

CHAPTER 05

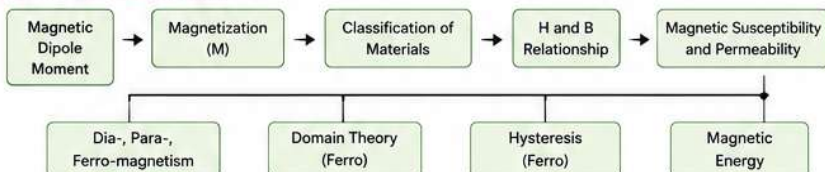
MAGNETISM AND MATTER

CBSE CLASS 12 PHYSICS – CHAPTER GIST

1 CHAPTER CORE IDEA

Magnetic behavior of materials arises from intrinsic atomic moments and their response to external magnetic field.

2 CONCEPT FLOW MAP



3 KEY LAWS & PRINCIPLES



Magnetic Dipole Moment (m)

A current loop acts as a magnetic dipole. Its strength and direction are given by the right hand rule.



Magnetization (M)

Magnetic dipole moment per unit volume of a material. It represents the overall magnetic strength of the material.



Magnetic Field (B) and Magnetizing Field (H)

B is the total magnetic field inside a material. H is the magnetizing field produced by free currents.



Magnetic Susceptibility (χ)

Measure of how much a material gets magnetized in an external field.



Permeability (μ)

Measure of ability of a material to allow the formation of magnetic field within it.



Domain Theory (Ferromagnetism)

Ferromagnetic materials consist of domains. Magnetization occurs due to alignment of domains in an external field.



Hysteresis

Lag of B behind H in a ferromagnetic material when magnetizing field is cycled. Shows retentivity and coercivity.

4 ESSENTIAL FORMULA BANK

- Magnetic dipole moment of a current loop:

$$m = NIA$$

N = number of turns
 I = current, A = area

- Magnetization:

$$M = \frac{m}{V}$$

m = magnetic dipole moment
 V = volume

- Relation between B and M:

$$B = \mu_0(H + M)$$

μ_0 = permeability of free space

- Magnetic susceptibility:

$$\chi_m = \frac{M}{H}$$

Dimensionless

- Relative permeability:

$$\mu_r = 1 + \chi_m$$

- Permeability of material:

$$\mu = \mu_0 \mu_r$$

- For linear, isotropic material:

$$B = \mu H$$

- Energy density in magnetic field:

$$u = \frac{1}{2} B \cdot H = \frac{1}{2} \mu H^2 \quad u = \text{energy per unit volume}$$

5 CLASSIFICATION OF MAGNETIC MATERIALS

Diamagnetic

- Weakly repelled by magnetic field
- χ_m is small and negative
- $\mu_r < 1$ (slightly less than 1)
- Ex: Bismuth, Copper, Water

Paramagnetic

- Weakly attracted by magnetic field
- χ_m is small and positive
- μ_r is slightly greater than 1
- Ex: Aluminium, Platinum, Oxygen

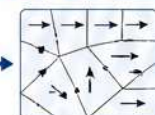
Ferromagnetic

- Strongly attracted by magnetic field
- χ_m is large and positive
- $\mu_r \gg 1$
- Ex: Iron, Cobalt, Nickel

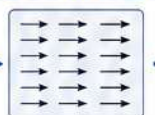
6 DOMAIN THEORY (FERROMAGNETIC MATERIALS)



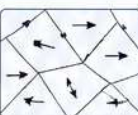
Unmagnetized State
Domains are randomly oriented. Net magnetization is zero.



Magnetization
Under external field, domains align in field direction. Material becomes magnetized.

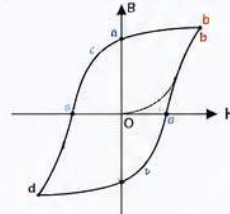


Saturation
All domains aligned. Further increase in field doesn't increase magnetization.



Demagnetization
When field is removed, domains become random again. Net magnetization is zero.

7 HYSTERESIS LOOP (FERROMAGNETIC MATERIALS)

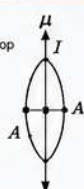


- Oa – Initial magnetization
- ab – To saturation
- bc – Field reduced to zero → **Retentivity (B_r)**
- cd – Reverse field → **Coercivity (H_c)**
- dO – Complete demagnetization

11 EXAM BOOSTER SECTION

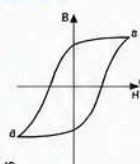
MOST IMPORTANT DERIVATIONS

- ✓ Expression for magnetic dipole moment of a current loop
- ✓ Relation $B = \mu_0(H + M)$
- ✓ Relation $\mu_r = 1 + \chi_m$
- ✓ Expression for energy density $u = \frac{1}{2} BH$
- ✓ Hysteresis loop and its parameters



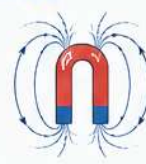
FREQUENTLY ASKED CONCEPTS

- ✓ Why do diamagnetic materials have $\mu_r < 1$?
- ✓ Why do ferromagnetic materials show hysteresis?
- ✓ Why do some materials retain magnetization?
- ✓ Why can't a permanent magnet be made of paramagnetic material?



HIGH-WEIGHTAGE FORMULAE

- ✓ $m = NIA$
- ✓ $M = \frac{m}{V}$
- ✓ $B = \mu_0(H + M)$
- ✓ $\chi_m = \frac{M}{H}, \mu_r = 1 + \chi_m$
- ✓ $u = \frac{1}{2} BH = \frac{1}{2} \mu H^2$



Multiple Choice Questions

1. A short bar magnet has a magnetic dipole moment m . Let B_{ax} and B_{eq} be the magnetic fields at an axial point and an equatorial point, respectively, at the same distance r from the centre of the magnet. Which of the following relations is correct?
(a) $B_{ax} = 2B_{eq}$ (b) $B_{ax} = -2B_{eq}$ (c) $B_{eq} = -2B_{ax}$ (d) $B_{ax} = B_{eq}$
2. A planar circular current-carrying loop of radius a has a magnetic dipole moment m . If the radius of the loop is doubled while keeping the current constant, what will be the new magnetic dipole moment?
(a) $2m$ (b) $4m$ (c) $m/2$ (d) $m/4$
3. According to Gauss's Law in magnetism, the surface integral of the magnetic field over a closed surface is zero. What is the fundamental physical implication of this law?
(a) Magnetic field lines are always straight. (b) Magnetic monopoles do not exist.
(c) Magnetic poles always attract each other. (d) The magnetic field inside a conductor is zero.
4. An alloy has a very broad hysteresis loop with high retentivity and high coercivity. Based on the hysteresis curve, this material is best suited for making:
(a) Electromagnets (b) Transformer core
(c) Temporary magnets (d) Permanent magnets
5. A magnetic material obeys Curie's law. If its absolute temperature is increased from 300 K to 600 K, its magnetic susceptibility will:
(a) Double (b) Become half (c) Remain constant (d) Become four times
6. The intensity of magnetization (I) of a magnetic material is defined as the magnetic moment per unit volume. If a bar magnet of pole strength q_m , magnetic length $2l$, and cross-sectional area A is considered, the intensity of magnetization I is equivalent to:
(a) q_m / A (b) $q_m / 2l$ (c) $q_m \times A$ (d) $q_m / (A \times 2l)$
7. Two identical bar magnets, each of geometric length 10 cm, are placed end-to-end. What is the approximate magnetic length of a single bar magnet from this pair?
(a) 10 cm (b) 5 cm (c) 8.4 cm (d) 11.6 cm
8. The residual magnetism left in a material when the external magnetizing force (H) is reduced to zero is known as:
(a) Coercivity (b) Susceptibility (c) Retentivity (d) Permeability
9. The unit of magnetic dipole moment is:
(a) Am (b) JT^{-1} (c) TmA^{-1} (d) Am^{-1}
10. A current loop of area A and N turns carries a current I . If you look at the face of the loop and the current appears to flow in the clockwise direction, what is the magnetic polarity of that face and the direction of the dipole moment relative to you?
(a) North polarity; dipole moment points towards you.
(b) South polarity; dipole moment points towards you.
(c) South polarity; dipole moment points away from you.
(d) North polarity; dipole moment points away from you.

Answer Key for MCQs

- | | | | | |
|--------|--------|--------|--------|---------|
| 1. (b) | 2. (b) | 3. (b) | 4. (d) | 5. (b) |
| 6. (a) | 7. (c) | 8. (c) | 9. (b) | 10. (c) |

Assertion-Reason Type Questions

Directions: For the following questions, select the correct option:

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

(B) Both Assertion (A) and Reason (R) are true, but (R) is not the correct explanation of (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false, but Reason (R) is true.

1. **Assertion (A):** The net magnetic flux through any closed Gaussian surface is always zero.
Reason (R): Magnetic poles always exist in pairs (dipoles), and isolated magnetic monopoles do not exist.
2. **Assertion (A):** The magnetic field at an equatorial point of a short bar magnet is parallel to the magnetic dipole moment of the magnet.
Reason (R): The angle between the equatorial field and the magnetic dipole moment is 180° .
3. **Assertion (A):** Steel is highly preferred over soft iron for making permanent magnets.
Reason (R): Steel has a thicker hysteresis loop with much higher coercivity than soft iron, meaning it is not easily demagnetized.
4. **Assertion (A):** When a magnetic dipole is placed in a uniform magnetic field, the net force acting on it is always zero, but it may experience a torque.
Reason (R): Torque on a magnetic dipole is given by $\tau = m \times B$.
5. **Assertion (A):** The magnetic susceptibility of a material varies directly with its absolute temperature.
Reason (R): Curie's law states that $m = C/T$, meaning magnetization is inversely proportional to temperature.

Answer Key for Assertion-Reason

1 (A)

2 (D)

3 (A)

4 (B)

5 (D)

Two-Mark Questions

1. A wire of constant length L carrying a current I can be bent into a single-turn circular loop or a single-turn square loop. Which shape will produce a greater magnetic dipole moment? Justify your answer mathematically.
2. A student calculates the magnetic dipole moment of a 15 cm long bar magnet by assuming its poles lie exactly at its geometrical ends. Will the true, measurable magnetic moment be lesser or greater than this calculated value? Give a physical reason for your answer.
3. Material X exhibits a broad hysteresis loop with high retentivity and high coercivity, while Material Y exhibits a narrow loop with low coercivity. Which of these materials is suitable for making (i) a transformer core, and (ii) a permanent magnet? Give one fundamental reason for each choice.
4. The ferromagnetic iron core of a heavy-duty electromagnet accidentally overheats, and its temperature approaches 1000 K. What will happen to its lifting capacity, and what specific phase transition occurs at this temperature? Name the law that governs this behaviour.
5. A cylindrical permanent magnet of volume V and magnetic moment m is sliced exactly in half along its longitudinal axis (parallel to its length). How does the Intensity of Magnetization (I) of each half compare to that of the original magnet?

Answers (Hints)

1. Magnetic dipole moment $m = IA$. For a constant perimeter L , a circle encloses a greater area ($A_{circle} = L^2/4\pi$) compared to a square ($A_{square} = L^2/16$). Since $A_{circle} > A_{square}$, the circular loop has the greater dipole moment.
2. The true magnetic poles reside slightly inside the geometrical boundaries of the magnet. Therefore, the effective magnetic length ($2l$) is shorter than the geometric length (15 cm), making the true dipole moment ($m = q_m \times 2l$) lesser than calculated.
3. Material Y's narrow loop ensures minimal hysteresis energy loss during AC magnetization cycles. Material X's high coercivity ensures the permanent magnet cannot be easily demagnetized by stray external fields or mechanical shocks.
4. At roughly 1000 K, iron reaches its Curie Temperature and undergoes a phase transition from strongly ferromagnetic to weakly paramagnetic. This thermal agitation randomized magnetic domains, governed by Curie's Law ($\chi \propto 1/T$).
5. Intensity of Magnetization is defined as $I = m/V$. Slicing the magnet longitudinally exactly halves its volume ($V \rightarrow V/2$) and its pole strength/magnetic moment ($m \rightarrow m/2$). Therefore, the ratio $(m/2)/(V/2)$ remains I , perfectly unchanged.

Three-Mark Questions

1. Derive the expression for the magnetic field B at an axial point of a magnetic dipole of magnetic length $2l$ and pole strength q_m . Deduce the expression for a short magnet.
2. Explain the analogy between a current-carrying planar loop and a magnetic dipole. State the Right-Hand Rule used to determine the direction of the dipole moment.
3. Draw a typical Hysteresis loop (Magnetization curve) for a ferromagnetic material. Label the points representing retentivity and coercivity. Based on the area of this loop, distinguish between materials used for temporary and permanent magnets.

Answers

1. Net field $B = B_N - B_S$

$$B = (\mu_0 q_m / 4\pi) * [1/(r-l)^2 - 1/(r+l)^2]$$

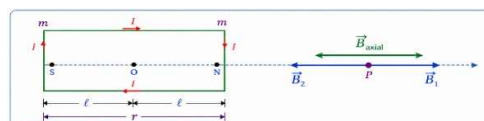
$$B = (\mu_0 q_m / 4\pi) * [4rl / (r^2 - l^2)^2]$$

Since dipole moment $m = q_m \times 2l$:

$$B_{ax} = (\mu_0 / 4\pi) * [2mr / (r^2 - l^2)^2]$$

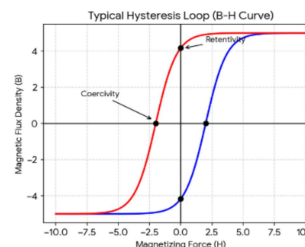
Short Magnet Approximation: If $r \gg l$, then $r^2 - l^2 \approx r^2$.

$$B_{ax} = (\mu_0 / 4\pi) * (2m / r^3)$$



2. A current-carrying planar loop acts as a magnetic dipole. A face with counter-clockwise current acts as a North pole; a face with clockwise current acts as a South pole. Dipole moment $m = IA$. Right-Hand Rule: Curl the fingers of your right hand in the direction of the current. Your extended thumb points in the direction of the magnetic dipole moment (and the North pole).

3. Retentivity: Residual magnetism when magnetizing field (H) is zero. Coercivity: Reverse field (-H) needed to fully demagnetize the material. Loop Area: Represents energy dissipated as heat per cycle. Distinction:
- Temporary Magnets (e.g., Soft Iron): Require narrow loop (small area) for low energy loss. Low coercivity.
 - Permanent Magnets (e.g., Steel): Require broad loop (large area) to resist demagnetization. High coercivity.



Case-Based Question

Magnetic Properties and Hysteresis

When a magnetic material is subjected to a cycle of magnetization, the intensity of magnetization (I) does not exactly track the magnetizing force (H). As H increases, I increases and eventually reaches saturation. When H is reduced to zero, the material retains some magnetism, a property known as retentivity. To completely demagnetize the material ($I=0$), an opposite magnetizing force must be applied, known as coercivity. The closed curve representing one complete cycle of magnetization and demagnetization is called a hysteresis loop. The area under the hysteresis loop represents the energy dissipated as heat during one cycle. Materials are chosen for specific applications based on the shape of this loop.

- The residual magnetism present in a substance when the external magnetizing force is reduced to zero is called:
 - Coercivity
 - Retentivity
 - Susceptibility
 - Permeability
- To completely demagnetize a material, a negative magnetizing force is applied. This required opposing force is termed:
 - Magnetic intensity
 - Retentivity
 - Coercivity
 - Saturation point
- A material designed to be used as a core for an electromagnet (a temporary magnet) should ideally possess:
 - High retentivity, low coercivity, and a thin hysteresis loop
 - Low retentivity, low coercivity, and a thin hysteresis loop
 - High retentivity, high coercivity, and a broad hysteresis loop
 - Low retentivity, high coercivity, and a broad hysteresis loop
- The physical significance of the area enclosed by a hysteresis loop is:
 - The maximum magnetic field the material can produce.
 - The magnetic flux density of the material.
 - The loss of energy per cycle of magnetization and demagnetization.
 - The Curie temperature of the material.

Answer Key for Assertion-Reason

- 1 (b) 2 (c) 3 (a) 4 (c)

Five-Mark Questions

- Consider a bar magnet of pole strength qm and magnetic length $2l$. Derive the mathematical expression for the magnetic field at a point P located on the equatorial line at a distance r from the center of the magnet.

- a) Show that for a short bar magnet, the magnetic field at an axial point is twice the magnetic field at an equatorial point located at the same distance.
2.
 - a) Define the following terms and state their SI units:
 - (i) Magnetic Field Intensity (H)
 - (ii) Magnetic Permeability (μ)
 - (iii) Magnetic Susceptibility (χ)
 - b) Establish the relation $I = m/V = q_m/A$, showing how the intensity of magnetization relates to pole strength and cross-sectional area.
3.
 - a) Explain how a current-carrying circular loop of radius a and current I behaves like a magnetic dipole. Use the magnetic field expression for a point on the axial line at a large distance ($x \gg a$) to prove this.
 - b) A circular coil of 100 turns and radius 5 cm carries a current of 2 A. Calculate its magnetic dipole moment.
 - c) Write the formula for the torque acting on this magnetic dipole if it is placed in a uniform magnetic field B at an angle θ .

Answers:

1. a) Equatorial Magnetic Field Derivation:

Let the point P be at distance r from the center. Distance from N or S pole to P is $\sqrt{(r^2 + l^2)}$.

Magnetic field at P due to North pole: $B_N = (\mu_0/4\pi) * [q_m / (r^2 + l^2)]$

Magnetic field at P due to South pole: $B_S = (\mu_0/4\pi) * [q_m / (r^2 + l^2)]$

Vertical components ($B \sin\theta$) cancel out. Horizontal components ($B \cos\theta$) add up.

Net Field $B_{eq} = 2 * B_N * \cos\theta$.

From geometry, $\cos\theta = l / \sqrt{(r^2 + l^2)}$.

$B_{eq} = 2 * (\mu_0/4\pi) * [q_m / (r^2 + l^2)] * [l / \sqrt{(r^2 + l^2)}]$

$B_{eq} = (\mu_0/4\pi) * [(q_m * 2l) / (r^2 + l^2)^{3/2}]$

Since magnetic dipole moment $m = q_m * 2l$: **$B_{eq} = (\mu_0/4\pi) * [m / (r^2 + l^2)^{3/2}]$**

b) Short Bar Magnet Comparison:

For a short magnet, $r \gg l$, so $(r^2 + l^2) \approx r^2$.

Equatorial field becomes: $B_{eq} = (\mu_0/4\pi) * (m / r^3)$

We know the Axial field is: $B_{ax} = (\mu_0/4\pi) * (2m / r^3)$: **$B_{ax} = 2 * B_{eq}$** . (Hence proved).

2. a) Definitions and SI Units:

(i) Magnetic Field Intensity (H): The degree or extent to which an external magnetic field can magnetize a substance. SI Unit: A/m (Ampere per meter).

(ii) Magnetic Permeability (μ): The ability of a material to allow the passage of magnetic field lines through it. SI Unit: T·m/A or H/m (Henry/meter).

(iii) Magnetic Susceptibility (χ): The ratio of the intensity of magnetization (I) induced in the material to the applied magnetizing field intensity (H). SI Unit: Dimensionless (No unit).

b) Establishing the Relation $I = m/V = q_m/A$:

Intensity of Magnetization (I) is defined as the magnetic dipole moment per unit volume:

$$I = m / V$$

For a bar magnet of length $2l$ and cross-sectional area A , Volume $V = A * 2l$

The magnetic dipole moment $m = q_m * 2l$ (where q_m is pole strength)

Substituting these into the formula: $I = (q_m * 2l) / (A * 2l)$

Cancelling $2l$ gives: $I = q_m / A$. (Hence proved).

3. a) Current Loop as a Magnetic Dipole:

A current-carrying loop has two faces behaving as opposite magnetic poles (Clockwise = South, Anticlockwise = North).

The magnetic field on the axis of a circular loop is: $B = (\mu_0 * I * a^2) / [2 * (x^2 + a^2)^{3/2}]$

For a large distance ($x \gg a$), a^2 is neglected: $B = (\mu_0 * I * a^2) / (2 * x^3)$

Multiply numerator and denominator by π : $B = (\mu_0 * I * \pi * a^2) / (2\pi * x^3)$

Since Area $A = \pi * a^2$, we get $B = (\mu_0 * 2IA) / (4\pi * x^3)$

Comparing this with a short bar magnet ($B = (\mu_0/4\pi) * 2m/x^3$), we see the loop acts as a dipole with magnetic moment $m = IA$.

b) Calculation of Magnetic Dipole Moment:

Formula: $m = N * I * A$

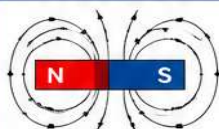
Given: $N = 100$, $I = 2 \text{ A}$, $r = 5 \text{ cm} = 0.05 \text{ m}$ Area $A = \pi * r^2 = 3.14 * (0.05)^2 = 0.00785 \text{ m}^2$

$m = 100 * 2 * 0.00785 = 1.57 \text{ A}\cdot\text{m}^2$

c) Torque Formula:

$\tau = mB \sin\theta$ (In vector form: $\tau = m \times B$)

Where m is the magnetic dipole moment, B is the magnetic field, and θ is the angle between them.



MAGNETISM AND MATTER

CLASS 12 PHYSICS – FORMULA SHEET

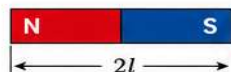


1. BAR MAGNET

- Magnetic dipole moment of a bar magnet

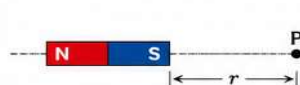
$$M = m(2l)$$

where, m = pole strength
 $2l$ = magnetic length



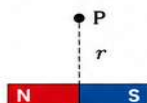
3. MAGNETIC FIELD DUE TO A MAGNETIC DIPOLE (BAR MAGNET)

- At a point on the axial line (distance r from centre)



$$B_{\text{axial}} = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$$

- At a point on the equatorial line (distance r from centre)



$$B_{\text{equatorial}} = \frac{\mu_0}{4\pi} \frac{M}{r^3}$$

(Direction opposite to dipole moment)

Where, M = magnetic dipole moment of the bar magnet
 r = distance of point from centre of dipole

6. WORK DONE IN ROTATION OF DIPOLE

(from θ_1 to θ_2)

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

8. MAGNETIC SUSCEPTIBILITY AND RELATIVE PERMEABILITY

- Magnetic susceptibility

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

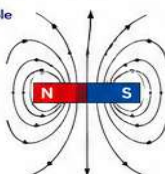
- Relative permeability

$$\mu_r = 1 + \chi_m$$

where, H = magnetising field intensity

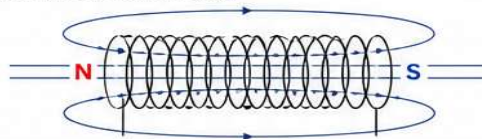
10. MAGNETIC FIELD LINES (KEY POINTS)

- Magnetic field lines emerge from North pole and enter South pole outside the magnet and form closed continuous curves.
- Inside the magnet, field lines go from South pole to North pole.
- No two magnetic field lines intersect each other.
- The tangent to a field line at any point gives the direction of $\vec{B}$ at that point.



2. BAR MAGNET AS AN EQUIVALENT SOLENOID

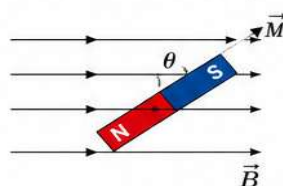
(Qualitative treatment only)



A bar magnet behaves like a current carrying solenoid.
 Outside field is similar to a bar magnet.

4. TORQUE ON MAGNETIC DIPOLE (BAR MAGNET) IN UNIFORM MAGNETIC FIELD

(Qualitative treatment only)



Torque (Vector form)

$$\vec{\tau} = \vec{M} \times \vec{B}$$

Torque (Magnitude)

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

5. POTENTIAL ENERGY OF MAGNETIC DIPOLE

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

where, θ = angle between $\vec{M}$ and $\vec{B}$

7. MAGNETISATION OF MATERIALS

- Magnetisation (I or M)

$$I = \frac{\text{Magnetic moment}}{\text{Volume}}$$

(SI unit : $A m^{-1}$)

9. EFFECT OF TEMPERATURE ON MAGNETIC PROPERTIES (PARAMAGNETIC MATERIALS)

- Curie's Law

$$\chi = \frac{C}{T}$$

where, χ = susceptibility
 C = Curie constant
 T = absolute temperature (in K)

As temperature increases, susceptibility decreases
 (paramagnetic materials become less magnetic).

11. MAGNETIC PROPERTIES OF MATERIALS

Property	Diamagnetic	Paramagnetic	Ferromagnetic
Susceptibility (χ_m)	Negative	Small Positive	Large Positive
Relative permeability (μ_r)	Less than 1	Slightly greater than 1	Much greater than 1
Nature	Weakly repelled	Weakly attracted	Strongly attracted
Examples	Bi, Cu, Au, Ag, Water	Al, Pt, Mg, O ₂	Fe, Co, Ni, Gd

KEY SYMBOLS

M : Magnetic dipole moment

r : Distance from centre

I or M : Magnetisation

m : Pole strength

$\vec{\tau}$: Torque

H : Magnetising field intensity

$2l$: Magnetic length

θ : Angle between $\vec{M}$ and $\vec{B}$

χ_m : Magnetic susceptibility

$\vec{B}$: Magnetic field

U : Potential energy

μ_r : Relative permeability