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CBSE

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2020-2010

Physics

CLASS XII

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Objective Questions

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Question Papers

CHAPTER 05

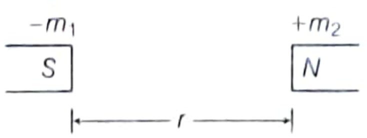
Magnetism and Matter

[TOPIC 1] Magnetic Dipole and Magnetic Field Lines

A magnet is a material or an object that produces a magnetic field. The magnetic field is invisible but is responsible for most notable property of magnet.

1.1 Force Between Two Magnetic Poles

Magnitude of force acting between two magnetic poles is given by



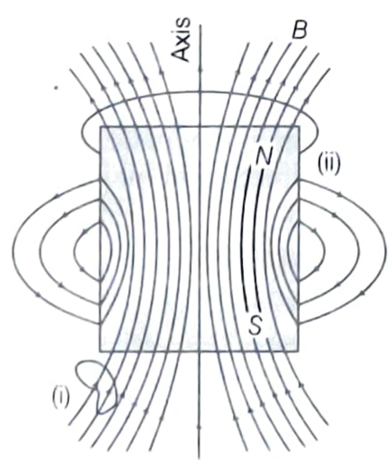
$$\mathbf{F} = k \frac{m_1 m_2}{r^2}$$

or $$\boxed{\mathbf{F} = \frac{\mu_0}{4\pi} \cdot \frac{m_1 m_2}{r^2}} \qquad \left[\because k = \frac{\mu_0}{4\pi}\right]$$

where, m_1 and m_2 are magnetic strength of poles and k is magnetic force constant. Its SI unit is A-m.

1.2 Magnetic Field Lines

These are imaginary lines which give pictorial representation for the magnetic field inside and around the magnet.



Their properties are given as below:

(i) These lines form continuous closed loops.

(ii) The tangent to the field line at a particular point gives the direction of the field at that point.

(iii) Larger the density of the lines, stronger will be the magnetic field.

(iv) These lines do **not** intersect one another.

1.3 Magnetic Dipole

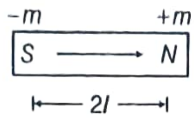
An arrangement of two equal and opposite magnetic poles separated by a small distance. e.g. A bar magnet.

Magnetic Dipole Moment (M)

It represents the strength of magnets. The magnetic dipole moment of a magnetic dipole is

given by $\boxed{\mathbf{M} = m \times 2l}$

where, m is pole strength and $2l$ is dipole length directed from S to N.



The SI unit of magnetic dipole moment is A-m^2 or J/T. It is a vector quantity and its direction is from South pole to North pole.

Magnetic field strength at a point due to a bar magnet at

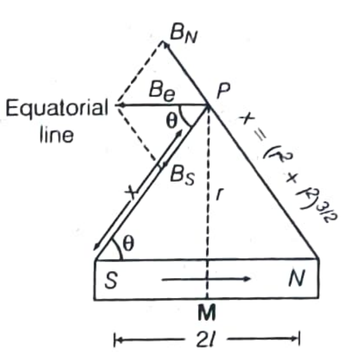
(i) **On axial line** (end-on-position)

$$\boxed{\mathbf{B}_a = \frac{\mu_0}{4\pi} \cdot \frac{2\mathbf{M}}{r^3}} \qquad (\because r >> l)$$

The direction of magnetic field is along the direction of magnetic dipole moment (M).

(ii) **On equatorial line** (broadside-on-position)

$$\boxed{\mathbf{B}_e = -\frac{\mu_0}{4\pi} \cdot \frac{\mathbf{M}}{r^3} = -\frac{\mu_0 \mathbf{M}}{4\pi r^3}}$$

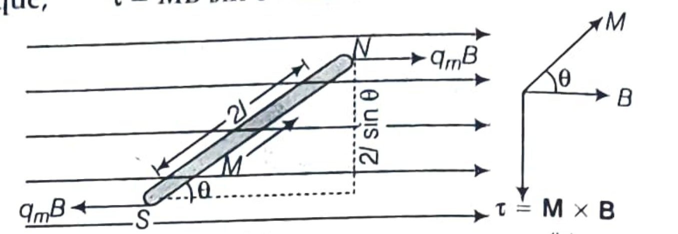


The direction of magnetic field is parallel to the magnetic dipole and opposite to the direction of dipole moment.

1.4 Torque on a Bar Magnet in a Uniform Magnetic Field

A uniform magnetic field **B** is represented by equidistant parallel lines, NS is a bar magnet of length $2l$ and strength of each pole is M.

Torque, $\tau = MB \sin\theta = \mathbf{M} \times \mathbf{B}$



(a) (b)

where, θ is the angle between **M** and **B**. Its SI unit is joule per tesla (JT^{-1}).

$\tau_{max} = MB$, when dipole is perpendicular to the field and $\tau = 0$, when dipole is parallel or anti-parallel to the field.

Potential Energy of a Magnet Dipole (Bar Magnet) in a Magnetic field

Potential energy of a magnetic dipole in a magnetic field is given by

$$\boxed{U = -MB\cos\theta = -\mathbf{M} \cdot \mathbf{B}}$$

where, θ is the angle between **M** and **B**.

Work done in rotating the dipole in a uniform magnetic field from θ_1 to θ_2 is given by

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

The direction of dipole moment can be obtained by right hand thumb rule. Its SI unit is A-m^2.

NOTE Current loop behaves like a magnetic dipole whose **dipole** moment is given by $M = IA$.

Oscillation of a Freely Suspended Magnet

The oscillations of a freely suspended magnet (magnetic dipole) in a uniform magnetic field are in SHM. The time period of oscillation,

$$\boxed{T = 2\pi\sqrt{I / MB}}$$

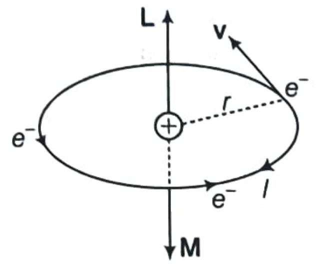
where, I = moment of inertia of the magnet,
M = magnetic moment
and B = magnetic field intensity.

1.5 Magnetic Dipole Moment

Magnetic dipole moment of a revolving electron is given by

$$M = \frac{evr}{2} \quad \text{or} \quad \boxed{M = \frac{e}{2m}L}$$

where, v is the speed of electron on a circular path of radius r. L is angular momentum and given as $L = mvr$.



Orbital magnetic moment of a revolving electron

1.6 Force Between two Magnetic Dipoles

Mutual force of interaction between two magnetic dipoles is given by

$$\boxed{F = \frac{\mu_0}{4\pi} \cdot \frac{6 M_1 M_2}{r^4}}$$

where, M_1 and M_2 are magnetic dipole moments of two different magnets.

Bar Magnet as an Equivalent Solenoid

The expression of magnetic field at distance r from centre is given by

$$\boxed{\mathbf{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\mathbf{M}}{r^3}}$$

This expression is equivalent to that of bar magnet.

1.7 The Electrostatic Analogue

The magnetic dipole is analogous to an electric dipole consisting of two equal charges of opposite sign ($\pm q$) seprated by a certain distance ($2\mathbf{a}$). It has an electric dipole moment

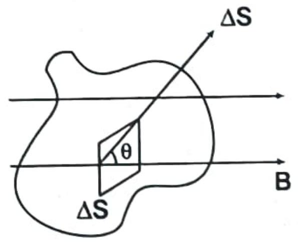
$$\boxed{\mathbf{p} = q(2\mathbf{a})}$$

The Dipole Analogy

Free Space Constant	Electrostatics ($1/\varepsilon_0$)	Magnetism (μ_0)
Dipole moment	$\mathbf{p}$	$\mathbf{M}$
Equatorial field for a short dipole	$-\mathbf{p}/4\pi\varepsilon_0 r^3$	$-\mu_0\mathbf{M}/4\pi r^3$
Axial field for a short dipole	$2\mathbf{p}/4\pi\varepsilon_0 r^3$	$\mu_0 2\mathbf{M}/4\pi r^3$
External field : Torque	$\mathbf{p} \times \mathbf{E}$	$\mathbf{M} \times \mathbf{B}$
External field : Energy	$-\mathbf{p} \cdot \mathbf{E}$	$-\mathbf{M} \cdot \mathbf{B}$

Magnetism and Gauss' Law

The net magnetic flux (ϕ_B) through any closed surface is always zero.



This law suggests that the number of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.

$$\boxed{\phi_B = \Sigma \mathbf{B} \cdot \Delta \mathbf{S} = 0 = \oint_S \mathbf{B} \cdot \Delta \mathbf{S} = 0}$$

PREVIOUS YEARS' EXAMINATION QUESTIONS

TOPIC 1

2 Marks Question

1. A small compass needle of magnetic moment M and moment of inertia I is free to oscillate in a magnetic field B. It is slightly disturbed from its equilibrium position and then released. Show that it executes simple harmonic motion. Hence, write the expression for its time period. **Delhi 2011C**

3 Marks Questions

2. Prove that the magnetic moment of the electron revolving around a nucleus in an orbit of radius r with orbital speed v is equal to $evr/2$. Hence using Bohr's postulate of quantisation of angular momentum, deduce the expression for the magnetic moment of hydrogen atom in the ground state. **All India 2019**

3. (a) State Gauss's law for magnetism. Explain its significance.
   (b) Write the four important properties of the magnetic field lines due to a bar magnet. **Delhi 2019**

4. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0.44 T. Calculate (a) the work done in turning the magnet to align its magnetic moment (i) normal to the magnetic field, (ii) opposite to the magnetic field and (b) the torque on the magnet in the final orientation in case (ii). **CBSE 2018**

Explanations

1. As the needle is displaced from the equilibrium position, the torque will try to bring it back in equilibrium position, hence acceleration will be related with negative of angular displacement.

When compass needle of magnetic moment M and moment of inertia I is slightly disturbed by an angle θ from the mean position of equilibrium.

Then, restoring torque begin to act on the needle which try to bring the needle back to its mean position which is given by

$$\tau = -MB\sin\theta$$

Since, θ is small

So, $\sin\theta \approx \theta$

$\therefore \quad \tau = -MB\theta \quad \ldots(i)$

But $\quad \tau = I\alpha \quad \ldots(ii)$

where, α = angular acceleration

and M = magnetic moment of dipole.

On comparing Eqs. (i) and (ii), we get

$\Rightarrow \quad I\alpha = -MB\theta$

$\Rightarrow \quad \alpha = -(MB/I)\theta$

$\therefore \quad \alpha \propto -\theta$ **(1)**

$\Rightarrow$ Angular acceleration $\propto$ – Angular displacement

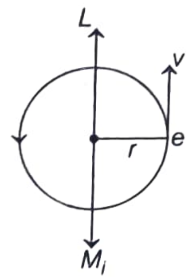
$\Rightarrow$ Therefore, needle execute SHM.

Hence, time period,

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{MB/I}} \quad \text{or} \quad T = 2\pi\sqrt{\frac{I}{MB}}$$ **(1)**

This is the required expression.

2. According to Bohr's model of atom, negatively charged electron revolves around the positively charged nucleus. This is same as that of a current loop of dipole moment = IA. Let the electron is moving in a circle with speed v in anti-clockwise direction of radius r and time period is T.



Current, $I = \frac{e}{T} = \frac{e}{2\pi r / v} = \frac{ev}{2\pi r}$ **(1)**

Area of loop $= \pi r^2$

$\therefore$ Orbital magnetic moment of electron is

$$M_l = IA = \frac{ev}{2\pi r} \times \pi r^2 = \frac{evr}{2}$$

The angular momentum of electron due to orbital motion is

$$L = m_e vr$$

It is directed upward in perpendicular direction to the plane.

$$\frac{M_l}{L} = \frac{evr/2}{m_e vr} = \frac{e}{2m_e}$$

This ratio is constant called gyromagnetic ratio. Its value is $8.8 \times 10^{10} \text{C kg}^{-1}$, so

$$M_l = \frac{e}{2m_e} L$$

The vector form

$$M_l = -\frac{e}{2m_e}\mathbf{L}$$ **(1)**

The negative sign shows that the direction of **L** is opposite to M_l. According to Bohr's quantisation condition, the angular momentum of an electron is an integral multiple of $\frac{h}{2\pi}$.

$$\therefore \quad L = \frac{nh}{2\pi}$$

$$\Rightarrow \quad M_l = n\left(\frac{eh}{4\pi m_e}\right)$$

This is the equation of magnetic moment of an electron revolving in nth orbit. **(1)**

3. (a) Refer to text on page 163 (Magnetism and Gauss' Law). **(1/2)**

(b) Refer to text on page 161 (Properties of Magnetic Field Lines). **(1/2)**

4. (a) Given, magnetic moment, $M = 6$ J/T

Aligned angle, $\theta_1 = 60°$

External magnetic field,

$$B = 0.44 \text{ T}$$

(i) When the bar magnet is align normal to the magnetic field, i.e. $\theta_2 = 90°$

$\therefore$ Amount of work done in turning the magnet,

$$W = -MB(\cos\theta_2 - \cos\theta_1)$$
$$= -6 \times 0.44(\cos 90° - \cos 60°)$$
$$= +6 \times 0.44 \times \frac{1}{2} \quad \left(\because \cos 90° = 0 \text{ and } \cos 60° = 1/2\right)$$
$$= 1.32 \text{ J}$$ **(1)**

(ii) When the bar magnet align opposite to the magnetic field, i.e. $\theta_2 = 180°$

$$\therefore W = -MB(\cos 180° - \cos 60°)$$
$$= -6 \times 0.44\left(-1 - \frac{1}{2}\right) \quad (\because \cos 180° = -1)$$
$$= 6 \times 0.44 \times \frac{3}{2}$$
$$= 3.96 \text{ J}$$ **(1)**

(b) We know that, torque,

$$\tau = \mathbf{M} \times \mathbf{B} = MB\sin\theta$$

For case (ii), $\theta = 180°$

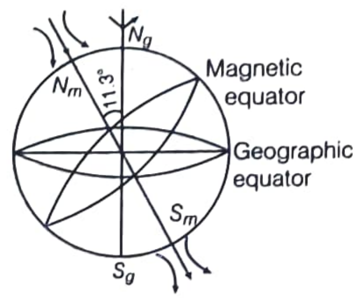
$$\therefore \quad \tau = MB\sin 180° \quad (\because \sin 180° = 0)$$
$$= 0$$

$\therefore$ Amount of torque is zero for case (ii). **(1)**

[TOPIC 2] Earth's Magnetism and Magnetic Properties of Materials

2.1 Earth as a Magnet

Earth behaves like a magnet whose North pole is somewhere close to geographical South pole and magnetic South pole is closed to geographical North pole.



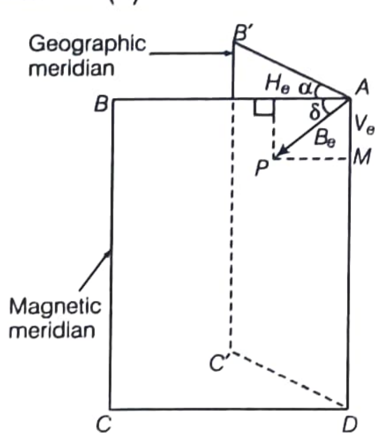
In outer core of the earth iron, nickel and small quantities of other metals are present in molten form and flow in a defined path. This flow of liquid iron and other metals generate electric currents, which in turn produce magnetic fields.

2.2 Magnetic Elements

There are three elements of the earth's magnetic field namely

(i) The angle between geographical meridian and magnetic meridian at a place is known as **angle of declination** (α).

(ii) **Magnetic Inclination or Dip** In magnetic meridian, the angle made by direction of the earth's total magnetic field (B_e) with the horizontal is known as dip (δ).



(iii) **Horizontal Component of the Earth's Magnetic Field** It is the component of the earth's total magnetic field along the horizontal direction.

$$H_e = B_e \cos \delta$$

- Relationship between horizontal and vertical components of the earth's magnetic field and angle of dip is given by

$$H_e = B_e \cos \delta$$

and $$V_e = B_e \sin \delta$$

$\therefore$ $$V_e / H_e = \tan \delta$$

Various Terms Related to Magnetism

Magnetic Intensity (H)

The capability of magnetic field to magnetise the substance is measured in terms of magnetic intensity of the field.

$$\boxed{\mathbf{B} = \frac{\mathbf{B}_0}{\mu_0}}$$

where, B_0 = magnetic field inside vacuum and $\mu_0 = 4\pi \times 10^{-7}$ T-mA^{-1}.

Its SI unit is A m^{-1}.

Intensity of Magnetisation (I)

The magnetic dipole moment induced per unit volume in the magnetic material due to magnetising field is known as intensity of magnetisation.

$$\boxed{\mathbf{I} = \mathbf{M}/V = m/A}$$

where, M = induced magnetic dipole moment,
m = pole strength,
V = volume of specimen
and A = cross-sectional area.

Magnetic Permeability (μ)

It is equal to the ratio of magnetic induction to intensity of magnetising field.

$$\boxed{\mu = \frac{\mathbf{B}}{\mathbf{H}}}$$

Magnetic Susceptibility (χ_m) It is equal to the ratio of intensity of magnetisation and magnetising field

$$\boxed{\chi_m = \frac{\mathbf{I}}{\mathbf{H}}}$$

It has no unit. It is a scalar quantity.

Magnetic Induction (B)

It is defined as the total number of magnetic lines of force crossing per unit area through the magnetic material.

$$\boxed{B = \mu_0 (H + I) = \mu_0 H(1 + \chi_m)}$$

where, μ_0 = permeability of free space,
H = magnetising field
and I = intensity of magnetisation.

The SI unit of magnetic induction is Tesla(T) or Wbm^{-2} which is equivalent to $Nm^{-1}A^{-1}$ or $JA^{-1}m^{-2}$.

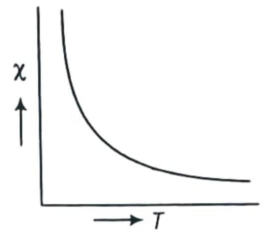
2.3 Classification of Magnetic substance

On the basis of mutual interactions or their behaviours, *the magnetic materials placed in a uniform magnetic field are classified into three parts*

(i) Paramagnetic substance
(ii) Diamagnetic substance
(iii) Ferromagnetic substance

Property	Paramagnetic substance	Diamagnetic substance	Ferromagnetic substance
When placed in a uniform magnetic field	Feebly magnetise along applied field	Feebly magnetise opposite to magnetic field or repelled by magnets	Strongly magnetise along magnetic field
Susceptibility (χ_m)	Small and positive $0 < \chi_m < \varepsilon$, ε = small number	Small and negative $-1 < \chi_m < 0$	Very large $\chi_m > 1000$
Relative permeability	$1 < \mu_r < 1 + \varepsilon$ ε = small number	Positive and less than one $0 < \mu_r < 1$	Large value $\mu_r > 1000$
Effect of temperature	$\chi_m \propto \frac{1}{T}$	Independent with temperature	$\chi_m \propto \frac{1}{T - T_C} (T > T_C)$
Variation of I with H	Linearly change	Linear change and saturable low temperature	Non-linear change and ultimately attains saturation
In a non-uniform magnetic field	Tends to move from weaker to stronger magnetic field	Tends to move from stronger to weaker magnetic field	Tends to move quickly from weaker to stronger magnetic field
Examples	Pb, H_2O, NaCl, Bi, Cu, Si, Sb	Na, Ca, O_2, $CuCl_2$, Al	Ni, Co, Fe, Fe_2O_3, Gd

Curie Law



It states that the magnetic susceptibility of paramagnetic substances is inversely proportional to the absolute temperature, i.e.

$$\chi \propto 1/T$$

For paramagnetic material,

$$\boxed{\chi = C/T} \quad [C = \text{Curie constant}]$$

Curie Temperature

With the rise of temperature, susceptibility of ferromagnetic materials decreases. At a certain temperature, ferromagnetic pass over to paramagnetic. This transition temperature called Curie temperature.

Curie-Weiss Law

This describes the magnetic susceptibility χ_m of a ferromagnet in the paramagnetic region above the Curie point. It is expressed as

$$\boxed{\chi_m = C/(T - T_C)} \qquad [\because T > T_C]$$

where, C is called Curie's constant. T is an absolute temperature in kelvin and T_C is Curie temperature.

2.4 Permanent Magnets and Electromagnets

The substances which are at room temperature retain their ferromagnetic property for a long period of time are called **permanent magnet**. Permanent magnet can be made by placing a rod of ferromagnetic material in a current carrying solenoid. The magnetic field of the solenoid magnetises the rod.

The material used for making permanent magnet should have high retentivity, so that the magnetisation is strong and high coercivity so that the magnetisation is not erased by stray magnetic field/temperature fluctuations or minor mechanical damage. Steel is favoured for making permanent magnet.

- Steel possesses high coercivity, hysteresis loss, moderate permeability, susceptibility and high retentivity, therefore it is fit for making permanent magnet.
- On placing a soft iron rod in a current carring solenoid the magnetism of the solenoid increases by thousands folds. On switching off the current flowing through solenoid the magnetism is effectively switched off. It is because the soft iron core has a low retentivity. Some suitable materials for making permanent magnets are alnico, cobalt, steel and ticonal.
- Soft iron possesses high permeability, susceptibility and low retentivity and low coercivity and low hysteresis loss, therefore it is fit for making **electromagnet.**

PREVIOUS YEARS' EXAMINATION QUESTIONS TOPIC 2

1 Mark Questions

1. The magnetic susceptibility of magnesium at 300K is 1.2×10^5. At what temperature will its magnetic susceptibility become 1.44×10^5?
   All India 2019
2. The magnetic susceptibility of χ of a given material is -0.5. Identify the magnetic material. **All India 2019**
3. At a place, the horizontal component of earth's magnetic field is **B** and angle of dip is 60°. What is the value of horizontal component of the earth's magnetic field at equator? **Delhi 2017**
4. In what way is the behaviour of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field? **All India 2016**
5. Relative permeability of a material $\mu_r = 0.5$. Identify the nature of the magnetic material and write its relation of magnetic susceptibility. **Delhi 2014**
6. What are permanent magnets? Give one example. **Delhi 2013**
7. Where on the surface of earth is the vertical component of earth's magnetic field zero? **Delhi 2013C; All India 2011**
8. The horizontal component of the earth's magnetic field at a place is B and angle of dip is 60°. What is the value of vertical component of the earth's magnetic field? **Delhi 2012**

9. What is the angle of dip at a place where the horizontal and vertical components of the earth's magnetic field are equal? **Foreign 2012**

10. A magnetic needle free to rotate in a vertical plane orients itself vertically at a certain place on the earth. What are the values of

(i) horizontal component of the earth's magnetic field and

(ii) angle of dip at this place? **Foreign 2012**

11. Where on the surface of earth is the angle of dip 90°? **All India 2011**

12. The permeability of a magnetic material is 0.9983. Name the type of magnetic material, it represents. **Delhi 2011**

13. The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic material, it represents. **Delhi 2011**

14. The susceptibility of a magnetic material is -4.2×10^{-6}. Name the type of magnetic material, it represents. **Delhi 2011**

15. What is the characteristic property of a diamagnetic material? **Foreign 2010**

2 Marks Questions

16. (i) Define the term magnetic susceptibility and write its relation in terms of relative magnetic permeability.

(ii) Two magnetic materials A and B have relative magnetic permeabilities of 0.96 and 500. Identify the magnetic materials A and B. **CBSE 2018C**

17. Show diagrammatically the behaviour of magnetic field lines in the presence of

(i) paramagnetic and

(ii) diamagnetic substances.

How does one explain this distinguishing feature? **All India 2014**

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

19. Give two points to distinguish between a paramagnetic and diamagnetic substance. **Delhi 2014C**

20. (i) How is an electromagnet different from a permanent magnet?

(ii) Write two properties of a material which makes it suitable for making electromagnet. **All India 2014C**

21. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties. **Delhi 2012**

22. (i) How does a diamagnetic material behave when it is cooled at very low temperature?

(ii) Why does a paramagnetic sample display greater magnetisation when cooled? Explain. **Delhi 2012**

23. Explain the following.

(i) Why do magnetic lines of force form continuous closed loops?

(ii) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field? **Foreign 2011**

24. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its North tip down at 60° with the horizontal. The horizontal component of the earth's magnetic field at the place is known to be 0.4 G. Determine the magnitude of the earth's magnetic field at the place. **Delhi 2011**

25. (i) Name the three elements of the Earth's magnetic field.

(ii) Where on the surface of the Earth is the vertical component of the Earth's magnetic field zero? **Foreign 2011**

26. Distinguish between diamagnetic and ferromagnetic materials in terms of

(i) susceptibility and

(ii) their behaviour in a non-uniform magnetic field. **All India 2011**

27. (i) Write two characteristics of a material used for making permanent magnets?

(ii) Why is core of an electromagnet made of ferromagnetic materials? **Delhi 2010**

28. The horizontal component of the earth's magnetic field at a place is $\sqrt{3}$ times its vertical component there. Find the value of the angle of dip at that place. What is the ratio of the horizontal component to the total magnetic field of the earth at that place? **All India 2010C**

29. The horizontal component of the earth's magnetic field at a place equals to its vertical component there. Find the value of the angle of dip at that place.

What is the ratio of the horizontal component to the total magnetic field of the earth at that place? **All India 2010C**

30. Draw magnetic field lines when a (i) diamagnetic, (ii) paramagnetic substance is placed in an external magnetic field. Which magnetic property distinguishes this behaviour of the field lines due to the two substances? **Delhi 2010**

3 Marks Questions

31. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each. **Delhi 2019**

32. The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **CBSE 2018**

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

34. Three identical specimens of a magnetic materials nickel, antimony and aluminium are kept in a non-uniform magnetic field. Draw the modification in the field lines in each case. Justify your answer. **Delhi 2011**

5 Marks Question

35. (i) A small compass needle of magnetic moment M is free to turn about an axis perpendicular to the direction of uniform magnetic field B. The moment of inertia of the needle about the axis is I. The needle is slightly disturbed from its stable position and then released. Prove that it executes simple harmonic motion. Hence, deduce the expression for its time period.

(ii) A compass needle free to turn in a vertical plane orients itself with its axis vertical at a certain place on the earth. Find out the values of

(a) horizontal component of the earth's magnetic field and

(b) angle of dip at the place.

Delhi 2013

Explanations

1. The susceptibility of magnetic material is inversely proportional to temperature, i.e.

$$\chi_m \propto \frac{1}{T}$$

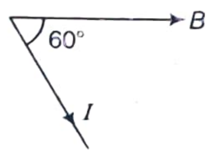
$$\therefore \quad \frac{\chi_m(T)}{\chi_m\ (300\ \text{K})} = \frac{300}{T}$$

$$\Rightarrow \quad T = \frac{300 \times 1.2 \times 10^5}{1.44 \times 10^5}$$

$$= 250\ \text{K}$$ **(1)**

2. Substance having (small) negative value (–0.5) of magnetic susceptibility χ_m are diamagnetic. **(1)**

3.



I is the total magnetic field.

Now, $I \cos 60° = B$

$$\Rightarrow \quad I = \frac{B}{\cos 60^\circ} = \frac{B}{1/2} = 2B$$

At equator, dip angle is 0°.

$\therefore \quad B_H = I \cos 0^\circ = I = 2B.$ **(1)**

4. When paramagnetic materials are placed in external magnetic field, these are feebly magnetised in the direction of the applied external magnetic field whereas in case of diamagnetic materials, these are feebly magnetised opposite to that of applied external magnetic field. **(1)**

5. The nature of magnetic material is a diamagnetic. The relation between relative permeability and magnetic susceptibility is

$$\mu_r = 1 + \chi_m \quad \textbf{(1)}$$

6. Permanent magnets are those magnets which have high retentivity and coercivity. The magnetisation of permanent magnet is not easily destroyed even if it is handled roughly or exposed in stray reverse magnetic field, e.g. steel. **(1)**

7. At equator, vertical component of earth's magnetic field will be zero. **(1)**

8. Horizontal component of earth's magnetic field,

$$H = B_e \cos 60^\circ = B \quad \text{(given)}$$

$$\Rightarrow \quad B_e \times \frac{1}{2} = B \quad \text{or} \quad B_e = 2B$$

Vertical component of earth's magnetic field,

$$V = B_e \sin 60^\circ \Rightarrow V = 2B \times (\sqrt{3}/2)$$

$$\Rightarrow \quad V = \sqrt{3}B \quad \textbf{(1)}$$

9. The angle of dip is given by

$$\delta = \tan^{-1}(B_V/B_H)$$

B_V = vertical component of the earth's magnetic field.

B_H = horizontal component of the earth's magnetic field.

So, as $\quad B_V = B_H$

Then, $\quad \delta = \tan^{-1}(1) = 45^\circ$

$\therefore$ The angle of dip will be $\delta = 45^\circ$. **(1)**

10. (i) The needle is free to move in vertical plane, it means that there is no component of the earth's magnetic field in horizontal direction, so the horizontal component of the earth's magnetic field is zero. **(1/2)**

(ii) The angle of dip is 0°. **(1/2)**

11. At poles, the angle of dip is 90°. **(1)**

12. The magnetic material is diamagnetic substance for which $\mu_r < 1$. **(1)**

13. The small and positive susceptibility of 1.9×10^{-5} represents paramagnetic substance. **(1)**

14. Negative susceptibility represents diamagnetic substance. **(1)**

15. Diamagnetic material acquires feeble magnetisation in the opposite direction of the magnetic field when they are placed in an external magnetic field. **(1)**

16. (i) The magnetic susceptibility of a magnetic material is defined as the ratio of the intensity of magnetisation (I) to the magnetic intensity (H).

i.e., $\quad \chi_m = \dfrac{I}{H}$

Relation between magnetic susceptibility (χ_m) and relative magnetic permeability (μ_r) is given as **(1)**

$$\mu_r = 1 + \chi_\mu$$

(ii) For material $A, \mu_r = 0.96 < 1$

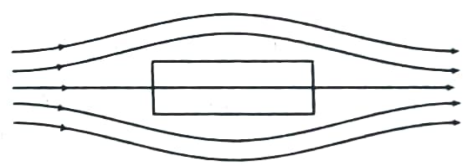
Hence, magnetic materia $1A$ is diamagnetic.

For material $B, \mu_r = 500$

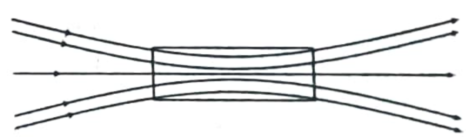
Since, μ_r is much greater than1 for material B, therefore B is ferromagnetic material. **(1)**

17. Magnetic permeability of paramagnetic is more than air, so it allows more lines to pass through it while permeability of diamagnetic is less than air, so it does not allow lines to pass through it.

(i) Behaviour of magnetic field lines when diamagnetic substance is placed in an external field.



(ii) Behaviour of magnetic field lines when paramagnetic substance is placed in a external field.



Magnetic susceptibility distinguishes the behaviour of the field lines due to diamagnetic and paramagnetic substance. **(1)**

This difference can be explained as diamagnetic substances repel or expel the magnetic field lines while paramagnetic substance attract the magnetic field lines. **(1)**

18. The nature of the material A is paramagnetic and its susceptibility χ_m is positive.

The nature of the material B is diamagnetic and its susceptibility χ_m is negative. **(2)**

19.

Paramagnetic substance	Diamagnetic substance
A paramagnetic substance is feebly attracted by magnet.	A diamagnetic substance is feebly repelled by a magnet.
For a paramagnetic substance, the intensity of magnetisation has a small positive value.	For a diamagnetic substance, the intensity of magnetism has a small negative value. **(2)**

20. (i) An electromagnet consist of a core made of a ferromagnetic material placed inside a solenoid. It behaves like a strong magnet when current flows through the solenoid and effectively loses its magnetism when the current is switched off.

A permanent magnet is also made up of a ferromagnetic material but it retains its magnetism at room temperature for a long time after being magnetised one. **(1)**

(ii) *Properties of material are as below:*

(a) High permeability (c) Low retentivity

(b) Low coercivity **(1)**

21. Ferromagnetic substance are those substances which have very high magnetic permeability. **(1)**

Properties (i) High retentivity

(ii) High susceptibility $(\chi_m > 1000)$ **(2 × 1/2)**

22. (i) For diamagnetic substances, the variation of susceptibility is very small $(0 < \chi_m < \epsilon)$, i.e. diamagnetic materials are unaffected by the change in temperature (except bismuth). **(1)**

(ii) Paramagnetic materials when cooled due to thermal agitation tendency alignment of magnetic dipoles decreases. Hence, they shows greater magnetisation. **(1)**

23. (i) Magnetic lines of force come out from North pole and enter into the South pole outside the magnet and travels from South pole to North pole inside the magnet. So, magnetic lines of force form closed loop, magnetic monopoles do not exist. **(1)**

(ii) The diamagnetic material gets slightly magnetised in a direction opposite to external field, therefore lines of force are repelled by diamagnetic material. **(1)**

NOTE When South pole of the magnet is viewed from the frame of reference, then inside the magnet, it appears as North pole and *vice-versa*. Due to this reason, magnetic field lines are traversed from South pole to North pole inside the magnet.

24. Angle of dip, $\delta = 60° = \pi/3$

Horizontal component of the earth's magnetic field, $H = 0.4$ G

Earth magnetic field $(B_e) = ?$

$\because$ Horizontal component of the earth's magnetic field, $H = B_e \cos\delta$ **(1)**

$$\Rightarrow \quad B_e = \frac{H}{\cos\delta} = \frac{0.4\text{ G}}{\cos 60°} = \frac{0.4\text{ G}}{(1/2)} = 0.8\text{ G}$$

$\therefore \quad B_e = 0.8$ G **(1)**

25. (i) The earth's magnetic field at a place can be completely described by three parameters which are called elements of earth's magnetic field. They are as follows **(1)**

(a) Angle of declination (θ)

(b) Angle of dip (δ) or magnetic inclination

(c) Horizontal component of earth's magnetic field (H_e)

(ii) At the magnetic equator, the dip needle rests horizontally, so that the angle of dip is zero at the magnetic equator. **(1)**

26. (i) **Susceptibility for diamagnetic material** It is independent of magnetic field and temperature (except for bismuth at low temperature). **(1)**

Susceptibility for ferromagnetic material The susceptibility of ferromagnetic materials decreases steadily with increase in temperature. At the Curie temperature, the ferromagnetic materials become paramagnetic.

(ii) **Behaviour in non-uniform magnetic field** Diamagnets are feebly repelled, whereas ferromagnets are strongly attracted by non-uniform field, i.e. diamagnets move in the direction of decreasing field, whereas ferromagnet feels force in the direction of increasing field intensity. **(1)**

27. (i) Two characteristics of material used for making permanent magnets are

(a) high coercivity

(b) high retentivity and high hysteresis loss. **(2 × 1/2)**

(ii) Core of an electromagnet made of ferromagnetic material because of its

(a) low coercivity

(b) low hysteresis loss **(2 × 1/2)**

28. According to the question, $H = \sqrt{3}V$

where, H and V are the horizontal and vertical components of the earth's magnetic field.

If angle of dip at that place is δ, then

$$\tan\delta = (V/H) = (V/\sqrt{3}V) \quad [\because H = \sqrt{3}V]$$

$$\tan\delta = \frac{1}{\sqrt{3}} \Rightarrow \delta = \frac{\pi}{6}$$ **(1)**

$\because$ Horizontal component of the earth's magnetic field, $H = B_e \cos\delta$

where, B_e = Earth's magnetic field

$$\frac{H}{B_e} = \cos\delta = \cos\frac{\pi}{6} = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \quad H : B_e = \sqrt{3} : 2$$ **(1)**

29. Refer to Sol. 28 on page 173 (Ans. $1 : \sqrt{2}$). **(2)**

30. (i) Refer to Sol. 17 on pages 171 and 172.

(ii) Refer to Sol. 17 on pages 171 and 172. **(1)**

Magnetic susceptibility distinguishes the behaviour of the field lines due to diamagnetic and paramagnetic substance. **(1)**

31. Difference between para-, dia- and ferro-magnetic materials

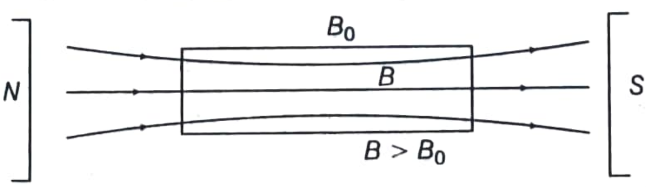
Refer to text on page 167.

32. Given, susceptibility, $\chi_m = 0.9853$

As the susceptibility of material is positive but small.

$\therefore$ The material is paramagnetic in nature. For paramagnetic material, magnetic lines of external magnetic field will passes through the material without much deviation, when it is placed in between magnetic poles.

The modification of the field pattern is shown in the following figure.



(3)

33. $\because$ Horizontal component,

$$H = B\cos\theta = 0.4\cos 60^\circ = 0.4 \times (1/2) = 0.2\,G$$

$$H = 0.2 \times 10^{-4}\ T \quad [\because \cos 60^\circ = 1/2]$$

This component is parallel to the plane of wheel. The wheel is rotating in a plane normal to the horizontal component, so it will cut the horizontal component only, vertical component of earth will contribute nothing in emf. **(1)**

Thus, the emf induced is given as

$$E = \frac{1}{2}Hl^2\omega$$

where, $\omega = 2\pi N/t$ and

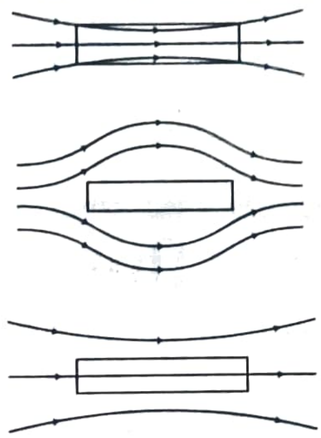
l = length of the spoke = 50 cm = 0.5 m

$$\therefore \quad E = \frac{1}{2} \times 0.2 \times 10^{-4} \times (0.5)^2 \times \frac{2 \times 3.14 \times 120}{60}$$

$$E = 3.14 \times 10^{-5}\ V$$ **(1)**

The value of emf induced is independent of the number of spokes as the emf's across the spokes are in parallel. So, the emf will be unaffected with the increase in spokes. **(1)**

34. The modifications are shown in the figure.



(½ × 3 = ½)

It happens because

(i) nickel is a ferromagnetic substance.

(ii) antimony is a diamagnetic substance.

(iii) aluminium is a paramagnetic substance.

(½ × 3 = 1 ½)

35. The torque always tries to bring back the needle in equilibrium position i.e. parallel to the existing field.

(i) The torque on the needle is $\tau = M \times B$

In magnitude, $\tau = MB\sin\theta$

Here, τ is restoring torque and θ is the angle between M and B.

Therefore, in equilibrium,

Restoring force = Deflecting torque

$$I\frac{d^2\theta}{dt^2} = -MB\sin\theta$$ **(1)**

Negative sign with $MB\sin\theta$ implies that restoring torque is in opposition to deflecting torque.

For small values of θ in radians, we approximate $\sin\theta = \theta$ and get

$$I\frac{d^2\theta}{dt^2} = -MB\theta \Rightarrow \frac{d^2\theta}{dt^2} = -\frac{MB}{I}\theta$$

$$\Rightarrow \quad d^2\theta/dt^2 = -\omega^2\theta$$ **(1)**

This equation represents a simple harmonic motion. The square of the angular frequency is

$$\omega^2 = MB/I$$

i.e. $\omega^2 = MB/I$ or $\omega = \sqrt{MB/I}$

Time period, $T = 2\pi/\omega = 2\pi\sqrt{I/MB}$ **(1)**

(ii) (a) As, horizontal component of earth's magnetic field, $B_H = B\cos\delta$

Putting $\delta = 90^\circ$ (as compass needle orients itself vertically)

$\therefore \quad B_H = 0$

(b) For a compass needle oriented itself with its axis vertical at a certain place, angle of dip, $\delta = 90^\circ$. **(2)**

Objective Questions

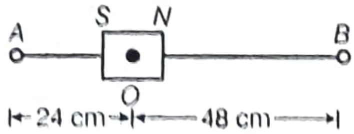
(For Complete Chapter)

1 Mark Questions

1. A magnetic wire of dipole moment 4π Am^2 is bent in the form of semicircle. The new magnetic moment is

(a) 4π Am^2 (b) 8π Am^2
(c) 4 Am^2 (d) None of these

2. A bar magnet of length 3 cm has points A and B along its axis at distances of 24 cm and 48 cm on the opposite sides. Ratio of magnetic fields at these points will be



(a) 8 (b) $1/2\sqrt{2}$ (c) 3 (d) 4

3. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.16 T experiences a torque of magnitude 0.032 J. The magnetic moment of the bar magnet will be

(a) 0.23 JT^{-1} (b) 0.40 JT^{-1}
(c) 0.80 JT^{-1} (d) zero

4. A bar magnet is placed in the position of stable equilibrium in a uniform magnetic field of induction B. If it is rotated through an angle 180°, then the work is (M = magnetic dipole moment of bar magnet)

(a) MB (b) $2MB$ (c) $\frac{MB}{2}$ (d) zero

5. A long magnet is cut into two equal parts such that the length of each half is same as that of original magnet. If the period of original magnet is T, then the period of new magnet is

(a) T (b) $\frac{T}{2}$ (c) $\frac{T}{4}$ (d) $2T$

6. At the magnetic pole of earth, the value of angle of dip is

(a) 0° (b) 30° (c) 45° (d) 90°

7. At a given place on the earth, the angle between the magnetic meridian and the geographic meridian is called

(a) magnetic longitude
(b) magnetic declination
(c) magnetic latitude
(d) magnetic dip

8. The angle of dip at a place on the earth gives

(a) the horizontal component of the earth's magnetic field
(b) the location of geographic meridian
(c) the vertical component of the earth's field
(d) the direction of the earth's magnetic field

9. The intensity of magnetisation of a bar magnet is 5.0×10^4 Am^{-1}. The magnetic length and the area of cross-section of the magnet are 12 cm and 1 cm^2, respectively. The magnitude of magnetic moment of this bar magnet (in SI unit) is

(a) 0.6 (b) 1.3 (c) 1.24 (d) 2.4

10. Relative permeability of iron is 5500, then its magnetic susceptibility will be

(a) 5500×10^7 (b) 5500×10^{-7}
(c) 5501 (d) 5499

11. Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show

(a) paramagnetism
(b) anti-ferromagnetism
(c) no magnetic property
(d) diamagnetism

12. Ferromagnetic materials used in a transformer must have
    (a) low permeability and high hysteresis loss
    (b) high permeability and low hysteresis loss
    (c) high permeability and high hysteresis loss
    (d) low permeability and low hysteresis loss

13. Permanent magnet has properties retentivity and coercivity respectively
    (a) high-high (b) low-low
    (c) low-high (d) high-low

Explanations

1. *(d)* If length of wire is $2l$, then magnetic moment
$$M = m \times 2l = 4\pi \text{ A-m}^2 \quad \text{(given)}$$
As wire is bent in the form of semicircle effective distance between the ends is $2r$.
So, new dipole moment $M' = m \times 2r$
As $\pi r = 2l, r = \frac{2l}{\pi}$
So, $M' = m \times 2 \times \frac{2l}{\pi} = \frac{2}{\pi}(m \times 2l)$
$$= \frac{2}{\pi} M = \frac{2}{\pi} 4\pi = 8 \text{ Am}^2$$

2. *(a)* Magnetic field due to a bar magnet at a distance r from the centre of magnet on axial position,
$$B = \frac{\mu_0}{4\pi} \cdot \frac{2M}{r^3}$$
$$\Rightarrow \quad \frac{B_1}{B_2} = \left(\frac{r_2}{r_1}\right)^3 = \left(\frac{48}{24}\right)^3 = 8$$

3. *(b)* Magnetic moment,
$$M = \frac{\tau}{B\sin\theta} = \frac{0.032}{0.16 \times \sin 30^\circ} = 0.40 \text{ JT}^{-1}$$

4. *(b)* We know that, $W = MB(\cos\theta_1 - \cos\theta_2)$
As $\theta_1 = 0^\circ$ and $\theta_2 = 180^\circ$
Then, $W = MB(\cos 0^\circ - \cos 180^\circ) = 2\,MB$

5. *(a)* Time period $T = 2\pi\sqrt{\frac{I}{MB}}$
As the magnet is cut into two equal parts along axis, then for each part $I' = \frac{I}{2}$, $M' = \frac{M}{2}$
$\therefore$ Time period of new magnet,
$$T' = \sqrt{\frac{I'}{M'B}} = \sqrt{\frac{I \times 2}{2 \times M \times B}} \Rightarrow T' = T$$

6. *(d)* At earth's magnetic poles, the angle of dip is 90°.

7. *(b)* The angle between the magnetic meridian and the geographic meridian is called magnetic declination.

8. *(d)* The angle of dip at a place on the earth gives the direction of the earth's magnetic field.

9. *(a)* We know that
Intensity of magnetisation $I = \frac{M}{V}$
where, M = magnetic moment and V = volume.
So, $M = IV$
$$= 5.0 \times 10^4 \times \frac{12}{100} \times \frac{1}{(100)^2}$$
$$= 60 \times 10^4 \times 10^{-6} = 0.6 \text{ Am}^2$$

10. *(d)* As we know that, $\mu_r = 1 + \chi_m$
$$\Rightarrow \quad 5500 = 1 + \chi_m$$
$$\Rightarrow \quad \chi_m = 5500 - 1 = 5499$$

11. *(a)* Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show a paramagnetism.

12. *(b)* Ferromagnetic materials used for transformers must have high permeability and low hysteresis loss.

13. *(a)* The materials for a permanent magnet should have high retentivity (so that the magnet is strong) and high coercivity (so that the magnetism is not wiped out by stray magnetic fields). As the material in this case is never put to cyclic changes of magnetisation, hence hysteresis is immaterial.