SAMPLE PAPER TEST 03 FOR BOARD EXAM 2025

SUBJECT: PHYSICS | **MAX. MARKS : 70**
CLASS : XII | **DURATION: 3 HRS**

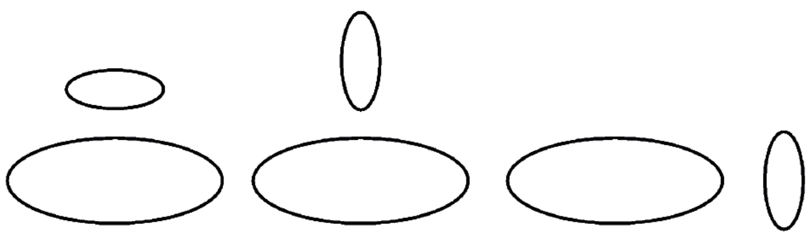
General Instructions:

1. There are 33 questions in all. All questions are compulsory
2. This question paper has five sections: Section A, Section B, Section C, Section D and Section E. All the sections are compulsory.
3. Section A contains sixteen questions, twelve MCQ and four Assertion-Reasoning based questions of 1 mark each, Section B contains five questions of two marks each, Section C contains seven questions of three marks each, section D contains three long questions of five marks each and Section E contains two case study based questions of 4 marks each.
4. There is no overall choice. However, an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choices in such questions.
5. Use of calculators is not allowed.

SECTION – A

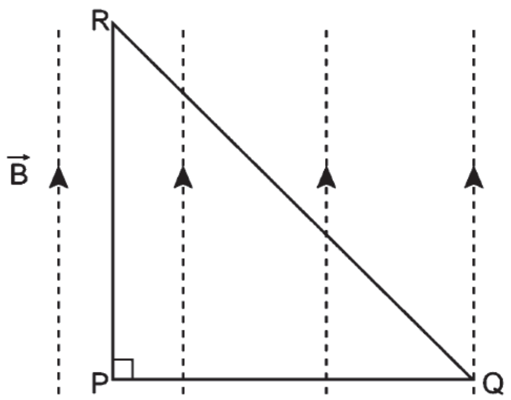
Questions 1 to 16 carry 1 mark each.

1. Two circular coils can be arranged in any of the three situations as shown in fig. Their mutual inductance will be:



(a) maximum in situation (i)　　(b) maximum in situation (i)
(c) maximum in situation (iii)　　(d) same in all situations

2. An isosceles right angled current carrying loop PQR is placed in a uniform magnetic field $\vec{B}$ pointing along PR. If the magnetic force acting on the arm PQ is F, then the magnetic force which acts on the arm OR will be



(a) F　　(b) F/√2　　(c) √2 F　　(d) -F

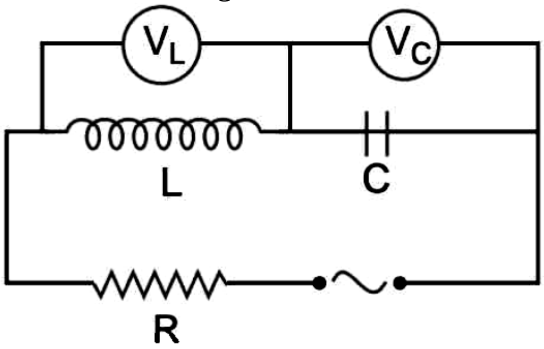
3. A magnetic needle is kept in a uniform magnetic field. It experiences
(a) a force and a torque　　(b) a force but not a torque
(c) a torque but not a force　　(d) neither a torque nor a force

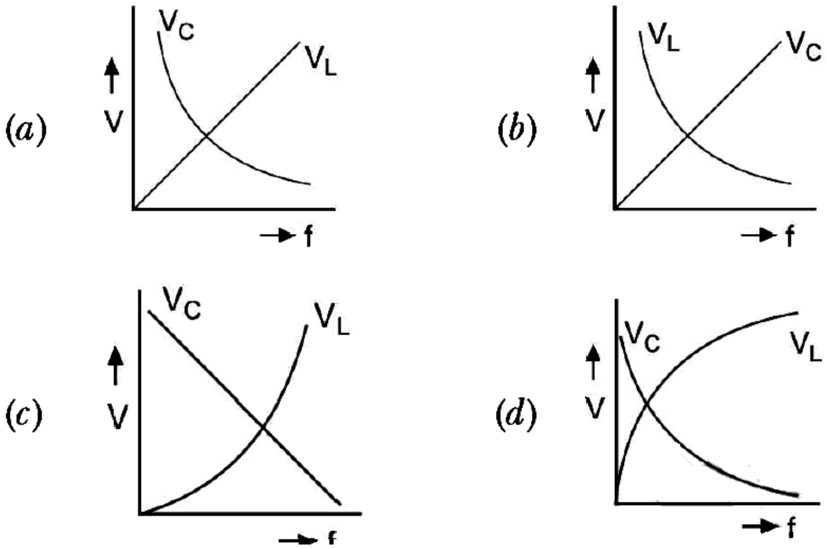
4. The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged object the electric field of magnitude, 16N/C will be at a distance of
(a) 1 m　　(b) 2 m　　(c) 3 m　　(d) 6 m

5. A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is

(a) 0.1 V (b) 0.5 V (c) 0.75 V (d) 1.0 V

6. A series LCR circuit is shown in figure. The source frequency f is varied, but the current is kept unchanged. Which of the curves shows changes of V_C, and V_L, with frequency?





7. According to Huygens principle, the amplitude of secondary wavelets is

(a) equal in both the forward and the backward directions.

(b) maximum in the forward direction and zero in the backward direction.

(c) large in the forward direction and small in the backward direction.

(d) small in the forward direction and large in the backward direction.

8. In an extrinsic semiconductor, the number density of holes is 4×10^{20} m^{-3}. If the number density of intrinsic carriers is 1.2×10^{15} m^{3}, the number density of electrons in it is

(a) 1.8×10^{9} m^{-3} (b) 2.4×10^{10} m^{-3} (c) 3.6×10^{9} m^{-3} (d) 3.2×10^{10} m^{-3}

9. A current of 0.8 A flows in a conductor of 40 W for 1 minute. The heat produced in the conductor will be

(a) 1445 J (b) 1536 J (c) 1569 J (d) 1640 J

10. In an-type semiconductor, which of the following statements is true?

(a) Electrons are majority carriers and trivalent atoms are the dopants.

(b) Electrons are minority carriers and pentavalent atoms are dopants.

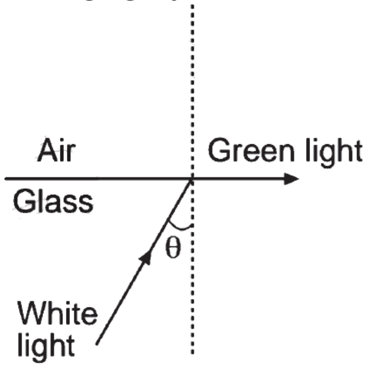
(c) Holes are minority carriers and pentavalent atoms are dopants.

(d) Holes are majority carriers and trivalent atoms are dopants.

11. In a photoelectric experiment, the stopping-potential for the incident light of wavelength 4000 Å is 2 volt. If the wavelength be changed to 3000 Å, the stopping potential will be

(a) 2 volt (b) less than 2 volt (c) zero (d) more than 2 volt

12. White light is incident on the interface of glass and air as shown in figure. If green light is just totally internally reflected, then the emerging ray in air contains



b

(a) yellow, orange, red Glass
(b) violet, indigo, blue
(c) all colours White
(d) all colours except green light

ASSERTION-REASON BASED QUESTIONS

In the following questions, a statement of assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.
(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

13. Assertion (A): Diamagnetic substances exhibit magnetism.
Reason (R): Diamagnetic materials do not have permanent magnetic dipole moment.

14. Assertion (A) : The conductivity of an electrolyte is very low as compared to a metal at room temperature.
Reason (R): The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier.

15. Assertion (A): In the Bohr model of the hydrogen, atom, v and E represent the speed of the electron and the total energy of the electron respectively. Then v/E is proportional to the quantum number n of the electron.
Reason (R): $v \propto n$ and $E \propto n^{-2}$

16. Assertion (A): An applied electric field polarises a polar dielectric.
Reason (R): The molecules of a polar dielectric possess a permanent dipole moment, but in the absence of electric field, these dipoles are randomly oriented and when electric field is applied these dipoles align along the direction of electric field.

SECTION – B

Questions 17 to 21 carry 2 marks each.

17. How are X-rays produced? Give any two uses of these.

18. Explain, how the heavy doping of both p-and n-sides of a p-n junction diode results in the electric field of the junction being extremely high even with a reverse bias voltage of a few volts.

19. The magnetic susceptibility of magnesium at 300 K is 1.2 x 10^5. At what temperature will its magnetic susceptibility become 1.44 x 10^5?

20. Suppose that the particle is an electron projected with velocity $v_x = 2.0 \times 10^6$ m/s. If electric field between the plates separated by 0.5 cm is 9.1×10^2 N/C, where will the electron strike the upper plate? ($|e| = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg.)

21. Draw a graph showing the variation of potential energy of a pair of nucleons as a function of their separation. Indicate the region in which the nuclear force is (a) attractive and (b) repulsive.

OR

A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleons in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV.

SECTION – C

Questions 22 to 28 carry 3 marks each.

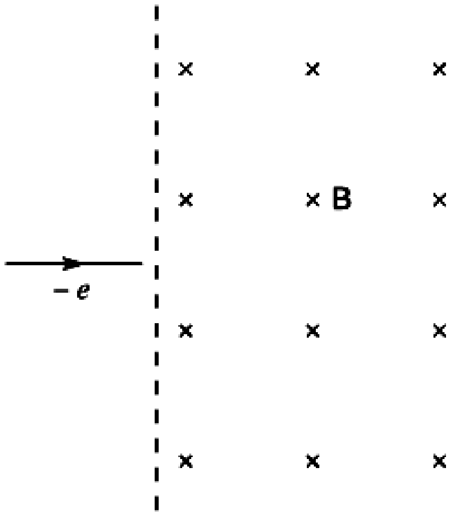
22. When is H_α line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition.

23. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (i) their kinetic energies, and (ii) if the radius of the circular path described by proton is 5 cm, determine the radii of the paths described by deuteron and alpha particle.

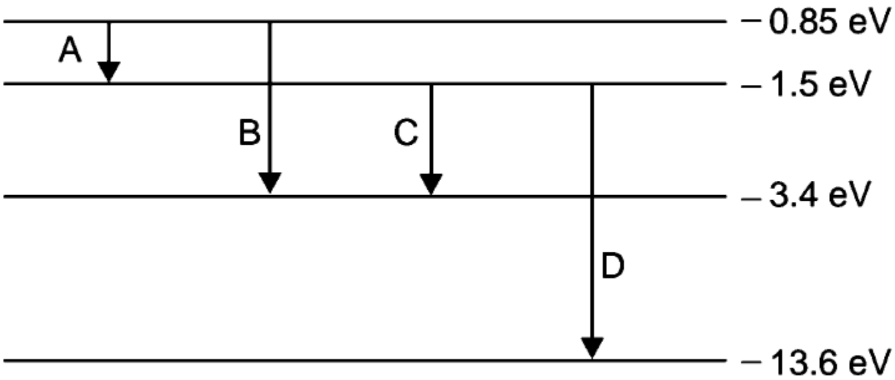
OR

(i) An electron moving horizontally with a velocity of 4×10^4 m/s enters a region of uniform magnetic field of 10^{-5} T acting vertically upward as shown in the figure. Draw its trajectory and find out the time it takes to come out of the region of magnetic field.

(ii) A straight wire of mass 200 g and length 1.5 m carries current of 2A. It is suspended in mid air by a uniform magnetic field B. What is the magnitude of the magnetic field?



24. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.

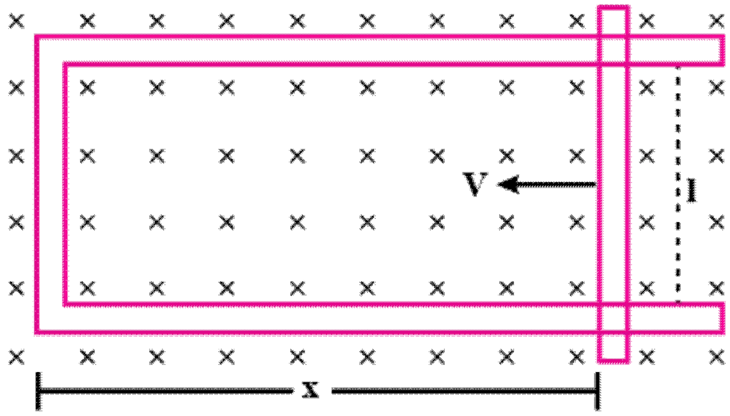


25. Draw V- I characteristics of a p-n junction diode. Answer the following questions, giving reasons:

(i) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

(ii) Why does the reverse current show a sudden increase at the critical voltage?

26. (i) A rod of length *l* is moved horizontally with a uniform velocity 'v' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.

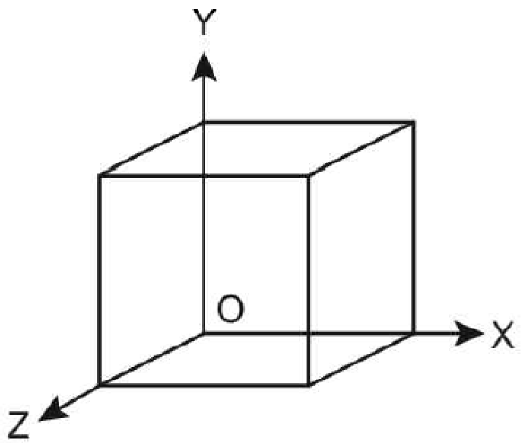


(ii) How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain.

OR

Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare (i) the induced emf and (ii) the current produced in the two coils. Justify your answer.

27. A cube of side 20 cm is kept in a region as shown in the figure. An electric field $\vec{E}$ exists in the region such that the A potential at a point is given by V = 10x + 5, where V is in volt and x is in m.



Find the (i) electric field, and (ii) total electric flux through the cube.

28. A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is 3/4 th of the angle of prism. Calculate the speed of light in the prism.

OR

The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding, then will the focal length of lens change? Will the power change?

SECTION – D (Case Study Based Questions)

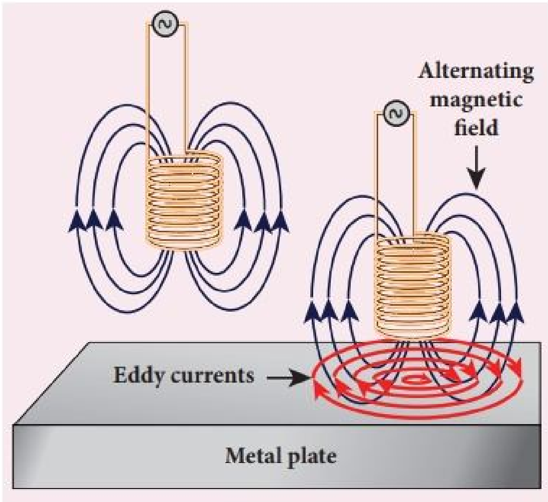
Questions 29 to 30 carry 4 marks each.

29. Case-Study 1:

Read the following paragraph and answer the questions

Eddy Currents and their Effects

Currents can be induced not only in conducting coils, but also in conducting sheets or blocks. Current is induced in solid metallic masses when the magnetic flux threading through them changes. Such currents flow in the form of irregularly shaped loops throughout the body of the metal. These currents look like eddies or whirlpools in water so they are known as eddy currents. Eddy currents have both undesirable effects and practically useful applications. For example it causes unnecessary heating and wastage of power in electric motors, dynamos and in the cores of transformers.



(i) The working of speedometers of trains is based on
(a) wattless currents (b) eddy currents (c) alternating currents (d) pulsating currents

(ii) Identify the wrong statement.
(a) Eddy currents are produced in a steady magnetic field.
(b) Induction furnace uses eddy currents to produce heat.
(c) Eddy currents can be used to produce braking force in moving trains.
(d) Power meters work on the principle of eddy currents.

(iii) Which of the following is the best method to reduce eddy currents?
(a) Laminating core (b) Using thick wires
(c) By reducing hysteresis loss (d) None of these

(iv) The direction of eddy currents is given by
(a) Fleming's left hand rule (b) Biot-Savart law
(c) Lenz's law (d) Ampere-circuital law

OR

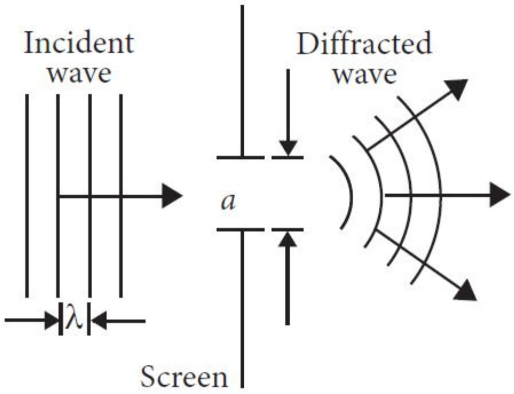
(v) Eddy currents can be used to heat localised tissues of the human body. This branch of medical therapy is called
(a) Hyperthermia (b) Diathermy
(c) Inductothermy (d) none of these.

30. Case-Study 2:

Read the following paragraph and answer the questions.

Diffraction of Light

The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light. The light thus deviates from its linear path. The deviation becomes much more pronounced, when the dimensions of the aperture or the obstacle are comparable to the wavelength of light.



(i) Light seems to propagate in rectilinear path because
(a) its spread is very large
(b) its wavelength is very small
(c) reflected from the upper surface of atmosphere
(c) it is not absorbed by atmosphere

(ii) In diffraction from a single slit the angular width of the central maxima does not depends on
(a) λ of light used (b) width of slit
(c) distance of slits from the screen (d) ratio of λ and slit width

(iii) For a diffraction from a single slit, the intensity of the central point is
(a) infinite
(b) finite and same magnitude as the surrounding maxima
(c) finite but much larger than the surrounding maxima
(d) finite and substantially smaller than the surrounding maxima

(iv) Resolving power of telescope increases when
(a) wavelength of light decreases (b) wavelength of light increases
(c) focal length of eye-piece increases (d) focal length of eye-piece decreases

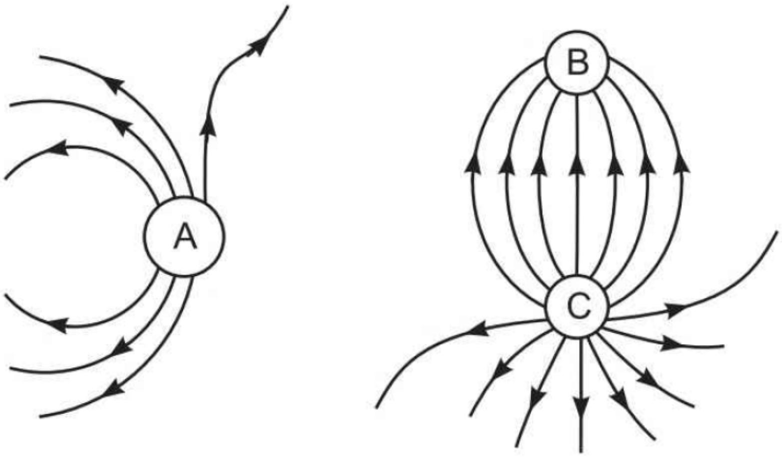
OR

(v) In a single diffraction pattern observed on a screen placed at D metre distance from the slit of width d metre, the ratio of the width of the central maxima to the width of other secondary maxima is
(a) 2 : 1 (b) 1 : 2 (c) 1 : 1 (d) 3 : 1

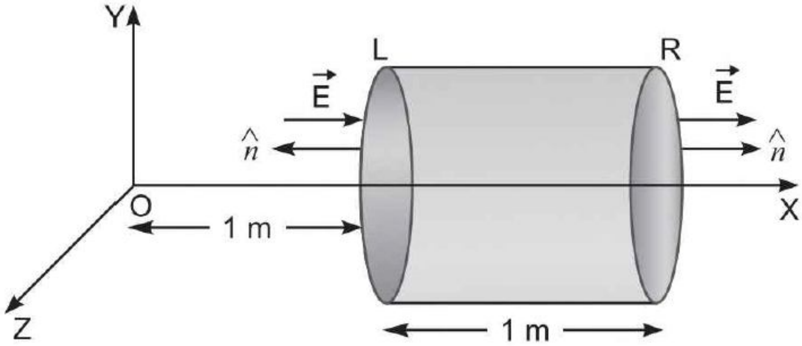
SECTION – E

Questions 31 to 33 carry 5 marks each.

31. (i) The given figure shows the electric field lines around three point charges A, B and C.
(a) Which charges are positive?
(b) Which charge has the largest magnitude? Why?
(c) In which region or regions of the picture could the electric field be zero? Justify your answer.
(1) near A (2) near B (3) near C (4) nowhere.



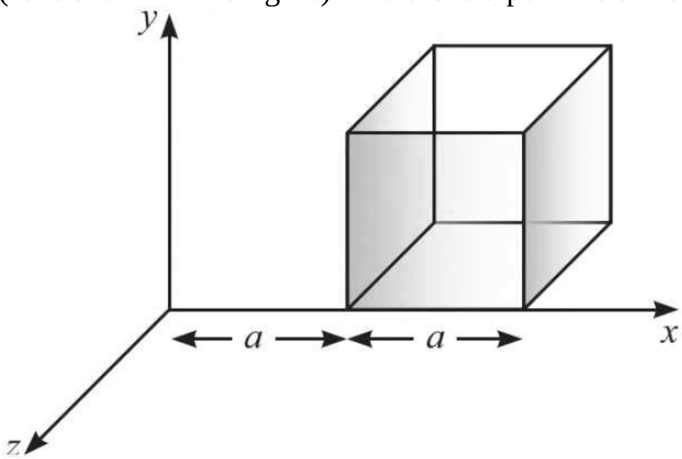
(ii) A hollow cylindrical box of length 1 m and area of cross-section 25 cm? is placed in a three dimensional coordinate y system as shown in the figure.



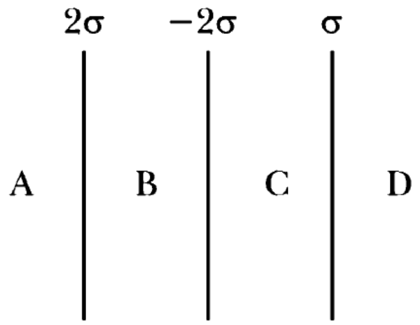
The electric field in the region is given by E = $50x\hat{i}$, where E is in NC^{-1} and x is in metres.
Find: (a) net flux through the cylinder.
(b) charge enclosed by the cylinder.

OR

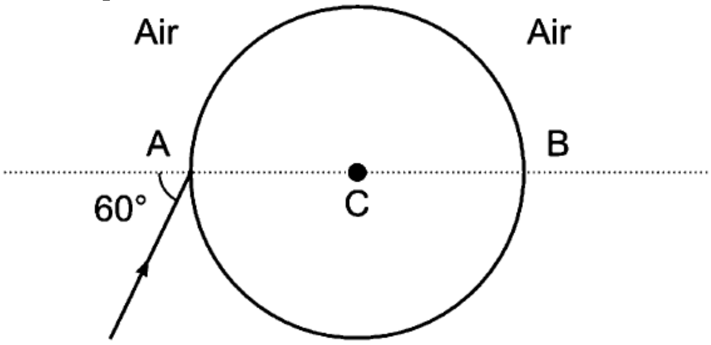
(i) State Gauss's law in electrostatics. A cube with y each side 'a' is kept in an electric field given by $\vec{E}$ = C x $\hat{r}$, (as is shown in the figure) where C is a positive dimensional constant.



Find out (a) the electric flux through the cube, and
(b) the net charge inside the cube.
(ii) In the figure there are three infinite long thin sheets having surface charge density +2σ, -2σ and +σ respectively. Give the magnitude and direction of electric field at a point to the left of sheet of charge density +2σ and to the right of sheet of charge density +σ.



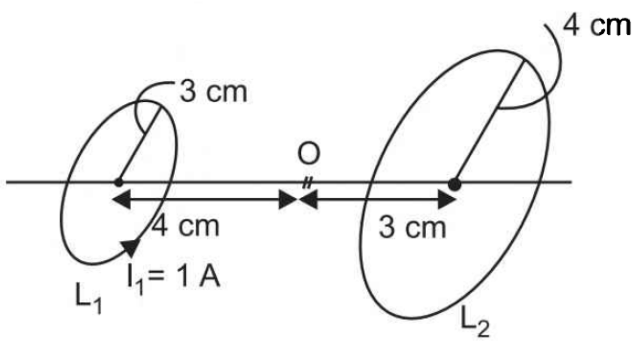
32. (i) Use Huygens' principle to show how a plane wavefront propagates from a denser to rarer medium. Hence, verify Snell's law of refraction.
(ii) A ray of light falls on a transparent sphere with centre C as shown in the figure. The ray emerges from the sphere parallel to the line AB. Find the angle of refraction at A if refractive index of the material of the sphere is √3.



OR

(i) Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.
(ii) A convex lens made of a material of refractive index n1, is kept in-a medium of refractive index n_2. Parallel rays of light are incident on the lens. Complete the path of rays of light emerging from the convex lens if: (i) $n_1 > n_2$ (ii) $n_1 = n_2$ (iii) $n_1 < n_2$.

33. (i) Using Biot-Savart's law, derive an expression for magnetic field at any point on axial line of a current carrying circular loop. Hence, find magnitude of magnetic field intensity at the centre of circular coil.
(ii) Two co-axial circular loops L_1 and L_2 of radii 3 cm and 4 cm are placed as shown. What should be the magnitude and direction of the current in the loop L_2 so that the net magnetic field at the point O be zero?



OR

(i) Derive an expression for torque acting on a rectangular current carrying loop kept in a uniform magnetic field B. Indicate the direction of torque acting on the loop.
(ii) A magnetised needle of magnetic moment 4.8 x 10^7 JT^{-1} is placed at 30° with the direction of uniform magnetic field of magnitude 3 x 10^{-2} T. Calculate the torque acting on the needle.

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CLASS : XII **DURATION: 3 HRS**

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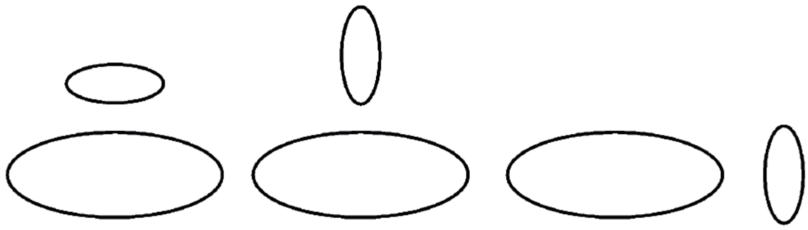
SECTION – A

Questions 1 to 16 carry 1 mark each.

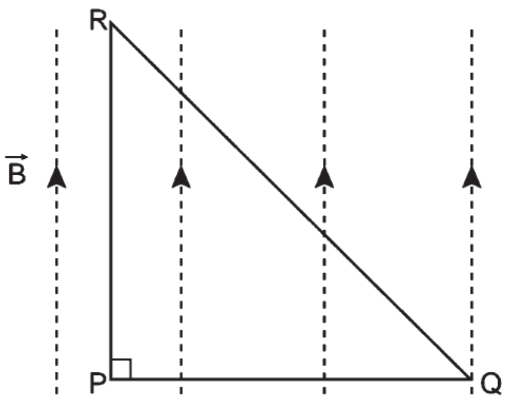
1. Two circular coils can be arranged in any of the three situations as shown in fig. Their mutual inductance will be:



(i) (ii) (iii)

(a) maximum in situation (i) (b) maximum in situation (i)
(c) maximum in situation (iii) (d) same in all situations
Ans: (a) maximum in situation (i)
The magnetic field is along the axis of a circular coil. The maximum flux linkage between the coils is in situation (i).

2. An isosceles right angled current carrying loop PQR is placed in a uniform magnetic field $\vec{B}$ pointing along PR. If the magnetic force acting on the arm PQ is F, then the magnetic force which acts on the arm OR will be



(a) F (b) F/√2 (c) √2 F (d) -F
Ans: (d) -F

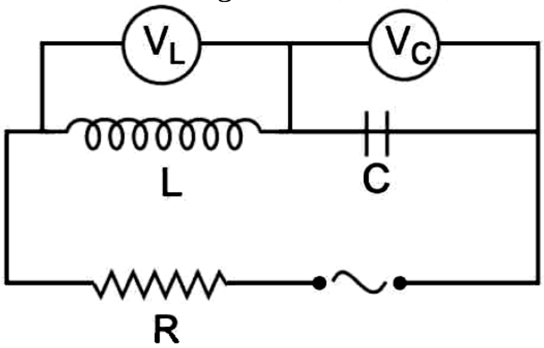
3. A magnetic needle is kept in a uniform magnetic field. It experiences
(a) a force and a torque (b) a force but not a torque

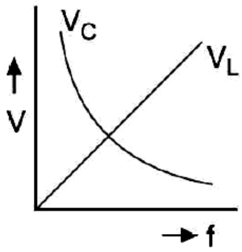
(c) a torque but not a force (d) neither a torque nor a force
Ans: (c) a torque but not a force

4. The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged object the electric field of magnitude, 16N/C will be at a distance of
(a) 1 m (b) 2 m (c) 3 m (d) 6 m
Ans: (c) 3 m

5. A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is
(a) 0.1 V (b) 0.5 V (c) 0.75 V (d) 1.0 V
Ans: (d) 1.0 V

6. A series LCR circuit is shown in figure. The source frequency f is varied, but the current is kept unchanged. Which of the curves shows changes of V_C, and V_L, with frequency?



(*a*)


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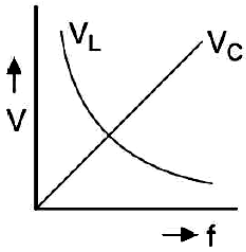

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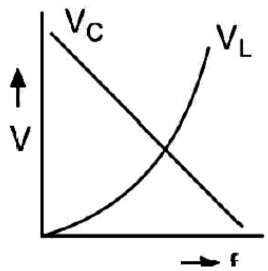
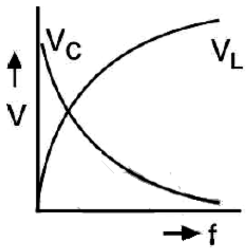


(*d*)


Ans: (a) $V_C = \frac{1}{2\pi fC} \propto \frac{1}{f}$ and $V_L = 2\pi fL \propto f$

7. According to Huygens principle, the amplitude of secondary wavelets is
(a) equal in both the forward and the backward directions.
(b) maximum in the forward direction and zero in the backward direction.
(c) large in the forward direction and small in the backward direction.
(d) small in the forward direction and large in the backward direction.
Ans: (b) maximum in the forward direction and zero in the backward direction.

8. In an extrinsic semiconductor, the number density of holes is 4×10^{20} m^{-3}. If the number density of intrinsic carriers is 1.2×10^{15} m^{3}, the number density of electrons in it is
(a) 1.8×10^{9} m^{-3} (b) 2.4×10^{10} m^{-3} (c) 3.6×10^{9} m^{-3} (d) 3.2×10^{10} m^{-3}
Ans: (c) 3.6×10^{9} m^{-3}

9. A current of 0.8 A flows in a conductor of 40 W for 1 minute. The heat produced in the conductor will be

(a) 1445 J (b) 1536 J (c) 1569 J (d) 1640 J

Ans: (b) 1536 J

10. In an-type semiconductor, which of the following statements is true?

(a) Electrons are majority carriers and trivalent atoms are the dopants.
(b) Electrons are minority carriers and pentavalent atoms are dopants.
(c) Holes are minority carriers and pentavalent atoms are dopants.
(d) Holes are majority carriers and trivalent atoms are dopants.

Ans: (c) Holes are minority carriers and pentavalent atoms are dopants.

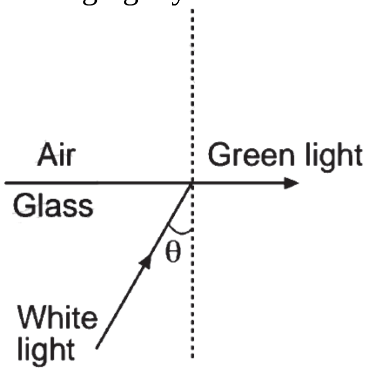
In n-type semiconductor, pentavalent atoms such as phosphorus, antimony, arsenic act as dopant and majority and minority change carriers are electrons and holes respectively.

11. In a photoelectric experiment, the stopping-potential for the incident light of wavelength 4000 Å is 2 volt. If the wavelength be changed to 3000 Å, the stopping potential will be

(a) 2 volt (b) less than 2 volt (c) zero (d) more than 2 volt

Ans: (d) more than 2 volt

12. White light is incident on the interface of glass and air as shown in figure. If green light is just totally internally reflected, then the emerging ray in air contains



b

(a) yellow, orange, red Glass
(b) violet, indigo, blue
(c) all colours White
(d) all colours except green light

Ans: (a) yellow, orange, red Glass

For green colour critical angle, $C = \theta$

Critical angle increases with decrease of refractive index or increase of wavelength, so critical angles for yellow, orange, red will be more than θ, hence these rays will get refracted.

ASSERTION-REASON BASED QUESTIONS

In the following questions, a statement of assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

13. Assertion (A): Diamagnetic substances exhibit magnetism.

Reason (R): Diamagnetic materials do not have permanent magnetic dipole moment.

Ans: (a) Both Assertion (A) and Reason (R) are true and (R) is the correct explanation of (A).

The assertion is true. Diamagnetic substance shows faint repulsion. It is a property of magnetism. So, assertion is true. The above property is observed in the substances which have even number of electrons in each atom/molecule. Electrons with opposite spins form pairs and so no net dipole moment is generated. Diamagnetic substances are such substances and hence exhibit the above magnetic property. So, the reason is true it explains the assertion.

14. Assertion (A) : The conductivity of an electrolyte is very low as compared to a metal at room temperature.
Reason (R): The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier.
Ans: (a) Both A and R are true and R is the correct explanation of A.
The number density of free ions in electrolyte is much smaller as compared to number density of free electrons in metals. Further, ions drift much more slowly, being heavier.

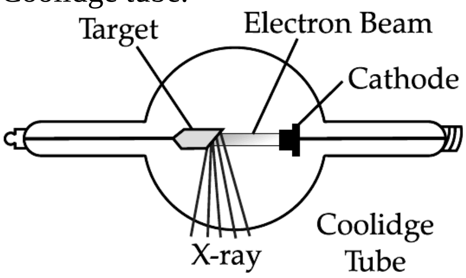
15. Assertion (A): In the Bohr model of the hydrogen, atom, v and E represent the speed of the electron and the total energy of the electron respectively. Then v/E is proportional to the quantum number n of the electron.
Reason (R): $v \propto n$ and $E \propto n^{-2}$
Ans: (c) A is true but R is false.

16. Assertion (A): An applied electric field polarises a polar dielectric.
Reason (R): The molecules of a polar dielectric possess a permanent dipole moment, but in the absence of electric field, these dipoles are randomly oriented and when electric field is applied these dipoles align along the direction of electric field.
Ans: (a) Both A and R are true and R is the correct explanation of A.
When an electric field is applied to a polar dielectric, it polarize the dielectric, it means all the positive charge is on one side of the dielectric and the negative is on the other and in the absence of electric field, they are just randomly distributed.

SECTION – B

Questions 17 to 21 carry 2 marks each.

17. How are X-rays produced? Give any two uses of these.
Ans: (b) **Production of X-rays**:
- X-rays are produced when high energy electron beam bombards metallic target of high melting and point heavy atomic weight.
- X-ray is produced in Coolidge tube.



Uses of X-ray:
- It is used to photograph bones for the diagnosis of any fracture and dislocation.
- It is used to radiotherapy to destroy cancerous cells and to shrink tumors.

18. Explain, how the heavy doping of both p-and n-sides of a p-n junction diode results in the electric field of the junction being extremely high even with a reverse bias voltage of a few volts.
Ans: If p-type and n-type semiconductor are heavily doped. Then due to diffusion of electrons from n-region to p-region, and of holes from p-region to n-region, a depletion region formed of size of order less than 1 μm. The electric field directing from n-region to p-region produces a reverse bias voltage of about 5 V and electric field becomes very large.

$$E = \frac{\Delta V}{\Delta x} = \frac{5V}{1\mu m} \approx 5\times10^{6}\ \ V/m$$

19. The magnetic susceptibility of magnesium at 300 K is 1.2 x 10^5. At what temperature will its magnetic susceptibility become 1.44 x 10^5?

Ans: The susceptibility of a paramagnetic substance is inversely proportional to the absolute temperature.

According to Curie's law, $\chi \propto \frac{1}{T} \Rightarrow \chi = \frac{C}{T}$ (where C is curie constant)

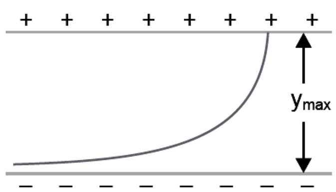
Here, $\chi_1 = 1.2\times10^5, T_1 = 300K$, $\chi_1 = 1.44\times10^5, T_2 = ?$

$$\chi_1 = \frac{C}{T_1} \Rightarrow C = \chi_1 T_1$$

$$\therefore \chi_2 = \frac{C}{T_2} \Rightarrow T_2 = \frac{C}{\chi_2} = \frac{\chi_1 T_1}{\chi_2} = \frac{1.2\times10^5}{1.44\times10^5}\times300 = 250K$$

20. Suppose that the particle is an electron projected with velocity v_x = 2.0 x 10^6 m/s. If electric field between the plates separated by 0.5 cm is 9.1 x 10^2 N/C, where will the electron strike the upper plate? (|e| = 1.6 x 10^{-19} C, m = 9.1 x 10^{-31} kg.)

Ans:



Vertical deflection for distance x along X-axis is

$$y = \frac{qEx^2}{2mv_x^2} \quad \Rightarrow \quad x = \sqrt{\frac{2my}{qE}}\, v_x$$

Given $m = 9.1\times10^{-31}$ kg, y = 0.5 cm$=0.5\times10^{-2}$ m,

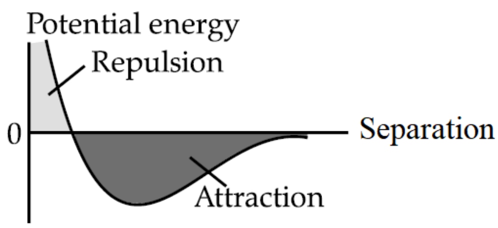
$v_x = 2.0\times10^6\,\text{ms}^{-1}, q = |e| = 1.6\times10^{-19}\,\text{C}, E = 9.1\times10^2\,\text{N/C}.$

$$\therefore x = \sqrt{\frac{2\times9.1\times10^{-31}\times0.5\times10^{-2}}{1.6\times10^{-19}\times9.1\times10^2}}\times2.0\times10^6\,\text{m}$$

$$= \sqrt{\frac{1}{1.6}}\times10^{-8}\times2.0\times10^6 \approx 0.8\times2\times10^{-2}\ \text{m} = 1.6\times10^{-2}\ \text{m} = \mathbf{1.6\ cm}$$

21. Draw a graph showing the variation of potential energy of a pair of nucleons as a function of their separation. Indicate the region in which the nuclear force is (a) attractive and (b) repulsive.

Ans: Graph showing variation of potential energy of a pair of nucleons as a function of their separation:



OR

A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleons in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV.

Ans: ${}^{240}P \rightarrow {}^{110}Q + {}^{130}R$

The binding energy of P = 240 × 7.6 MeV = 1824 MeV

The binding energy of the products

= 110 × 8.5 + 130 × 8.4

= 935 + 1092 = 2027 MeV
The energy released during fission is
= 2027 – 1824 MeV
= 203 MeV

SECTION – C

Questions 22 to 28 carry 3 marks each.

22. When is H_α line in the emission spectrum of hydrogen atom obtained? Calculate the frequency of the photon emitted during this transition.

Ans: The line with the longest wavelength of the Balmer series is called H_α.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

where λ = wavelength

R = 1.097×10^7 m^{-1} (Rydberg constant)

When the electron jumps from the orbit with n = 3 to n = 2, we have

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \Rightarrow \frac{1}{\lambda} = \frac{5}{36}R$$

The frequency of photon emitted is given by $\nu = \frac{c}{\lambda} = 3\times10^8 \times \frac{5}{36} \times 1.097\times10^7\, Hz$

= 4.57×10^{14} Hz

23. A proton, a deuteron and an alpha particle, are accelerated through the same potential difference and then subjected to a uniform magnetic field $\vec{B}$, perpendicular to the direction of their motions. Compare (i) their kinetic energies, and (ii) if the radius of the circular path described by proton is 5 cm, determine the radii of the paths described by deuteron and alpha particle.

Ans: (i) Since $qV = \frac{1}{2}mv^2$

For proton, $\frac{1}{2}m_p v_1{}^2 = qV$

For deuteron, $\frac{1}{2}m_d v_2{}^2 = qV$

For alpha particle, $\frac{1}{2}m_\alpha v_3{}^2 = 2qV$

$\Rightarrow$ $(K.E.)_p : (K.E.)_d : (K.E.)_\alpha = 1 : 1 : 2$

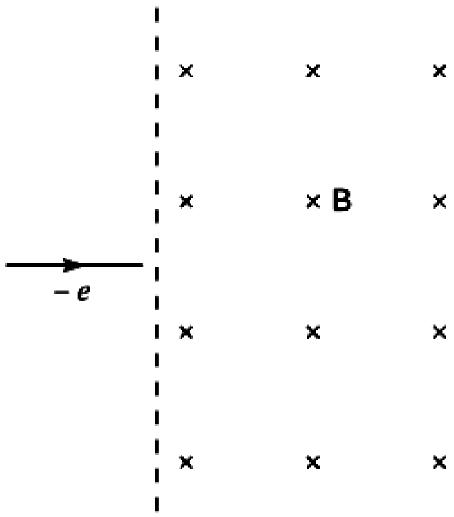
(ii) We have, $Bqv = \frac{mv^2}{r} \Rightarrow r_p = \frac{mv}{Bq} = 5cm;$

$\Rightarrow$ $r_p : r_d : r_\alpha = v_p : v_d : v_\alpha = 1 : \sqrt{2} : \sqrt{2}$

$\therefore$ $r_d = 5\sqrt{2}$cm, $r_\alpha = 5\sqrt{2}$cm

OR

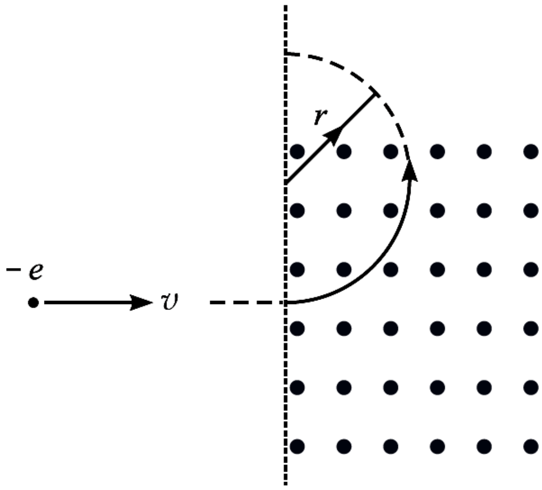
(i) An electron moving horizontally with a velocity of 4 x 10^4 m/s enters a region of uniform magnetic field of 10^{-5} T acting vertically upward as shown in the figure. Draw its trajectory and find out the time it takes to come out of the region of magnetic field.



(ii) A straight wire of mass 200 g and length 1.5 m carries current of 2A. It is suspended in mid air by a uniform magnetic field B. What is the magnitude of the magnetic field?

Ans: (i) From Flemings left hand rule, the electron deflects in anticlockwise direction.

As the electron comes out the magnetic field region, it will describe a semi-circular path.

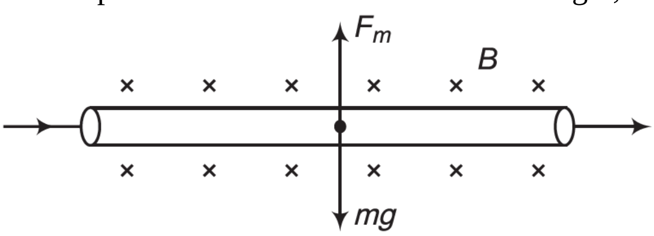


Magnetic force provides a centripetal force. So, $evB = \frac{mv^2}{r} \Rightarrow eB = \frac{mv}{r}$

$Time\ \ Taken,\ T = \frac{\pi r}{v} = \frac{\pi m}{eB}$

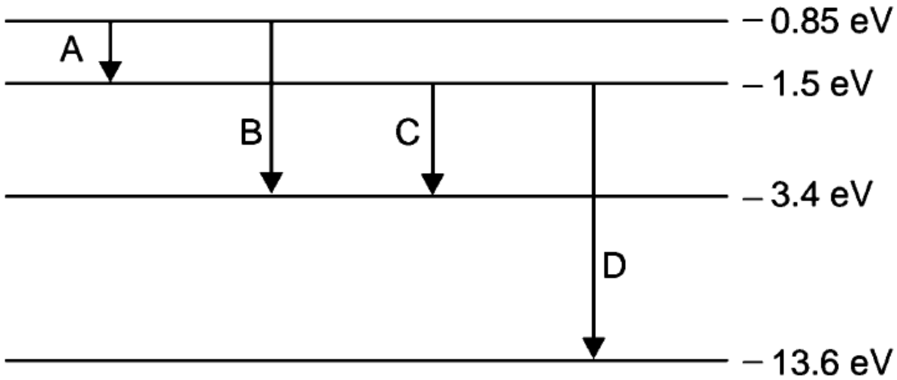
$\Rightarrow T = \frac{3.14\times 9.1\times 10^{-31}}{1.6\times 10^{-19}\times 10^{-5}} = \frac{3.14\times 9.1\times 10^{-7}}{1.6} = 1.78\times 10^{-6}s$

(ii) If Ampere's force acts in upward direction and balances the weight, that is,



$F_m = mg \Rightarrow BIl = mg \Rightarrow B = \frac{mg}{Il} = \frac{0.2\times 10}{2\times 1.5} = \frac{2}{3} = 0.67T$

24. The energy level diagram of an element is given below. Identify, by doing necessary calculations, which transition corresponds to the emission of a spectral line of wavelength 102.7 nm.



Ans: $\Delta E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{102.7\times10^{-9}} J$

$= \frac{6.6\times10^{-34}\times3\times10^{8}}{102.7\times10^{-9}\times1.6\times10^{-19}} eV = \frac{66\times3000}{1027\times16} = 12.04 eV$

Now, $\Delta E = |-13.6 - (-1.50)|$

= 12.1 eV

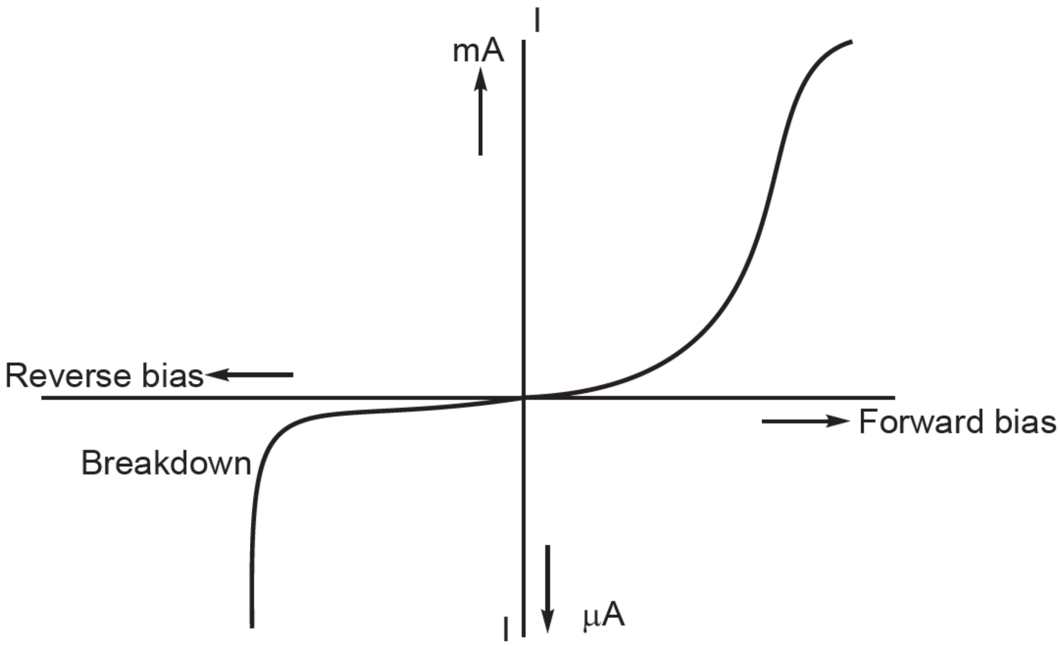
Hence, transition shown by arrow D corresponds to emission of λ = 102.7 nm.

25. Draw V- I characteristics of a p-n junction diode. Answer the following questions, giving reasons:

(i) Why is the current under reverse bias almost independent of the applied potential upto a critical voltage?

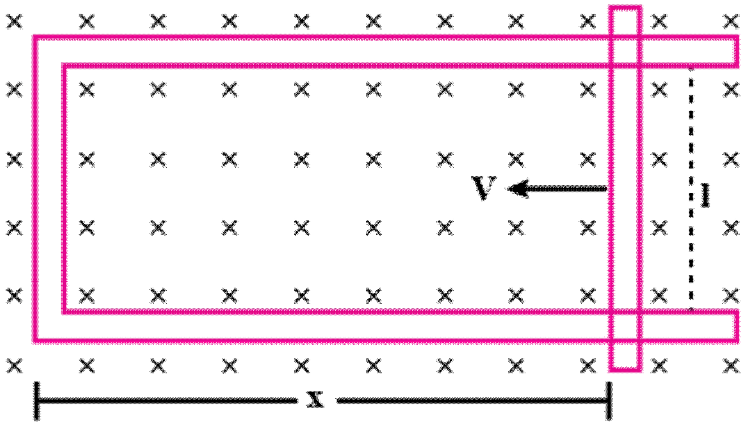
(ii) Why does the reverse current show a sudden increase at the critical voltage?

Ans: (i) In the reverse biasing, the current of order of μA is due to movement/drifting of minority charge carriers from one region to another through the junction. A small applied voltage is sufficient to sweep the minority charge carriers through the junction. So, reverse current is almost independent of critical voltage.



(ii) At critical voltage (or breakdown voltage), a large number of covalent bonds break, resulting in the increase of large number of charge carriers. Hence, current increases at critical voltage.

26. (i) A rod of length *l* is moved horizontally with a uniform velocity 'v' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.



(ii) How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain.

Ans: (i) Suppose a rod of length 'l' moves with velocity v inward in the region having uniform magnetic field B.

Initial magnetic flux enclosed in the rectangular space is φ =|B|*l*x

As the rod moves with velocity $-v = \frac{dx}{dt}$

Using Lenz's law, $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx) = Bl\left(-\frac{dx}{dt}\right) \Rightarrow \varepsilon = Blv$

(ii) Suppose any arbitrary charge 'q' in the conductor of length 'l' moving inward in the field as shown in figure, the charge q also moves with velocity v in the magnetic field B.

The Lorentz force on the charge 'q' is F = qvB and its direction is downwards.

So, work done in moving the charge 'q' along the conductor of length *l* is W = F.*l*

⇒ W = qvB*l*

Since emf is the work done per unit charge

$\therefore \varepsilon = \frac{W}{q} = Blv$

This equation gives emf induced across the rod.

OR

Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare (i) the induced emf and (ii) the current produced in the two coils. Justify your answer.

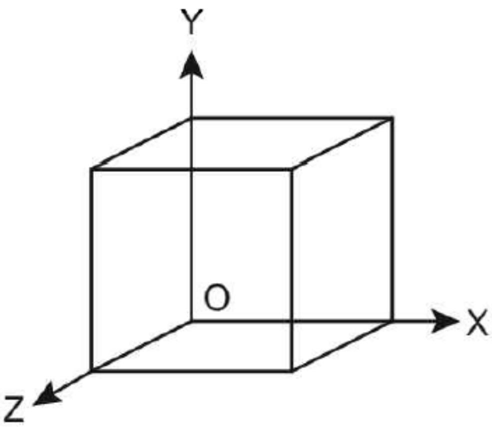
Ans: (i) Induced emf, $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA\cos\omega t) = BA\omega\sin\omega t$

As B, A, ω are same for both loops, so induced emf is same in both loops.

(ii) Current induced, $I = \frac{\varepsilon}{R} = \frac{\varepsilon}{\rho l / A} = \frac{\varepsilon A}{\rho l}$

As area A, length *l* and emf ε are same for both loops but resistivity ρ is less for copper, therefore current I induced is larger in copper loop.

27. A cube of side 20 cm is kept in a region as shown in the figure. An electric field $\vec{E}$ exists in the region such that the A potential at a point is given by V = 10x + 5, where V is in volt and x is in m.



Find the (i) electric field, and (ii) total electric flux through the cube.

Ans: (i) $E = -\dfrac{dV}{dx} = -\dfrac{d}{dx}(10x+5)$

$\Rightarrow \vec{E} = -10\hat{i} \;\; N/C$

(ii) Electric flux through the cube, φ = sum of electric flux through six faces.

Electric flux through perpendicular Y and Z axis = 0

(∵ E is along x axis)

Electric flux through faces perpendicular to x – axis,

$\varphi = \varphi 1 + \varphi 2$

$= 10 \times (0.2)^2 - 10 \times (0.2)^2 = 0$

28. A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is 3/4 th of the angle of prism. Calculate the speed of light in the prism.

Ans: Angle of prism, A = 60° (Since prism is an equilateral glass prism)

We are given that $i = \dfrac{3}{4}A = \dfrac{3}{4} \times 60^0 = 45^0$

At minimum deviation, $r = \dfrac{A}{2} = 30^0$

$$\therefore \; n = \frac{\sin i}{\sin r} = \frac{\sin 45^0}{\sin 30^0} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

∴ Speed of light in the prism is given by $v = \dfrac{c}{n} = \dfrac{3\times 10^8}{\sqrt{2}} = 2.1\times 10^8 m/s$

OR

The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding, then will the focal length of lens change? Will the power change?

Ans: Focal length of lens $\dfrac{1}{f} = (n-1)\left(\dfrac{1}{R} + \dfrac{1}{R}\right)$

When one surface is made plane, $\dfrac{1}{f} = (n-1)\left(\dfrac{1}{R} + \dfrac{1}{\infty}\right)$

$$\therefore \; f' = \frac{R}{n-1} = 2f$$

That is, the focal length will be doubled.

As P = 1/f, so power will be halved.

SECTION – D (Case Study Based Questions)

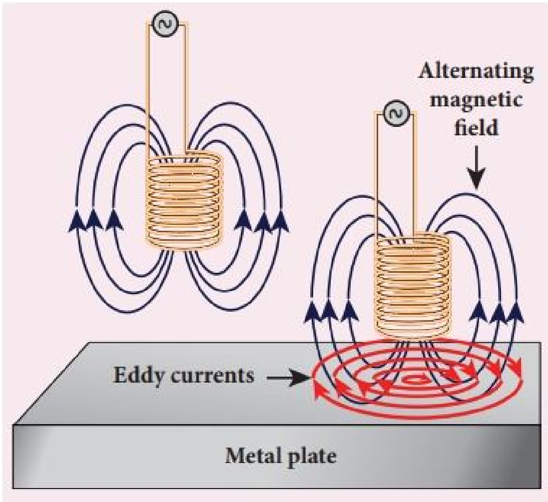
Questions 29 to 30 carry 4 marks each.

29. Case-Study 1:

Read the following paragraph and answer the questions

Eddy Currents and their Effects

Currents can be induced not only in conducting coils, but also in conducting sheets or blocks. Current is induced in solid metallic masses when the magnetic flux threading through them changes. Such currents flow in the form of irregularly shaped loops throughout the body of the metal. These currents look like eddies or whirlpools in water so they are known as eddy currents. Eddy currents have both undesirable effects and practically useful applications. For example it causes unnecessary heating and wastage of power in electric motors, dynamos and in the cores of transformers.



(i) The working of speedometers of trains is based on
(a) wattless currents (b) eddy currents (c) alternating currents (d) pulsating currents

(ii) Identify the wrong statement.
(a) Eddy currents are produced in a steady magnetic field.
(b) Induction furnace uses eddy currents to produce heat.
(c) Eddy currents can be used to produce braking force in moving trains.
(d) Power meters work on the principle of eddy currents.

(iii) Which of the following is the best method to reduce eddy currents?
(a) Laminating core (b) Using thick wires
(c) By reducing hysteresis loss (d) None of these

(iv) The direction of eddy currents is given by
(a) Fleming's left hand rule (b) Biot-Savart law
(c) Lenz's law (d) Ampere-circuital law

OR

(v) Eddy currents can be used to heat localised tissues of the human body. This branch of medical therapy is called
(a) Hyperthermia (b) Diathermy
(c) Inductothermy (d) none of these.

Ans. (i) (b) : The working of speedometers is based on eddy currents.
(ii) (a)
(iii) (a) : To reduce the eddy currents in the metal armature of motors, wire is wrapped around a number of thin metal sheets called lamination.
(iv) (c) : Eddy currents also oppose the change in magnetic flux, so their direction is given by Lenz's law.

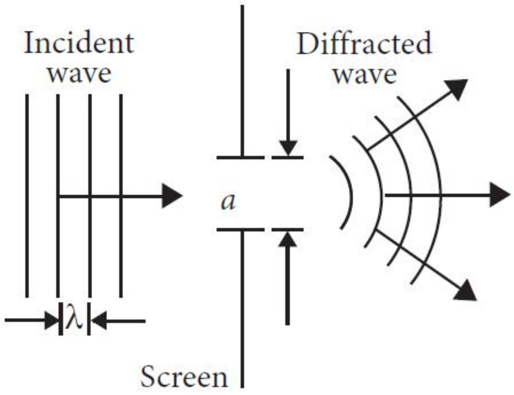
(v) (c)

30. Case-Study 2:

Read the following paragraph and answer the questions.

Diffraction of Light

The phenomenon of bending of light around the sharp corners and the spreading of light within the geometrical shadow of the opaque obstacles is called diffraction of light. The light thus deviates from its linear path. The deviation becomes much more pronounced, when the dimensions of the aperture or the obstacle are comparable to the wavelength of light.



(i) Light seems to propagate in rectilinear path because
(a) its spread is very large
(b) its wavelength is very small
(c) reflected from the upper surface of atmosphere
(c) it is not absorbed by atmosphere

(ii) In diffraction from a single slit the angular width of the central maxima does not depends on
(a) λ of light used (b) width of slit
(c) distance of slits from the screen (d) ratio of λ and slit width

(iii) For a diffraction from a single slit, the intensity of the central point is
(a) infinite
(b) finite and same magnitude as the surrounding maxima
(c) finite but much larger than the surrounding maxima
(d) finite and substantially smaller than the surrounding maxima

(iv) Resolving power of telescope increases when
(a) wavelength of light decreases (b) wavelength of light increases
(c) focal length of eye-piece increases (d) focal length of eye-piece decreases

OR

(v) In a single diffraction pattern observed on a screen placed at D metre distance from the slit of width d metre, the ratio of the width of the central maxima to the width of other secondary maxima is
(a) 2 : 1 (b) 1 : 2 (c) 1 : 1 (d) 3 : 1
Ans. (i) (b) its wavelength is very small
(ii) (c) distance of slits from the screen
(iii) (c) finite but much larger than the surrounding maxima
(iv) (a) wavelength of light decreases
(v) (a) 2 : 1

SECTION – E

Questions 31 to 33 carry 5 marks each.

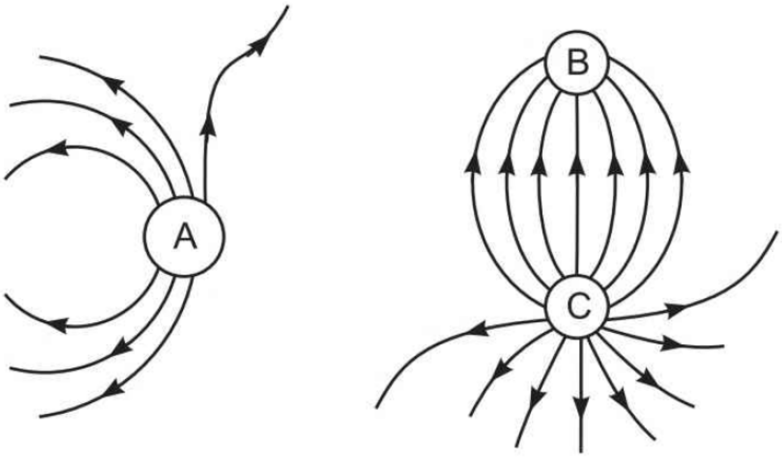
31. (i) The given figure shows the electric field lines around three point charges A, B and C.

(a) Which charges are positive?

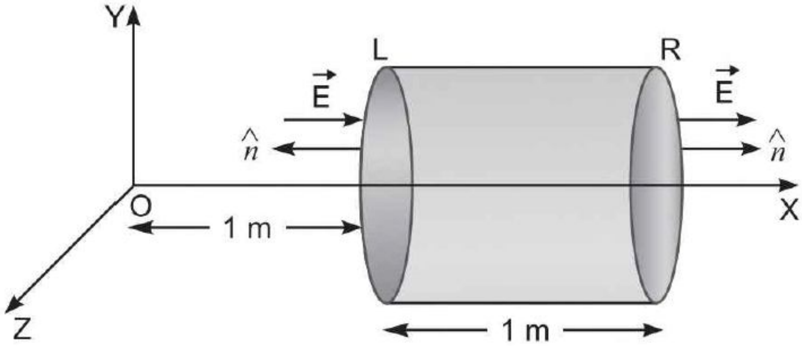
(b) Which charge has the largest magnitude? Why?

(c) In which region or regions of the picture could the electric field be zero? Justify your answer.

(1) near A (2) near B (3) near C (4) nowhere.



(ii) A hollow cylindrical box of length 1 m and area of cross-section 25 cm? is placed in a three dimensional coordinate y system as shown in the figure.



The electric field in the region is given by E = $50x\hat{i}$, where E is in NC^{-1} and x is in metres.

Find: (a) net flux through the cylinder.

(b) charge enclosed by the cylinder.

Ans: (i) (a) Charges A and C are positive since lines of force emanate from them.

(b) Charge C has the largest magnitude since maximum number of field lines are associated with it.

(c) (i) near A.

Justification: There is no neutral point between a positive and a negative charge. A neutral point may exist between two like charges. From the figure we see that a neutral point exists between charges A and C. Also between two like charges the neutral point is closer to the charge with smaller magnitude. Thus, electric field is zero near charge A.

(ii) (a) Electric flux through a surface, $\phi = \vec{E}.\vec{S}$

Flux through the left surface, $\phi_L = ES\cos 180^0 = -ES = (-50x)S$

Since x = 1 m, $\phi_L = -50\times1\times25\times10^{-4} = -1250\times10^{-4} = -0.125 Nm^2C^{-1}$

Flux through the right surface, $\phi_R = ES\cos 0^0 = ES = (50x)S$

Since x = 2 m, $\varphi_R = 50 \times 2 \times 25 \times 10^{-4} = 2500 \times 10^{-4} = 0.250\ Nm^2C^{-1}$

Net flux through the cylinder, $\varphi_{net} = \varphi_R + \varphi_L$

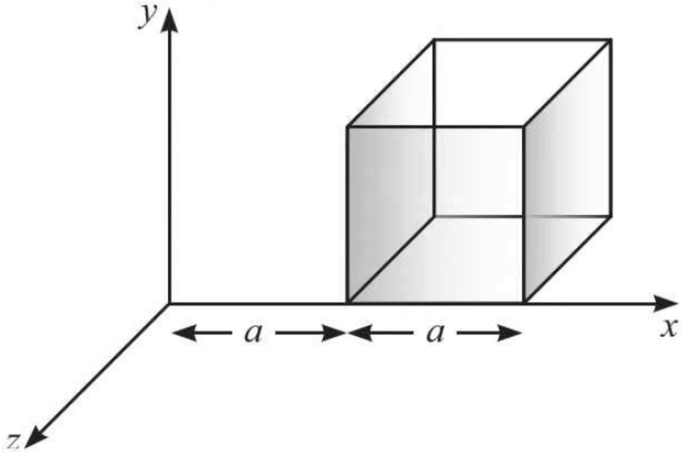
$= 0.250 – 0.125 = 0.125\ Nm^2C^{-1}$

(b) Charge inside the cylinder, by Gauss's Theorem

$$\phi_{net} = \frac{q}{\varepsilon_0} \Rightarrow q = \varepsilon_0 \phi_{net} = 8.854 \times 10^{-12} \times 0.125 = 1.107 \times 10^{-12} C$$

OR

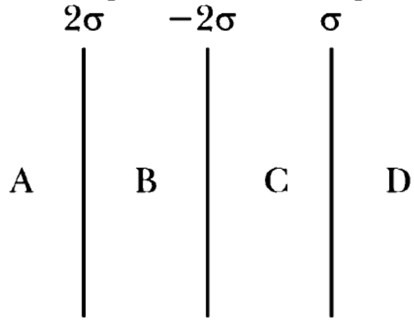
(i) State Gauss's law in electrostatics. A cube with y each side 'a' is kept in an electric field given by $\vec{E} = C \text{ x } \hat{r}$, (as is shown in the figure) where C is a positive dimensional constant.



Find out (a) the electric flux through the cube, and

(b) the net charge inside the cube.

(ii) In the figure there are three infinite long thin sheets having surface charge density +2σ, -2σ and +σ respectively. Give the magnitude and direction of electric field at a point to the left of sheet of charge density +2σ and to the right of sheet of charge density +σ.



Ans: (i) Gauss's Law in electrostatics states that the total electric flux through a closed surface enclosing a charge is equal to $\frac{1}{\varepsilon_0}$ times the magnitude of that charge.

$$\phi = \oint \vec{E}.\vec{dS} = \frac{q}{\varepsilon_0}$$

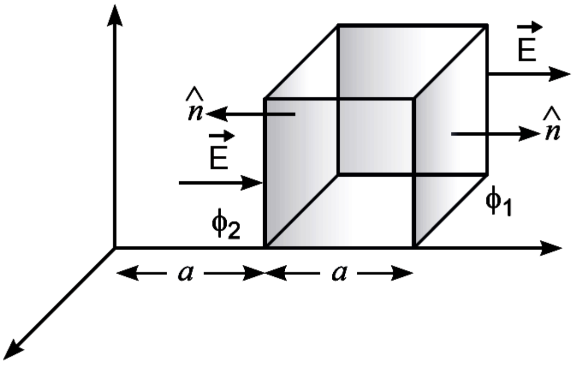
(a) Net flux, $\phi = \phi_1 + \phi_2$ where $\phi_1 = \vec{E}.\vec{dS}$

$= 2aCdS \cos 0^0 = 2aC \times a^2 = 2a^3C$

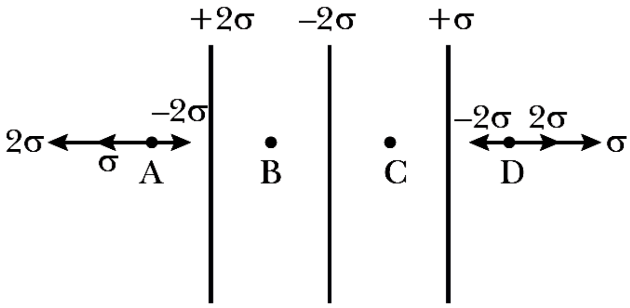
$\phi_2 = aC \times a^2 \cos 180^0 = -a^3C$

$\phi = 2a^3C + (-a^3C) = a^3C \quad Nm^2C^{-1}$

(b) Net charge (q) = $\varepsilon_0 \times \varphi = a^3C\ \varepsilon_0$ coulomb



(ii) At A, both 2σ and 2σ will act in left and –2σ will act in right, so, charge density at A can be given as $E_A = \frac{2\sigma}{2\varepsilon_0} - \frac{2\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}$

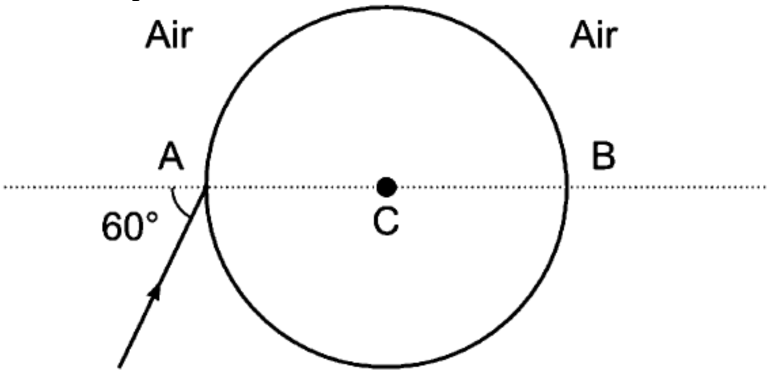


The net electric field at A is towards left.
Similarly at point D, σ and 2σ will act in right and –2σ will act in left

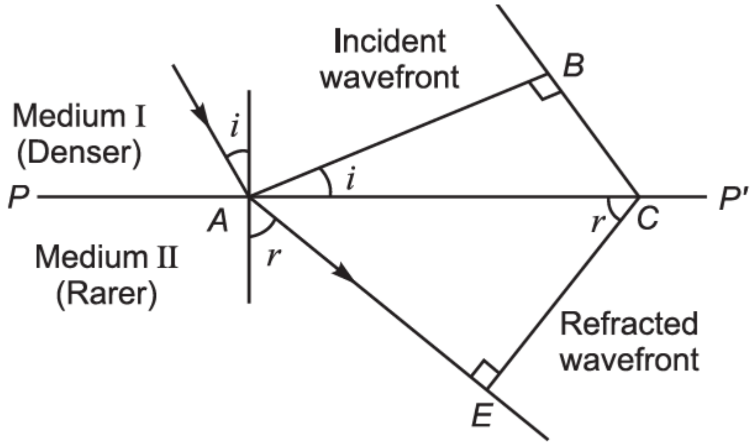
So, charge density $E_D = \frac{2\sigma}{2\varepsilon_0} - \frac{2\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}$

The net electric field at D is towards right.

32. (i) Use Huygens' principle to show how a plane wavefront propagates from a denser to rarer medium. Hence, verify Snell's law of refraction.
(ii) A ray of light falls on a transparent sphere with centre C as shown in the figure. The ray emerges from the sphere parallel to the line AB. Find the angle of refraction at A if refractive index of the material of the sphere is √3.



Ans: (i) We assume a plane wavefront AB propagating in denser medium incident on the interface PP' at angle i as shown in Fig. Let t be the time taken by the wave front to travel a distance BC. If v_1 is the speed of the light in medium I.



So, BC = v_1 t

In order to find the shape of the refracted wavefront, we draw a sphere of radius AE = v_2 t, where v_2 is the speed of light in medium II (rarer medium). The tangent plane CE represents the refracted wavefront.

In ΔABC, $\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$

and in ΔACE, $\sin r = \frac{AE}{AC} = \frac{v_2 t}{AC}$

$\therefore \frac{\sin i}{\sin r} = \frac{BC}{AE} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2}$ ……. (i)

Let c be the speed of light in vacuum

So, $n_1 = \frac{c}{v_1}$ and $n_2 = \frac{c}{v_2} \Rightarrow \frac{n_2}{n_1} = \frac{v_1}{v_2}$ …(ii)

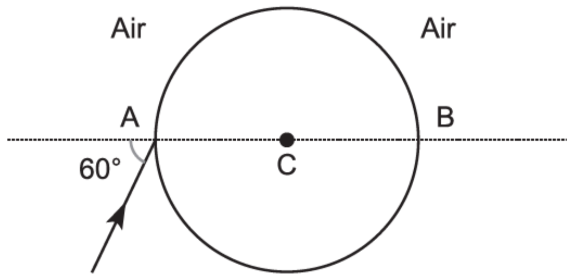
From equations (i) and (ii), we have

$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} \Rightarrow n_1 \sin i = n_2 \sin r$

It is known as Snell's law.

(ii) Refractive index, $n = \frac{\sin i}{\sin r} \Rightarrow \sqrt{3} = \frac{\sin 60^0}{\sin r}$

$\Rightarrow \sin r = \frac{\sqrt{3}}{2} \times \frac{1}{\sqrt{3}} = \frac{1}{2}$



$\Rightarrow \sin r = \sin 30° \Rightarrow r = 30°$

Angle of refraction = 30°.

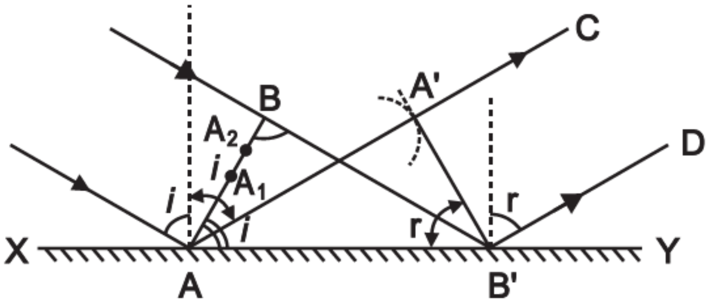
OR

(i) Define the term wavefront. Using Huygen's wave theory, verify the law of reflection.

(ii) A convex lens made of a material of refractive index n1, is kept in-a medium of refractive index n_2. Parallel rays of light are incident on the lens. Complete the path of rays of light emerging from the convex lens if: (i) $n_1 > n_2$ (ii) $n_1 = n_2$ (iii) $n_1 < n_2$.

Ans: **(i) Wavefront:** A wavefront is a locus of particles of medium all vibrating in the same phase.

Law of Reflection: Let XY be a reflecting surface at which a wavefront is being incident obliquely. Let v be the speed of the wavefront and at time t = 0, the wavefront touches the surface XY at A. After time t, the point B of wavefront reaches the point B′ of the surface.



According to Huygen's principle each point of wavefront acts as a source of secondary waves. When the point A of wavefront strikes the reflecting surface, then due to presence of reflecting surface, it cannot advance further; but the secondary wavelet originating from point A begins to spread in all directions in the first medium with speed v. As the wavefront AB advances further, its points A_1, A_2, A_3 ... etc. strike the reflecting surface successively and send spherical secondary wavelets in the first medium.

First of all the secondary wavelet starts from point A and traverses distance AA' (= vt) in first medium in time t. In the same time t, the point B of wavefront, after travelling a distance BB', reaches point B' (of the surface), from where the secondary wavelet now starts. Now taking A as centre we draw a spherical arc of radius AA' (= vt) and draw tangent A'B' on this arc from point B'. As the incident wavefront AB advances, the secondary wavelets starting from points between A and B', one after the other and will touch A'B' simultaneously. According to Huygen's principle wavefront A'B' represents the new position of AB, i.e., A'B' is the reflected wavefront corresponding to incident wavefront AB.

Now in right-angled triangles ABB' and AA'B'

∠ABB' = ∠AA'B' (both are equal to 90°)

side BB' = side AA' (both are equal to vt)

and side AB' is common.

i.e., both triangles are congruent.

∴ ∠ BAB' = ∠ AB'A'

i.e., incident wavefront AB and reflected wavefront A'B' make equal angles with the reflecting surface XY. As the rays are always normal to the wavefront, therefore the incident and the reflected rays make equal angles with the normal drawn on the surface XY, i.e.,

Angle of incidence (i) = Angle of reflection (r)

This is the second law of reflection.

Since AB, A'B' and XY are all in the plane of paper, therefore the perpendiculars dropped on them will also be in the same plane. Therefore, we conclude that the incident ray, reflected ray and the normal at the point of incidence, all lie in the same plane. This is the first law of reflection. Thus, Huygen's principle explains both the laws of reflection.

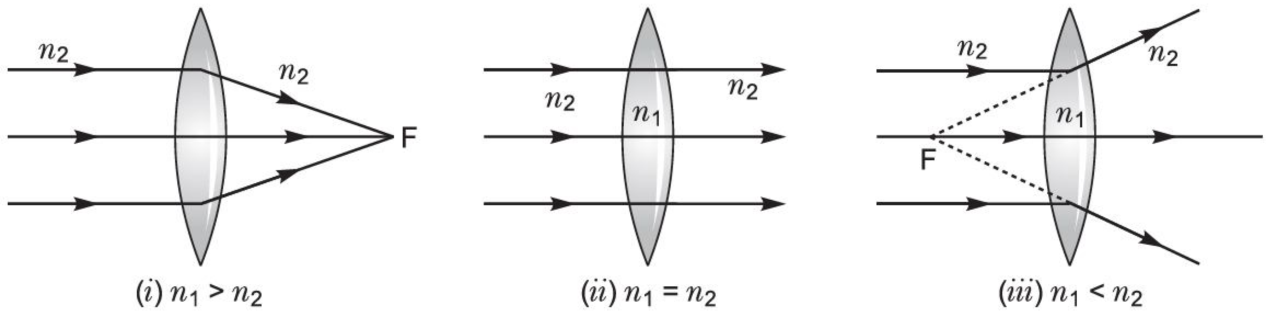
(ii) From lens maker's formula, $\frac{1}{f}=\left(\frac{n_1}{n_2}-1\right)\left(\frac{1}{R_2}+\frac{1}{R_2}\right)$

In case (i) $n_1 > n_2$, the lens behaves as convergent lens.

In case (ii) $n_1 = n_2$, the lens behaves as a plane plate.

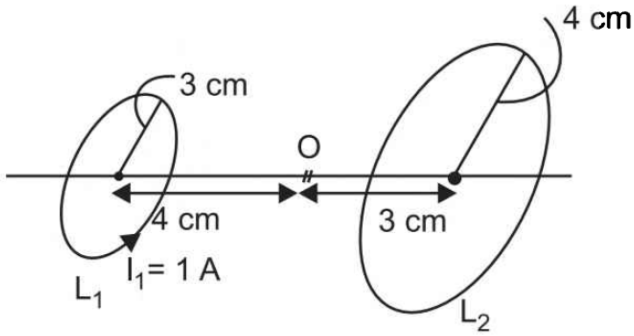
In case (iii) $n_1 < n_2$, the lens behaves as a divergent lens.

The path of rays in all the three cases is shown in fig.



33. (i) Using Biot-Savart's law, derive an expression for magnetic field at any point on axial line of a current carrying circular loop. Hence, find magnitude of magnetic field intensity at the centre of circular coil.

(ii) Two co-axial circular loops L_1 and L_2 of radii 3 cm and 4 cm are placed as shown. What should be the magnitude and direction of the current in the loop L_2 so that the net magnetic field at the point O be zero?



Ans: (i) Magnetic field at the axis of a circular loop: Consider a circular loop of radius R carrying current I, with its plane perpendicular to the plane of paper. Let P be a point of observation on the axis of this circular loop at a distance x from its centre O. Consider a small element of length *dl* of the coil at point A. The magnitude of the magnetic induction $\overrightarrow{dB}$ at point P due to this element is given by

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{Idl\sin\alpha}{r^2} \qquad ...(i)$$

The direction of $\overrightarrow{dB}$ is perpendicular to the plane containing $\overrightarrow{dl}$ and $\vec{r}$ and is given by right hand screw rule. As the angle between I$\overrightarrow{dl}$ and $\vec{r}$ and is 90°, the magnitude of the magnetic induction $\overrightarrow{dB}$ is given by,

$$\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{Idl\sin 90^2}{r^2} = \frac{\mu_0 Idl}{4\pi r^2} \qquad ...(ii)$$

If we consider the magnetic induction produced by the whole of the circular coil, then by symmetry the components of magnetic induction perpendicular to the axis will be cancelled out, while those parallel to the axis will be added up. Thus the resultant magnetic induction B at axial point P is along the axis and may be evaluated as follows:

The component of $\overrightarrow{dB}$ along the axis,

$$\overrightarrow{dB}_x = \frac{\mu_0 Idl}{4\pi r^2}\sin\alpha \qquad ...(iii)$$

But $\sin\alpha = \frac{R}{r}$ and $r = (R^2 + x^2)^{1/2}$

$$\therefore \overrightarrow{dB}_x = \frac{\mu_0 Idl}{4\pi r^2}\frac{R}{r} = \frac{\mu_0 IR}{4\pi r^3}dl = \frac{\mu_0 IR}{4\pi(R^2+x^2)^{3/2}}dl \qquad ..(iv)$$

Therefore, the magnitude of resultant magnetic induction at axial point P due to the whole circular coil is given by

$$\vec{B} = \oint \frac{\mu_0 IR}{4\pi(R^2+x^2)^{3/2}} dl = \frac{\mu_0 IR}{4\pi(R^2+x^2)^{3/2}} \oint dl$$

But $\oint dl$ = length of the loop = 2πR ...(v)

Therefore, $B = \frac{\mu_0 IR}{4\pi(R^2+x^2)^{3/2}} \times 2\pi R$

$$\vec{B} = B_x \hat{i} = \frac{\mu_0 IR^2}{2(R^2+x^2)^{3/2}} \hat{i} \qquad \left[At\ centre, x = 0, \vec{B} = \frac{\mu_0 I}{2R} \right]$$

If the coil contains N turns, then $B = \frac{\mu_0 NIR^2}{2(R^2+x^2)^{3/2}} tesla$

(ii) The magnetic field, $B = \frac{\mu_0 NIa^2}{2(a^2+x^2)^{3/2}}$

Here N= 1, a_1 = 3 cm, x_1 = 4 cm, I_1 =1 A

∴ Magnetic field at O due to coil L_1 is $B = \frac{\mu_0 \times 1 \times (3\times10^{-2})^2}{2[(3\times10^{-2})^2 + (4\times10^{-2})^2]^{3/2}} = \frac{\mu_0 (9\times10^{-4})}{2\times125\times10^{-6}}$

Here a_2 = 4cm, x_2 = 3 cm

Magnetic field at O due to coil L_2 is $B = \frac{\mu_0 \times I_2 \times (4\times10^{-2})^2}{2[(4\times10^{-2})^2 + (3\times10^{-2})^2]^{3/2}} = \frac{\mu_0 I_2 (16\times10^{-4})}{2\times125\times10^{-6}}$

For zero magnetic field at O, the currents I_1 and I_2 should be in same direction, so current I_2 should be in opposite directions and satisfy the condition,

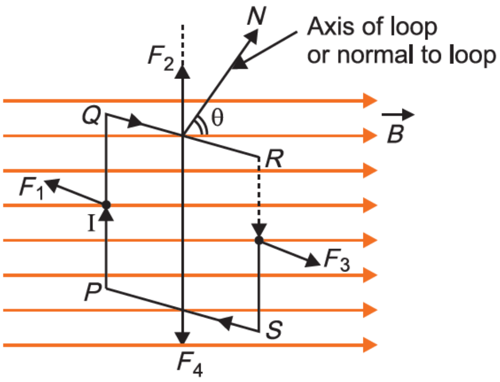
$$B_1 = B_2 \Rightarrow \frac{\mu_0 (9\times10^{-4})}{2\times125\times10^{-6}} = \frac{\mu_0 I_2 (16\times10^{-4})}{2\times125\times10^{-6}} \Rightarrow I_2 = \frac{9}{16} A$$

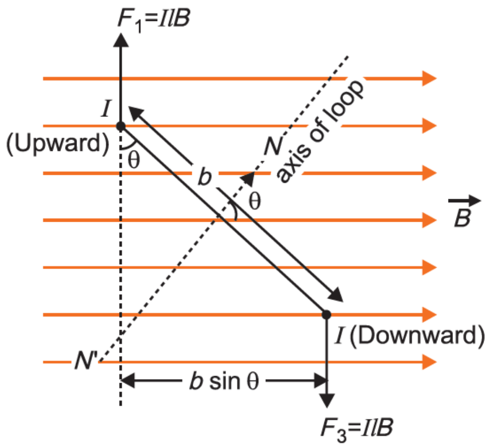
OR

(i) Derive an expression for torque acting on a rectangular current carrying loop kept in a uniform magnetic field B. Indicate the direction of torque acting on the loop.

(ii) A magnetised needle of magnetic moment 4.8 x 10^7 JT^{-1} is placed at 30° with the direction of uniform magnetic field of magnitude 3 x 10^{-2} T. Calculate the torque acting on the needle.

Ans: (i) Torque on a current carrying loop: Consider a rectangular loop PQRS of length *l*, breadth b suspended in a uniform magnetic field $\vec{B}$. The length of loop = PQ = RS= *l* and breadth QR = SP = *b*. Let at any instant the normal to the plane of loop make an angle θ with the direction of magnetic field $\vec{B}$ and I be the current in the loop. We know that a force acts on a current carrying wire placed in a magnetic field. Therefore, each side of the loop will experience a force. The net force and torque acting on the loop will be determined by the forces acting on all sides of the loop. Suppose that the forces on sides PQ, QR, RS and SP are $\vec{F_1}, \vec{F_2}, \vec{F_3}$ and $\vec{F_4}$ respectively. The sides QR and SP make angle (90°– θ) with the direction of magnetic field. Therefore each of the forces $\vec{F_2}$ and $\vec{F_4}$ acting on these sides has same magnitude F′ = B*lb* sin (90°– θ) = B*lb* cos θ.





According to Fleming's left hand rule the forces $\vec{F_2}$ and $\vec{F_4}$ are equal and opposite but their line of action is same. Therefore, these forces cancel each other i.e., the resultant of forces $\vec{F_2}$ and $\vec{F_4}$ is zero.

The sides PQ and RS of current loop are perpendicular to the magnetic field, therefore the magnitude of each of forces $\vec{F_1}$ and $\vec{F_3}$ is F=I*l*B sin 90°=I*l*B

According to Fleming's left hand rule the forces $\vec{F_1}$ and $\vec{F_3}$ acting on sides PQ and RS are equal and opposite, but their lines of action are different; therefore, the resultant force of $\vec{F_1}$ and $\vec{F_3}$ is zero, but they form a couple called the deflecting couple. When the normal to plane of loop makes an angle with the direction of magnetic field the perpendicular distance between $\vec{F_1}$ and $\vec{F_3}$ is b sin θ.

∴ Moment of couple or Torque, τ = (Magnitude of one force F) × perpendicular distance
=(BI*l*). (*b* sin θ)=I (*lb*) B sin θ
But *lb* = area of loop =A (say)
∴ Torque, τ = IAB sin θ
If the loop contains N-turns, then τ = NI AB sin θ
In vector form, $\vec{\tau} = NI\vec{A}\times\vec{B}$
The magnetic dipole moment of rectangular current loop = M = NIA
∴ $\vec{\tau} = \vec{M}\times\vec{B}$
Direction of torque is perpendicular to direction of area of loop as well as the direction of magnetic field i.e., along $I\vec{A}\times\vec{B}$
The current loop would be in stable equilibrium, if magnetic dipole moment is in the direction of the magnetic field ($\vec{B}$).
(ii) We have, τ = M B sin θ
where τ ⟶ Torque acting on magnetic needle
M ⟶ Magnetic moment
B ⟶ Magnetic field strength

Then $\tau = 4.8 \times 10^{-2} \times 3 \times 10^{-2} \sin 30^0 = 4.8 \times 10^{-2} \times 3 \times 10^{-2} \times \frac{1}{2}$

$\Rightarrow \tau = 7.2 \times 10^{-4}$ Nm