Magnetism and Matter

Some commonly known ideas about magnetism

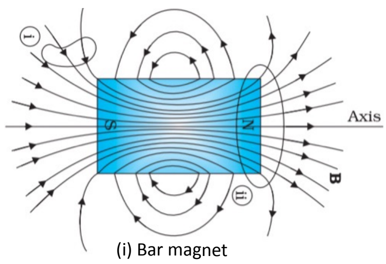
i. The earth behaves like a magnetic with the magnetic field pointing approximately from the geographical south to north.
ii. A bar magnet when suspended freely points in the North-South direction. The tip which points to the geographical north is called the north pole of the magnet and that which points to the geographical south is called the south pole of the magnet.
iii. Like poles of the magnet repel and unlike poles attract.
iv. Magnetic monopoles do not exist. If we cut a magnet in half, we end up with two smaller magnets with both north and south pole.
v. It is possible to make magnets out of iron and its alloys

Bar magnet

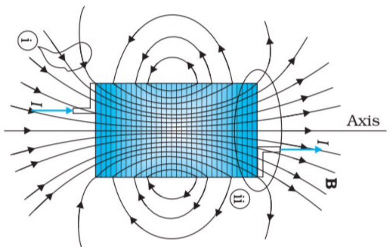
A bar magnet has two poles. One pole is designated as the North pole and the other as the south pole. When iron filings are sprinkled around a bar magnet, they are arranged in a pattern similar to the one seen around a current carrying solenoid.

Magnetic field lines (PYQ 2019)

- Magnetic field lines for a bar magnet or a current carrying solenoid form closed loops, this is because magnetic monopoles do not exist.
- Tangent to a field line at a point gives the direction of the magnetic field at that point.
- The greater the density of field lines in a region, the greater is the magnitude of the magnetic field in that region.
- Magnetic field lines do not intersect. This is because, at the point of intersection there will be two tangents which means that the magnetic field at that point will have two directions, which is not possible.



(i) Bar magnet

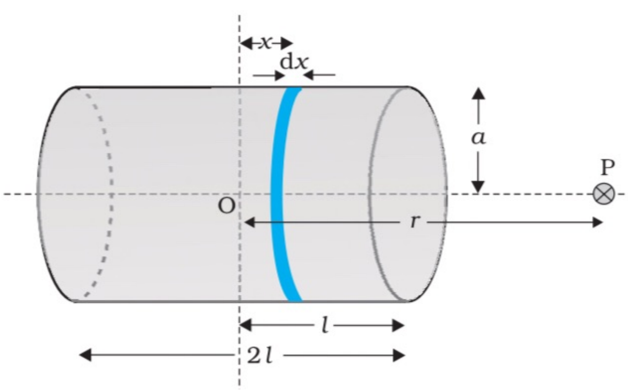


(ii) solenoid

Note: 1. For a bar magnet (or a current carrying solenoid) the direction of magnetic field is from the North pole to the South pole outside the magnetic and from the south pole to the north pole inside the magnet.
2. Unlike in electrostatics, the magnetic field lines do not indicate the direction of force on a moving charge.

Bar magnet as an equivalent solenoid

Ampere hypothesized that all magnetic phenomenon are due to circulating currents. The similarity between magnetic field lines produced due to a bar magnet and a current carrying solenoid suggests that a bar magnet may be thought of as a large number circulating atomic currents in analogy with a solenoid.



Consider a solenoid of length 2L and radius a carrying current I, having no of turns per unit length as n. Let us calculate the field at a point P on its axis at a distance r from its center. Consider a differential element of thickness dx a distance x from the center. It consists of n.dx turns. We know the expression for field due a to a circular element at a point on its axis-

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

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

For $r \gg a, r \gg l$

$$\left[(r-x)^2 + a^2\right]^{x_2} \approx r^3$$

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

$$B = \frac{\mu_0 n I a^2}{2r^3} \times 2l$$

$$m = n(2l)I(\pi a^2) \qquad (:m = NIA)$$

$$\boxed{B = \frac{\mu_0}{4 \times \pi} \times \frac{2m}{r^3}}$$

This is also the magnetic field for a bar magnet a point far on its axis (obtained experimentally). Thus, a bar magnet and a solenoid produce similar magnetic fields. The magnetic moment of a bar magnet is thus equal to that of an equivalent solenoid which produces the same magnetic field.

Magnetic pole strength/ Magnetic charge (q_m)

1. It is called magnetic charge and is analogous to electric charge| SI unit- A m (ampere-meter)
2. It depends on area of cross-section and intensity of magnetization
3. North pole has a magnetic charge $+q_m$ and south pole has $-q_m$
4. Magnetic moment of a bar magnet of length 2L can be written as –

$$\boxed{m = q_m \cdot (2l)}$$

5. Consider a solenoid of length L, current I and n no of turns per unit length. Its magnetic moment can be written as-

$$m = nlIA$$

Also-

$$m = q_m l$$

Equating both-

$$q_m l = nIA$$

$$\boxed{q_m = nIA}$$

6. The magnetic field strength due to q_m at a distance can be written as- $\boxed{B = \frac{\mu_0}{4 \times \pi} \times \frac{q_m}{r^2}}$

Dipole in a uniform magnetic field (PYQ 2013)

Consider a magnetic needle of magnetic moment **m** and moment of inertia I kept in a magnetic field **B** making an angle θ with the field. The needle experiences a torque which is given by-

$$\boxed{\begin{aligned}\vec{\tau} &= \vec{m}\times\vec{B}\\ \tau &= mB\sin\theta\end{aligned}}$$

$$\tau = I\alpha$$

$$I\alpha = mB\sin\theta$$

Where **τ** is restoring torque (-ve sign indicates that torque is restoring) which can be written as-

$$\frac{d^2\theta}{dt^2} = -\frac{mB}{I}\times\sin\theta$$

For small angular displacements (θ→0), sinθ→θ therefore,

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

$$\frac{d^2\theta}{dt^2} + \frac{mB}{I}\theta = 0 \quad -1$$

This represents simple harmonic motion-

$$\frac{d^2x}{dt^2} + \omega^2 x = 0 \quad -2$$

Comparing both equations, we get-

$$\omega^2 = \frac{mB}{I}$$

$$\boxed{\begin{aligned}\omega &= \sqrt{\frac{mB}{I}}\\ T &= \frac{2\times\pi}{\omega} = 2\times\pi\times\sqrt{\frac{I}{mB}}\end{aligned}}$$

Important PYQs

Ques: A small compass needle of magnetic moment m is free to turn about an axis perpendicular to the direction magnetic field B. The moment of inertia of the needle is I. the needle is slightly displaced from the equilibrium position and released. Prove that it executes SHM and hence find its Time period **(PYQ 2013) [3M]**

Ans: (Exactly as given above)

Potential energy of dipole in magnetic field

Potential energy of dipole in magnetic field can be calculated similar to that in electrostatic field. the potential energy (U) is given by-

$$U = \int \tau(\theta)\cdot d\theta$$

$$U = \int mB\sin\theta d\theta$$

$$U = -mB\cos\theta$$

$$\boxed{U = -\vec{m}\cdot\vec{B}}$$

Note: -The zero of potential energy is taken when the dipole is perpendicular to the field i.e. θ=90°
-Potential energy is minimum at θ=0° (stable equilibrium) | maximum at θ=180° (unstable equilibrium).

Electrostatic analogue

The equation for magnetic field due to bar magnet of moment **m** can be obtained from the equation of field due to an electric dipole of moment **p** by making the following replacements

E → B | p → m | $1/4\pi\varepsilon_0 \rightarrow \mu_0/4\pi$

The field at equatorial position (B_E) of a bar magnet at a distance r (r>>L), where L is the length of the magnet-

$$\vec{B}_E = \frac{-\mu_0 \vec{m}}{4 \times \pi r^3}$$

The field at axial position (B_A) of a bar magnet at a distance r (r>>L), where L is the length of the magnet-

$$\vec{B}_A = \frac{\mu_0}{4 \times \pi} \times \frac{2\vec{m}}{r^3}$$

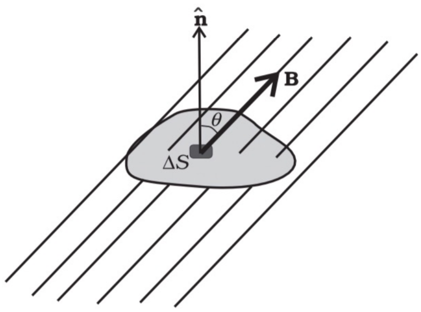
	Electrostatics	Magnetism
	$1/\varepsilon_0$	μ_0
Dipole moment	**p**	**m**
Equatorial Field for a short dipole	$-\mathbf{p}/4\pi\varepsilon_0 r^3$	$-\mu_0\,\mathbf{m}\,/\,4\pi\,r^3$
Axial Field for a short dipole	$2\mathbf{p}/4\pi\varepsilon_0 r^3$	$\mu_0\,2\mathbf{m}\,/\,4\pi\,r^3$
External Field: torque	$\mathbf{p} \times \mathbf{E}$	$\mathbf{m} \times \mathbf{B}$
External Field: Energy	$-\mathbf{p}\cdot\mathbf{E}$	$-\mathbf{m}\cdot\mathbf{B}$

Gauss' law in Magnetism (PYQ 2019)

Gauss' law in magnetism states that the net flux through any closed surface is zero

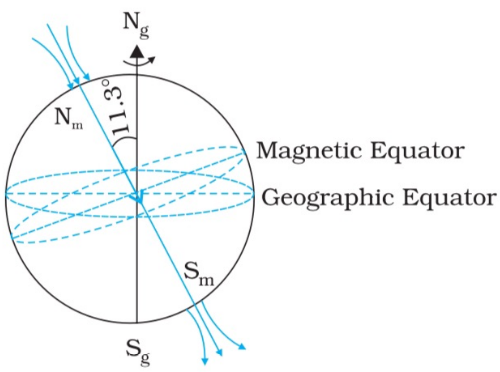
$$\oint \vec{B} \cdot d\vec{s} = 0$$

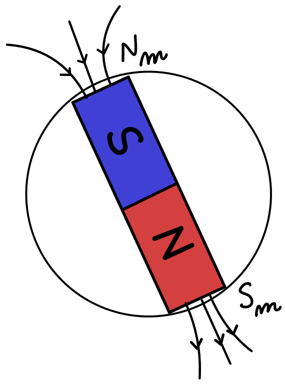
This follows from the fact that magnetic field lines always form closed loops so for any given Gaussian surface, the no of field lines entering the surface will be equal to the number of field lines exiting the surface. Gauss' law for magnetism is a reflection of the fact that magnetic monopoles do not exist.



Earth's Magnetism

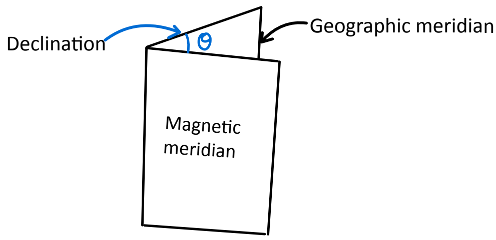
- The earth's magnetic field is thought to arise due to electric currents produced by convection and rotation of molten metallic fluids (nickel and iron) in the outer core of the earth. This is known as the dynamo effect.
- The magnetic field lines of the earth resemble that of a hypothetical magnetic dipole located at the center of the earth. The axis of this dipole is at angle of 11.3° to the axis of rotation of the earth.
- The pole near the geographical north pole is called the north magnetic pole and that near the geographical south pole is called the south magnetic pole
- But the field lines enter the earth from the north magnetic pole and exit from the south magnetic pole. This convention came around because magnetic north was the direction in which the north pole of a magnet pointed.
- Thus, in reality the north magnetic pole of earth behaves like the south pole of a bar magnet and vice-versa.

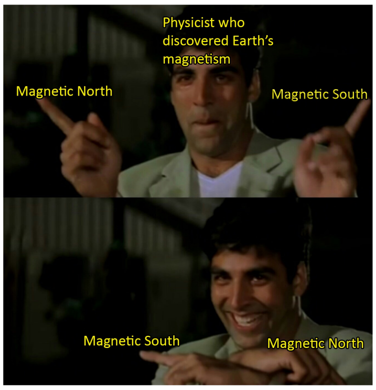




Let us define some terms-

1. **Geographic meridian-** At a given place, it is the plane containing the longitude and the Earth's axis
2. **Magnetic meridian-** At a given place it is a vertical plane containing a freely suspended magnet
3. **Declination (θ)-** At a given place, it is the angle between the magnetic meridian and the geographic meridian.
   Declination is greater near high latitudes and smaller near the equator.
   For e.g. A declination of 10° west means magnetic north is 10° west of geographic north.





Earth's magnetic field-

- **At magnetic south,** is vertically upwards
- **At magnetic north,** is vertically downwards
- **At equator,** is parallel to the surface
- **In southern hemisphere,** is inclined above the horizontal
- **In northern hemisphere,** is inclined below the horizontal

Inclination/ Dip (δ) (PYQ 2020, 2013, 2012)

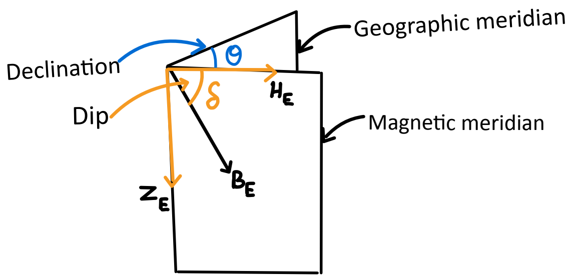
It is the angle that a freely suspended magnet makes with the horizontal. The earth's magnetic field $\mathbf{B_E}$ at a point can be resolved into a horizontal component $\mathbf{H_E}$ and a vertical component $\mathbf{Z_E}$. The angle that $\mathbf{B_E}$ makes with $\mathbf{H_E}$ is the angle of dip δ

At poles, $\delta = \pi / 2$

At equator, $\delta = 0$

Convention- Dip in the northern hemisphere is positive | southern hemisphere is negative

$$H_E = B_E \cos\delta$$
$$Z_E = B_E \sin\delta$$
$$\frac{Z_E}{H_E} = Tan\delta$$
$$|B_E| = \sqrt{Z_E^2 + H_E^2}$$



Note: Dip needle- it is a compass pivoted to move in a vertical circle containing the magnetic field of the earth.

Important PYQs

Ques: Earth's magnetic field and the angle of dip at a point is 0.3G and 30°. Calculate the vertical component of Earth's magnetic field. **(PYQ 2020) [1M]**

Ans: $Z_E = B_E \sin\delta$

$Z_E = 0\cdot 3 \times \sin 30^\circ = 0\cdot 3 \times 0\cdot 5 = 0\cdot 15G$

Ques: A compass needle free to turn in the vertical plane, orients itself vertically at a certain place on the earth. Calculate (i) the horizontal component 0f earth's magnetic field (ii) the angle of dip **(PYQ 2013) [2M]**

Ans: (i) $\delta = \pi / 2$ ($\because$ Vertically aligned)

(ii) $H_E = B_E \cos\delta$

$H_E = B_E \cos\frac{\pi}{2}$

$H_E = 0$

Ques: The horizontal component of Earth's magnetic field at a point is B and the angle of dip is 60°. What is the vertical component? **(PYQ 2012) [1M]**

Ans: $\frac{Z_E}{H_E} = Tan\delta$

$Z_E = H_E \tan\delta = BTan60^{\circ} = \sqrt{3}B$

Time period of oscillation in earth's magnetic field

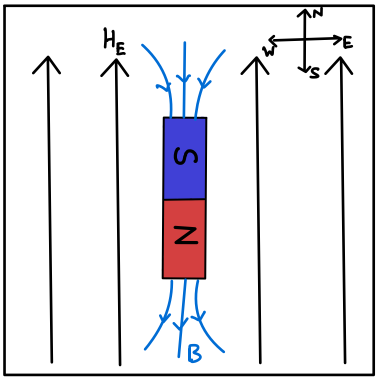
For a compass in the horizontal plane-

$$T = 2 \times \pi \times \sqrt{\frac{I}{mH_E}}$$

Neutral Points (NCERT back Ques 5.13, 5.14, 5.18)

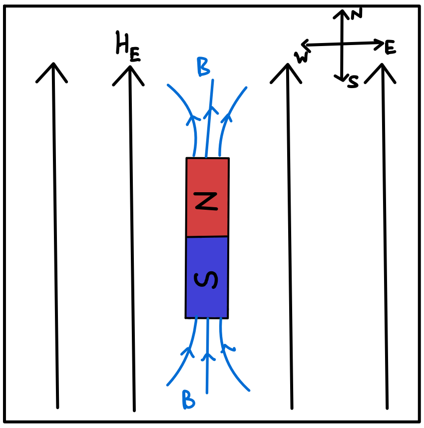
Neutral points are those points where field due toa magnet cancels out the horizontal component of Earth's magnetic field at that point

Case I:



- The field due to the magnet will be opposite to $\mathbf{H_E}$ along the axial line
- There will be two neutral points

Case 2:



- Field due to the magnet will be opposite to $\mathbf{H_E}$ in the equatorial plane
- There will be infinite neutral points

NCERT BACK EXERCISES

5.13 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.)

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

Ans 5.13 We know that for a Bar magnet-

$$B_A = \frac{\mu_0}{4\times\pi}\times\frac{2m}{r^3} \quad -1$$

ATQ,

$$H_E = B_E\cos\delta = B_E\cos 0^\circ = B_E \quad -2$$

Equating 1,2

$$B_A = B_E$$

$$\frac{\mu_0}{4\times\pi}\times\frac{2m}{r^3} = B_E \quad -3$$

Also, we know-

$$B_{Eq} = \frac{\mu_0}{4\times\pi}\times\frac{m}{r^3} \quad -4$$

From 3,4

$$B_{Eq} = \frac{B_E}{2}$$

$$B_{Eq} = \frac{0\cdot 36G}{2} = 0.18G$$

$$\vec{B_T} = \vec{B_{Eq}} + \vec{B_E} = 0\cdot 18 + 0\cdot 36$$

$B_T = 0.54G$ (in the direction of Earth's field)

5.14 This is similar to case 2 mentioned above

From the previous part we know that-

$$B_{Eq} = \frac{\mu_0}{4\times\pi}\times\frac{m}{r^3} = \frac{B_E}{2}$$

$$m = \frac{B_E\cdot 4\cdot\pi\cdot r^3}{2\mu_0}$$

Now, ATQ

$$B_{Eq} = B_E$$

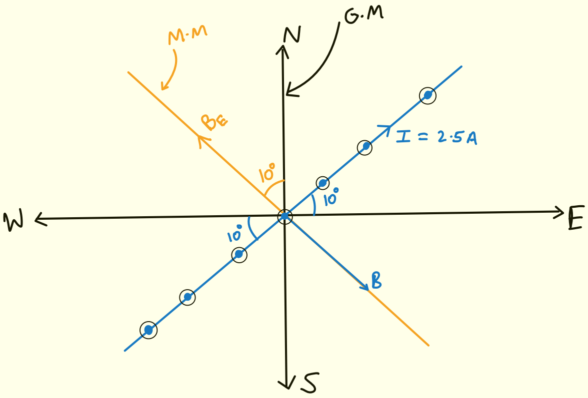
$$\Rightarrow \frac{\mu_0}{4\times\pi}\times\frac{m}{r_1^3} = B_E$$

$$r_1^3 = \frac{\mu_0}{4\times\pi}\cdot\frac{B_E\cdot 4\cdot\pi_1 r^3}{2\mu_0\cdot B_E}$$

$$r_1 = r\times 2^{-1/3}$$

$r_1 = 14\times 2^{-1/3} = 11\cdot 1\text{cm}$ (On the perpendicular bisector)

5.18 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.)



Ans: We know field due to an infinite current element-

$$B = \frac{\mu_0 I}{2 \times \pi d}$$

ATQ,

$$H_E = B_E \cos\delta = B_E \cos 0^\circ$$

$$H_E = B_E$$

To obtain null point we equate the two-

$$H_E = B$$

$$\frac{\mu_0 I}{2 \times \pi d} = 0.33G$$

$$d = \frac{2 \times 10^{-7} \times 25}{0 \cdot 33 \times 10^{-4}}$$

$$d = 1.5\text{cm}$$

Therefore, the line of null points will be parallel to the wire at a distance of 1.5 cm above the wire (using right hand rule)

3 Magnetic vectors

1. **Magnetization vector (M or I) –** It is a characteristic of material. The magnetic moment of various electrons in a bulk material can add up vectorially and give a non-zero net magnetic moment. The magnetization of a sample is defined as the net magnetic moment per unit volume| SI unit- A m^{-1}

$$\boxed{\mathbf{M} = \frac{\mathbf{m}_{net}}{V}}$$

2. **Magnetic field intensity (H)-** it is a characteristic of field| SI unit- A m^{-1}

3. **Magnetic field/ Magnetic induction vector (B)-** it is a characteristic of field| SI Unit – Tesla

Relation between H, B, M

The magnetic field in the interior of a solenoid is given by-

If the interior of the solenoid is filled with a material with non-zero magnetization, the field inside the solenoid will be greater than **B₀**. the net field **B** may be expressed as-

$$\mathbf{B} = \mathbf{B}_0 + \mathbf{B}_m$$

Where $\mathbf{B}_m$ is the field contributed by the material core. It is found that this additional field is directly proportional to **M**-

$$\boxed{\mathbf{B}_m = \mu_0 \mathbf{M}}$$

Also,

$$\mathbf{H} = \frac{\mathbf{B}}{\mu_0} - \mathbf{M}$$

$$\boxed{\mathbf{B} = \mu_0 (\mathbf{H} + \mathbf{M})}$$

Here we see that the net magnetic field inside the solenoid is due to factors. One, due to external factors like current in the solenoid which is represented by **H**, and two, due to nature of magnetic material represented by **M**. mathematically, we can write-

$$\boxed{\mathbf{M} = \chi \mathbf{H}}$$

Where χ_m is a dimensionless quantity called magnetic susceptibility. So, we can write-

$$\mathbf{B} = \mu_0 (1 + \chi)\mathbf{H}$$

$$= \mu_0 \mu_r \mathbf{H}$$

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

Where $\mu = \mu_0 \mu_r = \mu_0 (1+\chi)$.

Magnetic susceptibility (χ_m) (PYQ 2018)
It is a measure of how magnetic materials respond to external magnetic field.
For paramagnetic materials χ_m is small and positive| for diamagnetic materials χ_m is small and negative

Relative magnetic permeability (μ_r)
It is a dimensionless quantity given by-

$$\boxed{\mu_r = 1 + \chi}$$

It is the analog of dielectric constant in electrostatics. The magnetic permeability of a substance thus can be written as-

$$\boxed{\mu = \mu_0 \mu_r = \mu_0 (1+\chi).}$$

Calculating H due to various magnetic configurations

1. **Due to solenoid**

Consider a solenoid with number of turns per unit length n and carrying current I. We know,

$$B = \mu_0 n I$$

Also,

$$B = \mu_0 H$$

Equating

$$\mu_0 H = \mu_0 n I$$

$$\boxed{H = nI}$$

2. **Due to toroid**

Consider a toroid of total turns N and current I. we know,

$$B = \frac{\mu_0 N I}{2 \times \pi R}$$

Also,

$$B = \mu_0 H$$

Equating

$$\mu_0 H = \frac{\mu_0 N I}{2 \times \pi R}$$

$$\boxed{H = \frac{NI}{2 \times \pi R}}$$

Note: Even if the solenoid or toroid are filled with a magnetic material the value of **B** will change but **H** will remain the same. Therefore, we can say that **H** is the property of the geometry and NOT the material.

Magnetizing current (I_m)

It is the additional amount of current that needs to be passed through the windings of the solenoid in absence of the core which would give the value of B as in the presence of the core i.e.-

NCERT EXAMPLE

Ques: A solenoid has a core of 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 meter, calculate a) **H** b) **M** c) **B** d) magnetizing current. **(NCERT e.g. 5.10)**

Ans:

a) $H = nI$

$$H = 1000 \times 2 = 2000 Am^{-1}$$

c) $B = \mu_0 \mu_R H$

$$B = 4 \times \pi \times 10^{-7} \times 400 \times 2000$$

$$B = 1.0T$$

b) $H = \frac{B}{\mu_0} - M$

$$M = \frac{B}{\mu_0} - H = \frac{(B - \mu_0 H)}{\mu_0}$$

$$M = \frac{(\mu_0 \mu_R H - \mu_0 H)}{\mu_0}$$

$$M = (M_R - 1)H = 399 \times 2000$$

$$M \approx 8 \times 10^5 \times A/m$$

d) $\mu_0 n(I + I_m) = \mu_0 \mu_R n I = 1T$

$$I_m = 794A$$

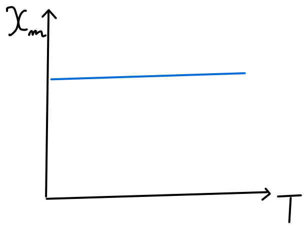
Magnetic Properties of materials (PYQ 2019, 2018, 2012)

1. Diamagnetism

- The substances which are weakly repelled by magnetic field are called diamagnetic substances
- They move from a region of stronger field to a weaker field.
- The resultant magnetic moment of a diamagnetic atom is zero.
- E.g. Bismuth, Copper, Lead, Silicon, Nitrogen (STP), Water, NaCl

Explanation for diamagnetism-
When an external field is applied, the electrons having orbital magnetic moment slow down and those having that in the opposite direction speed up (this happens in accordance with Lenz' law). Therefore, the substance develops a net magnetic moment is the direction opposite to the external field and hence is repelled.

Susceptibility of diamagnetic materials- It is small and negative. It is independent of temperature.

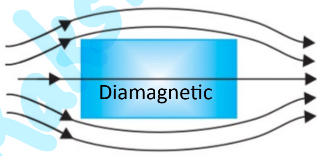


Diamagnetic

$-1 \leq \chi < 0$

$0 \leq \mu_r < 1$

$\mu < \mu_0$



Superconductors- They are the most exotic diamagnetic materials. They are metals which when cooled to very low temperatures exhibit perfect conductivity and perfect diamagnetism. Here, the magnetic field lines are completely expelled out of the substance. For a superconductor-

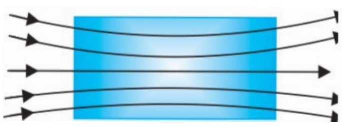
$$\boxed{\chi = -1 \qquad \mu_R = 0}$$

The phenomenon of diamagnetism in super conductors is called Meissner effect. They are used to make magnetically levitated superfast trains.

2. Paramagnetism

- They are substances which weakly magnetized when kept in an external field. They are weakly attracted towards the field
- They move from a region of weak field to strong field
- E.g. Aluminum, Sodium, Calcium, Oxygen (STP), Copper Chloride

Explanation
The individual atoms/ions/molecules of a paramagnetic material have a permanent magnetic dipole moment. In the absence of an external field, due to random thermal motion of the constituent atoms, the net magnetic moment of a paramagnetic material is zero. But, in the presence of an external field **B**$_o$ and at low temperatures, the magnetic moments of constituent atoms align in the direction of field and we get a net magnetic moment in the direction of external field. The field lines get concentrated inside the material and the field inside the material gets enhanced.



Susceptibility-
For paramagnetic materials, it is small and positive

Paramagnetic
$0 < \chi < \varepsilon$
$1 < \mu_r < 1 + \varepsilon$
$\mu > \mu_0$

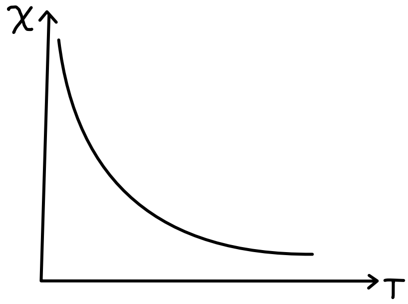
Curie's Law
The susceptibility of a paramagnetic substance is inversely proportional to Absolute temperature i.e.

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

$$\chi = C\frac{\mu_0}{T}$$

$$M = C\frac{B_0}{T}$$

(Where C is called Curie's constant)

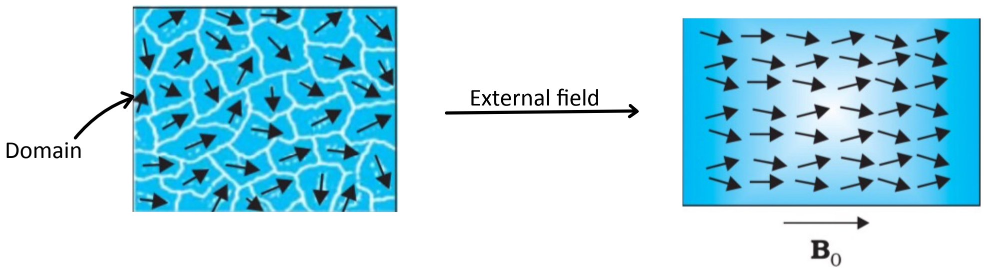


Note: As the field is increased or the temperature is lowered, the magnetization increases until it reaches its saturation M_S at which point the dipoles are perfectly aligned with the field. Beyond this point, curie's law is no longer valid.

3. Ferromagnetism

- They are materials which get strongly magnetized when placed in an external magnetic field.
- They move from region of weak field to region of strong field i.e. they are strongly attracted

Explanation-
The constituent atoms/ions/molecules of ferromagnetic substances possess a permanent dipole moment and they align themselves in a common direction over a macroscopic volume called domain (a domain contains about 10^{11} atoms). In absence of external field, the orientation of the domains is random and hence there is no net magnetic moment. In the presence external field, the domains orient themselves in its direction. Hence, the field inside the ferromagnet becomes stronger and the field lines inside become extremely dense



Hard ferromagnets- When external field is removed, in some ferromagnetic substances, the magnetization persists. E.g. Alnico, an alloy of iron, aluminum, nickel, cobalt and copper; Lodestone. They are used to make permanent magnets like compass needle

Soft ferromagnets- when external field is removed, the magnetization is also removed. E.g. Soft Iron

Susceptibility- for ferromagnetic substances, it is very large and positive

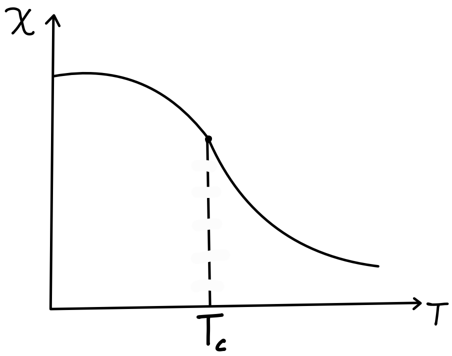
Ferromagnetic
$\chi >> 1$
$\mu_r >> 1$
$\mu >> \mu_0$

Curie- Weiss Law

At temperatures above Curie Temperature (T_C), ferromagnets become paramagnetic. The domain structures disintegrate with increase in temperature. The susceptibility above the curie temperature is described as-

$$\chi = \frac{C}{T - T_c} \quad (T > T_c)$$

(This C is NOT curie's constant)



Important PYQs 

Ques: Two magnetic materials A and B have relative magnetic permeability as 0.96 and 500 resp. Identify A and B **(PYQ 2018) [1M]**

Ans: A- diamagnetic (μ_r<1)
B- ferromagnetic (μ_r>>1)

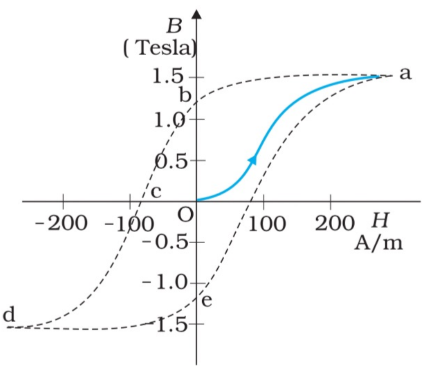
Ques: The magnetic susceptibility of a material is -2.6×10^{-5}. Identify the material **(PYQ 2012) [1M]**

Ans: Since $\chi_m < 0$, it is diamagnetic

Hysteresis curve

Hysteresis means 'lagging behind'. Let us study the relation between **B** and **H.** Consider a unmagnetized ferromagnetic substance kept inside a solenoid.

- As the current in the solenoid is increased, the value of B also rises and becomes saturated as shown in the curve oa. At this point all the domains are aligned with external field.
- Now, when H (or I) is decreased to zero, we see that B does not come down to 0, represented with curve ab. The value of B at H=0 is called **retentivity** or **remanence**
- Next, the current in solenoid is increased in the opposite direction till the value of B becomes 0, represented by curve bc. The value of H when B=0 is called **coercivity**.
- Therefore, we conclude that for a given value of H, B is not unique but depends on the previous history of the sample. This phenomenon is called hysteresis.
- The area under B-H curve of hysteresis cycle gives loss of energy per unit volume during a cycle of magnetization and demagnetization.



Permanent Magnets and Electromagnets (PYQ 2017, 2013)

1. Permanent magnets-

Substances which at room temperature retain their ferromagnetic property for a long period of time are called permanent magnets.

Preparation- 1. Hammering an iron rod kept in the north-south direction

2. Stroking a steel rod with one end of a bar magnet in the same sense repeatedly.
3. Placing a ferromagnet in the center of a solenoid and pass a current. The magnetic field of the solenoid magnetizes the rod

Properties of materials used as permanent magnets-

1. **High retentivity-** so that magnet is strong
2. **High coercivity**- so magnetization is not removed by stray fields, temp fluctuations or minor mechanical damage.
3. **High permeability**

e.g.- steel, alnico, Cobalt steel and ticonal (alnico + Titanium)

3. Electromagnets

They are ferromagnetic materials which are made into magnets by passing a current through it using a coil

Properties of materials used to make electromagnets-

1. **High permeability**
2. **Low retentivity**

e.g. soft iron

3. The area under hysteresis curve should be small so that loss of energy in cycle of magnetization and demagnetization is less e.g. in the case of transformer cores and telephone diaphragm

4. high resistivity- to lower eddy current losses

Uses- electric bells, loudspeakers, telephone diaphragm, cranes.