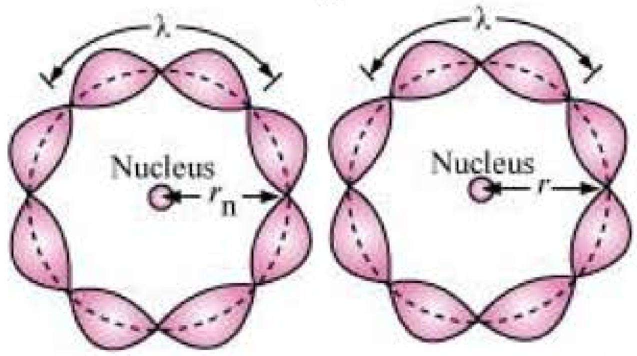
$$\frac{1}{2}mv^2 = E = 20 \text{ MeV} = 20\times1.6\times10^{-13} \text{ J}$$

$$b = \frac{79\times(1.6\times10^{-19})^2\cot\left(\frac{90}{2}\right)}{4\pi\epsilon_0\times20\times1.6\times10^{-13}}$$
$$= \frac{9\times10^9\times79\times1.6^2\times10^{-38}\times\sqrt{2}}{20\times1.6\times10^{-13}}$$
$$= 8.044\times10^{-15}\ \text{m}$$

82. According to de Broglie, the wave associated with an electron revolving in an orbit has wavelength,

$$\lambda = \frac{h}{mv_n} \qquad ...(1)$$

Let the velocity of an electron in the n^{th} orbit be v_n.



For the electron to have a wave associated with it, the circumference of its orbit must be an integral multiple of λ.
Therefore,
$2\pi r_n = n\lambda_n$ … (2)
(Where, r_n is the radius of the n^{th} orbit)
On substituting the value of r_n in equation (1), we obtain:

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$$2\pi r_n = \frac{nh}{mv_n}$$

$$mv_n r_n = \frac{nh}{2\pi}$$

Or, angular momentum $= \frac{nh}{2\pi}$

Nuclei

83. Nuclear fission: It is the phenomenon of splitting of a heavy nucleus (usually $A > 230$) into two or more lighter nuclei.

$${}_{92}U^{235} + {}_{0}n^{1} \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + Q$$

Here, the energy released per fission of ${}_{92}U^{235}$ is 200.4 MeV.

Nuclear fusion: It is the phenomenon of fusion of two or more lighter nuclei to form a single heavy nucleus.
The mass of the product nucleus is slightly less than the sum of the masses of the lighter nuclei fusing together. This difference in masses results in the release of tremendous amount of energy.
Example:

$${}_{1}H^{1} + {}_{1}H^{1} \rightarrow {}_{1}H^{2} + e^{+} + \nu + 0.42\ \text{MeV}$$
$${}_{1}H^{2} + {}_{1}H^{2} \rightarrow {}_{2}He^{3} + n + 3.27\ \text{MeV}$$
$${}_{1}H^{2} + {}_{1}H^{2} \rightarrow {}_{1}H^{3} + {}_{1}H^{1} + 4.03\ \text{MeV}$$
$${}_{1}^{2}H + {}_{1}^{3}H \rightarrow {}_{2}^{4}He + n$$

$$\Delta m = (2.014102 + 3.016049) - (4.002603 + 1.008665)$$
$$\therefore \quad = 0.018883\ u$$

Energy released, $Q = 0.018883 \times 931.5\ \mathrm{MeV}/c^2$
$= 17.589$ MeV

84. (i) The number of atoms at any instant in a radioactive sample is given by

$N = N_0 e^{-\lambda t}$

where

N = total number of atoms at any instant

N_0 = number of atoms in radioactive substance at $t = 0$

λ = decay constant

t = time

When $t = T$ (Where T is the half life of the sample)

$$N = \frac{N_0}{2}$$

$$\Rightarrow \frac{N_0}{2} = N_0 e^{-\lambda t}$$

$$\Rightarrow \frac{1}{2} = e^{-\lambda T}$$

$$\Rightarrow e^{\lambda T} = 2$$

Taking log on both the sides, we get

$\lambda T = \log_e 2 = 2.303 \log_{10} 2$

$$\Rightarrow T = \frac{2.303 \log_{10} 2}{\lambda}$$

$$\Rightarrow T = \frac{2.303 \times 0.3010}{\lambda}$$

$$\Rightarrow T = \frac{0.6931}{\lambda}$$

Thus, half life of a radioactive substance is inversely propotional to decay constant.

(ii) Let t be the required time after which the undecayed fraction of the material will be 6.25%.

Number of nuclei of undecayed material left $= 6.25\% = \frac{6.25}{100} = \frac{1}{16}$

$\therefore N = \frac{N_0}{16}$

But $N = N_0(\frac{1}{2})^n$

where $n = \frac{t}{T}$

$\Rightarrow \frac{N_0}{16} = N_0(\frac{1}{2})^n$

$\Rightarrow n = 4$

$\therefore \text{Time}, t = n \times T$

$\Rightarrow t = 4 \times 100$

$t = 400$ days

85. (a)

The basic nuclear process involved in the emission of β^+ in a symbolic form, by a radioactive nucleus

$p \rightarrow n + \beta^+ + \nu$

For a *beta-plus* decay, a proton transforms into a neutron within the nucleus, according to the above reaction.

(b) (i)

$^{11}_{6}C \rightarrow ^{z}_{y}B + x + v$

$\Rightarrow ^{11}_{6}C \rightarrow ^{11}_{5}B + ^{0}_{1}\beta + v$

The corresponding y and z are 5 and 11, respectively. The x is the positron.

(ii)

$$^{12}_{6}C + ^{12}_{6}C \rightarrow ^{20}_{a}Ne + ^{c}_{b}He$$

$\Rightarrow$

$$^{12}_{6}C + ^{12}_{6}C \rightarrow ^{20}_{10}Ne + ^{4}_{2}He$$

The corresponding values of a, b and c are 10, 2 and 4, respectively.

86. (a) In a nuclear reaction, the sum of the masses of the target nucleus ($^{2}_{1}H$) and the bombarding particle ($^{2}_{1}H$) may be greater or less than the sum of the masses of the product nucleus ($^{3}_{1}He$) and the outgoing particle ($^{1}_{0}n$). So from the law of conservation of mass-energy some energy (3.27 MeV) is evolved or involved in a nuclear reaction. This energy is called Q-value of the nuclear reaction.

(b) Density of the nucleus = $\dfrac{\text{mass of nucleus}}{\text{volume of nucleus}}$

Mass of the nucleus = A amu = A $\times 1.66 \times 10^{-27}$ kg

Volume of the nucleus = $\dfrac{4}{3}\pi R^3 = \dfrac{4}{3}\pi(R_0A^{1/3})^3 = \dfrac{4}{3}\pi R_0^{\,3}A$

Thus, density = $\dfrac{A \times 1.66 \times 10^{-27}}{(\frac{4}{3}\pi R_0^{\,3})A} = \dfrac{1.66 \times 10^{-27}}{(\frac{4}{3}\pi R_0^{\,3})}$ which shows that the density is independent of mass number A.

Using $R_0 = 1.1 \times 10^{-15}$ m and density = $2.97\times10^{17}\ \text{kg m}^{-3}$

87. The formation of a nucleus requires the release of a huge amount of energy, known as the nuclear binding energy, which holds the entity of the nucleus together. This energy comes from the difference in mass between the nucleus and the sum of the masses of its constituents. Thus, the mass of a nucleus is always less than the sum of the masses of its constituent protons and neutrons.

88. (a) Average life $=\dfrac{1}{\lambda}$

$$\lambda = \frac{1}{\text{Average life}}$$
$$= \frac{1}{2\text{ days}}$$
$$= \frac{1}{2\times24\times60\times60}$$
$$= 5.78\times10^{-06}\ \text{s}$$

(b) After 16 days, number of half-lives completed = 4

Remaining amount of sample, $N = \dfrac{N_0}{2^4} = \dfrac{16}{2^4} = 1\ \text{g}$

Hence, amount disintegrated = 16 − 1 = 15 g

(c) The duration in which the amount of radioactive nuclei and the rate of its disintegration both reduce to e^{-1} of their initial values is known as the average life..

Half-life is the time required by a radioactive nucleus for the amount of nuclei to reduce to half their original number.

Semiconductor Electronics: Materials, Devices and Simple Circuits

89. Given:

Output voltage, $V_o = 2$ V, output resistance, $R_o = 2$ kΩ, base resistance, $R_i = 1$ kΩ

Current amplification factor, $\beta = 100$

Then input signal voltage is calculated as:

$$\frac{V_o}{V_i} = \frac{R_o}{R_i} \times \beta \Rightarrow \frac{2}{V_i} = \frac{2}{1} \times 100$$

$$\Rightarrow V_i = 10 \text{ mV}$$

Now, collector current is

$$I_C = \frac{V_o}{R_o} = \frac{2}{2} = 1 \text{ mA}$$

Therefore, base current is

$$I_B = \frac{I_C}{\beta} = \frac{1 \text{ mA}}{100} = 10 \text{ μA}$$

90. (i) Dynamic output resistance is given as:

$$R_o = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_b \text{ constant}} = \frac{12-8}{(3.6-3.4)\times 10^{-3}} = \frac{4}{0.2\times 10^{-3}} = 20 \text{ k}\Omega$$

(ii)

$$\text{d.c current gain}, \beta_{d.c} = \frac{I_C}{I_B} = \frac{3.5 \text{ mA}}{30 \ \mu\text{A}} = \frac{3.5\times 10^{-3}}{30\times 10^{-6}} = \frac{350}{3} = 116.67$$

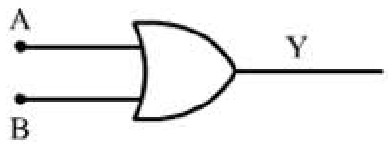
(iii)

$$\text{a.c current gain}, \beta_{a.c} = \frac{\Delta I_C}{\Delta I_B} = \frac{(4.7\text{-}3.5) \text{ mA}}{(40-30) \ \mu\text{A}} = \frac{1.2\times 10^{-3}}{10\times 10^{-6}} = 120$$

91.Truth table for the given circuit:

A	B	Y_1	Y_2	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

From the table, we can conclude that the given circuit represents an OR gate.
The logic symbol and truth table for OR gate is given below:



A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

92. The given figure is Common Emitter (CE) configuration of an npn transistor. The input circuit is forward biased and collector circuit is reverse biased.
As the base resistance R decreases, the input circuit will become more forward biased thus decreasing the base current (I_B) and increasing the emitter current (I_E). This will increase the collector current (I_C) as $I_E = I_B + I_C$.
When I_C increases which flows through the lamp, the voltage across the bulb will also increase thus making the lamp brighter and as the voltmeter is connected in parallel with the lamp, the reading in the voltmeter will also increase.

93. Since arsenic is monovalent, each atom contributes one electron.
Assuming there are no thermally generated free electrons,

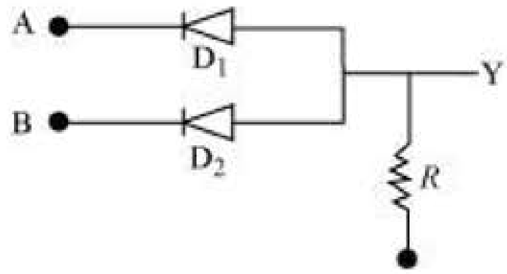
$$n_e n_h = n_i^2$$

$$n_h = \frac{n_i^2}{n_e}$$

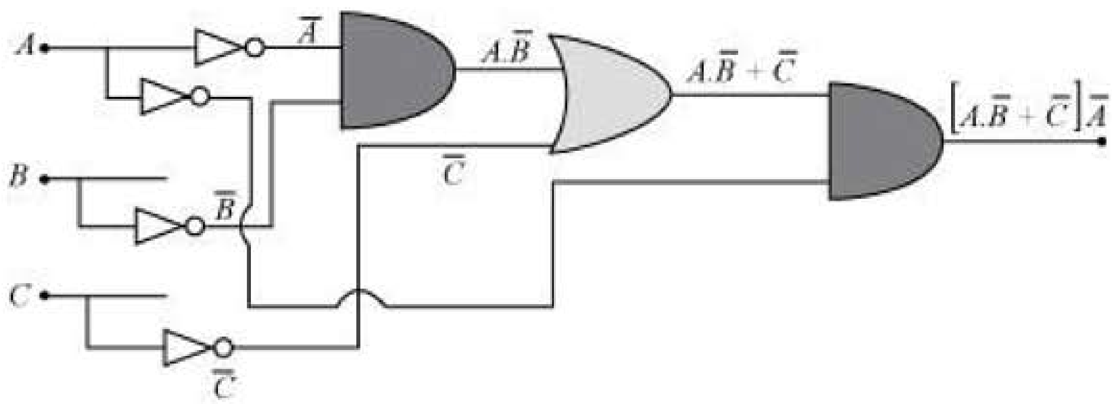
$$= \frac{(1.5\times10^{16})^2}{2\times10^{21}}$$

$$n_h = 1.125\times10^{11}\ \text{m}^{-3}$$

94. (a)



(b)



(c)

A	B	C	$\overline{A}$	$\overline{B}$	$\overline{C}$	$A.\overline{B}$	$A.\overline{B}+\overline{C}$	$(A.\overline{B}+\overline{C}).\overline{A}$
0	0	0	1	1	1	0	1	1
0	0	1	1	1	0	0	0	0
0	1	0	1	0	1	0	1	1
0	1	1	1	0	0	0	0	0
1	0	0	0	1	1	1	1	0
1	0	1	0	1	0	1	1	0

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1	1	0	0	0	1	0	1	0
1	1	1	0	0	0	0	0	0

Communication System

95. Modulation index (μ) is the ratio of the amplitude of the modulating signal to the amplitude of the carrier wave.

The generalised equation of a carrier wave is given below:
$c(t) = A_c \sin\omega_c t$

The generalised equation of a modulating wave is given below:

$c_m(t) = A_c \sin\omega_c t + \mu A_c \sin\omega_m t \sin\omega_c t$

Here, μ is defined as $\dfrac{A_m}{A_c}$.

On comparing this with the equations of carrier wave and modulating wave, we get:

Amplitude of modulating signal, $A_{\mathrm{m}} = 1\ \mathrm{V}$

Amplitude of carrier wave, $A_{\mathrm{c}} = 2\ \mathrm{V}$

$$\therefore \mu = \frac{A_{\mathrm{m}}}{A_{\mathrm{c}}} = \frac{1}{2} = 0.5$$

96. Space wave are used for the line of sight (LOS) communication.
The range of their frequencies is 40 MHz and above.

We have, height of transmitting antenna, $h_T = 20$ m and height of receiving antenna, $h_R = 45$ m
Then, Maximum distance between the two antennas,

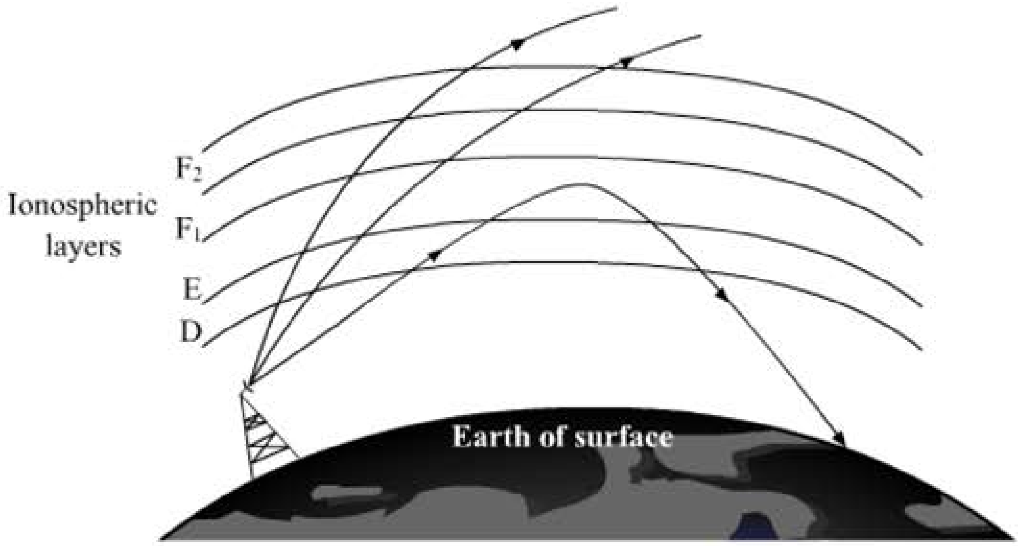
$$d_m = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

$$\Rightarrow d_m = \sqrt{2\times6.4\times10^6\times20} + \sqrt{2\times6.4\times10^6\times45} = 2\times8\times10^3 + 3\times8\times10^3 = 40 \text{ km.}$$

Thus, the maximum distance between the antennas is 40 km.

97. Ground wave − When the radio waves from the transmitting antenna propagate along the surface of the earth so as to reach the receiving antenna. Frequency range is less than a few MHz.
Sky waves − In this wave propagation, the radio waves from the transmitting antenna reach the receiving antenna after reflection from the ionosphere. Frequency ranges from a few MHz up of 30 to 40 MHz.
(a) The e.m. waves of frequencies greater than 40 MHz penetrate the ionosphere and escape so, the sky wave propagation is restricted to the frequencies upto 40 MHz.
(b) In television broadcast and satellite communication, the space wave mode of propagation is used.

98. (i) Sky wave propagation is used by shortwave broadcast services having frequency range from few MHz to 30 MHz.



The sky waves reach the receiver after reflection from the ionosphere. The oscillating electric field of electromagnetic wave changes the velocity of the electrons in the ionosphere which changes the effective dielectric constant and hence refractive index. In a single reflection from the ionosphere, the radio-waves cover a distance of not less than 4000 km. In this way, a very long distance communication is possible with the help of sky waves.

(ii) The ionosphere acts as a reflector for a certain range of frequencies (1710 kHz to 40 MHz). Waves above 40 MHz get refracted through ionosphere and escape. This is why there is an upper limit to the frequency used in this mode.

99. (a)

We know that range of transmission, $d_m = \sqrt{2Rh_T} + \sqrt{2Rh_R}$

Where R, h_T and h_R are the radius of the Earth and heights of the transmitter and receiver antenna respectively.

Now, d_m must at least be 50 km.

$$50 = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

$$h_T = 100 \text{ m} = 0.1 \text{ km}$$

$$50 = \sqrt{2 \times 6400 \times 0.1} + \sqrt{2 \times 6400 \times h_R}$$

$$h_R = 0.0158 \text{ km} = 15.8 \text{ m}$$

Hence, the height of the receiving antenna must at least be 15.8 m.

(b) $f = 20$ MHz $= 20 \times 10^6$ Hz

$$c = f\lambda$$

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{20\times10^6} = 15 \text{ m}$$

The minimum length of the transmitting antenna is $\frac{\lambda}{4}$.

Thus, length of transmitting antenna $= \frac{\lambda}{4}$

$$= \frac{15}{4}$$
$$= 3.75 \text{ m}$$

(c) Power radiated, $P \propto \frac{1}{\lambda^2}$

$$\propto \frac{1}{\left(\frac{c}{f}\right)^2}$$

$$\propto \frac{f^2}{c^2}$$

Here, c is the speed of electromagnetic waves.
Hence, the power radiated is directly proportional to the square of the frequency.

100.