MAGNETISM

12th Standard CBSE

Date : 17-Nov-22

Physics

Reg.No. :

Exam Time : 02:00:00 Hrs

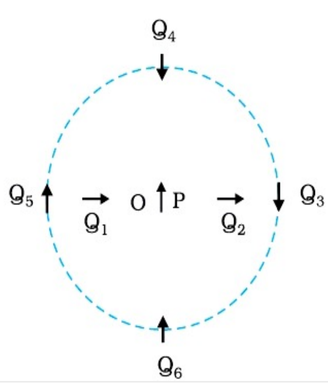
Total Marks : 100

33 x 5 = 165

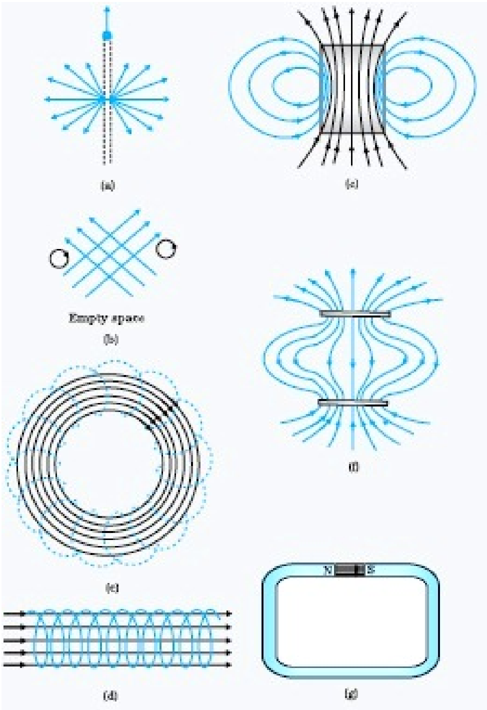
1) A short bar magnet placed with its axis at 30° with an external field of 800 G experiences a torque of 0.016 Nm.
(a) What is the magnetic moment of the magnet?
(b) What is the work done in moving it from its most stable to most unstable position?
(c) The bar magnet is replaced by a solenoid of cross-sectional area 2 x 10^{-4} m^2 and 1000 turns, but of the same magnetic moment. Determine the current flowing through the solenoid.

2) (a) What happens if a bar magnet is cut into two pieces:
(i) transverse to its length,
(ii) along its length?
(b) A magnetised needle in a uniform magnetic field experiences a torque but no net force. An iron nail near a bar magnet, however, experiences a force of attraction in addition to a torque. Why?
(c) Must every magnetic configuration have a north pole and a south pole? What about the field due to a toroid?
(d) Two identical looking iron bars A and B are given, one of which is definitely known to be magnetised. (We do not know which one.) How would one ascertain whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? [Use nothing else but the bars A and B.]

3) Figure shows a small magnetised needle P placed at a point O. The arrow shows the direction of its magnetic moment. The other arrows show different positions (and orientations of the magnetic moment) of another identical magnetised needle Q.
(a) In which configuration the system is not in equilibrium?
(b) In which configuration is the system in
(i) stable, and
(ii) unstable equilibrium?
(c) Which configuration corresponds to the lowest potential energy among all the configurations shown?



4) Many of the diagrams given in Fig. show magnetic field lines (thick lines in the figure) wrongly. Point out what is wrong with them. Some of them may describe electrostatic field lines correctly Point out which ones.



5) (a) Magnetic field lines show the direction (at every point) along which a small magnetised needle aligns (at the point). Do the magnetic field lines also represent the lines of force on a moving charged particle at every point?
(b) Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?
(c) If magnetic monopoles existed, how would the Gauss's law of magnetism be modified?
(d) Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?
(e) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?

6) A solenoid has a core of a material with relative permeability 400. The windings of the solenoid are insulated from the core and carry a current of 2A. If the number of turns is 1000 per metre, calculate (a) H, (b) M, (c) B and (d) the magnetising current I_m.

7) A domain in ferromagnetic iron is in the form of a cube of side length 1μm. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetisation of the domain. The molecular mass of iron is 55 g/mole and its density is 7.9 g/cm^3. Assume that each iron atom has a dipole moment of 9.27×10^{-24} A m^2.

8) Answer the following questions regarding earth's magnetism:
(a) A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.
(b) The angle of dip at a location in southern India is about 18°. Would you expect a greater or

smaller dip angle in Britain?

(c) If you made a map of magnetic field lines at Melbourne in Australia, would the lines seem to go into the ground or come out of the ground?

(d) In which direction would a compass free to move in the vertical plane point to, if located right on the geomagnetic north or south pole?

(e) The earth's field, it is claimed, roughly approximates the field due to a dipole of magnetic moment 8×10^{22} J T^{-1} located at its centre. Check the order of magnitude of this number in some way.

(f) Geologists claim that besides the main magnetic N-S poles, there are several local poles on the earth's surface oriented in different directions. How is such a thing possible at all?

9) Answer the following questions:

(a) The earth's magnetic field varies from point to point in space. Does it also change with time? If so, on what time scale does it change appreciably?

(b) The earth's core is known to contain iron. Yet geologists do not regard this as a source of the earth's magnetism. Why?

(c) The charged currents in the outer conducting regions of the earth's core are thought to be responsible for earth's magnetism. What might be the 'battery' (i.e., the source of energy) to sustain these currents?

(d) The earth may have even reversed the direction of its field several times during its history of 4 to 5 billion years. How can geologists know about the earth's field in such distant past?

(e) The earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km). What agencies may be responsible for this distortion?

(f) Interstellar space has an extremely weak magnetic field of the order of 10^{-12} T. Can such a weak field be of any significant consequence? Explain.

10) A short bar magnet of magnetic moment m = 0.32 JT^{-1} is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its

(a) stable, and

(b) unstable equilibrium?

What is the potential energy of the magnet in each case?

11) A bar magnet of magnetic moment 1.5 J T^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment:

(i) normal to the field direction,

(ii) opposite to the field direction?

(b) What is the torque on the magnet in cases (i) and (ii)?

12) A closely wound solenoid of 2000 turns and area of cross-section 1.6×10^{-4} m^2, carrying a current of 4.0 A, is suspended through its centre allowing it to turn in a horizontal plane.

(a) What is the magnetic moment associated with the solenoid?

(b) What is the force and torque on the solenoid if a uniform
horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid?

13) A circular coil of 16 turns and radius 10 cm carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5.0×10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of $2.0\ s^{-1}$. What is the moment of inertia of the coil about its axis of rotation?

14) A short bar magnet has a magnetic moment of $0.48\ J\ T^{-1}$. Give the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on
(a) the axis,
(b) the equatorial lines (normal bisector) of the magnet.

15) A short bar magnet placed in a horizontal plane has its axis aligned along the magnetic north-south direction. Null points are found on the axis of the magnet at 14 cm from the centre of the magnet. The earth's magnetic field at the place is 0.36 G and the angle of dip is zero. What is the total magnetic field on the normal bisector of the magnet at the same distance as the null–point (i.e., 14 cm) from the centre of the magnet? (At null points, field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field.)

16) If the bar magnet in exercise 5.13 is turned around by 180°, where will the new null points be located?

17) A short bar magnet of magnetic moment $5.25 \times 10^{-2}\ J\ T^{-1}$ is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with earth's field on (a) its normal bisector and (b) its axis. Magnitude of the earth's field at the place is given to be 0.42 G. Ignore the length of the magnet in comparison to the distances involved.

18) (a) Why does a paramagnetic sample display greater magnetisation (for the same magnetising field) when cooled?
(b) Why is diamagnetism, in contrast, almost independent of temperature?
(c) If a toroid uses bismuth for its core, will the field in the core be (slightly) greater or (slightly) less than when the core is empty?
(d) Is the permeability of a ferromagnetic material independent of the magnetic field? If not, is it more for lower or higher fields?
(e) Magnetic field lines are always nearly normal to the surface of a ferromagnet at every point. (This fact is analogous to the static electric field lines being normal to the surface of a conductor at every point.) Why?
(f) Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetisation of a ferromagnet?

19) Answer the following questions:
(a) Explain qualitatively on the basis of domain picture the irreversibility in the magnetisation curve of a ferromagnet.
(b) The hysteresis loop of a soft iron piece has a much smaller area than that of a carbon steel piece. If the material is to go through repeated cycles of magnetisation, which piece will dissipate

greater heat energy?
(c) 'A system displaying a hysteresis loop such as a ferromagnet, is a device for storing memory?' Explain the meaning of this statement.
(d) What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player, or for building 'memory stores' in a modern computer?
(e) A certain region of space is to be shielded from magnetic fields. Suggest a method.

20) A long straight horizontal cable carries a current of 2.5 A in the direction 10° south of west to 10° north of east. The magnetic meridian of the place happens to be 10° west of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable). (At neutral points, magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field.)

21) A telephone cable at a place has four long straight horizontal wires carrying a current of 1.0 A in the same direction east to west. The earth's magnetic field at the place is 0.39 G, and the angle of dip is 35°. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm below the cable?

22) A compass needle free to turn in a horizontal plane is placed at the centre of circular coil of 30 turns and radius 12 cm. The coil is in a vertical plane making an angle of 45° with the magnetic meridian. When the current in the coil is 0.35 A, the needle points west to east.
(a) Determine the horizontal component of the earth's magnetic field at the location.
(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90° in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

23) A monoenergetic (18 keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.04 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm (me = 9.11×10^{-19} C). [Note: Data in this exercise are so chosen that the answer will give you an idea of the effect of earth's magnetic field on the motion of the electron beam from the electron gun to the screen in a TV set.]

24) A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment 1.5×10^{-23} J T^{-1}. The sample is placed under a homogeneous magnetic field of 0.64 T, and cooled to a temperature of 4.2 K. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K? (Assume Curie's law)

25) A Rowland ring of mean radius 15 cm has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. What is the magnetic field B in the core for a magnetising current of 1.2 A?

26) The magnetic moment vectors μs and μl associated with the intrinsic spin angular momentum S and orbital angular momentum l, respectively, of an electron are predicted by quantum theory (and

verified experimentally to a high accuracy) to be given by:
$\mu_s = -(e/m)\ S$,
$\mu_l = -(e/2m)\ l$
Which of these relations is in accordance with the result expected classically? Outline the derivation of the classical result.

27) (i) Discuss briefly electron theory of magnetism for diamagnetic and paramagnetic materials.
(ii) Give two methods to destroy the magnetism of a magnet.

28) (i) A bar magnet of magnetic moment M is aligned parallel to the direction of a uniform magnetic field B. What is the work done, to turn the magnets, so as to align its magnetic moment
(a) opposite to field direction and
(b) normal to field direction?
(ii) Steel is preferred for making permanent magnets, whereas soft iron is preferred for making electromagnets. Give one reason.

29) A magnetic needle suspended in a vertical plane at 30° from the magnetic meridian makes an angle of 45° with the horizontal. Find the true angle of dip.

30) A solenoid of 600 turns per metre is carrying a current of 4 A. Its core is made of iron with relative permeability of 5000. Calculate the magnitudes of magnetic intensity, intensity of magnetisation and magnetic field inside the core.

31) A solenoid having 5000 turns/m carries a current of 2A. An aluminium ring at temperature 300K inside the solenoid provides the core.
(a) If the magnetisation I is 2×10^{-2} A/m, find the susceptibility of aluminium at 300 K.
(b) If temperature of the aluminium ring is 320 K, what will be the magnetisation?

32) Derive the expression for the magnetic field at the site of a point nucleus in a Hydrogen atom due to the circular motion of the electron. Assume that the atom is in its ground state and give the answer in terms of fundamental constants.

33) Draw the magnetic field lines due to a circular loop of area $\vec{A}$ carrying current I. Show that it acts as a bar magnet of magnetic moment $\vec{m} = \overrightarrow{IA}$.
(b) Derive the expression for the magnetic field due to a solenoid of length 2I, radius a having n number of turns per unit length and carrying a steady current I at a point on the axial line, distance r from the centre of the solenoid. How does this expression compare with the axial magnetic field due to a bar magnet of magnetic moment m?

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33 x 5 = 165

1)

(a) From Eq. τ = m B sin θ, θ = 30º, hence sinθ = 1/2.

Thus, 0.016 = m x (800 x 10^{-4} T) x (1/2)

m = 160 x 2/800 = 0.40 A m^2

(b) From Eq. the most stable position is θ = 0º and the most unstable position is θ = 180º. Work done is given by

W = U_m (θ = 180°) −U_m (θ = 0°)

= 2 m B = 2 x 0.40 x 800 x 10^{-4} = 0.064 J

(c) From Eq. m_s = NIA. From part (a), ms = 0.40 A m^2

0.40 = 1000 x I x 2 x 10^{-4}

I = 0.40 x 10^4/(1000 x 2) = 2A

2)

(a) In either case, one gets two magnets, each with a north and south pole.

(b) No force if the field is uniform. The iron nail experiences a nonuniform field due to the bar magnet. There is induced magnetic moment in the nail, therefore, it experiences both force and torque. The net force is attractive because the induced south pole (say) in the nail is closer to the north pole of magnet than induced north pole.

(c) Not necessarily. True only if the source of the field has a net nonzero magnetic moment. This is not so for a toroid or even for a straight infinite conductor.

(d) Try to bring different ends of the bars closer. A repulsive force in some situation establishes that both are magnetised. If it is always attractive, then one of them is not magnetised. In a bar magnet

the intensity of the magnetic field is the strongest at the two ends (poles) and weakest at the central region. This fact may be used to determine whether A or B is the magnet. In this case, to see which one of the two bars is a magnet, pick up one, (say, A) and lower one of its ends; first on one of the ends of the other (say, B), and then on the middle of B. If you notice that in the middle of B, A experiences no force, then B is magnetised. If you do not notice any change from the end to the middle of B, then A is magnetised.

3)

Potential energy of the configuration arises due to the potential energy of one dipole (say, Q) in the magnetic field due to other (P). Use the result that the field due to P is given by the expression.

$\mathbf{B}_{\mathrm{p}} = -\frac{\mu_0}{4\pi}\frac{\mathbf{m}_{\mathrm{p}}}{r^3}$ (on the normal bisector)

$\mathbf{B}_{\mathrm{P}} = \frac{\mu_0 2}{4\pi}\frac{\mathbf{m}_{\mathrm{p}}}{r^3}$ (on the axis)

where m_P is the magnetic moment of the dipole P.

Equilibrium is stable when m_Q is parallel to B_P, and unstable when it is anti-parallel to B_P.

For instance for the configuration Q_3 for which Q is along the perpendicular bisector of the dipole P, the magnetic moment of Q is parallel to the magnetic field at the position 3. Hence Q_3 is stable.

Thus,

(a) PQ_1 and PQ_2

(b) (i) PQ_3, PQ_6 (stable);

(ii) PQ_5, PQ_4 (unstable)

(c) PQ_6

4)

(a) Wrong. Magnetic field lines can never emanate from a point, as shown in figure. Over any closed surface, the net flux of B must always be zero, i.e., pictorially as many field lines should seem to enter the surface as the number of lines leaving it. The field lines shown, in fact, represent electric field of a long positively charged wire. The correct magnetic field lines are circling the straight conductor, as described.
(b) Wrong. Magnetic field lines (like electric field lines) can never cross each other, because otherwise the direction of field at the point of intersection is ambiguous. There is further error in the figure. Magnetostatic field lines can never form closed loops around empty space. A closed loop of static magnetic field line must enclose a region across which a current is passing. By contrast, electrostatic field lines can never form closed loops, neither in empty space, nor when the loop encloses charges.
(c) Right. Magnetic lines are completely confined within a toroid. Nothing wrong here in field lines forming closed loops, since each loop encloses a region across which a current passes. Note, for clarity of figure, only a few field lines within the toroid have been shown. Actually, the entire region enclosed by the windings contains magnetic field.
(d) Wrong. Field lines due to a solenoid at its ends and outside cannot be so completely straight and confined; such a thing violates Ampere's law. The lines should curve out at both ends, and meet eventually to form closed loops
(e) Right. These are field lines outside and inside a bar magnet. Note carefully the direction of field lines inside. Not all field lines emanate out of a north pole (or converge into a south pole). Around both the N-pole, and the S-pole, the net flux of the field is zero.
(f) Wrong. These field lines cannot possibly represent a magnetic field. Look at the upper region. All the field lines seem to emanate out of the shaded plate. The net flux through a surface surrounding the shaded plate is not zero. This is impossible for a magnetic field. The given field lines, in fact, show the electrostatic field lines around a positively charged upper plate and a negatively charged lower plate. The difference between Fig. (e) and (f) should be carefully grasped.
(g) Wrong. Magnetic field lines between two pole pieces cannot be precisely straight at the ends. Some fringing of lines is inevitable. Otherwise, Ampere's law is violated. This is also true for electric field lines.

5)

(a) No. The magnetic force is always normal to B (remember magnetic force = qv x B). It is misleading to call magnetic field lines as lines of force.
(b) If field lines were entirely confined between two ends of a straight solenoid, the flux through the cross-section at each end would be non-zero. But the flux of field B through any closed surface must always be zero. For a toroid, this difficulty is absent because it has no 'ends'.
(c) Gauss's law of magnetism states that the flux of B through any closed surface is always zero $\oint_S \mathbf{B} \cdot d\mathbf{s} = 0$
If monopoles existed, the right hand side would be equal to the monopole (magnetic charge) q_m enclosed by S.
[Analogous to Gauss's law of electrostatics $\int_S \mathbf{B} \cdot d\mathbf{s} = \mu_0 q_m$ where q_m is the (monopole) magnetic charge enclosed by S.]
(d) No. There is no force or torque on an element due to the field produced by that element itself. But there is a force (or torque) on an element of the same wire. (For the special case of a straight wire, this force is zero.)
(e) Yes. The average of the charge in the system may be zero. Yet, the mean of the magnetic moments due to various current loops may not be zero. We will come across such examples in connection with paramagnetic material where atoms have net dipole moment through their net charge is zero.

6)

(a) The field H is dependent of the material of the core, and is

$H = nI = 1000 \times 2.0 = 2 \times 10^3$ A/m.

(b) The magnetic field B is given by

$B = \mu_r \mu_0 H$

$= 400 \times 4\pi \times 10^{-7}$ (N/A^2) $\times 2 \times 10^3$ (A/m)

= 1.0 T

(c) Magnetisation is given by

$M = (B - \mu_0 H)/ \mu 0$

$= (\mu_r \mu_0 H - \mu_0 H) / \mu_0 = (\mu_r - 1)H = 399 \times H$

d) The magnetising current I_M is the additional current that needs to be passed through the windings of the solenoid in the absence of the core which would give a B value as in the presence of the core. Thus $B = \mu_r n_0 (I + I_M)$. Using I = 2A, B = 1 T, we get I_M = 794 A.

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7)

The volume of the cubic domain is

$V = (10^{-6}\ m)^3 = 10^{-18}\ m^3 = 10^{-12}\ cm^3$

Its mass is volume × density = 7.9 g $cm^{-3} \times 10^{-12}\ cm^3$= 7.9×10^{-12} g

It is given that Avagadro number (6.023 x 1023) of iron atoms have a mass of 55 g. Hence, the number of atoms in the domain is

$N = \frac{7.9 \times 10^{-12} \times 6.023 \times 10^{23}}{55}$

$= 8.65 \times 10^{10}$ atoms

The maximum possible dipole moment m_{max} is achieved for the (unrealistic) case when all the atomic moments are perfectly aligned.

Thus,

$m_{max} = (8.65 \times 10^{10}) \times (9.27 \times 10^{-24})$

$= 8.0 \times 10^{-13}$ A m^2

The consequent magnetisation is

$M_{max} = m_{max}$ / Domain volume

$= 8.0 \times 10^{-13}\ Am^2 / 10^{-18}\ m^3$

$= 8.0 \times 10^5\ Am^{-1}$

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8)

(a) The three independent quantities that are conventionally used for specifying the earth's magnetic field are:
i. Magnetic declination,
ii . The angle of dip, and
iii. The horizontal component of the earth's magnetic field.
(b) The angle of dip is the angle made with the horizontal by the Earth's magnetic field lines. It depends on how far the point is located from the North or the South pole. Since Britain is much closer to the North pole than the India. Hence the angle of dip will be greater in Britain.
(c) Earth's magnetic field is hypothetically considered that a huge bar magnet is dipped inside the earth with its north pole near the geographic South Pole and its south pole near the geographic North Pole. The magnetic field lines emerge from a magnetic north pole (earth's south pole) and terminate at a magnetic south pole (earth's north pole). Hence, in a map earth's magnetic field lines at Melbourne in Australia would seem to come out of the ground.
(d) The earth's magnetic field is exactly vertical at the geomagnetic poles (both north and south). The compass needle is free to rotate in the horizontal plane. Hence it may point in any direction.
(e) Given: The dipole moment of magnetic moment = 8×10^{22} JT^{-1}
We know the magnetic strength of a bar magnet is given as,
$B=\frac{\mu_0}{4\pi}\frac{M}{d^3}$
Where, μ_o = Permeability of free space = $4\pi \times 10^{-7}$ T m A^{-1}
M = Magnetic moment
Now, the magnetic field at an equatorial point of earth's dipole can be written as,
$B=\frac{\mu_0}{4\pi}\frac{M}{R^3}$ [R is the radius of the earth]
B = $10^{-7} \times \frac{(8\times10^{22})}{(6.4\times10^{6})^3}$ = 3.052×10^{-5} T
This value of the magnetic field is the same as Earth' magnetic field strength at the equator.
(f) Yes, the geologist claims that besides the main magnetic N-S poles, there are several other local poles on the earth's surface oriented in different directions is true. On the surface of the earth, there are many places of magnetising mineral deposits. These deposits create their own magnetic N-S poles, which can interfere with the earth's magnetic field.

9)

(a) Earth’s magnetic field varies with time and it takes a couple of hundred years to change by an obvious sum. The variation in the Earth’s magnetic field with respect to time can’t be ignored.
(b) The Iron core at the Earth’s centre cannot be considered as a source of Earth’s magnetism because it is in its molten form and is non-ferromagnetic.
(c) The radioactivity in the earth’s interior is the source of energy that sustains the currents in the outer conducting regions of the earth’s core. These charged currents are considered to be responsible for the earth’s magnetism.(d) The Earth’s magnetic field reversal has been recorded several times in the past about 4 to 5 billion years ago. These changing magnetic fields were weakly recorded in rocks during their solidification. One can obtain clues about the geomagnetic history from the analysis of this rock magnetism.
(e) Due to the presence of ionosphere, the Earth’s field deviates from its dipole shape substantially at large distances. The Eart’s field is slightly modified in this region because of the field of single ions. The magnetic field associated with them is produced while in motion.
(f) A remarkably weak magnetic field can deflect charged particles moving in a circle. This may not be detectable for a large radius path. With reference to the gigantic interstellar space, the deflection can alter the passage of charged particles.

10) Moment of the bar magnet, $M = 0.32\ JT^{-1}$

External magnetic field, $B = 0.15\ T$

(a) The bar magnet is aligned along the magnetic field. This system is considered as being in stable equilibrium.

Hence, the angle θ, between the bar magnet and the magnetic field is 0°.

Potential energy of the system = $-MB\cos\theta$

$= -0.32 \times 0.15 \cos 0°$

$= -4.8 \times 10^{-2} J$

(b) The bar magnet is oriented 180° to the magnetic field. Hence, it is in unstable equilibrium. $\theta = 180°$

Potential energy = $-MB\cos\theta$

$= -0.32 \times 0.15 \cos 180°$

$= -4.8 \times 10^{-2} J$

11) **(a)** Magnetic moment, $M = 1.5\ J\ T^{-1}$

Magnetic field strength, $B = 0.22\ T$

(i) Initial angle between the axis and the magnetic field, $\theta_1 = 0°$

Final angle between the axis and the magnetic field, $\theta_2 = 90°$

The work required to make the magnetic moment normal to the direction of the magnetic field is given as:

$W = -MB(\cos\theta_2 - \cos\theta_1)$

$= -1.5 \times 0.22(\cos 90° - \cos 0°)$

$= -0.33(0 - 1)$

$= 0.33\ J$

(ii) Initial angle between the axis and the magnetic field, $\theta_1 = 0°$

Final angle between the axis and the magnetic field, $\theta_2 = 180°$

The work required to make the magnetic moment opposite to the direction of the magnetic field is given as:

$W = -MB(\cos\theta_2 - \cos\theta_1)$

$= -1.5 \times 0.22(\cos 180° - \cos 0°)$

$= -0.33(-1 - 1)$

$= 0.66\ J$

(b) For case (i):

$\theta = \theta_2 = 90°$

$\therefore$ Torque, $\tau = MB\sin\theta$

$= MB\sin 90°$

$= 0.33\ J$

The torque tends to align the magnitude moment vector along B.

For case (ii):

$\theta = \theta_2 = 180°$ $\therefore$ Torque, $\tau = MB\sin\theta$

$= MB\sin 180°$

$= 0$

12) Number of turns on the solenoid, n = 2000

Area of cross-section of the solenoid, A = 1.6 x 10^{-4} m^2

Current in the solenoid, I = 4.0 A

(a) The magnetic moment along the axis of the solenoid is calculated as:

M = nAI

= 2000 x 4 x 1.6 x 10^{-4}

= 1.28 Am^2

(b) Magnetic field, B = 7.5 x 10^{-2}

The angle between the magnetic field and the axis of the solenoid, θ = 30°

Torque, τ = MB sinθ

=1.28 x 7.5 x 10^{-2} sin30°

= 0.048J

Since the magnetic field is uniform, the force on the solenoid is zero. The torque on the solenoid is 0.048 J

13) Number of turns in the circular coil, N = 16

Radius of the coil, r = 10 cm = 0.1 m

Cross-section of the coil, A = πr^2 = n x $(0.1)^2$ m^2

Current in the coil, I = 0.75 A

Magnetic field strength, B = 5.0 x 10^{-2} T

Frequency of oscillations of the coil, v = 2.0 s^{-1}

∴ Magnetic moment, M = NIA = N I πr^2 16 x 0.75 x n x $(0.1)^2$

= 0.377 J T^{-1}

Frequency is given by the relation:

$$v = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$$

Where,

I = Moment of inertia of the coil

Rearranging the above formula, we get:

$$\therefore I = \frac{MB}{4\pi^2 v^2}$$

$$= \frac{0.377 \times 5 \times 10^{-2}}{4\pi^2 \times (2)^2}$$

= 1.2 x 10^{-4} kg m^2

Hence, the moment of inertia of the coil about its axis of rotation is 1.19\times 10^{-4} kg m^2.

14) Magnetic moment of the bar magnet, M = 0.48 J T^{-1}

(a) Distance, d = 10 cm = 0.1 m

The magnetic field at distance d, from the centre of the magnet on the axis, is given by the relation:

$B = \frac{\mu_0 2M}{4\pi d^3}$

Where,

μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ Tm A^{-1} $\therefore B = \frac{4\pi \times 10^{-7} \times 2 \times 0.48}{4\pi \times (0.1)^3}$

= 96 x 10^{-4} T = 0.96 G

The magnetic field is along the S - N direction.

(b) The magnetic field at a distance of 10 cm (i.e., d = 0.1 m) on the equatorial line of the magnet is given as:

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

$= \frac{4\pi \times 10^{-7} \times 0.48}{4\pi (0.1)^3}$

= 0.48 G

The magnetic field is along with the N – S direction.

---

15) Earth's magnetic field at the given place, H = 0.36 G

The magnetic field at a distance d, on the axis of the magnet, is given as:

$B_1 = \frac{\mu_0 2M}{4\pi d^3} = H$ ....(i)

Where,

μ_0 = Permeability of free space

M = Magnetic moment

The magnetic field at the same distance d, on the equatorial line of the magnet, is given as:

$B_2 = \frac{\mu_0 M}{4\pi d^3} = \frac{H}{2}$ [Using equation (i)]

Total magnetic field, B = $B_1 + B_2$

$= H + \frac{H}{2}$

= 0.36 + 0.18 = 0.54 G

Hence, the magnetic field is 0.54 G in the direction of earth's magnetic field.

---

16) The magnetic field on the axis of the magnet at a distance d_1 = 14 cm, can be written as:

$B_1 = \frac{\mu_0 2M}{4\pi (d_1)^3} = H$ ....(i)

Where

M = Magnetic moment

μ_0 = Permeability of free space

H = Horizontal component of the magnetic field at d_1

If the bar magnet is turned through, then the neutral point will lie on the equatorial line.

Hence, the magnetic field at a distance d_2, on the equatorial line of the magnet can be written as:

$B_1 = \frac{\mu_0 2M}{4\pi (d_1)^3} = H$ ....(ii)

Equating equations (1) and (2), we get:

$\frac{2}{(d_1)^3} = \frac{1}{(d_2)^3} \left[\frac{d_2}{d_1}\right]^3 = \frac{1}{2} \therefore d_2 = d_1 \times \left(\frac{1}{2}\right)^{\frac{1}{3}}$

= 14 x 0.794 = 11.1 cm

The new null points will be locked 11.1 cm on the normal bisector.

---

17) Magnetic moment of the bar magnet, M = 5.25 x 10^{-2} J T^{-1}

Magnitude of earth's magnetic field at a place, H = 0.42 G = 42 x 10^{-4} T

(a) The magnetic field at a distance R from the centre of the magnet on the ordinary bisector is given by:

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

Where,

$\mu 0$ = Permeability of free space = 4π x 10^{-7} TmA^{-1}

When the resultant field is inclined at 45° with earth's field, B = H

$\therefore \frac{\mu_0 M}{4\pi R^3}=H=0.42\times 10^{-4} R^3=\frac{\mu_0 M}{0.42\times 10^{-4}\times 4\pi}$

$=R^3=\frac{4\pi\times 10^{-7}\times 6.45\times 10^{-2}}{4\pi\times 0.42\times 10^{-4}}$

=12.5 x 10^{-5} ∴ R = 0.05 m = 5cm

(b) The magnetic field at a distanced 'R' from the centre of the magnet on its axis is given as

$B'=\frac{\mu_0 2M}{4\pi R^3}$

The resultant field is inclined at 45° with the earth's field.

$\therefore B'=H\frac{\mu_0 2M}{4\pi (R')^3}=H(R')^3=\frac{\mu_0 2M}{4\pi\times H}$

$=\frac{4\pi\times 10^{-7}\times 2\times 5.25\times 10^{-2}}{4\pi\times 0.42\times 10^{-4}}=25\times 10^{-5}$ ∴ R = 0.063 m = 6.3 cm

18)

(a) Owing to therandom thermal motion of molecules, the alignments of dipoles get disrupted at high temperatures. On cooling, this disruption is reduced. Hence, a paramagnetic sample displays greater magnetisation when cooled.

(b) The induced dipole moment in a diamagnetic substance is always opposite to the magnetising field. Hence, the internal motion of the atoms (which is related to the temperature) does not affect the diamagnetism of a material.

(c) Bismuth is a diamagnetic substance. Hence, a toroid with a bismuth core has a magnetic field slightly greater than a toroid whose core is empty.

(d)The permeability of ferromagnetic materials is not independent of the applied magnetic field. It is greater for a lower field and vice versa.

(e)The permeability of a ferromagnetic material is not less than one. It is always greater than one. Hence, magnetic field lines are always nearly normal to the surface of such materials at every point.

(f)The maximum possible magnetisation of a paramagnetic sample can be of the same order of magnitude as the magnetisation of a ferromagnet. This requires high magnetising fields for saturation.

19)

(i) To explain qualitatively the domain picture of the irreversibility in the magnetisation curve of a ferromagnet, we draw the hysteresis curve for ferromagnetic substance. We can observe that the magnetisation persists even when the external field is removed. This gives the idea of irreversibility of a ferromagnet.
(ii) As we know that, in hysteresis curve, the energy dissipated per cycle is direcdy proportional to the area of hysteresis loop. So, as according to the question, the area of hysteresis loop is more for carbon steel, thus carbon steel piece will dissipate greater heat energy.
(iii) The magnetisation of a ferromagnet depends not only on the magnetising field, but also on the history of magnetisation (i.e. how many times it was already magnetised in the past). Thus, the value of magnetisation of a specimen is a record of memory of the cycles of magnetisation, it had undergone. The system displaying such a hysteresis loop can thus act as a device for storing memory.
(iv) The ferromagnetic materials which are used for coating magnetic tapes in a cassette player or for building memory stores in the modern computer are ferrites.
(v) To shield any space from magnetic field, surround the space with soft iron ring. As the magnetic field lines will be drawn into the ring, the enclosed region will become free of magnetic field.

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20)

Given,
Current in the wire, I = 2.5 A
Angle of dip at the given location on earth, δ = 0°
Earth's magnetic field, B = 0.33 G = 0.33 x 10^{-4} T
If B is the earth's magnetic field at the point, then, horizontal component of the earth's magnetic field,
BH = B cos δ
Using the given values, we get,
BH = 0.33 x 10^{-4} x cos 0
= 0.33 x 10^{-4} T
Let the neutral point be at a distance R from the cable, then the magnetic field due to current carrying cable and the horizontal component of earth's magnetic field must be equal and in opposite direction. That is,
$$\mathrm{B_H} = \frac{\mu_o \mathrm{I}}{2\pi \mathrm{R}}$$
$$\Rightarrow \mathrm{R} = \frac{\mu_o \mathrm{I}}{2\pi \mathrm{B_H}}$$
Using the values, we get,
$$\mathrm{R} = \frac{4\pi\times10^{-7}\times2.5}{2\pi\times0.33\times10^{-4}}$$
= 1.51 x 10^{-2}m
= 1.51 cm
Therefore, neutral points are located on a line parallel to and above the cable at a normal distance of 1.51 cm.

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21)

Number of horizontal wires in the telephone cable, n = 4
Current in each wire, I = 1.0 A
Earth's magnetic field at a location, H = 0.39 G = 0.39 x 10^{-4} T
Angle of dip at the location, δ = 35°
Angle of declination, $\theta \sim 0°$

For a point 4 cm below the cable

Distance, r = 4 cm = 0.04 m
Let the magnetic field produced due to 4 straight current carrying conductors be, B_1, then,
$$\mathrm{B_1} = 4 \times \frac{\mu_o \mathrm{I}}{2\pi \mathrm{r}}$$
Where,
μ_o = Permeability of free space = 4π x 10^{-7} Tm A^{-1}

μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ Tm/A

Using the values, we get,

$B_1 = 4 \times \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.04}$

= 0.2 x 10^{-4} T = 0.2 G

Now, the horizontal component of resultant magnetic field can be written as,

Bh = H cos δ – B1

Putting the values, we get,

Bh = 0.39 cos 35° − 0.2Bh = 0.39 cos 35° - 0.2

= 0.39 x 0.819 − 0.2 ≈ 0.12 G= 0.39 x 0.819 - 0.2 ≈ 0.12 G

The vertical component of the resultant field is the same as the vertical component of earth's magnetic field. That is,

Bv = Hv = H sin δ = 0.39 x sin 35° = 0.22 G

The angle made by the field with its horizontal component is given by the relation,

$\theta = \tan^{-1} \frac{B_v}{B_h}$

$= \tan^{-1} \frac{0.22}{0.12}$

= $\tan^{-1}$ 1.83

= 61.39°

The resultant field at this point is given by,

$B = \sqrt{B_h^2 + B_v^2}$

$= \sqrt{0.12^2 + 0.22^2}$

= 0.25 G

For a point 4 cm above the cable

The horizontal component of resultant magnetic field can be written as,

Bh = H cos δ+ B1

Putting the values, we get,

Bh = 0.39 cos 35°+ 0.2

= 0.39 x 0.819 + 0.2 ≈ 0.52 G

The vertical component of the resultant field is the same as the vertical component of earth's magnetic field. That is,

Bv = Hv = H sin δ

= 0.39 x sin 35° = 0.22 G

The angle made by the field with its horizontal component is given by the relation,

$\theta = \tan^{-1} \frac{B_v}{B_h}$

$= \tan^{-1} \frac{0.22}{0.52}$

= $\tan^{-1}$ 0.43

= 22.9°

The resultant field at this point is given by,

$B = \sqrt{B_h^2 + B_v^2}$

$= \sqrt{0.52^2 + 0.22^2}$

= 0.56 G

22)

Given,

Radius of the circular coil, r = 12 cm = 0.12 m

Current in the coil, I = 0.35 A

Number of turns in the circular coil, N = 30

Angle of dip, $\delta = 45°$

a. The magnetic field due to current I, at a distance r from the centre of the coil, is given by,

$$B = \frac{\mu_o NI}{2r}$$

Where,

μ_o = Permeability of free space = $4\pi \times 10^{-7}$ Tm A^{-1}

Using the values, we get,

$$B = \frac{4 \times 3.14 \times 10^{-7} \times 30 \times 0.35}{2 \times 0.12}$$

= 5.49×10^{-5} T

The compass needle points from West to East, the horizontal component of earth's magnetic field is equal to the horizontal component of the magnetic field due to the coil. That is,

BH = B sin δ

= 5.49×10^{-5} sin45° = 5.49×10^{-5} sin45°

= 3.88×10^{-5} T = 3.88×10^{-5} T

= 0.388 G

b. When the current in the coil is reversed and the coil is rotated about its vertical axis by an angle of 90°, the needle will reverse its original direction. In this case, the needle will point from East to West.

23)

Given,

Energy of an electron beam, E = 18 keV = 18 x 10^3 eV

Magnetic field, B = 0.4 G = 0.4 x 10^{-4} T

Mass of an electron, m_e = 9.11 x 10^{-31} kg

Distance travelled by the electron beam, d = 30 cm = 0.3 m

We know that, e = 1.6 x 10^{-19} C

And, 1 eV = 1.6 x 10^{-19} J

Therefore, E = 18 x 10^3 x 1.6 x 10^{-19} J

We can write the kinetic energy of the electron beam as,

$$\mathrm{E}=\frac{1}{2}\ \mathrm{m_e v^2}$$
$$\Rightarrow \mathrm{v^2}=\frac{2\mathrm{E}}{\mathrm{m_e}}$$
$$\Rightarrow \mathrm{v}=\sqrt{\frac{2\mathrm{E}}{\mathrm{m_e}}}$$

Now, since magnetic field and v are at right angles, the electron beam deflects along a circular path (say of radius, r), the force due to the magnetic field balances the centripetal force. That is,

$$\frac{\mathrm{m_e v^2}}{\mathrm{r}}=\mathrm{Bev}$$
$$\Rightarrow \mathrm{r}=\frac{\mathrm{m_e v}}{\mathrm{Be}}$$
$$=\frac{\mathrm{m_e}}{\mathrm{Be}}\sqrt{\frac{2\mathrm{E}}{\mathrm{m_e}}}$$
$$=\frac{\sqrt{2\mathrm{Em_e}}}{\mathrm{Be}}$$

Putting the values, we get,

$$\Rightarrow \mathrm{r}=\frac{\sqrt{2\times18\times10^3\times1.6\times10^{-19}\times9.11\times10^{-31}}}{0.4\times10^{-4}\times1.6\times10^{-19}}\quad=\frac{7.2439\times10^{-23}}{0.64\times10^{-23}}$$

=11.3 m

The angle subtended by the arc joining the initial and final position of the electron beam will be given by,

$$\theta=\sin^{-1}\frac{\mathrm{d}}{\mathrm{r}}$$
$$=\sin^{-1}\frac{0.3}{11.3}=1.521^\circ$$

Let the up/down deflection of the electron beam be x, then,

x = r(1− cos θ)

= 11.3(1−cos 1.521°)

≈ 0.004 m

= 4 mm

Therefore, the up and down deflection of the beam is approximately 4 mm.

---

24)

Given,

Number of atomic dipoles, n = 2.0 x 10^{24}

Dipole moment of each atomic dipole, M = 1.5 x 10^{-23} J T^{-1}

In the first case, when the magnetic field, B_1 = 0.64 T, T_1 = 4.2° K

Total dipole moment of all the dipoles,

M_{tot} = n x M

= 2 x 1024 x 1.5 x 10^{-23}

= 30 J T^{-1}

The magnetic saturation is achieved at 15% of magnetic moment, therefore, effective dipole moment,

$\mathrm{M}_1 = \frac{15}{100} \times 30 = 4.5 \text{ J T}^{-1}$

In the second case, when the magnetic field, B_2 = 0.98 T, T_2 = 2.8° K

Let the effective dipole moment in this case be M_2

Now according to Curie's law,

$\frac{\mathrm{M}_2}{\mathrm{M}_1} = \frac{\mathrm{B}_2}{\mathrm{B}_1} \times \frac{\mathrm{T}_1}{\mathrm{T}_2}$

$\Rightarrow \mathrm{M}_2 = \mathrm{M}_1 \times \frac{\mathrm{B}_2}{\mathrm{B}_1} \times \frac{\mathrm{T}_1}{\mathrm{T}_2}$

$= 4.5 \times \frac{0.98}{0.64} \times \frac{4.2}{2.8} = 10.336 \text{ J T}^{-1}$

Therefore, the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K is 10.336 J T^{-1}.

25) The magnetic field in the core at is given by,

$\mathrm{B} = \frac{\mu_r \mu_o \mathrm{NI}}{2\pi \mathrm{r}}$

Where,

μ_o = Permeability of free space = 4π x 10^{-7} Tm A^{-1}

Now using the given values,

Mean radius of a Rowland ring, r = 15 cm = 0.15 m

Number of turns on a ferromagnetic core, N = 3500

Relative permeability of the core material, μ_r = 800

Magnetising current, I = 1.2 A

we get,

$\mathrm{B} = \frac{800 \times 4 \times \pi \times 10^{-7} \times 3500 \times 1.2}{2 \times \pi \times 0.15}$

= 4.48 T

Therefore, the magnetic field in the core is 4.48 T.

26) The relations

$\mu_l = -\left(\frac{e}{2m}\right) l$

is in accordance with the result expected classically.

Proof:

μ_l is defined as,

μl = iA

$\Rightarrow \mu_l = \frac{-e\pi r^2}{T}$ ......(i)

Also,

$l = mvr = \frac{2\pi mr^2}{T}$ ......(ii)

Where,

i = current associated due to revolution of electron,

A = the area of orbit,

T = time period of revolution of electron,

m = mass of electron, and,

- *e* = charge on the electron

Dividing equation (i) by equation (ii), we get,

$\frac{\mu_l}{l} = \frac{-e\pi r^2}{T} \times \frac{T}{2\pi mr^2}$

$= \frac{-e}{2m}$

$\Rightarrow \mu_l = -\left(\frac{e}{2m}\right) l$

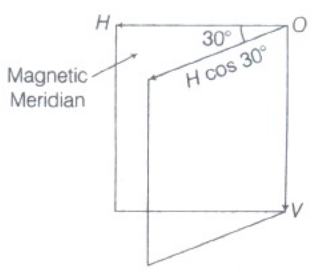
27) (ii) We can destroy the magnetism of a magnet

(a) by heating it.

(b) by applying magnetic field across it in reverse direction.

28) (i) W = -ME (cos θ - cos θ_0)

29) In a vertical plane at 30° from the magnetic meridian, the horizontal component is,



H' = H cos 30°

While vertical component is still V. Therefore, apparent dip will be given by tan $\theta' = \frac{V}{H'} = \frac{V}{H\cos 30^\circ}$

but $\frac{V}{H} = \tan\theta'$ (where, θ = true angle of dip)

$\therefore \quad \tan\theta' = \frac{\tan\theta}{\cos 30^\circ}$

$\therefore$ θ = tan $^{-1}$ [tan θ' cos 30°]

= tan^{-1} [(tan 45°)(cos 30°)] $\approx$ 41°

30) Given, current, I = 4A

Number of turns per unit length, n = 600

Relative permeability, μ_r = 5000

Since, magnetic intensity, H = nI = 600 x 4 = 2400Am^{-1}

Since, $\mu_r = 1 + X_m$

$\Rightarrow$ Xm = μ_r - 1

= 5000 -1 = 4999 $\approx$ 5000

Here, Xm = magnetic susceptibility.

Intensity of magnetisation can be given as

1 = X_mH = 5000 x 2400

= 1.2 x 10^7 Am^{-l}

Therefore, magnetic field, B = $\mu_r \mu_0$ H

= 5000 x (41t x 10^{-7}) x 2400

= 15T

31) (a) Here, H = I = 5000 x 2 = 10^4 A/m

and I = XH

$\therefore \chi = \frac{I}{H}$

$= \frac{2\times10^{-2}}{10^4} = 2 \times 10^{-6}$

(b) According to Curie law.

$x = \frac{c}{T}$

$\Rightarrow \quad \frac{\chi_2}{\chi_1} = \frac{T_2}{T_1}$

$\chi_2 = \frac{T_2}{T_1}\chi_1 = \frac{320}{300} \times 2 \times 10^{-6}$

= 2.13 x 10^{-6}

$\therefore$ Magnetisation at 320 K,

I = X_2H = 2.13 x 10^{-6} x 10^4

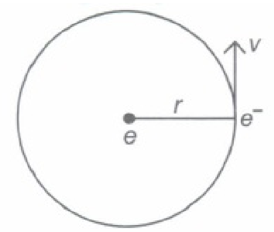
= 2.13 x 10^{-2}A/m

32)

Let v = speed of electron revolving around a neucleus (proton)

r = orbital radius.

According to the Bohr's second postulate,



$mvr = n\frac{h}{2\pi}$

$\therefore\ mvr = \frac{h}{2\pi}$ ($\because$ in ground state n = 1)

$\Rightarrow\ v = \frac{h}{2\pi mr}$ ....(i)

Therefore, the centripetal force for revolution of an electron is provided by the electrostatic force of attraction between nucleus (proton) and an electron.

$\therefore\ \frac{mv^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2} \Rightarrow v^2 = \frac{e^2}{4\pi\varepsilon_0 mr}$ ....(ii)

Using (i) and (ii), we get

$\frac{h^2}{4\pi^2m^2r^2} = \frac{e^2}{4\pi\varepsilon_0 mr}$

$\Rightarrow\ r = \frac{\varepsilon_0 h^2}{\pi me^2}$ ....(iii)

and $v = \frac{h}{2\pi m\frac{\varepsilon_0 h^2}{\pi me^2}} = \frac{e^2}{2\varepsilon_0 h}$ ....(iv)

$\therefore$ Magnetic field at the site of a point nucleus in a hydrogen atom due to the circular motion of the electron is given by

$B = \frac{\mu_0 i}{2r} = \frac{\mu_0}{2r}\cdot\frac{e}{T}$ ....(v)

$\because$ T = Time period of revolution of the electron

$T = \frac{\text{circumference}}{\text{speed}} \Rightarrow T = \frac{2\pi r}{v}$ ....(vi)

Using (iii) to (vi); we get

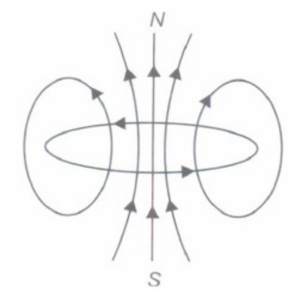
$B = \frac{\mu_0}{2r}\cdot\frac{ev}{2\pi r} = \frac{\mu_0 e\left(\frac{e^2}{2\varepsilon_0 h}\right)}{4\pi\left(\frac{\varepsilon_0 h^2}{\pi me^2}\right)^2} = \frac{\mu_0\pi m^2e^7}{8\varepsilon_0^3h^5}$

33)

(a) The magnetic field at any point on the axis of a circular current carrying loop is given by

$$B = \frac{\mu_0 I \pi R^2}{2\pi\left(x^2+R^2\right)^{3/2}}$$

where R is the radius of the loop and x is the distance of the point from the centre of the loop.



For $x >> R$,

$$B = \frac{\mu_0 IA}{2\pi x^3} \text{ or } \vec{B} = \frac{2\mu_0 \overrightarrow{IA}}{4\pi x^3} \quad ....(i)$$

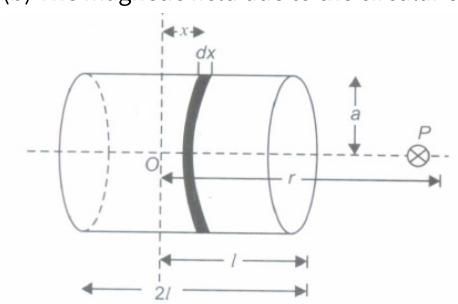
Magnetic field at point on the axis of a bar magnet is given by

$$\vec{B} = \frac{2\mu_0 m}{4\pi x^3} \quad ....(ii)$$

Comparing equations (i) and (ii), we get

$$\vec{m} = \overrightarrow{IA}$$

(b) The magnetic field due to the circular element of thickness dx.ofa solenoid at the distance x is given by



$$dB = \frac{\mu_0 n dx I a^2}{2\left[(r-x)^2+a^2\right]^{3/2}}$$

where a is the radius of loop, n is the number of turns per unit length of solenoid and r is the distance of point from the centre of a solenoid.

Now, the magnetic field due to whole solenoid is given by

$$B = \frac{\mu_0 n I a^2}{2} \int_{-l}^{1} \frac{dx}{\left[(r-x)^2+a^2\right]^{3/2}}$$

Considering $r \gg a$ and $r \gg> x$

$$\left[(r-x)^2+a^2\right]^{3/2} = r^3$$

$$\therefore\ B = \frac{\mu_0 n I a^2}{2r^3} \int_{-l}^{!} dx = \frac{\mu_0 n I}{2} \times \frac{2la^2}{r^3}$$

$$B = \frac{\mu_0 2M}{4\pi r^3} \quad \left[\because n(2l)I\left(\pi a^2\right) = M\right]$$

Same is the magnetic field due to a bar magnet at a point on axial line at a distance 'r'.