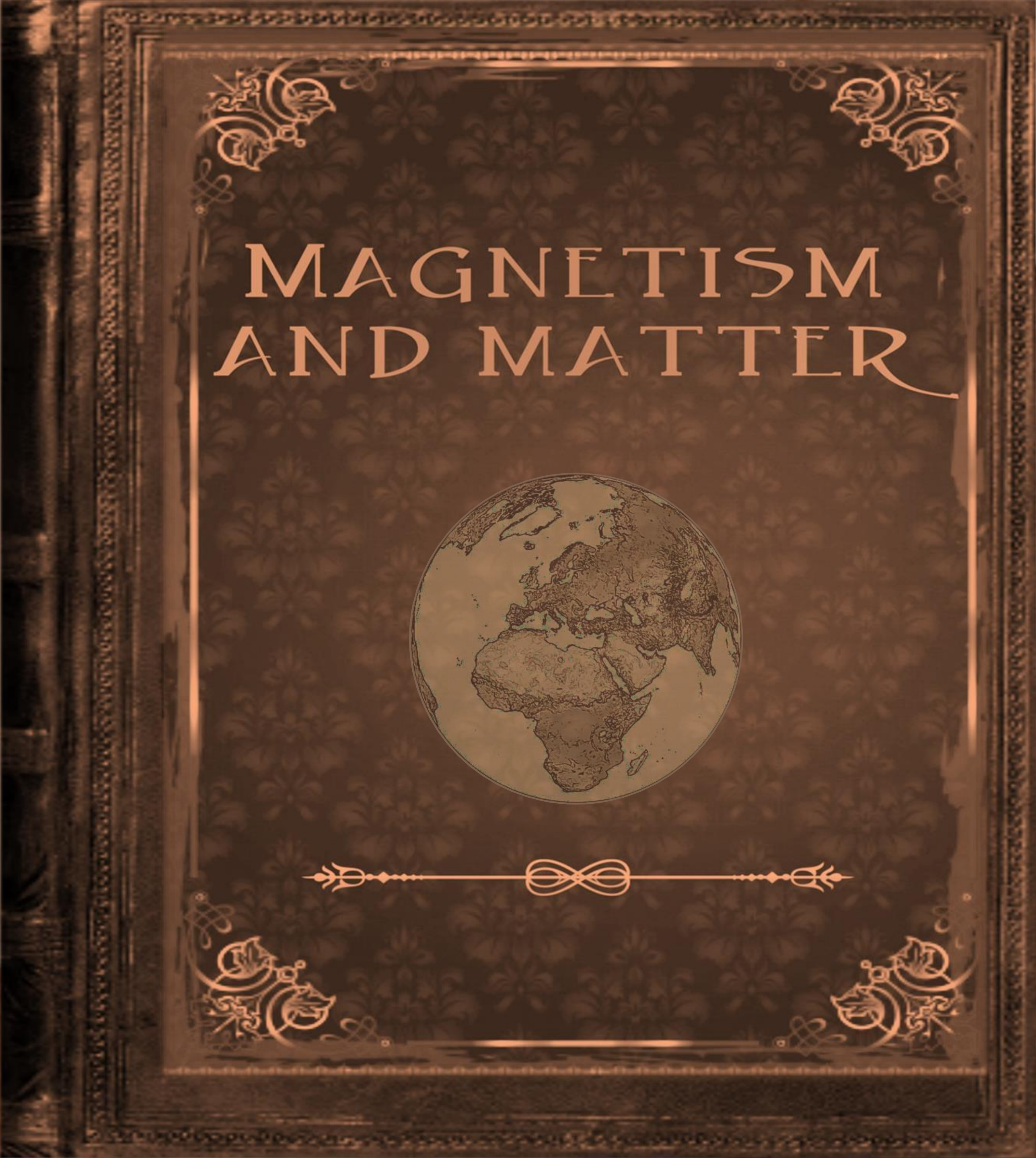
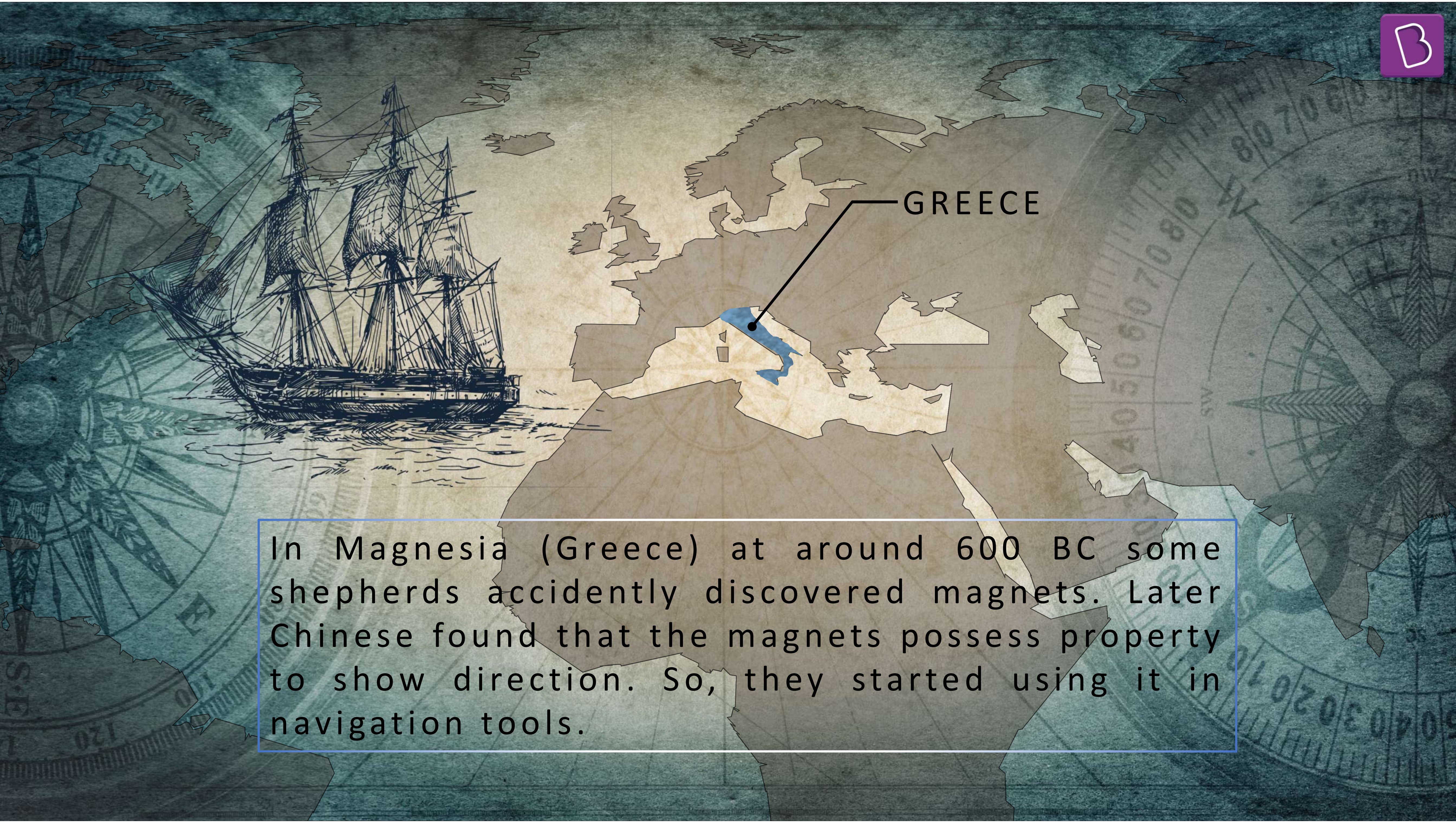
Welcome to

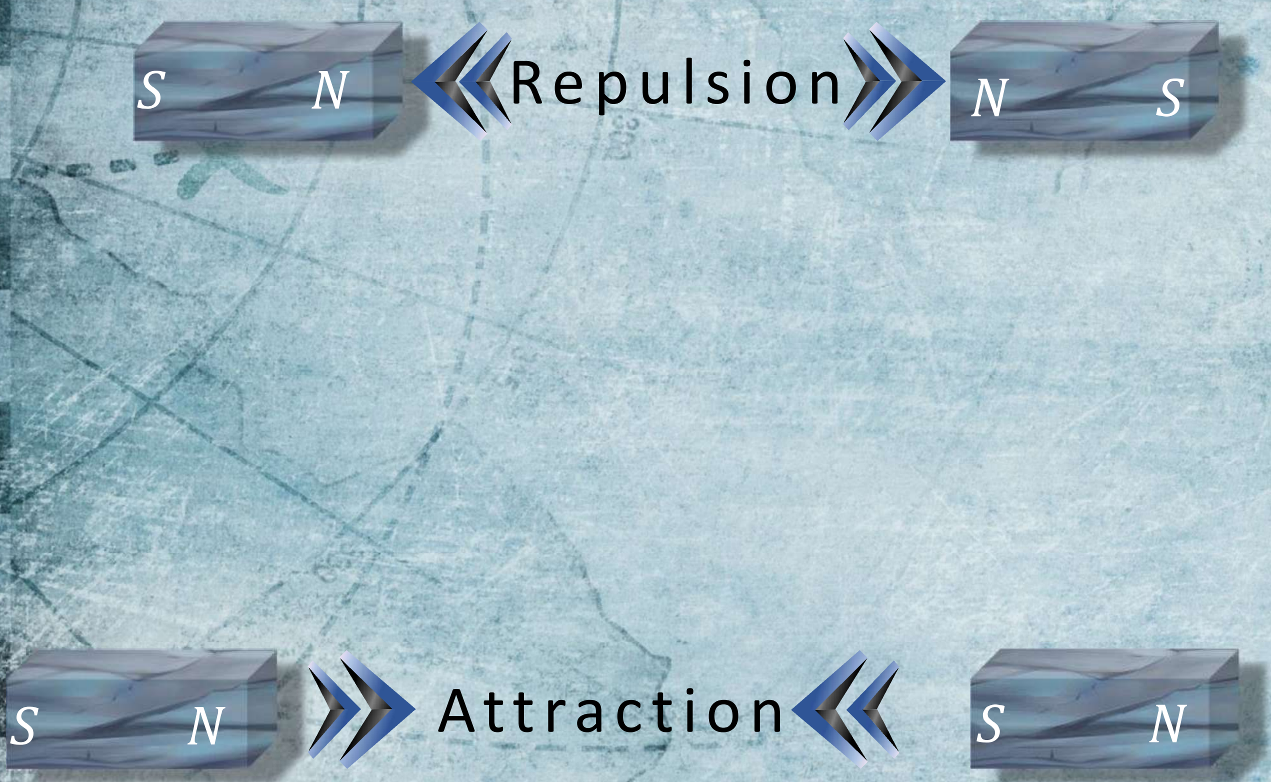
BYJU'S Classes

MAGNETIC MATERIALS AND PERMANENT MAGNET



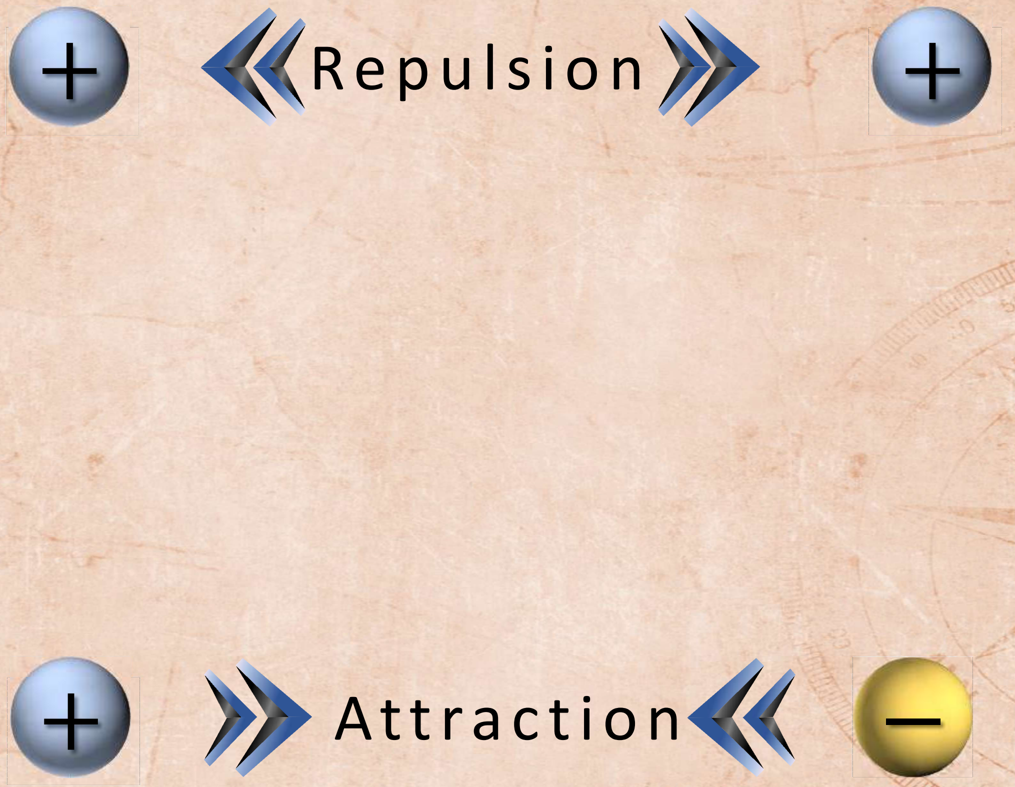


In Magnesia (Greece) at around 600 BC some shepherds accidently discovered magnets. Later Chinese found that the magnets possess property to show direction. So, they started using it in navigation tools.



Repulsion

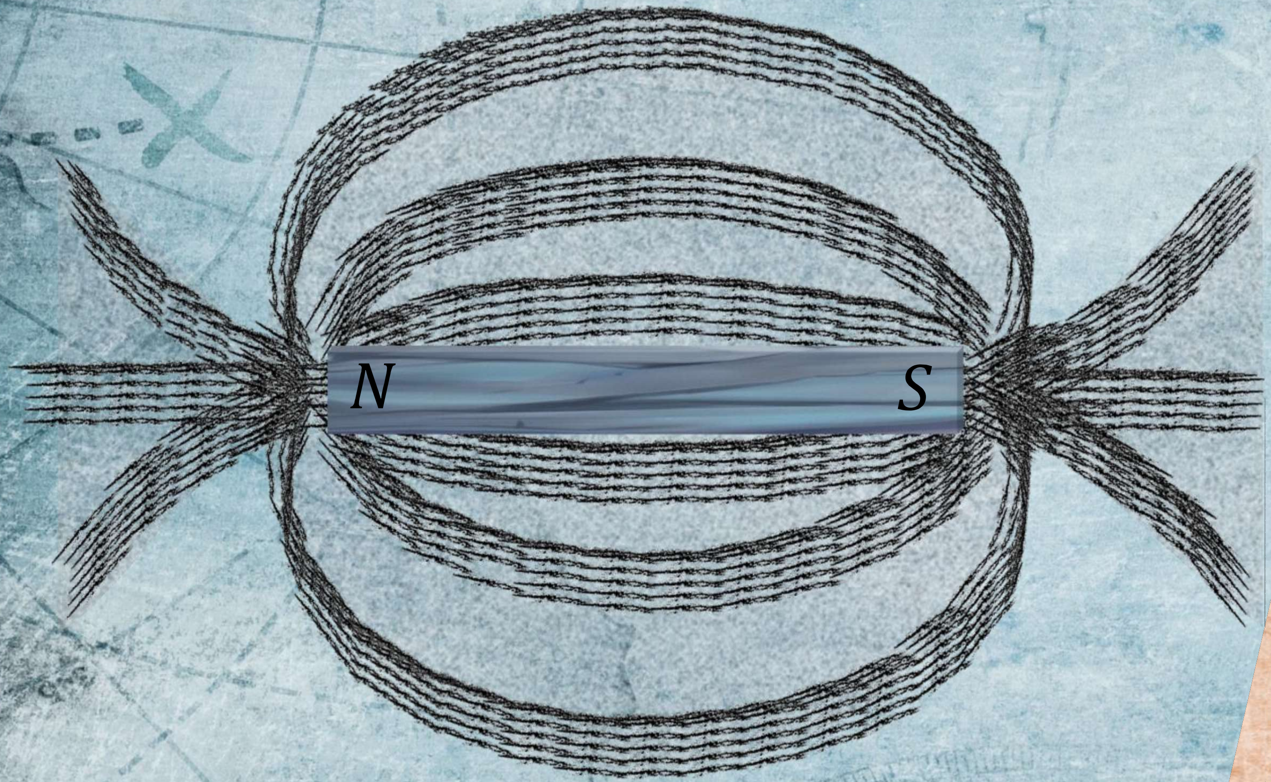
Attraction

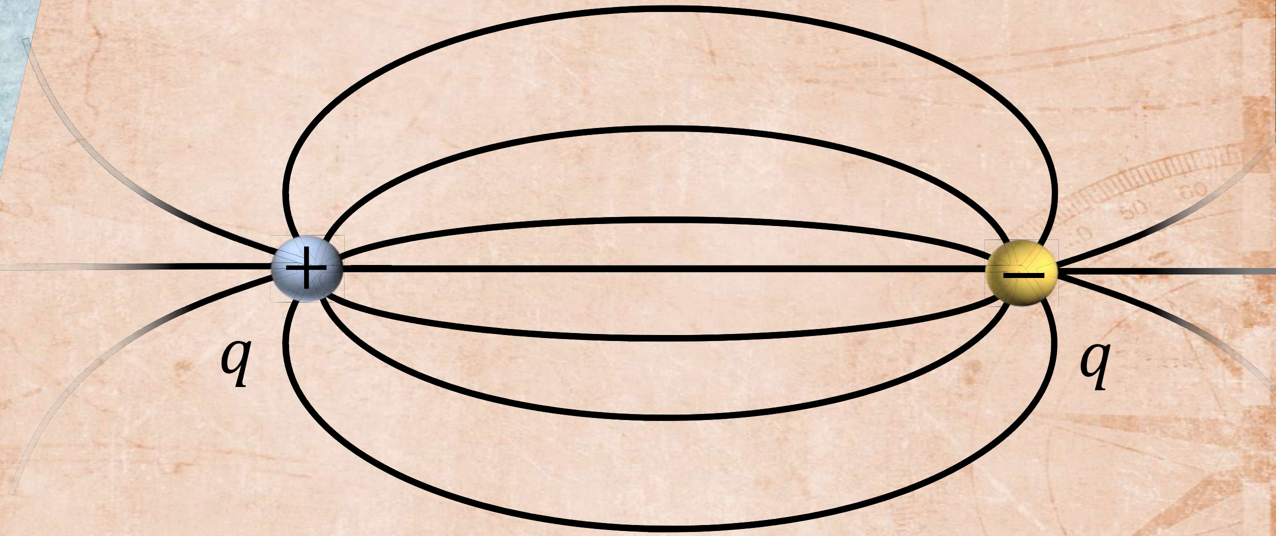


Repulsion

Attraction

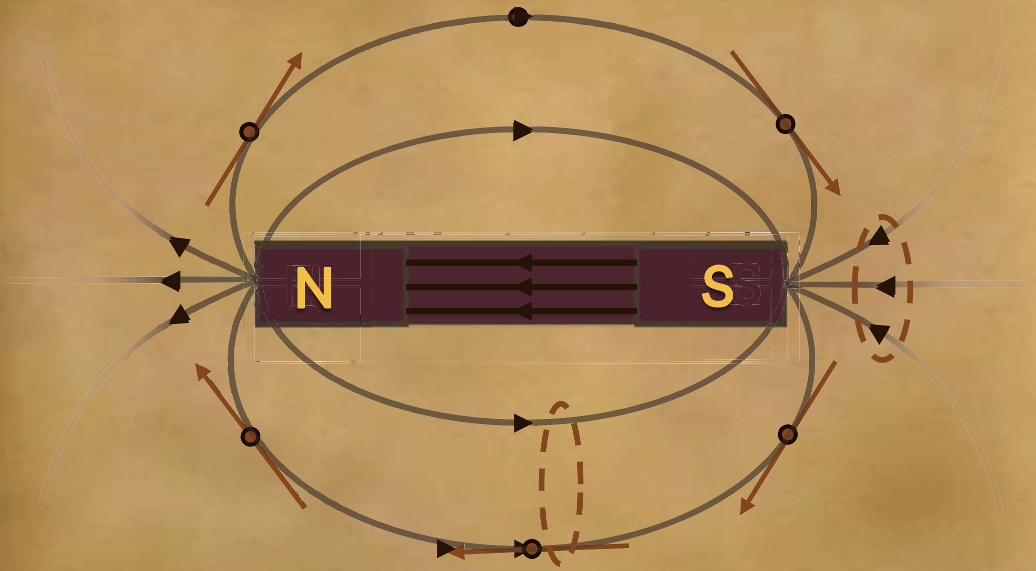
Opposite poles attract and similar poles repulse similar to the case of electric charges.

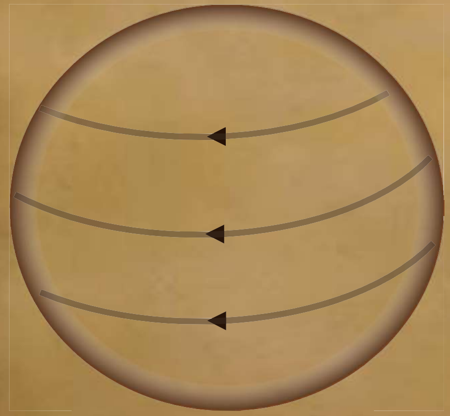




As an electric charge produces electric field in its surrounding region, a magnet also produces a field known as ‘Magnetic field’ in its surrounding region.

Magnetic field lines




Right

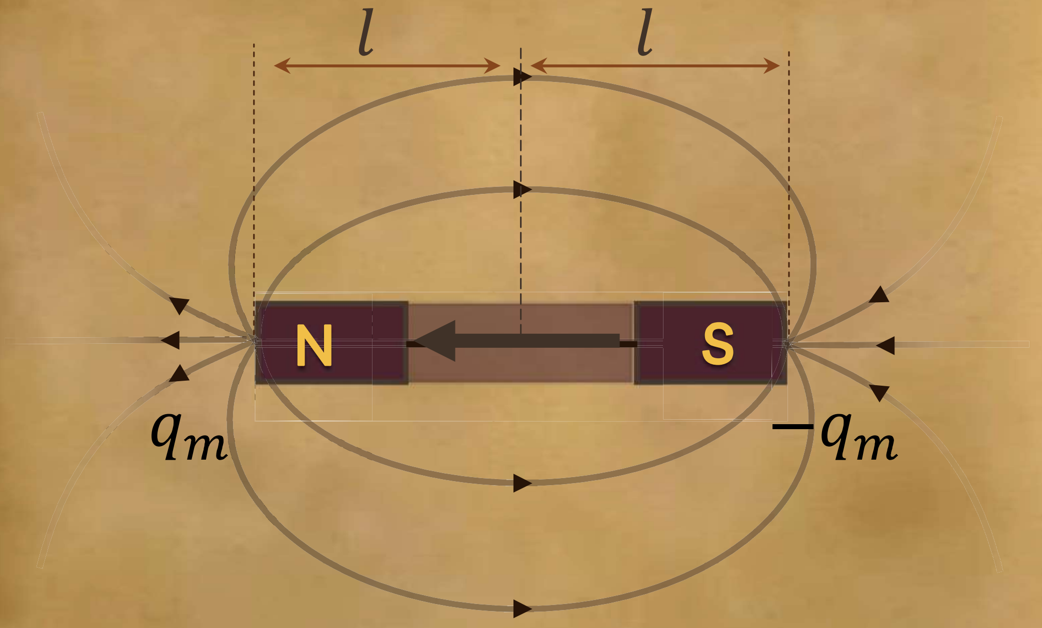

wrong

- The magnetic field lines are a visual and intuitive realization of the magnetic field.
- Outside the magnet, the field is directed from north pole to south pole. However, inside the magnet, the field is directed from south pole to north pole.

Properties of magnetic field lines:

- Magnetic field lines form closed loops.
- The tangent to the field line at a given point represents the direction of the net magnetic field $\vec{B}$ at that point.
- Closer the field lines, stronger is the magnetic field $\vec{B}$
- Magnetic field lines never intersects each other because at the intersection there will be two tangents giving two different directions of the field which is impossible.

Magnetic dipole moment

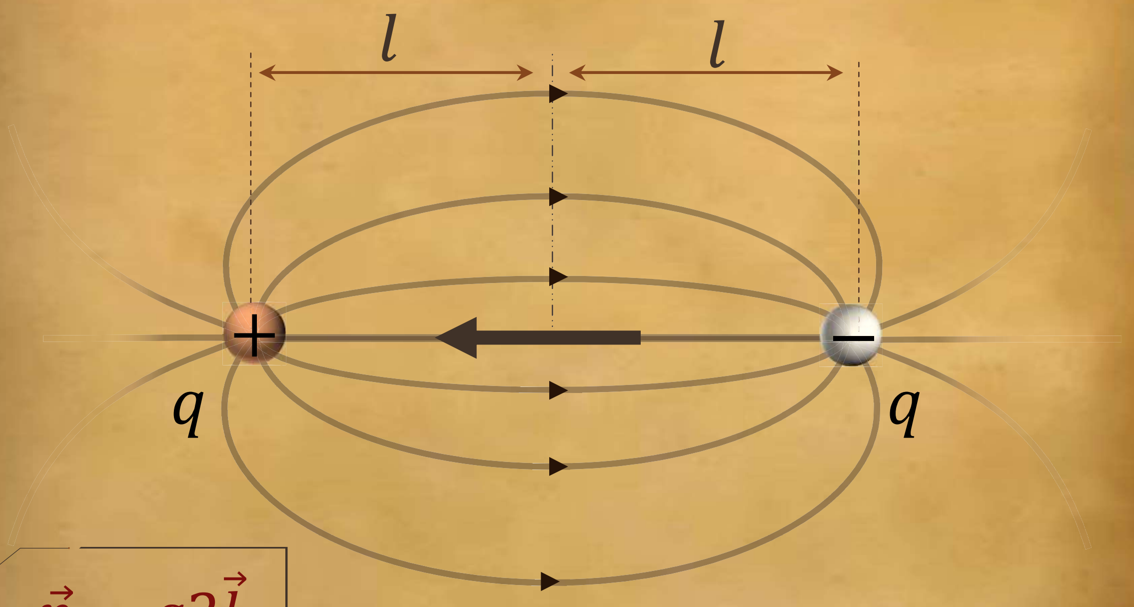


- Hypothetical $+q_m$ magnetic charge is assigned to north pole, also called as pole strength.
- Similarly, $-q_m$ magnetic charge is assigned to south pole.

$$\vec{M} = q_m 2\vec{l}$$

Along the vector joining south pole to north pole

Electric dipole moment

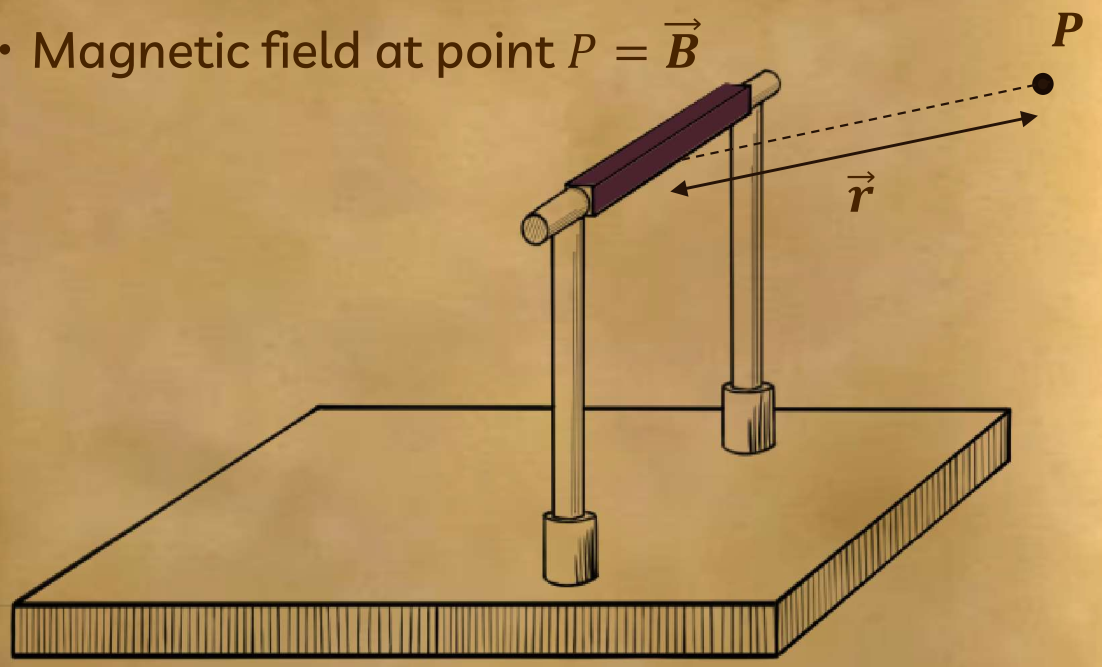


$$\vec{p} = q2\vec{l}$$

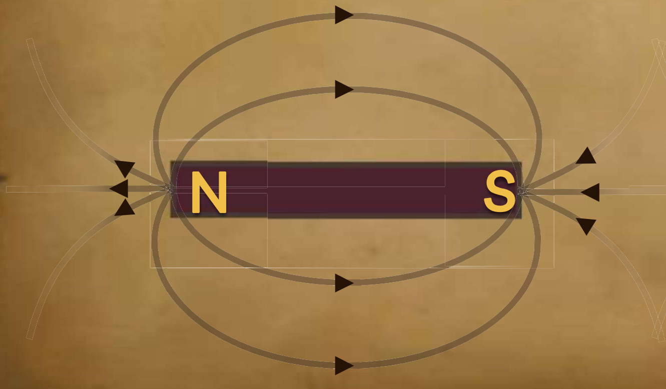
Along the vector joining $-ve$ charge to $+ve$ charge

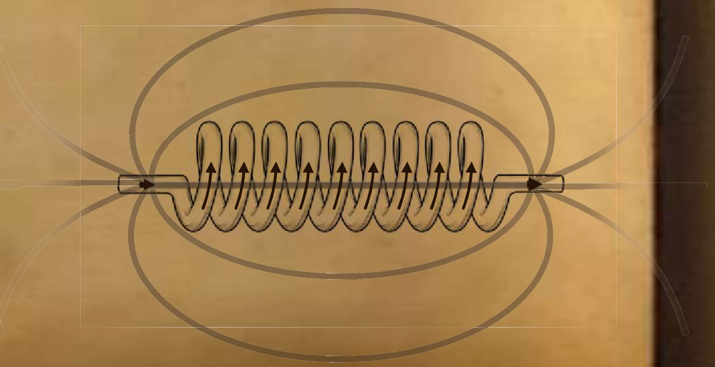
Magnetic dipole moment

- Magnetic field at point $P = \vec{B}$

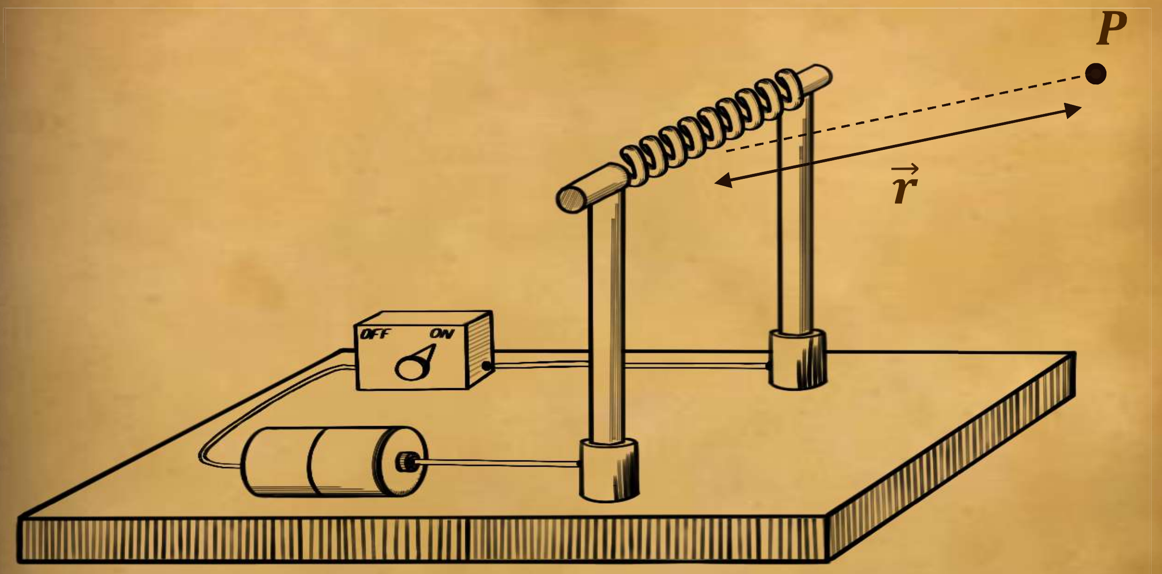


- Bar magnet and a solenoid produce similar magnetic fields.





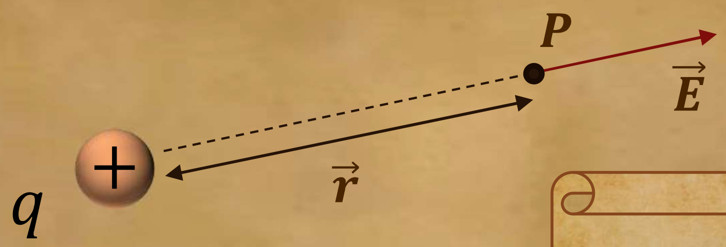
- Magnetic field at point $P = \vec{B}$



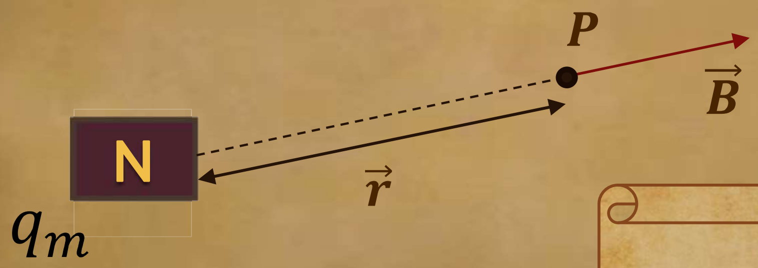
- The magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces the same magnetic field.
- Magnetic moment of solenoid

  M = Total number of turns × current × cross-sectional area
- A loop carrying current in clockwise direction acts as south pole and if current is in anti-clockwise direction, it acts as north pole.

Magnetic monopole (Hypothetical)



$$|\vec{E}| = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{q}{r^2}$$



$$|\vec{B}| = \left(\frac{\mu_0}{4\pi}\right)\frac{q_m}{r^2}$$

Electrostatic analogy

$$q_m \rightarrow q$$

$$\vec{B} \rightarrow \vec{E}$$

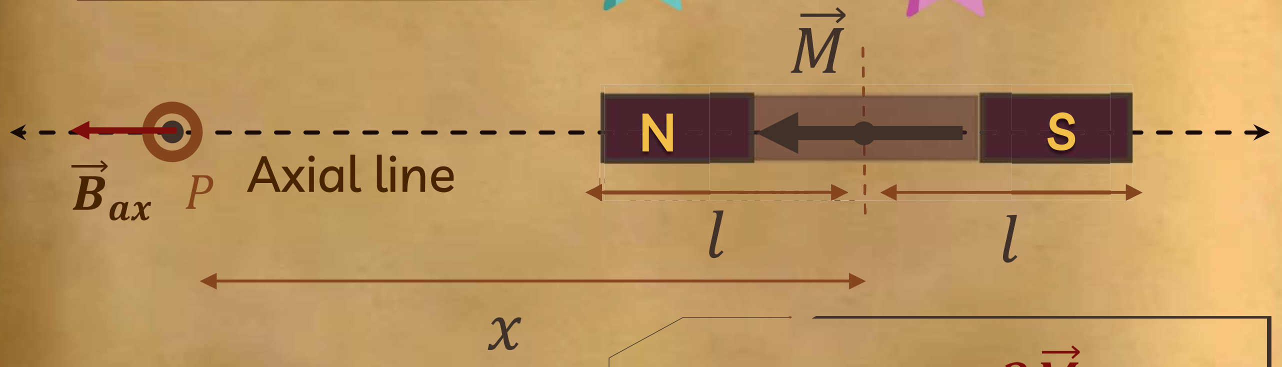
$$\vec{M} \rightarrow \vec{p}$$

$$\frac{\mu_0}{4\pi} \rightarrow \frac{1}{4\pi\epsilon_0}$$

Magnetic field due to magnetic dipole

At axial point

BOARDS NEET



$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}x}{(x^2 - l^2)^2}$$

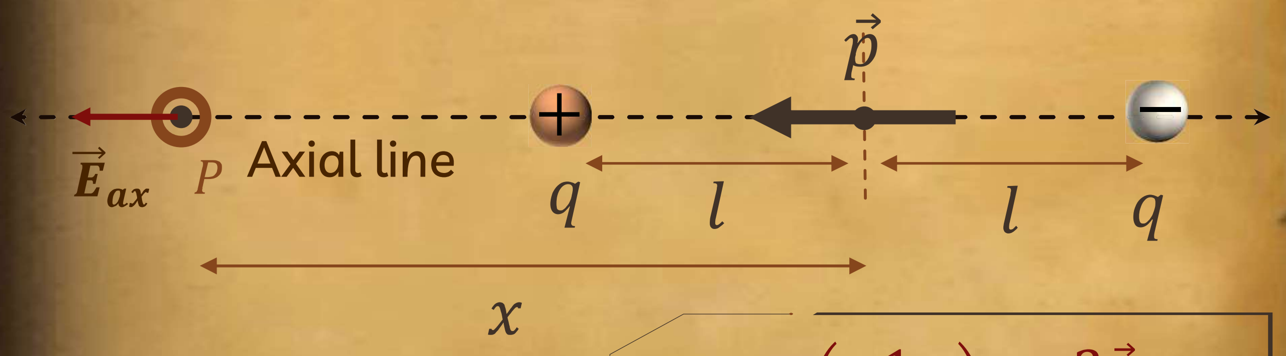
- For short magnets, $x \gg l$

$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}}{x^3}$$

- Direction of $\vec{B}_{ax}$ is along $\vec{M}$.

Electric field due to electric dipole

At axial point



$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}x}{(x^2 - l^2)^2}$$

- When $x \gg l$

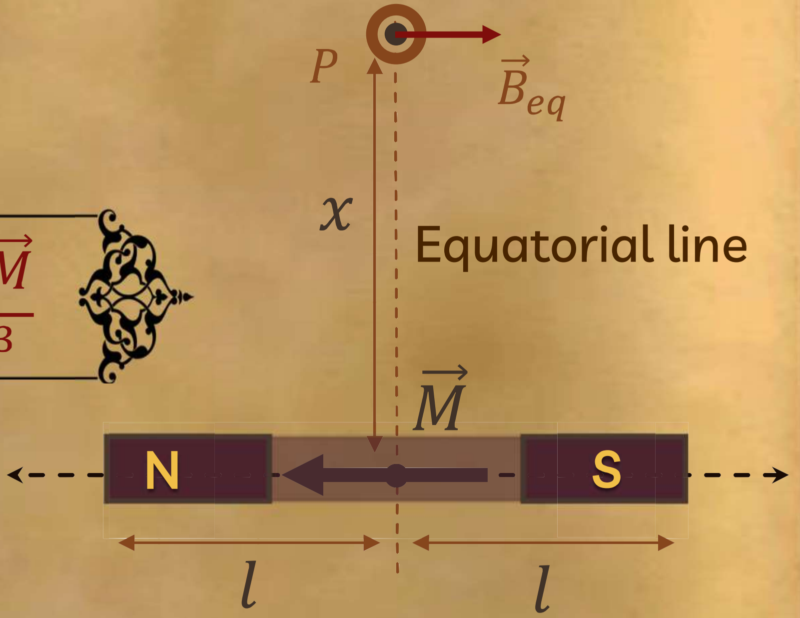
$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}}{x^3}$$

- Direction of $\vec{E}_{ax}$ is along $\vec{p}$.

Magnetic field due to magnetic dipole

At equatorial point BOARDS NEET

$$\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{-\vec{M}}{x^3}$$

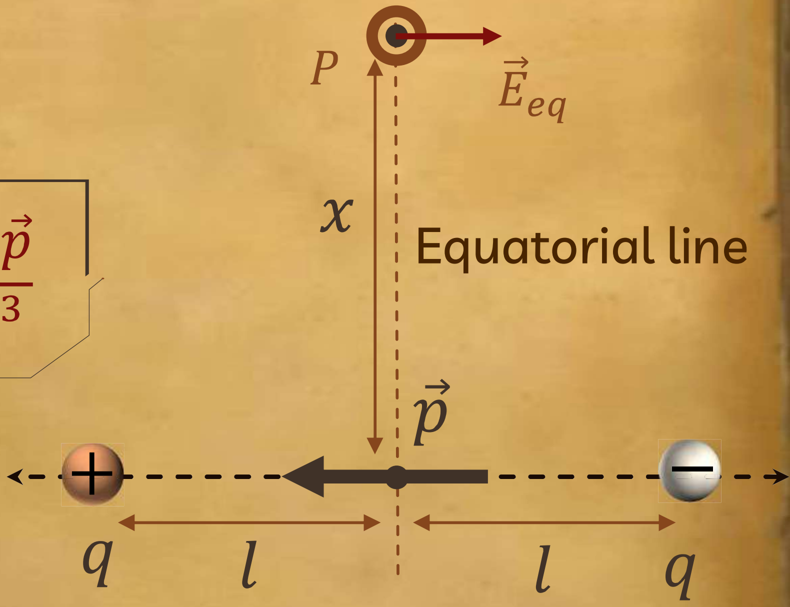


- Direction of $\vec{B}_{eq}$ is opposite to $\vec{M}$.

Electric field due to electric dipole

At equatorial point

$$\vec{E}_{eq} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{-\vec{p}}{x^3}$$



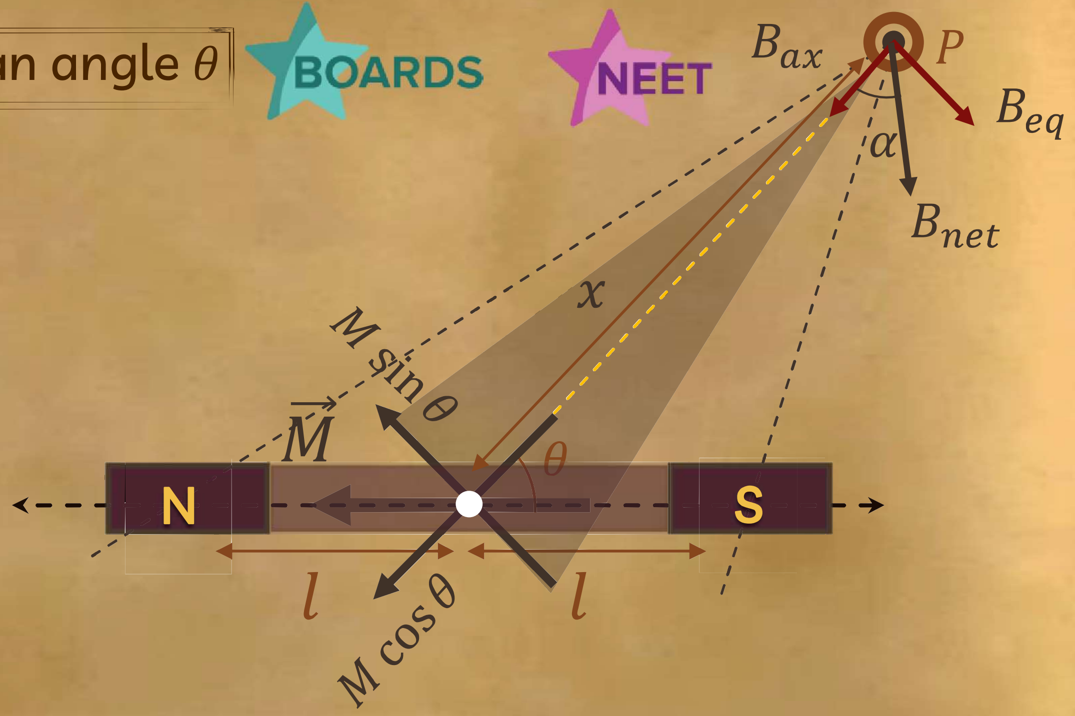
- Direction of $\vec{E}_{eq}$ is opposite to $\vec{p}$.

Magnetic field due to magnetic dipole

At an angle θ

BOARDS

NEET

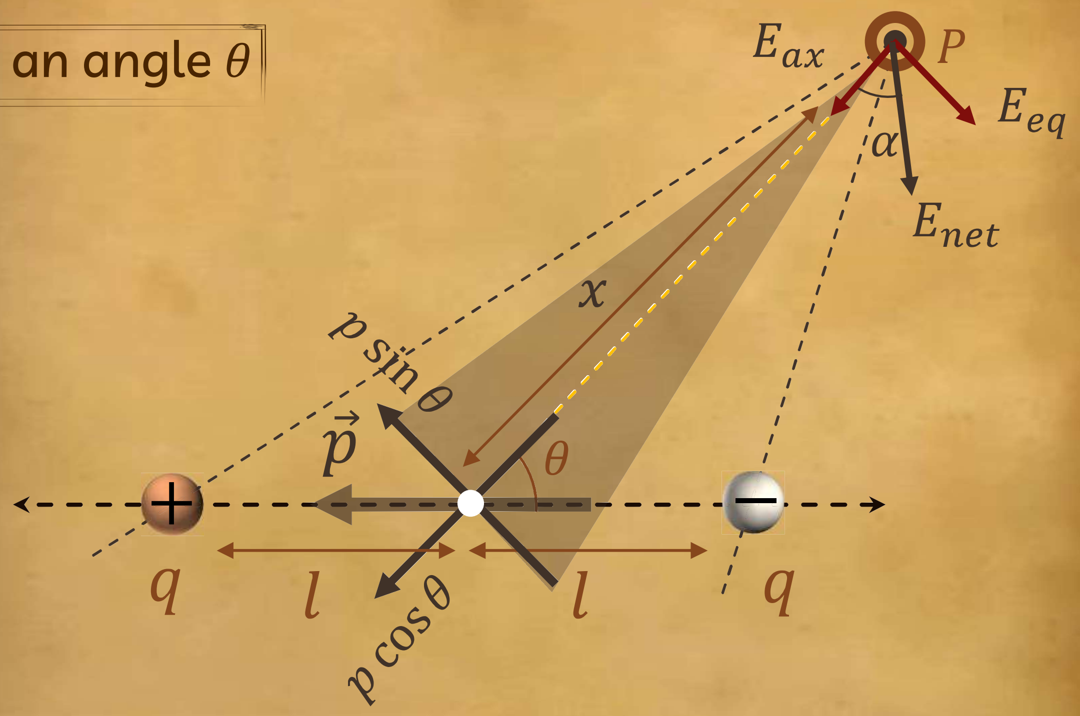


$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}\cos\theta}{x^3}$$

$$\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{(-\vec{M}\sin\theta)}{x^3}$$

Electric field due to electric dipole

At an angle θ

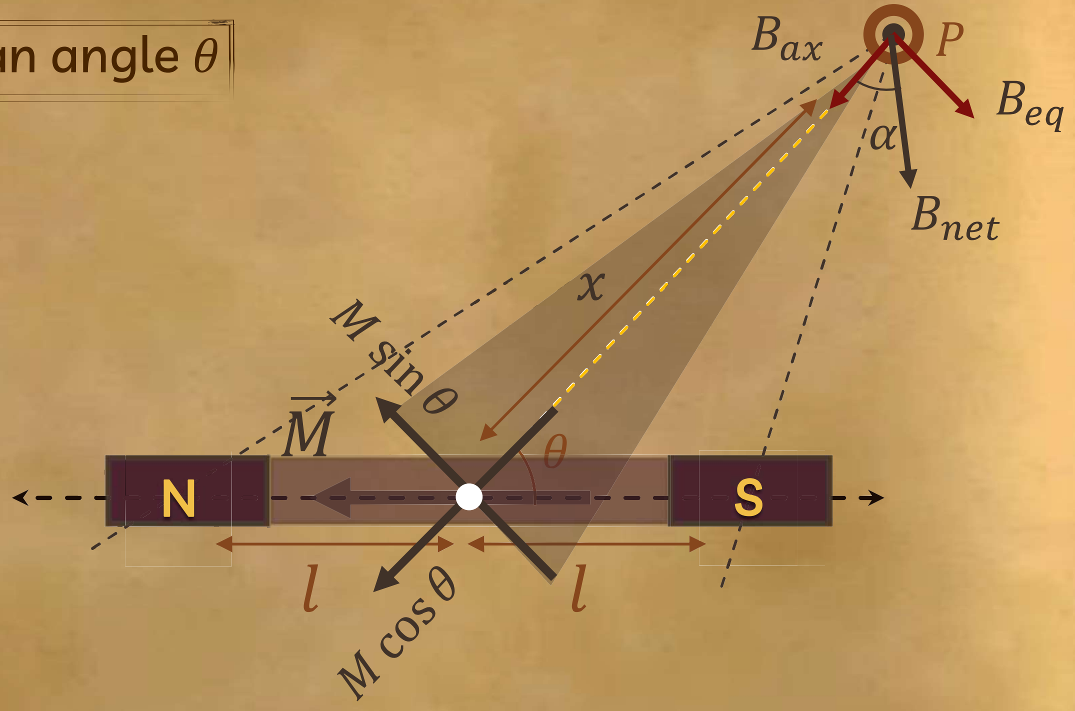


$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}\cos\theta}{x^3}$$

$$\vec{E}_{eq} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{(-\vec{p}\sin\theta)}{x^3}$$

Magnetic field due to magnetic dipole

At an angle θ

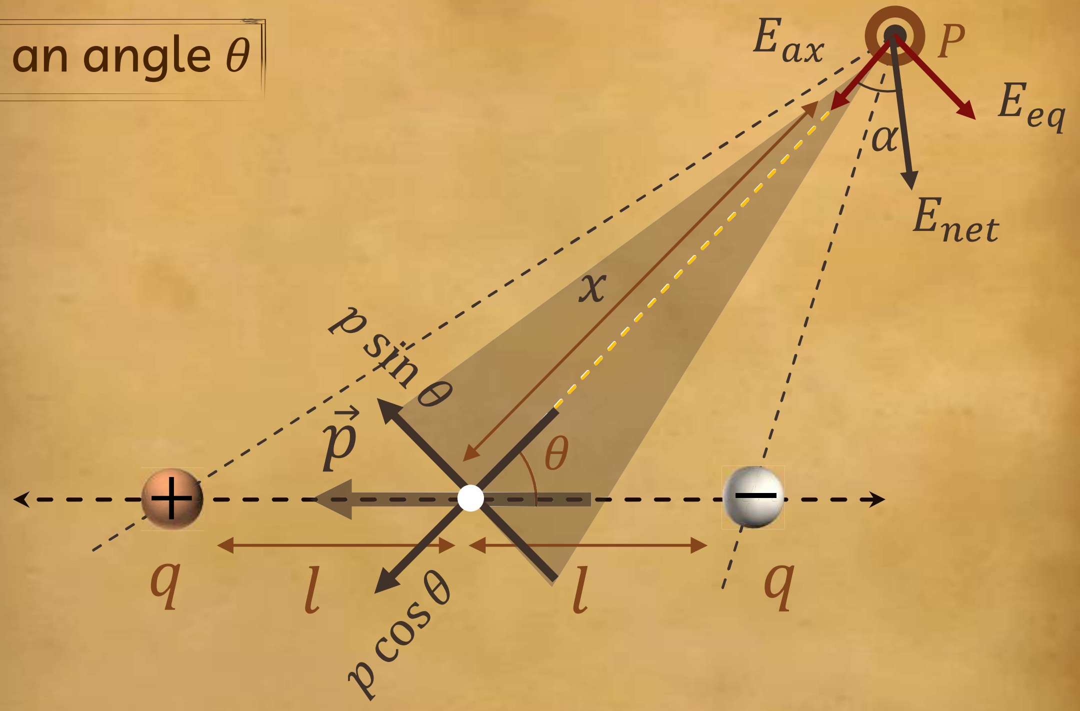


$$|\vec{B}_{net}| = \left(\frac{\mu_0}{4\pi}\right)\frac{|\vec{M}|}{x^3}\sqrt{1+3\cos^2\theta}$$

$$\tan\alpha = \frac{\tan\theta}{2}$$

Electric field due to electric dipole

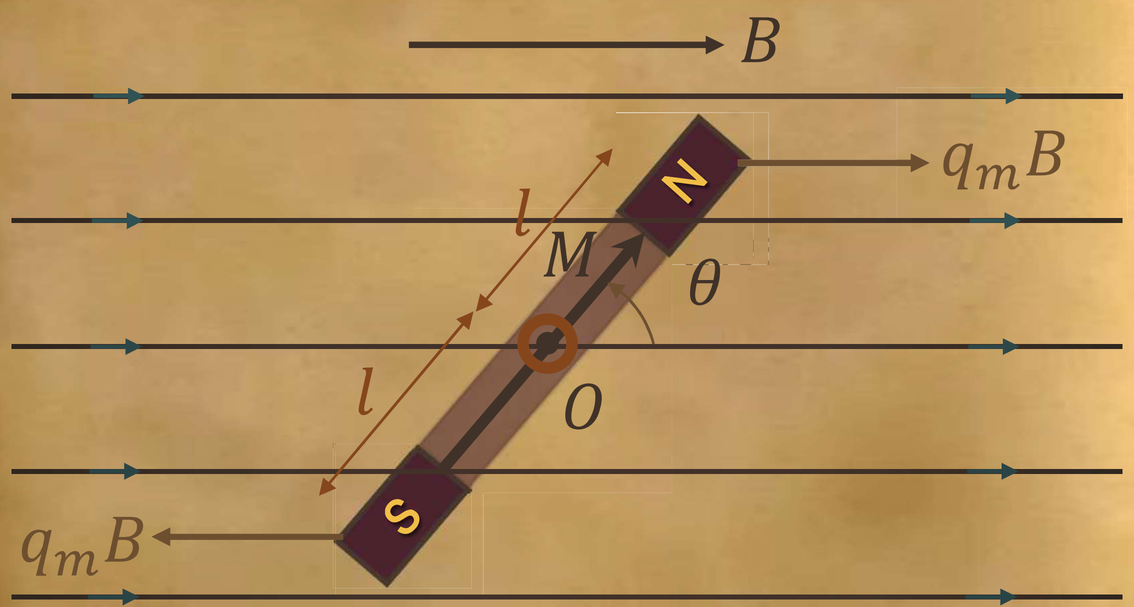
At an angle θ



$$|\vec{E}_{net}| = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{|\vec{p}|}{x^3}\sqrt{1+3\cos^2\theta}$$

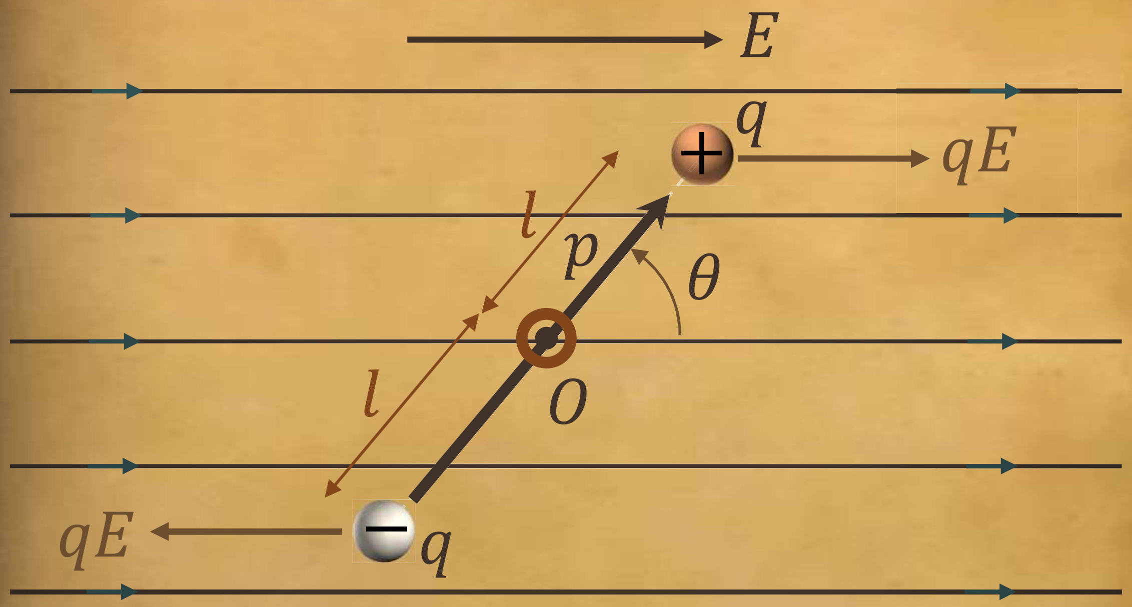
$$\tan\alpha = \frac{\tan\theta}{2}$$

Magnetic dipole in uniform magnetic field



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

Electric dipole in uniform electric field

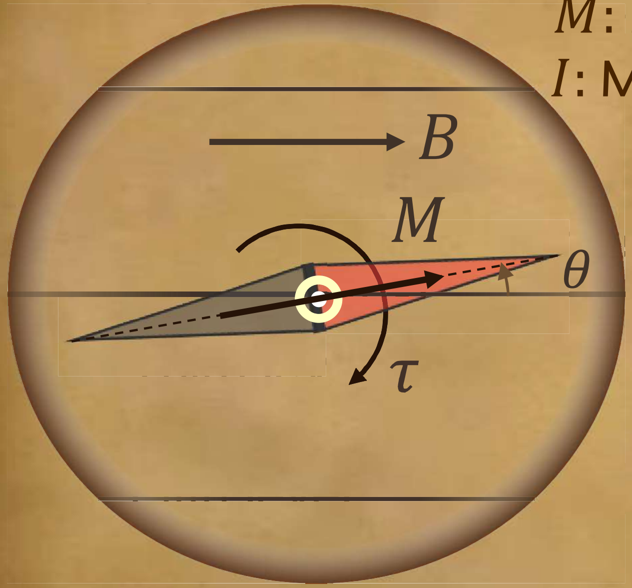


$$\vec{\tau}_{net} = \vec{p} \times \vec{E}$$

Magnetic dipole in uniform magnetic field

M: Magnetic dipole moment

I: Moment of inertia of magnet



- τ is restoring torque and θ is the angle between $\vec{M}$ and $\vec{B}$

$$\tau = MB\sin\theta \qquad \Big| \qquad \tau = I\frac{d^2\theta}{dt^2}$$

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

- $-ve$ sign implies that the restoring torque is opposite to deflecting torque.

- For small value of θ in radians.

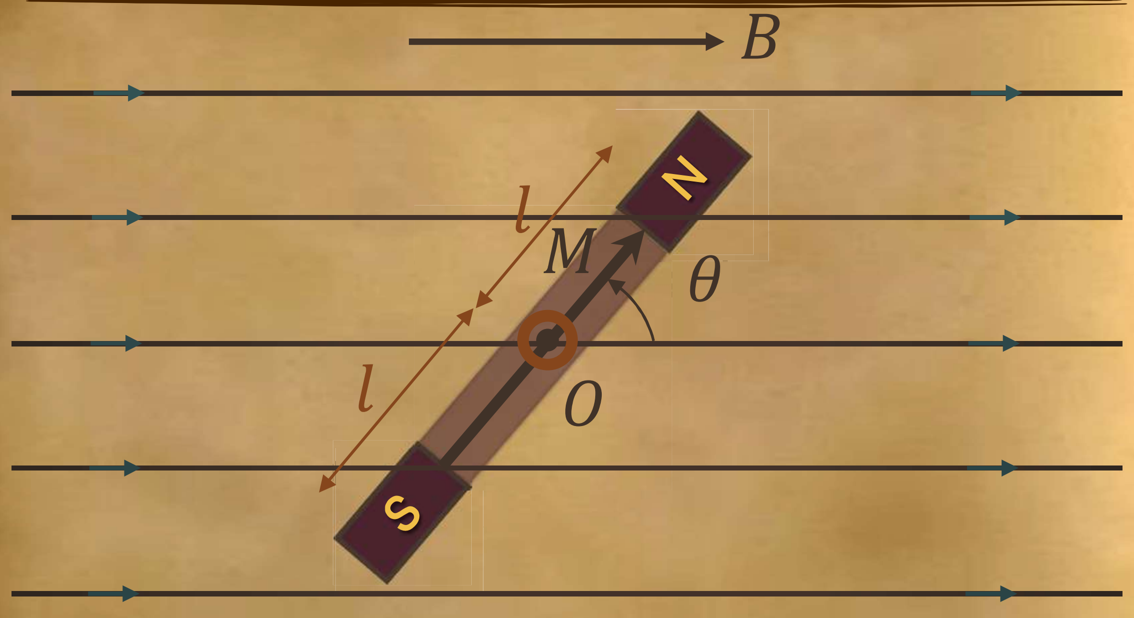
$$I\frac{d^2\theta}{dt^2} \approx -MB\theta \qquad \Rightarrow \qquad I\frac{d^2\theta}{dt^2} = -MB\theta$$

$$\frac{d^2\theta}{dt^2} = -\frac{MB\theta}{I} \qquad \Big| \qquad \frac{d^2x}{dt^2} = -\omega^2 x \text{ (S.H.M equation)}$$

$$\omega^2 = \frac{MB}{I} \qquad \text{OR} \qquad \omega = \sqrt{\frac{MB}{I}}$$

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{MB}}$$

Magnetic dipole in uniform magnetic field

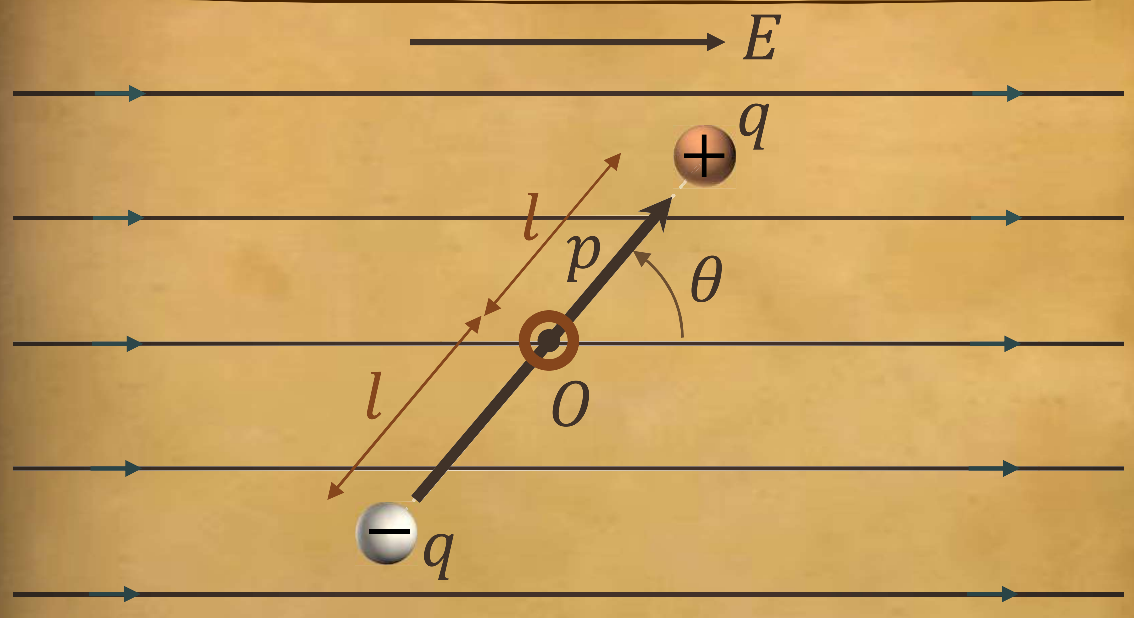


Potential energy

$$
\begin{aligned}
U &= -\vec{M}\cdot\vec{B}\\
&= -|\vec{M}||\vec{B}|\cos\theta
\end{aligned}
$$

Taking zero potential at $\theta = 90^\circ$

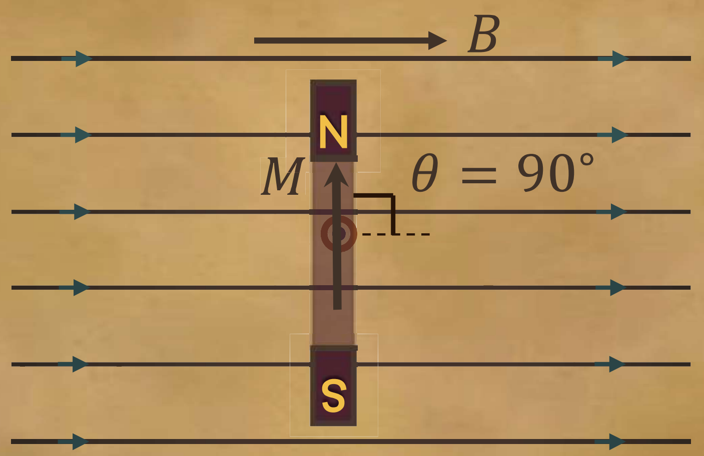
Electric dipole in uniform electric field



Potential energy

$$
\begin{aligned}
U &= -\vec{p}\cdot\vec{E}\\
&= -|\vec{p}||\vec{E}|\cos\theta
\end{aligned}
$$

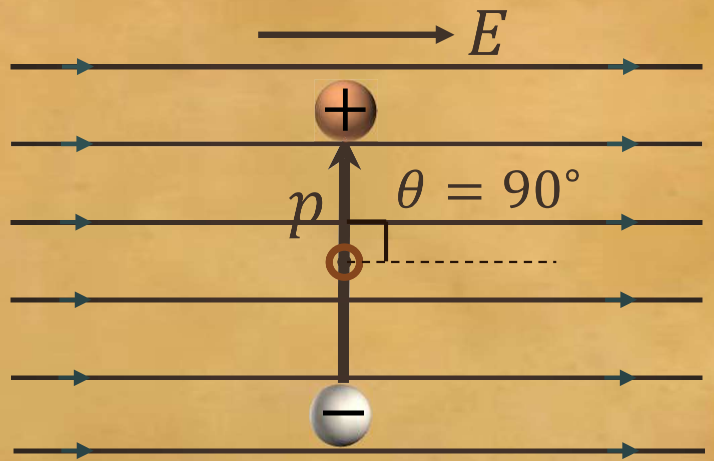
Magnetic dipole in uniform magnetic field



Case 1: $\theta = 90^\circ$

$$U = -|\vec{M}||\vec{B}|\cos 90^\circ$$
$$= 0$$

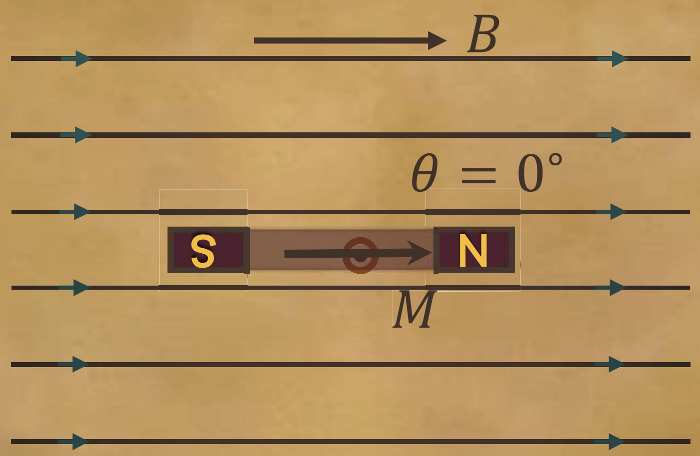
Electric dipole in uniform electric field



Case 1: $\theta = 90^\circ$

$$U = -|\vec{p}||\vec{E}|\cos 90^\circ$$
$$= 0$$

Magnetic dipole in uniform magnetic field



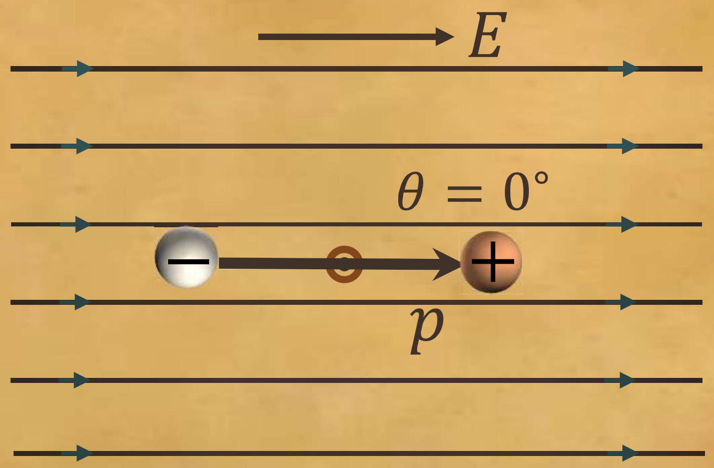
(Stable equilibrium)

Case 2: $\theta = 0^\circ$

$$U = -|\vec{M}||\vec{B}| \cos 0^\circ$$
$$= -|\vec{M}||\vec{B}|$$

- Potential energy is minimum.

Electric dipole in uniform electric field

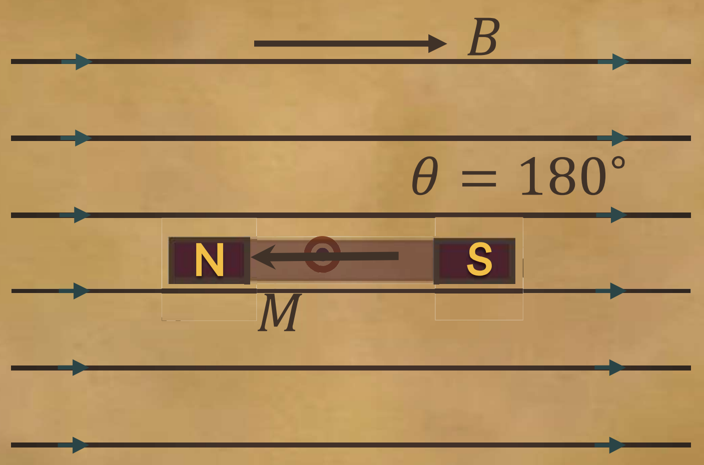


(Stable equilibrium)

Case 2: $\theta = 0^\circ$

$$U = -|\vec{p}||\vec{E}| \cos 0^\circ$$
$$= -|\vec{p}||\vec{E}|$$

Magnetic dipole in uniform magnetic field



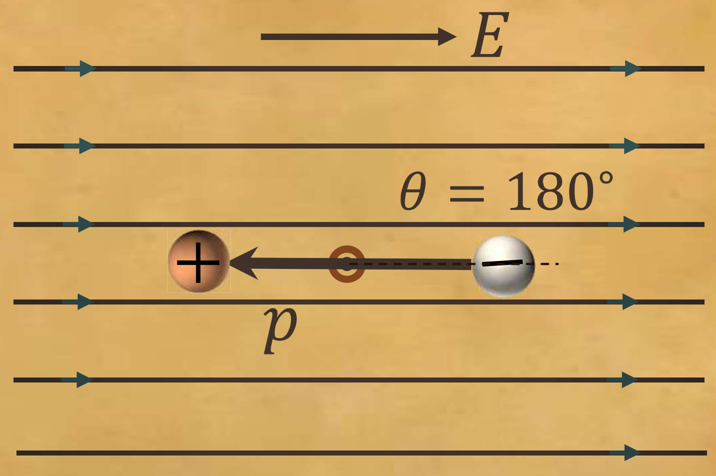
(Unstable equilibrium)

Case 3: $\theta = 180^\circ$

$$U = -|\vec{M}||\vec{B}| \cos 180^\circ$$
$$= |\vec{M}||\vec{B}|$$

- Potential energy is maximum.

Electric dipole in uniform electric field

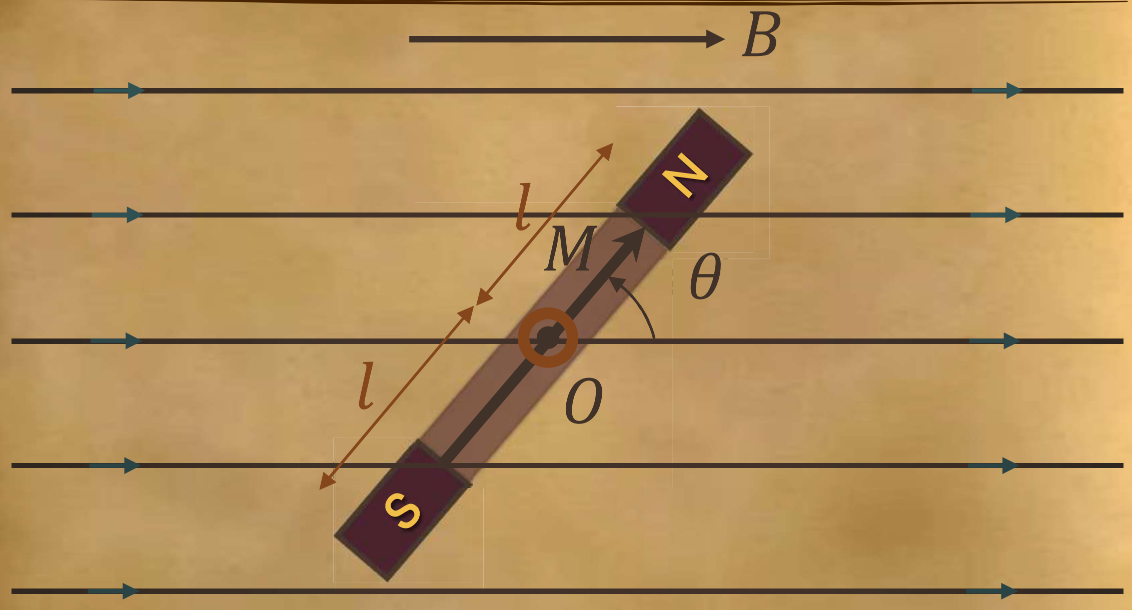


(Unstable equilibrium)

Case 3: $\theta = 180^\circ$

$$U = -|\vec{p}||\vec{E}| \cos 180^\circ$$
$$= |\vec{p}||\vec{E}|$$

Magnetic dipole in uniform magnetic field

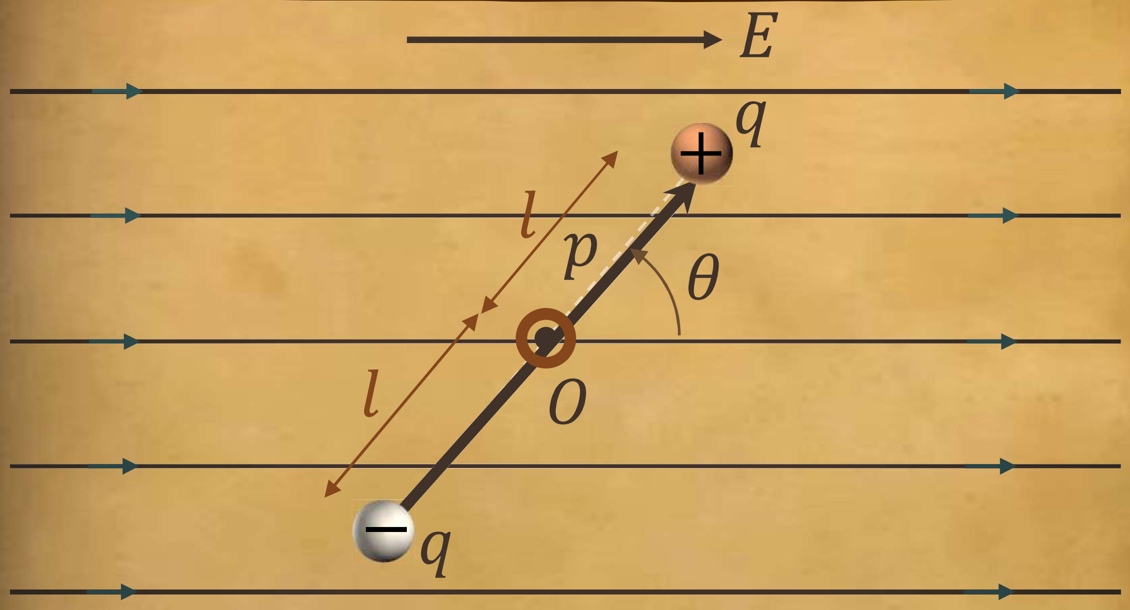


Work done by external force

$$W_{external} = \Delta U$$

- Taking zero potential at $\theta = 90^\circ$

Electric dipole in uniform electric field



Work done by external force

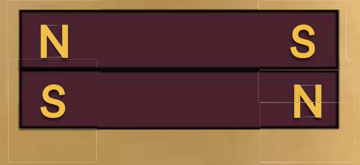
$$W_{external} = \Delta U$$

PROBLEM

Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment $\vec{M}$. Which configuration has highest net magnetic dipole moment?

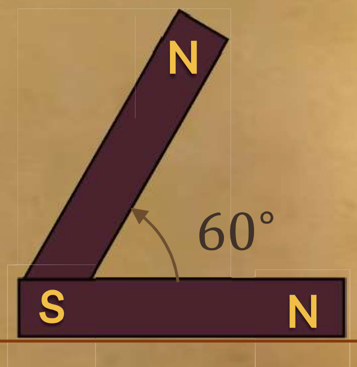
a.

b.



c.

d.

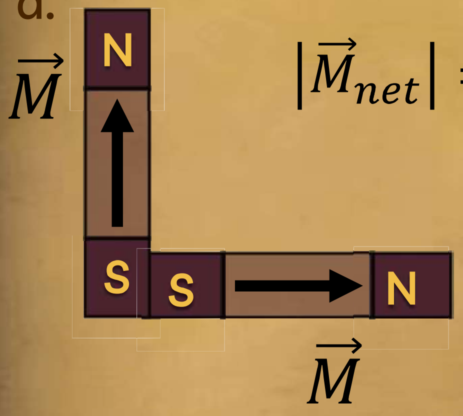


Solution

As magnetic moments have both direction and magnitude. We can find the net magnetic moment by adding them vectorially.

To find the configuration has highest net magnetic moment we need to find the magnetic moment for each configuration.

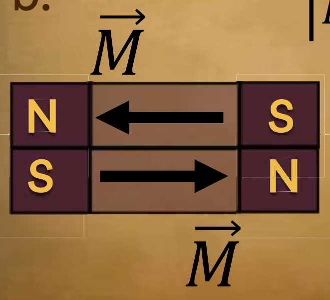
a.



$$|\vec{M}_{net}| = \sqrt{M^2 + M^2 + 2M^2 \cos 90^\circ}$$

$$= \sqrt{2}\, M$$

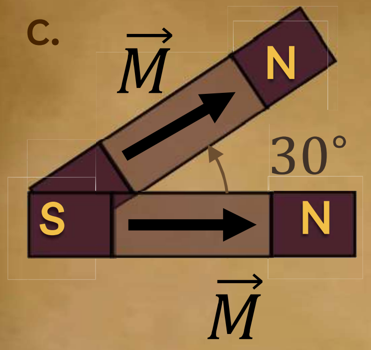
b.



$$|\vec{M}_{net}| = \sqrt{M^2 + M^2 + 2M^2 \cos 180^\circ}$$

$$= 0$$

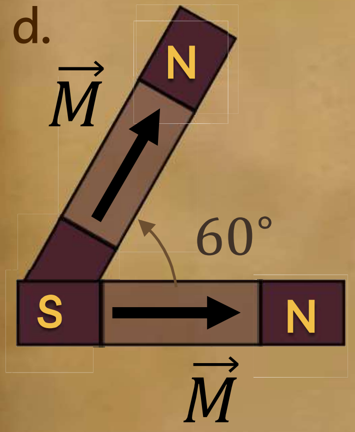
c.



$$|\vec{M}_{net}| = \sqrt{M^2 + M^2 + 2M^2 \cos 30^\circ}$$

$$= \sqrt{2 + \sqrt{3}}\, M$$

d.



$$|\vec{M}_{net}| = \sqrt{M^2 + M^2 + 2M^2 \cos 60^\circ}$$

$$= \sqrt{3}\, M$$

Therefore, option c is the correct answer.

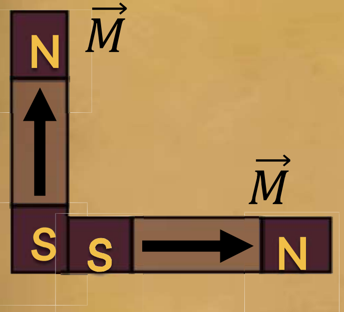
Short trick

We know that the direction of magnetic moment of a magnet is from south pole to north pole.

Thus, the configuration for which two magnets will have highest net magnetic moment is shown below.

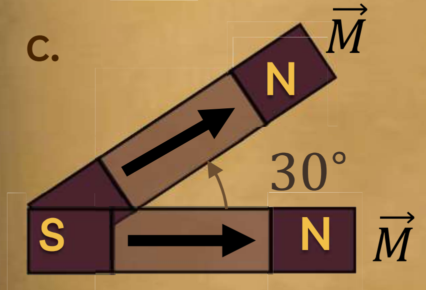
Now, from the given configurations, whichever is closest to the above configuration will have highest net magnetic dipole moment.

a.

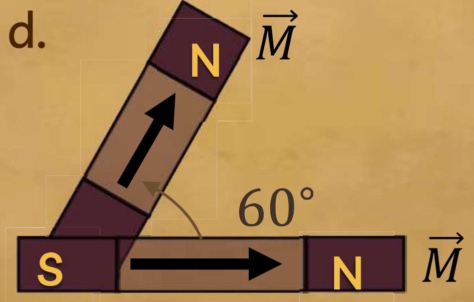


b.

c.



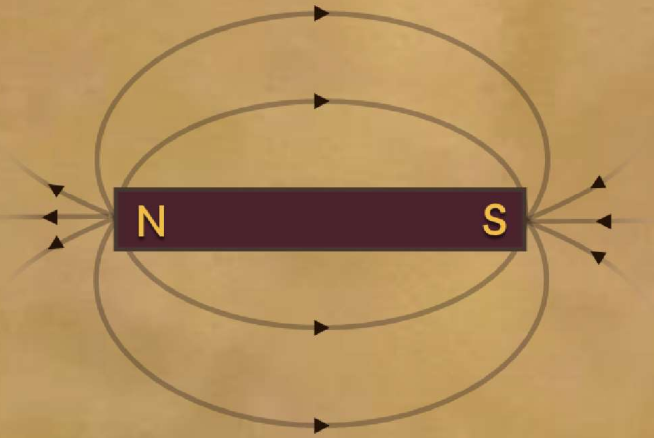
d.



Therefore, option c is the closest one. Thus, option c is the correct answer.

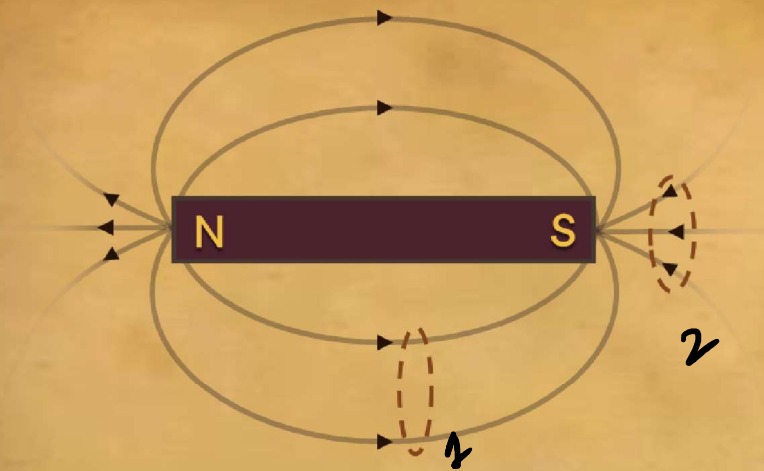
RECAP

Properties of magnetic field lines



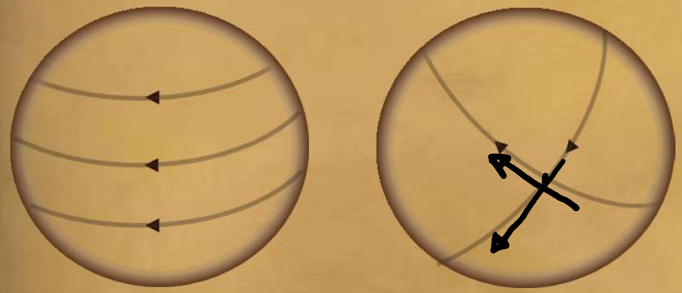
- Magnetic field lines form closed loops.

- The tangent to the field line at a given point represents the direction of the net magnetic field B at that point.



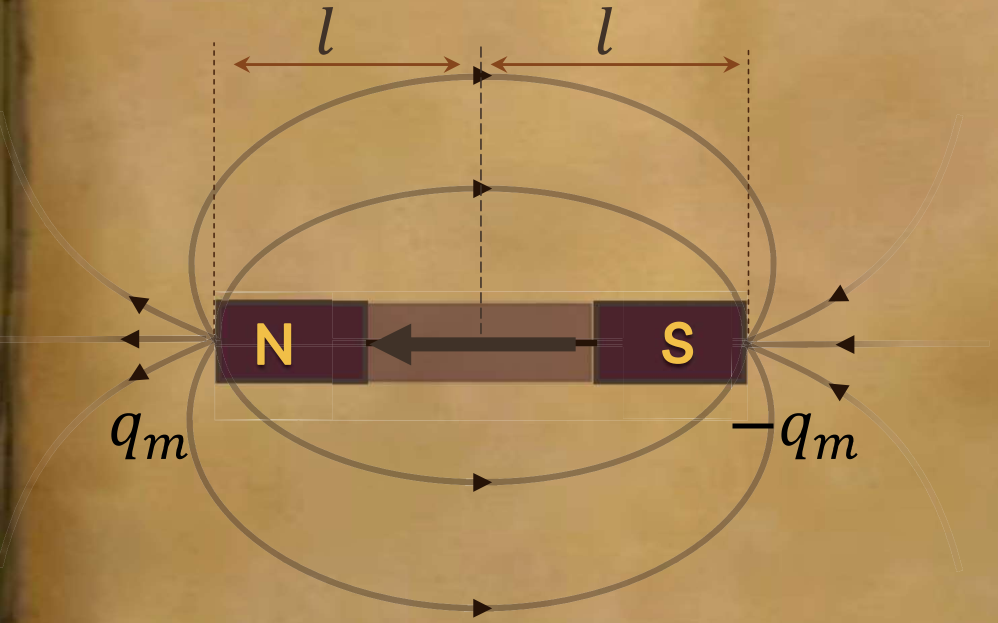
- Closer the field lines, stronger is the magnetic field $\vec{B}$

- Magnetic field lines never intersects each other.



RECAP

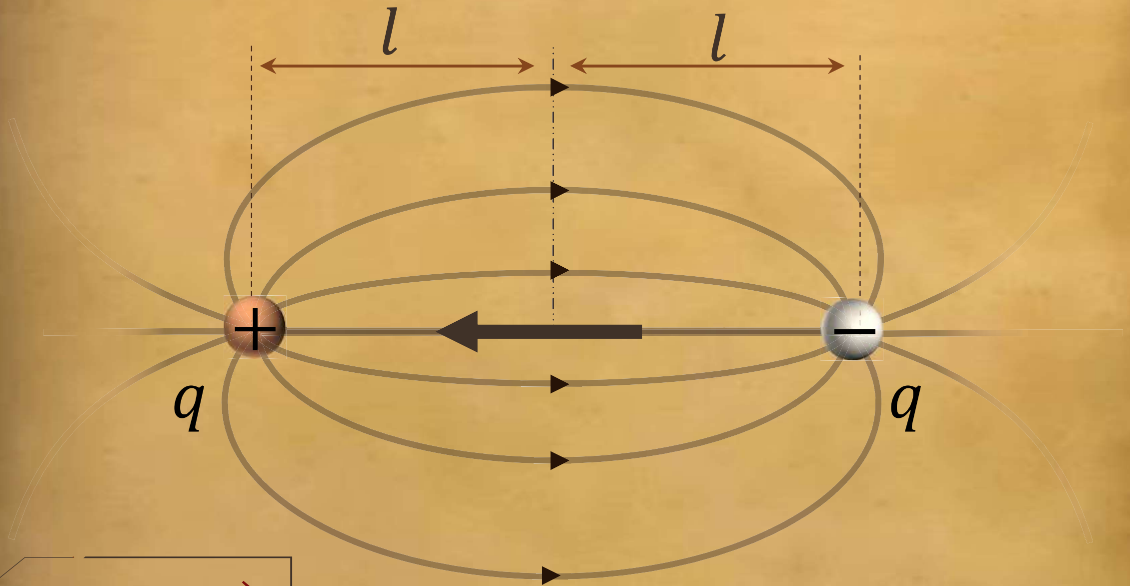
Magnetic dipole moment



$$\vec{m} = q_m 2\vec{l}$$

Along the vector joining south pole to north pole

Electric dipole moment

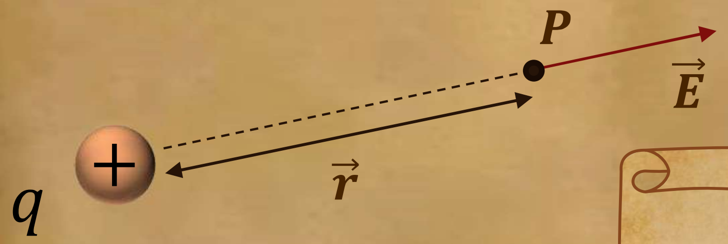


$$\vec{p} = q2\vec{l}$$

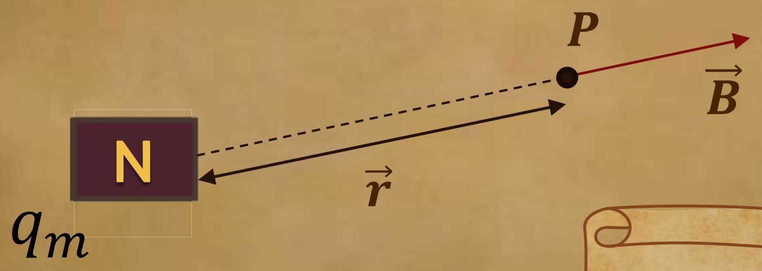
Along the vector joining $-ve$ charge to $+ve$ charge

RECAP

Magnetic monopole (Hypothetical)



$$|\vec{E}| = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{q}{r^2}$$



$$|\vec{B}| = \left(\frac{\mu_0}{4\pi}\right)\frac{q_m}{r^2}$$

Electrostatic analogy

$$q_m \rightarrow q$$

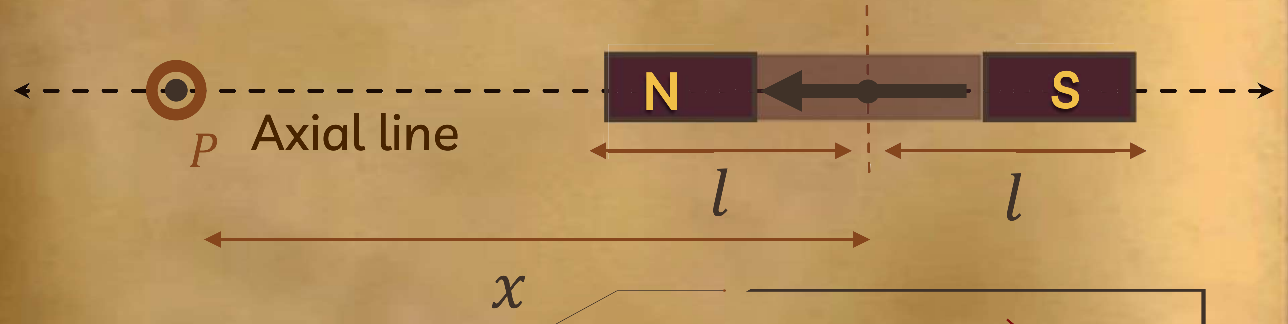
$$\vec{B} \rightarrow \vec{E}$$

$$\frac{\mu_0}{4\pi} \rightarrow \frac{1}{4\pi\epsilon_0}$$

RECAP

Magnetic field due to magnetic dipole

At axial point



$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}x}{(x^2 - l^2)^2}$$

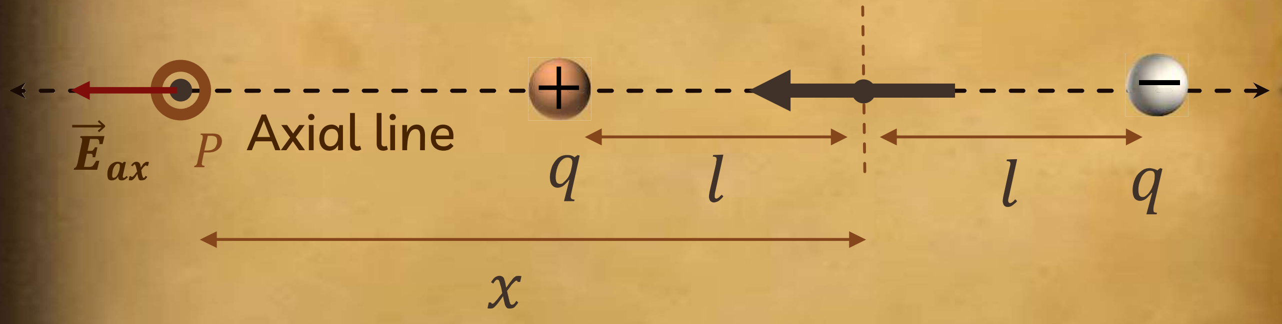
- For short magnets, $x \gg l$

$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}}{x^3}$$

- Direction of $\vec{B}_{ax}$ is along $\vec{M}$.

Electric field due to electric dipole

At axial point



$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}x}{(x^2 - l^2)^2}$$

- When $x \gg l$

$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}}{x^3}$$

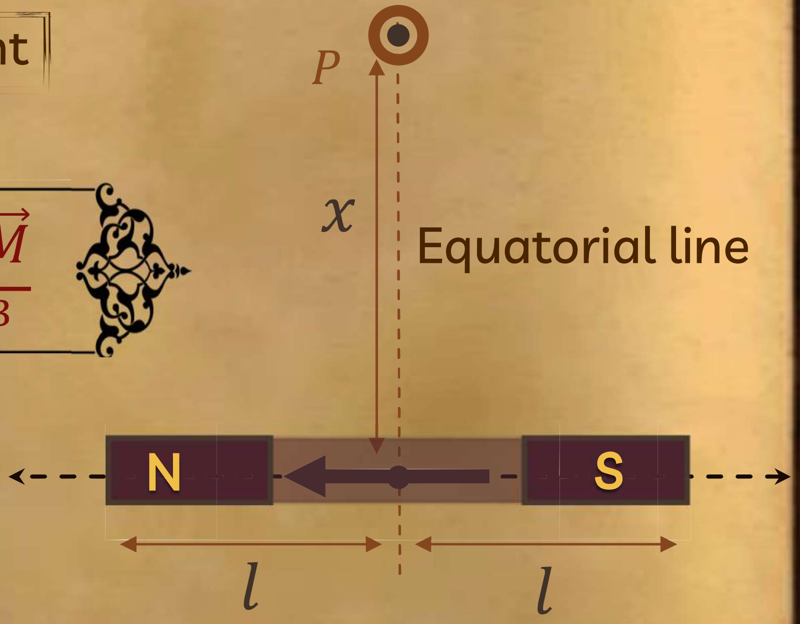
- Direction of $\vec{E}_{ax}$ is along $\vec{p}$.

RECAP

Magnetic field due to magnetic dipole

At equatorial point

$$\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{-\vec{M}}{x^3}$$

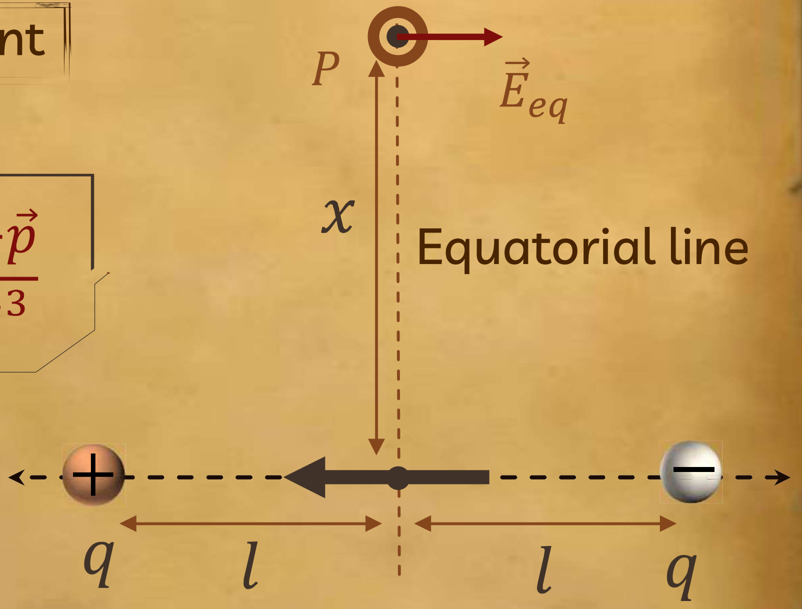


- Direction of $\vec{B}_{eq}$ is opposite to $\vec{M}$.

Electric field due to electric dipole

At equatorial point

$$\vec{E}_{eq} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{-\vec{p}}{x^3}$$

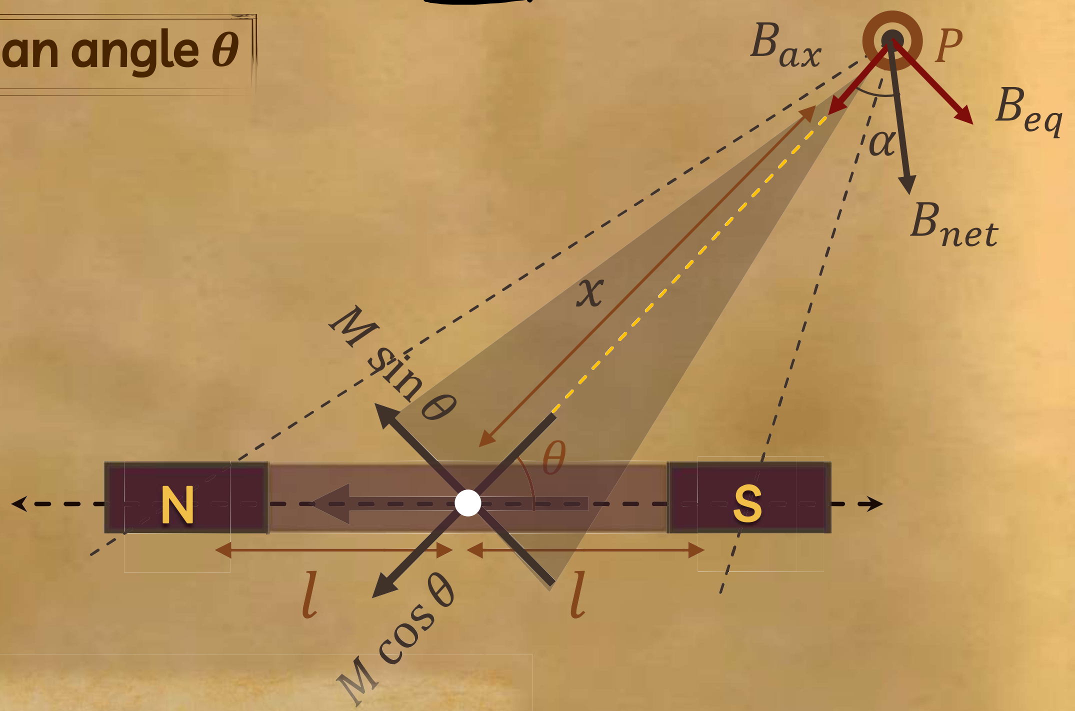


- Direction of $\vec{E}_{eq}$ is opposite to $\vec{p}$.

RECAP

Magnetic field due to magnetic dipole

At an angle θ

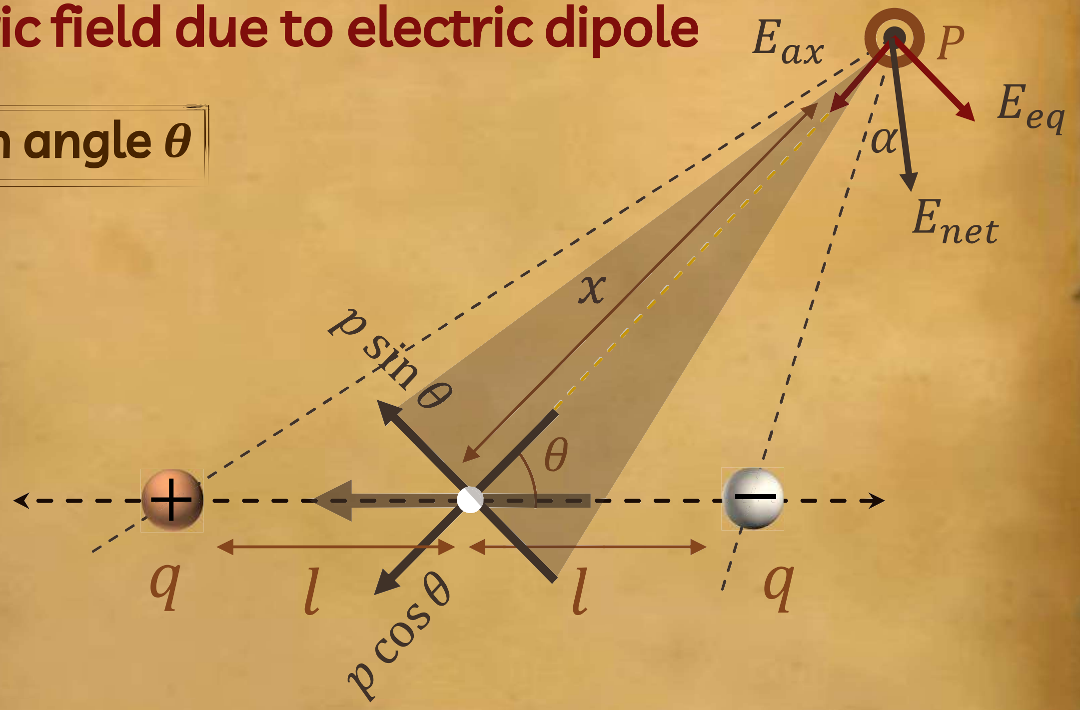


$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}\cos\theta}{x^3}$$

$$\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{-\vec{M}\sin\theta}{x^3}$$

Electric field due to electric dipole

At an angle θ

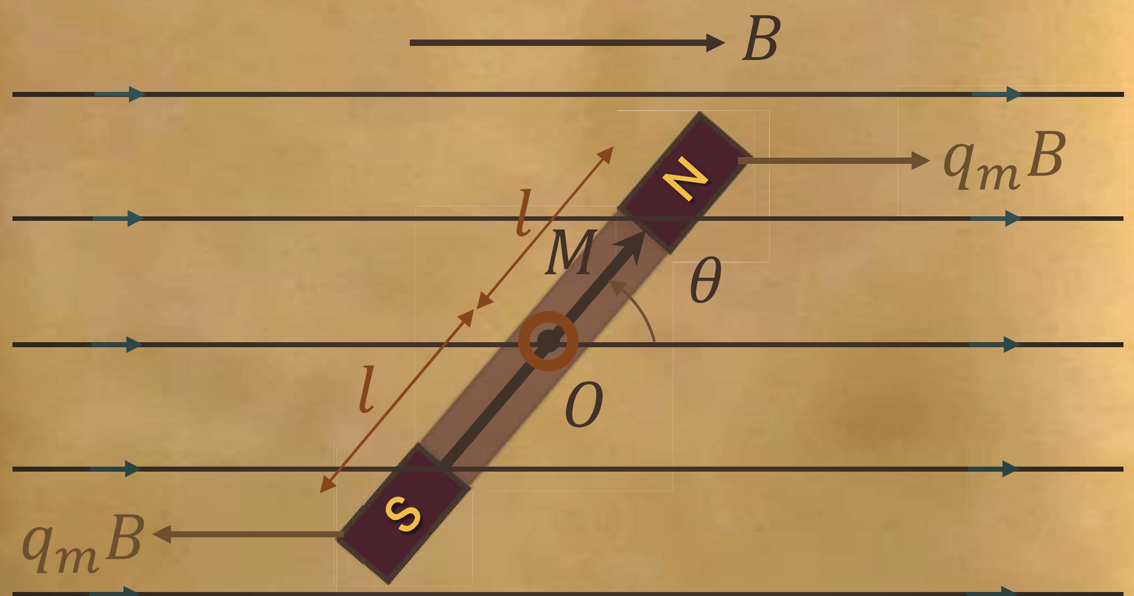


$$\vec{E}_{ax} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2\vec{p}\cos\theta}{x^3}$$

$$\vec{E}_{eq} = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{-\vec{p}\sin\theta}{x^3}$$

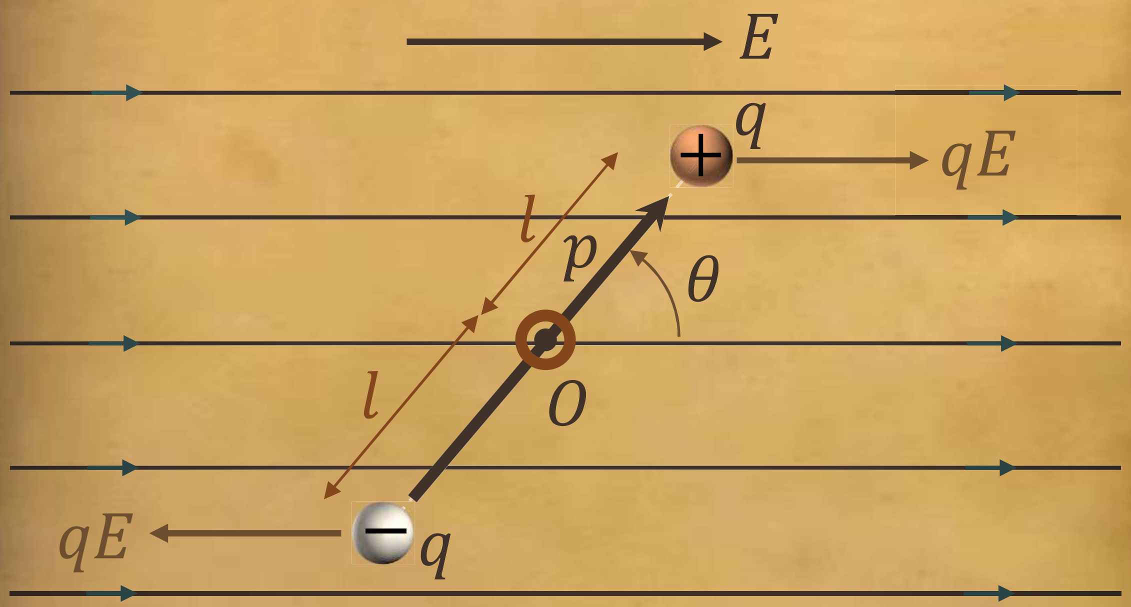
RECAP

Torque acting on a magnetic dipole



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

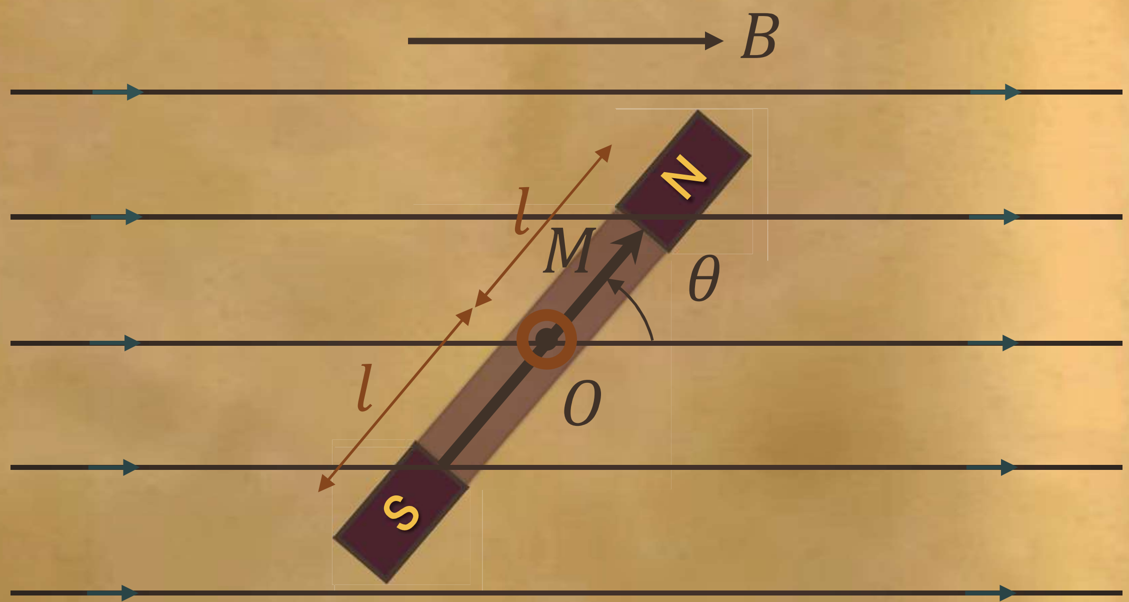
Torque acting on a electric dipole



$$\vec{\tau}_{net} = \vec{p} \times \vec{E}$$

RECAP

Potential energy of a magnetic dipole

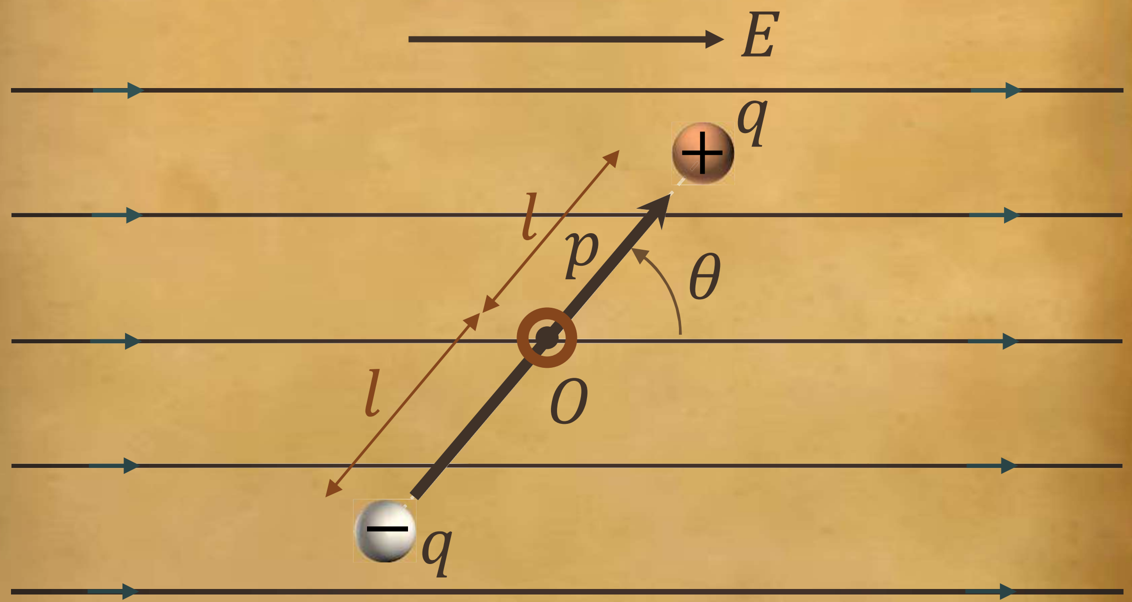


Potential energy

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

- Taking zero potential at $\theta = 90°$

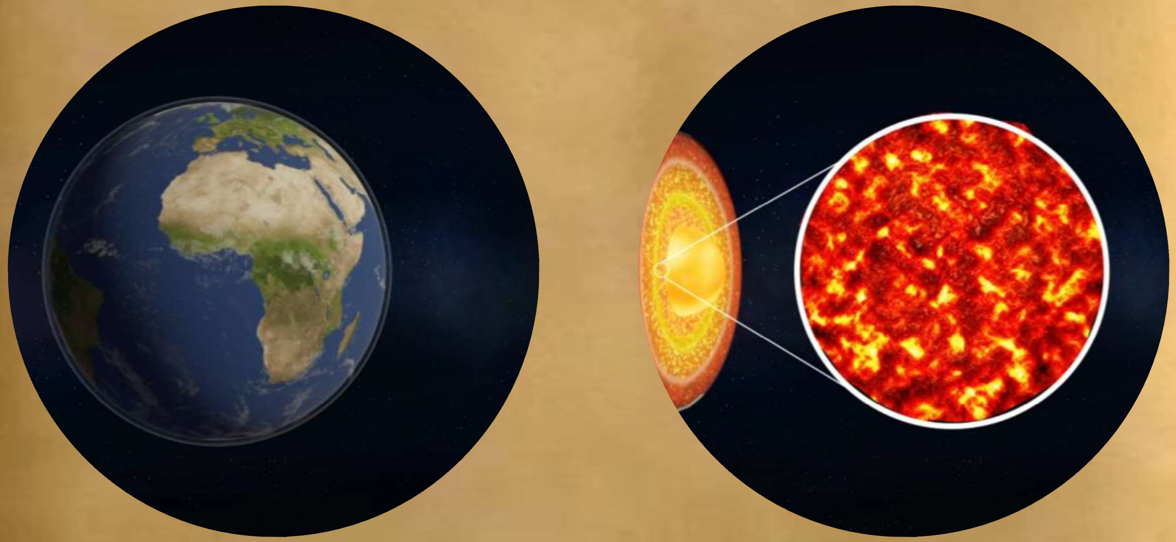
Potential energy of a electric dipole



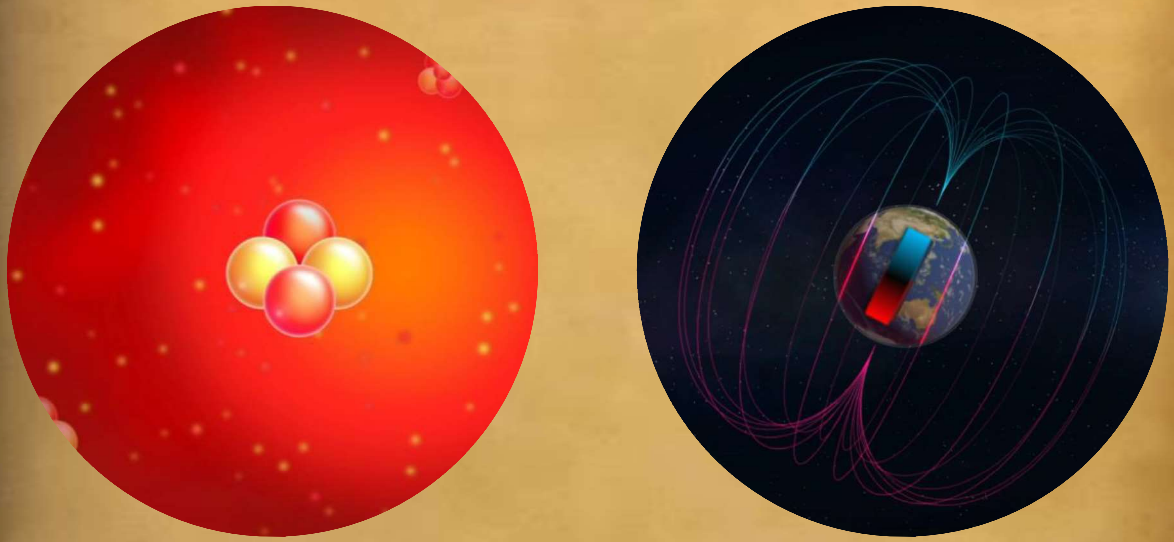
Potential energy

$$U = -\vec{p}\cdot\vec{E}$$
$$= -|\vec{p}||\vec{E}|\cos\theta$$

EARTH'S MAGNETIC FIELD

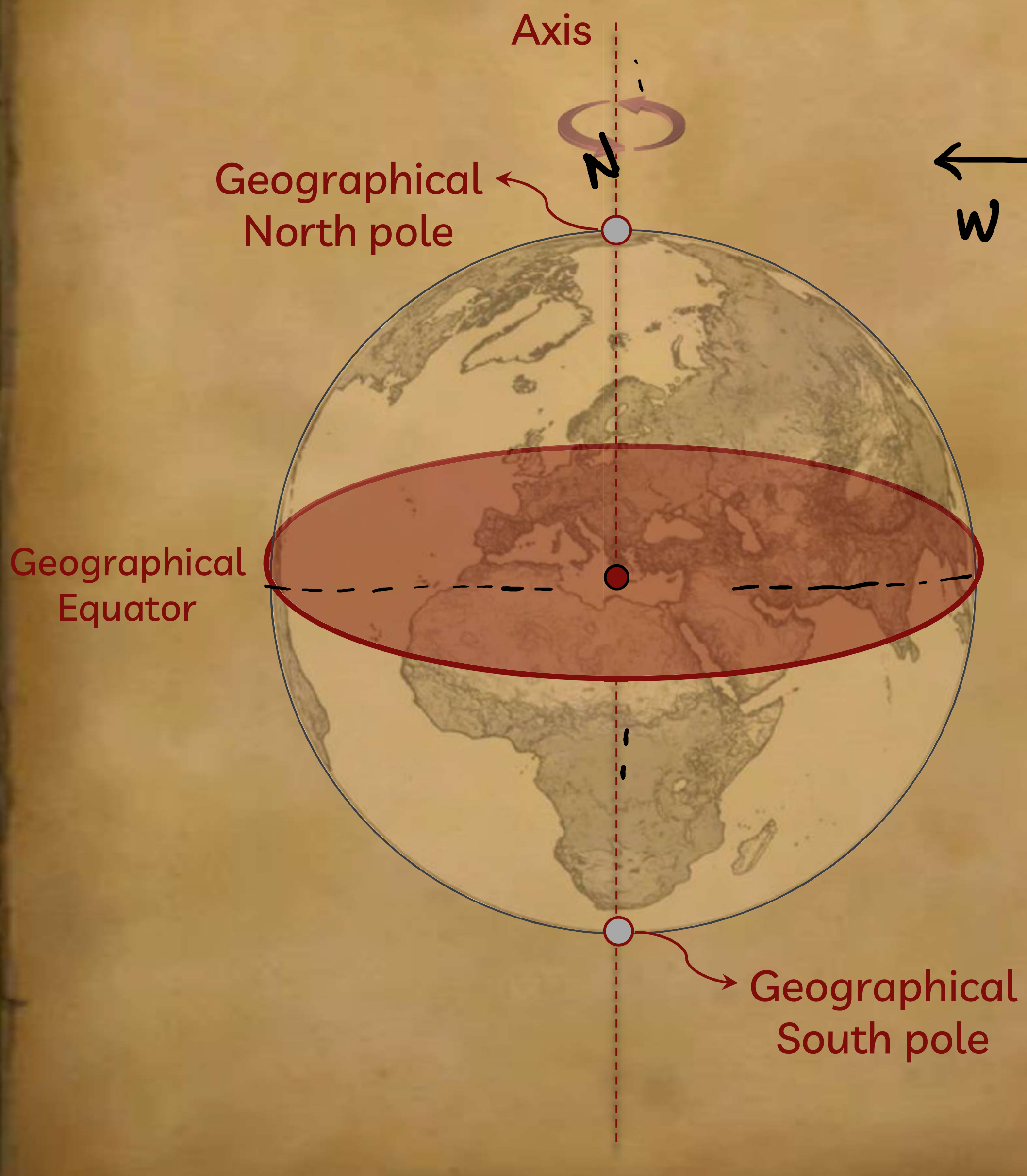


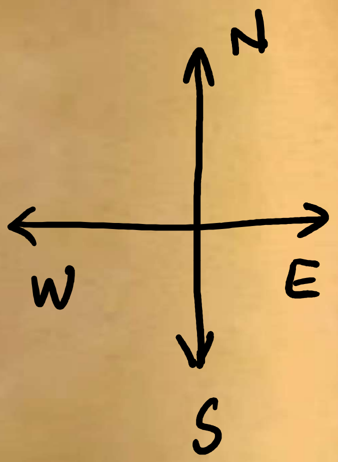
- Earth has magma inside its core which contains charged particles of various materials. These materials move and rotate with the rotation of Earth. Thus, forming the effect of magnetic field due to current carrying loop.
  This is one of the possible explanation for the earth's magnetic field.



- For simplicity in understanding we consider that there's a large magnet inside the earth that is responsible for the earth's magnetic field.
- Earth's magnetic field save us from the solar storms.

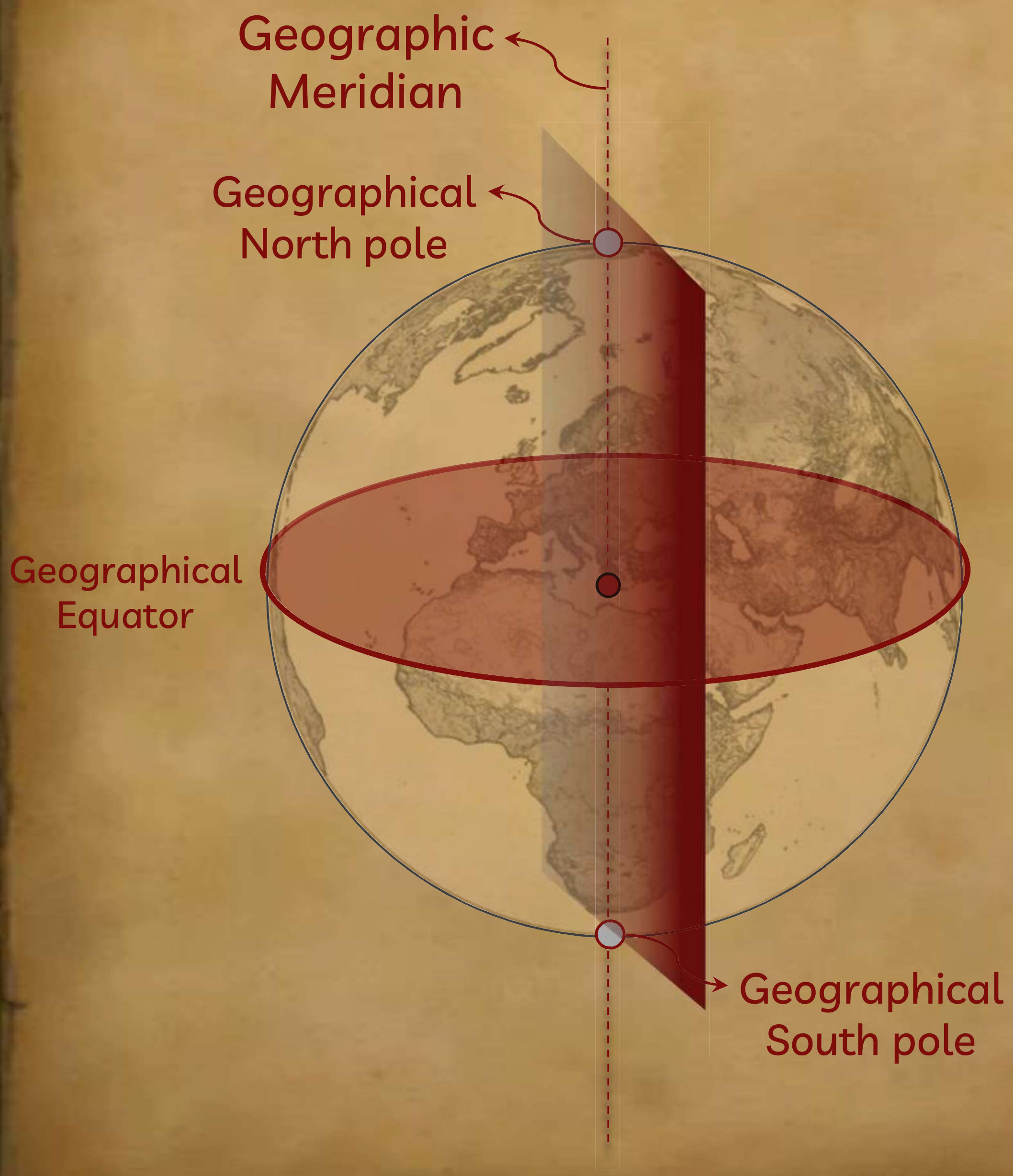
EARTH'S MAGNETISM

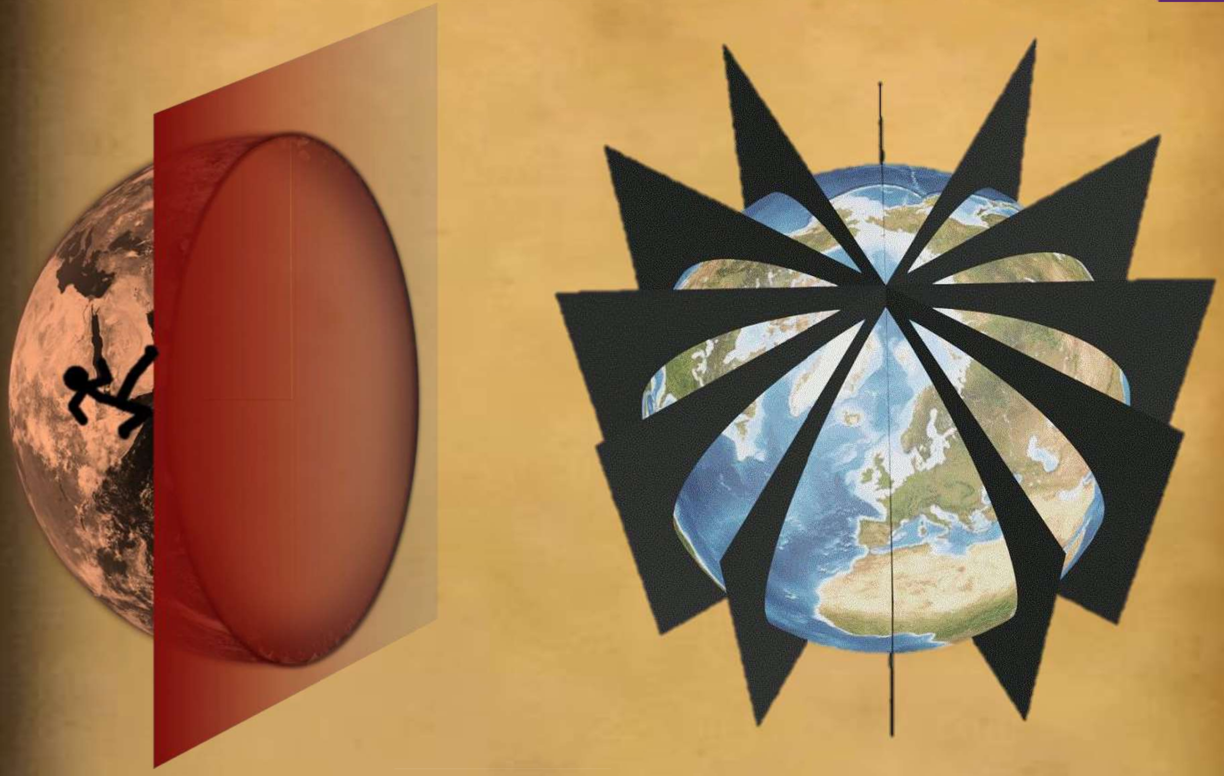




- The imaginary line joining the geographical north pole and south pole is called the axis of the earth. Whereas the line perpendicular to it and passing through the earth's centre is called equator of the earth.

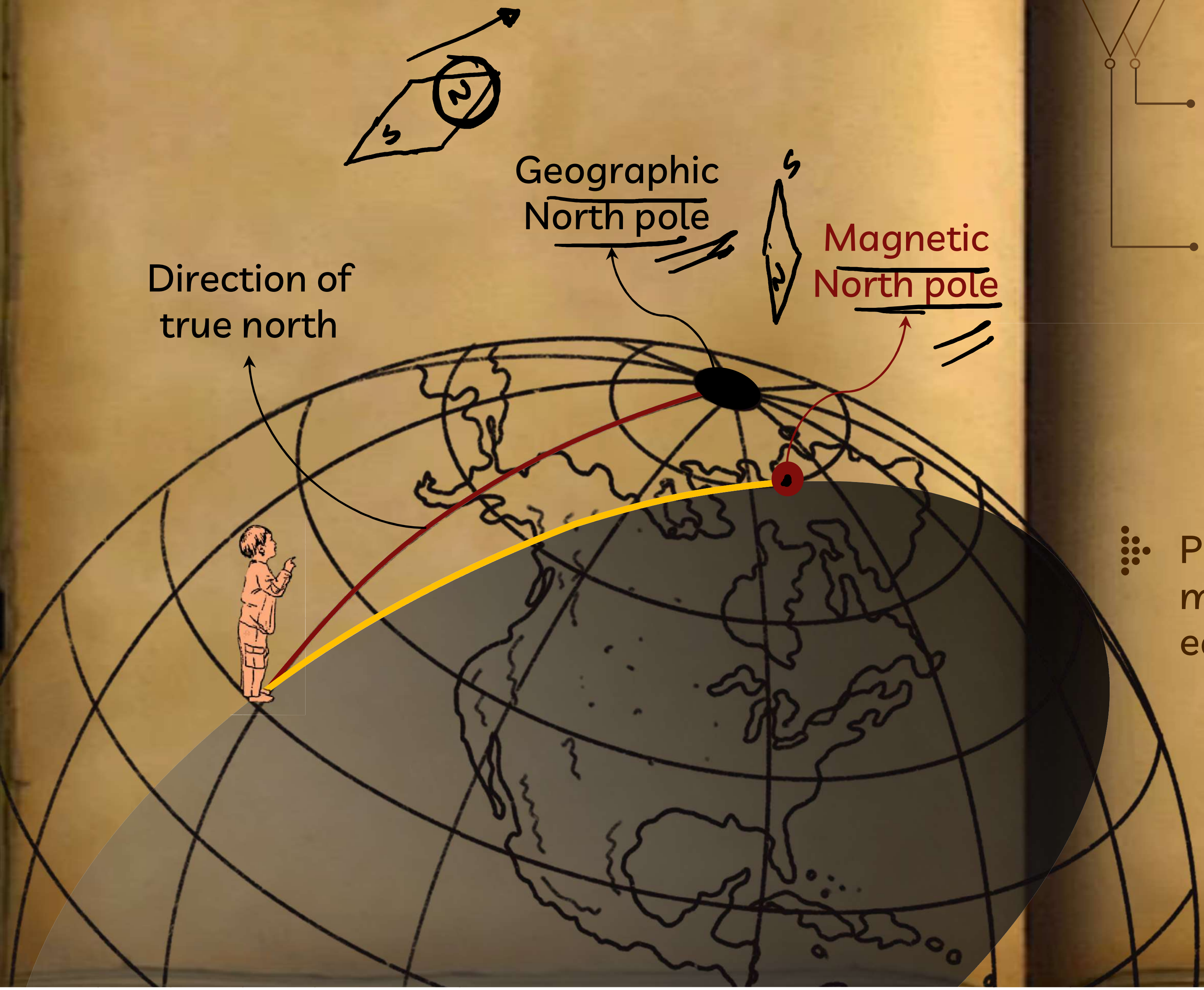
EARTH'S MAGNETISM





- Earth can be divided into many such **geographic meridian** i.e., the plane containing axis at the centre.
- Horizontal planes are called as **geographical equator**.

EARTH'S MAGNETISM

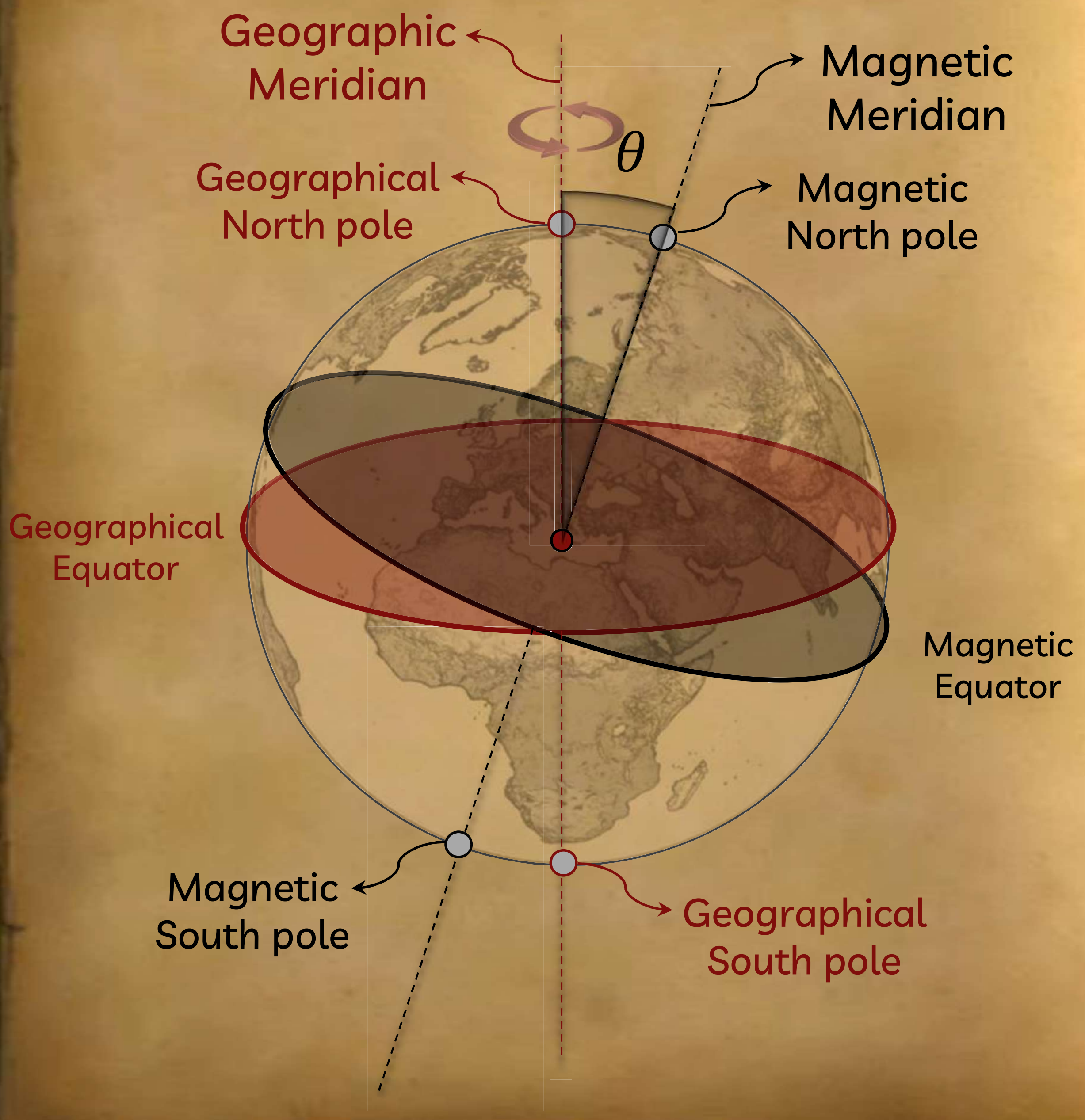


Boy with compass will not reach to Geographic north pole

- A magnetic compass does not point to the geographic north pole.
- A magnetic compass points to the earth's magnetic poles, which are not the same as earth's geographic poles.

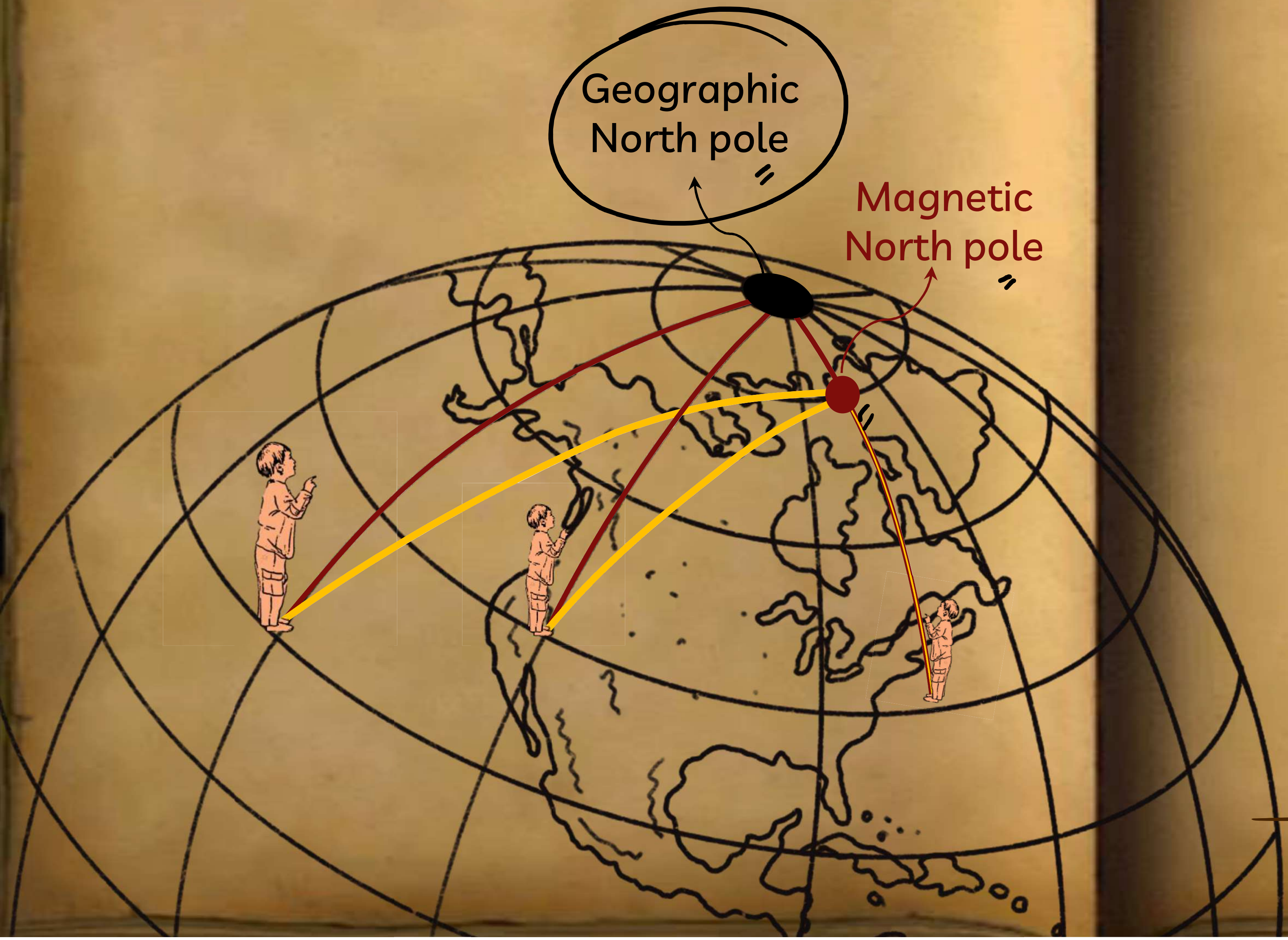
- Poles of Earth's magnet are opposite to the magnetic pole and geographical pole of the earth.

EARTH'S MAGNETISM



The magnetic meridian is a line joining the magnetic north pole with the magnetic south pole inside the earth.

ANGLE OF DECLINATION

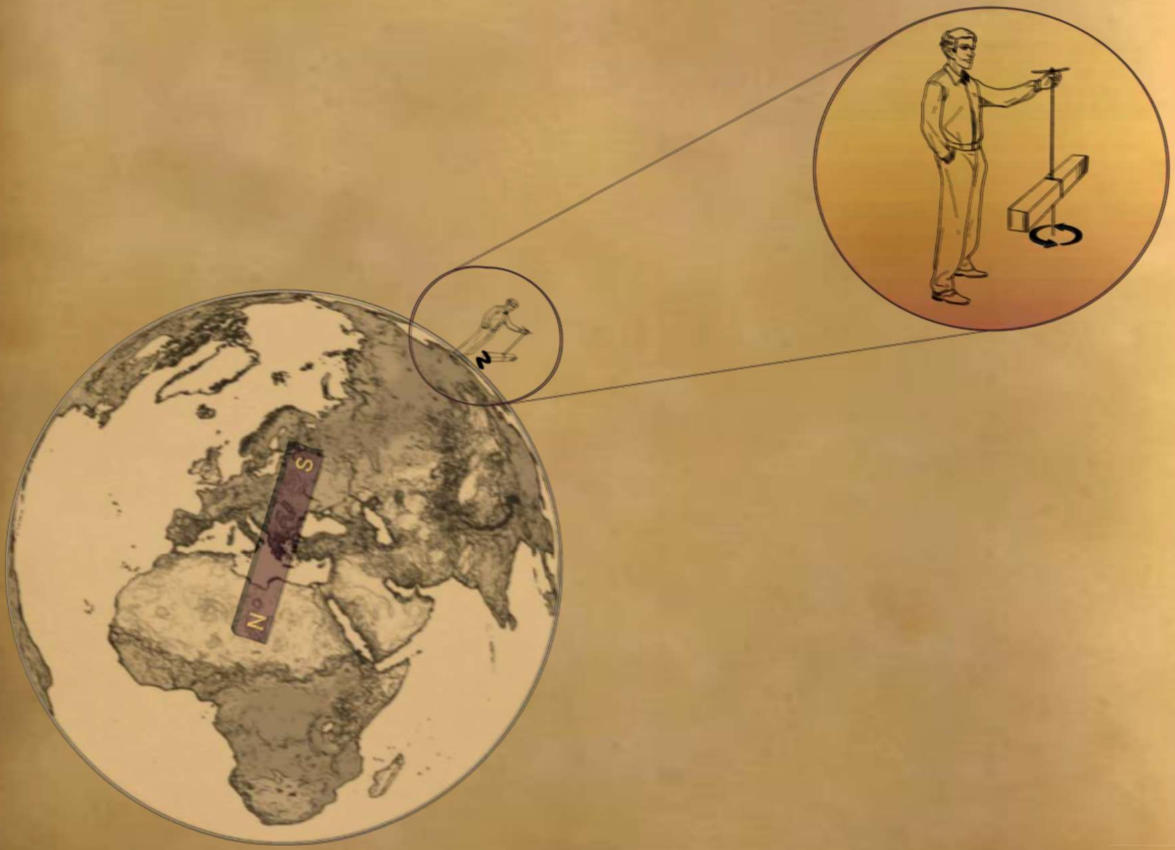


Angle of Declination

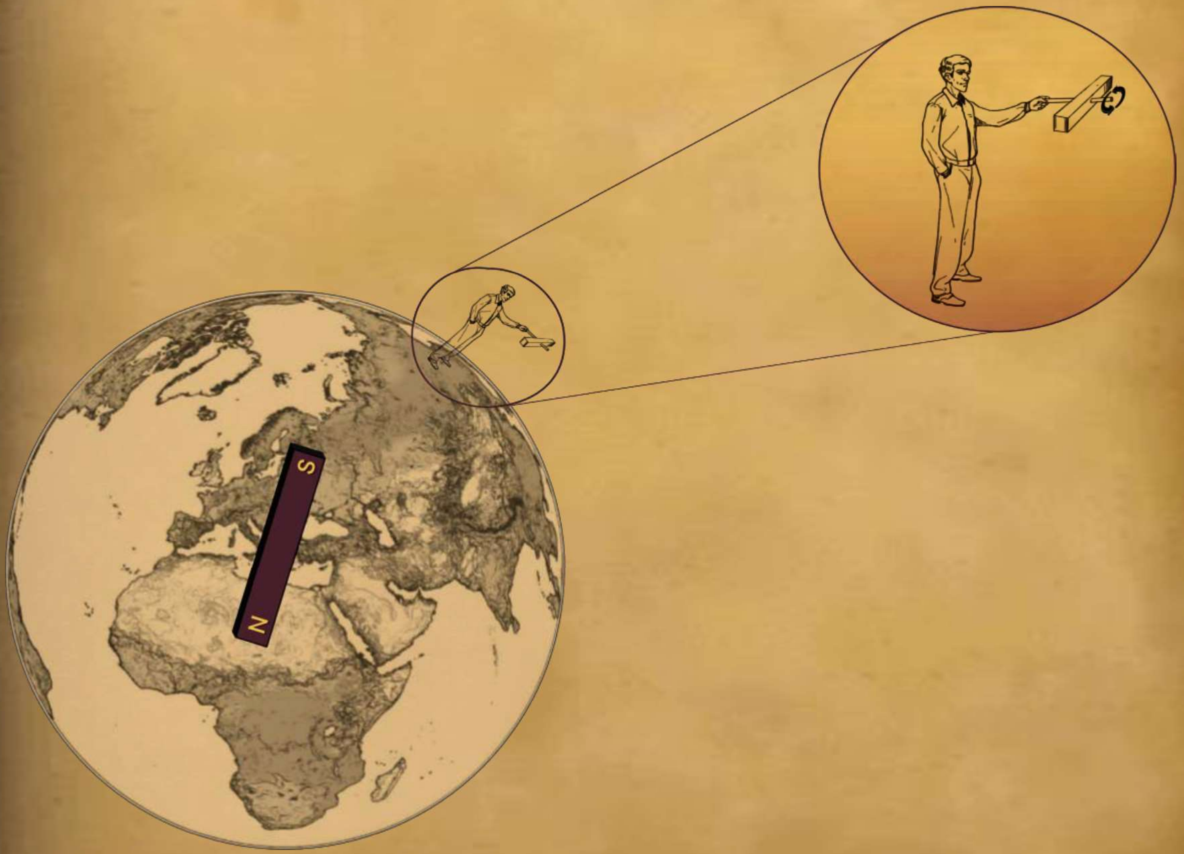
- The angle between true north (the line towards geographic north pole) and the direction towards which the compass points (horizontal component of the magnetic field) is called magnetic declination.

ANGLE OF DIP (INCLINATION)

If we hold a bar magnet at any point on the surface of the earth it will rotate to align itself to the magnetic poles of the earth.

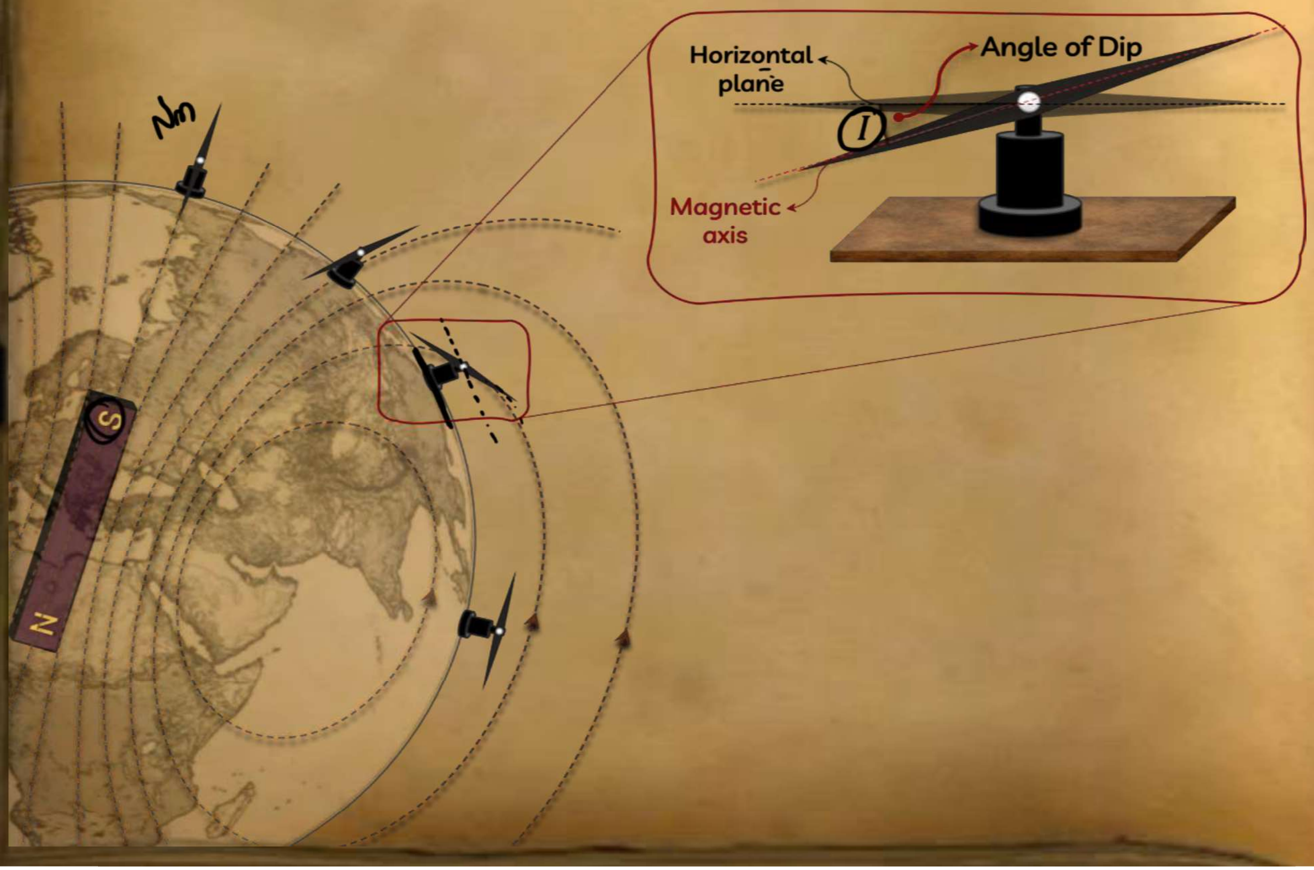


Angle of dip is the angle made by the earth's magnetic field lines with the horizontal.

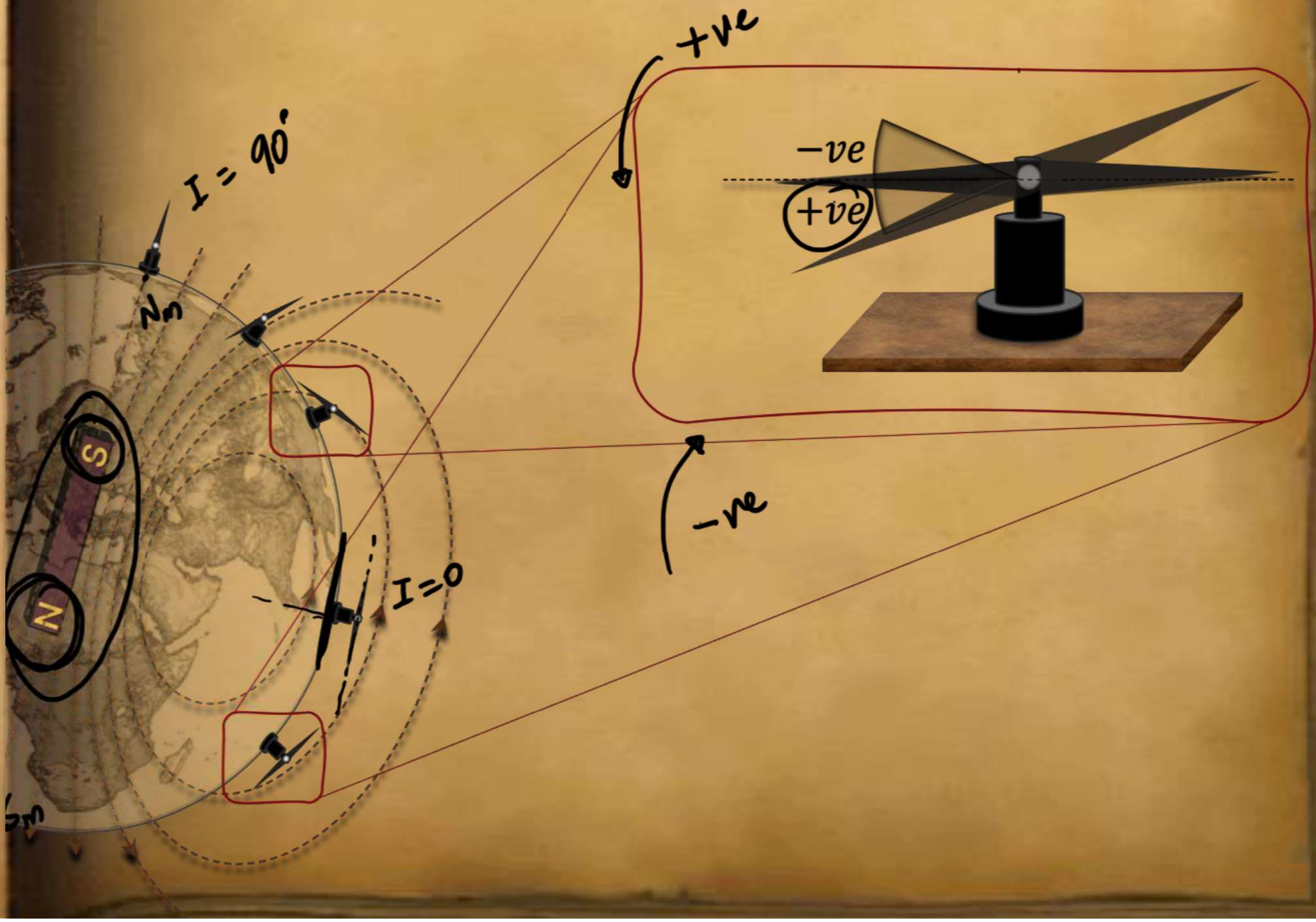


ANGLE OF DIP (INCLINATION)

Angle that is made by the earth's magnetic field lines with the horizontal.

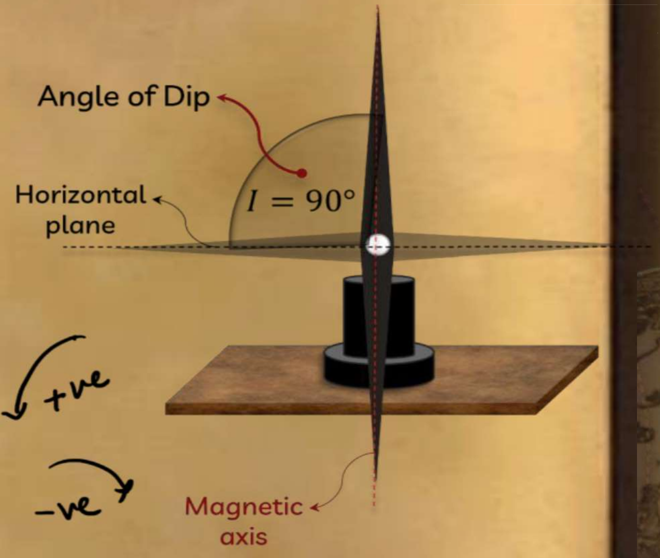


If the dip is in clockwise direction we take it as negative and if it is in anti-clockwise direction we take it as positive.



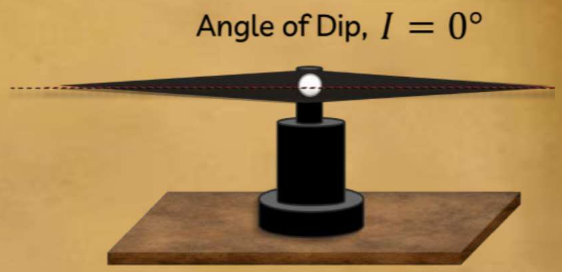
ANGLE OF DIP (INCLINATION)

Dip is positive at any point in northern hemisphere of the earth whereas it is negative in the southern hemisphere.

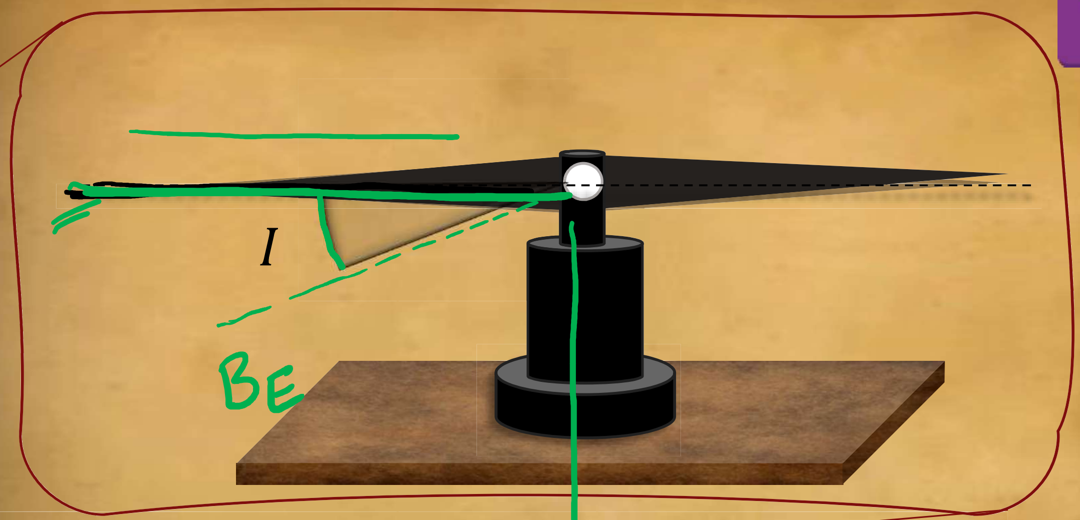


At equator: $I = 0°$

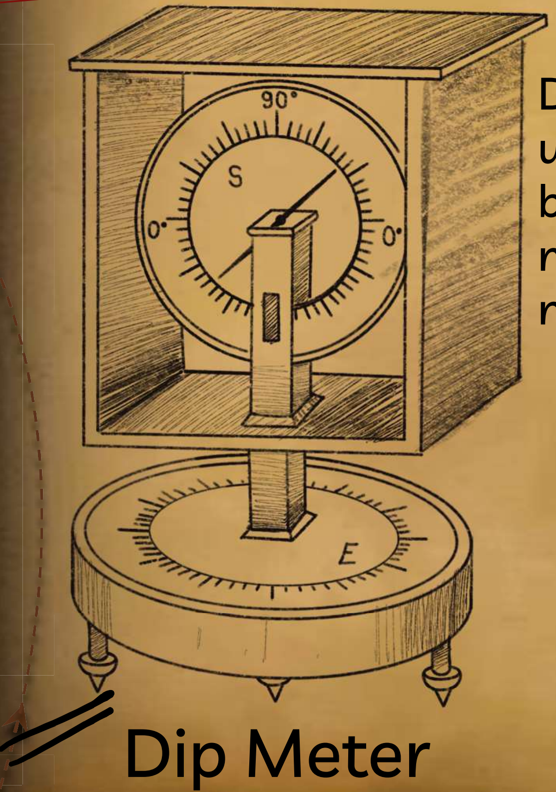
At magnetic poles, $I = 90°$



ANGLE OF DIP (INCLINATION)

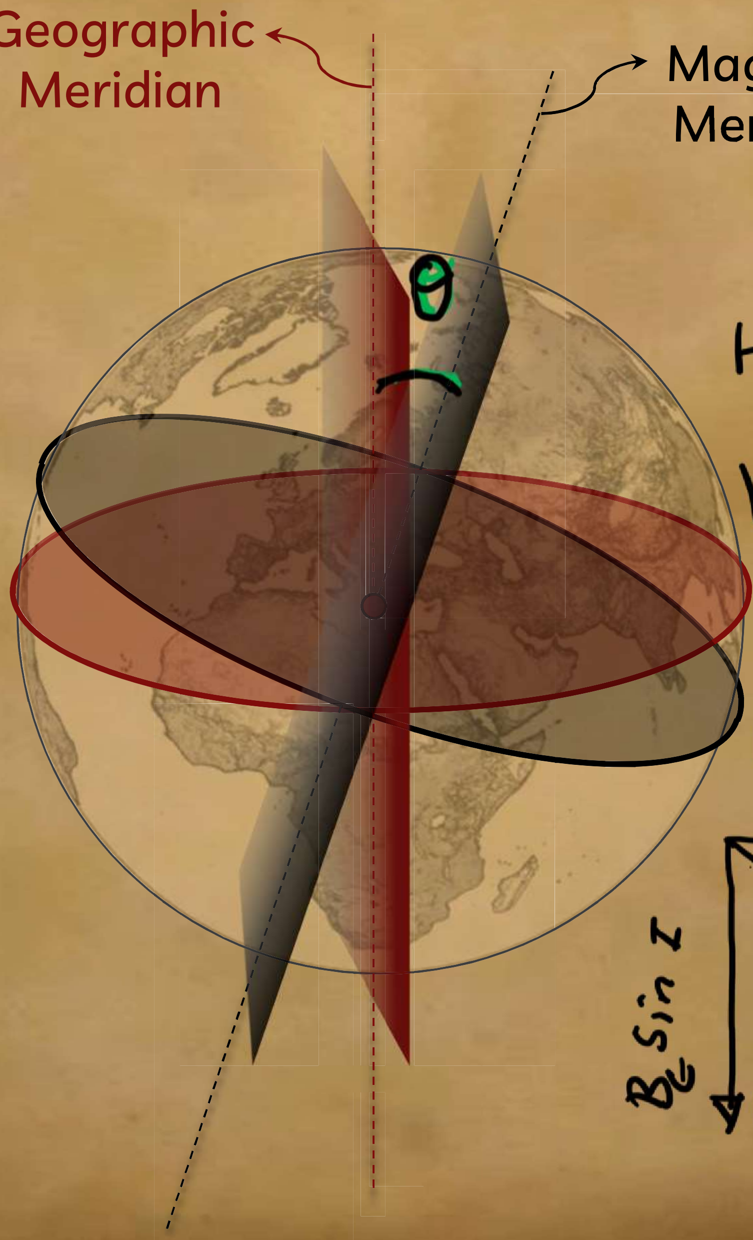


Dip meter is an instrument used to measure angle of dip by measuring the angle made by the magnetic needle with the horizontal.



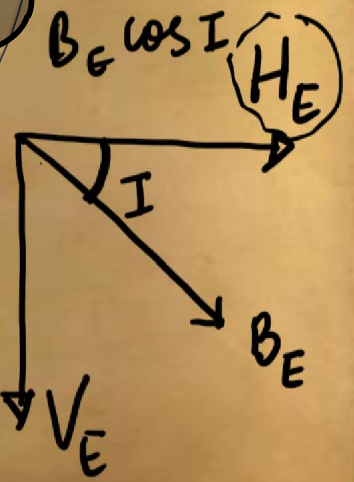
Dip Meter

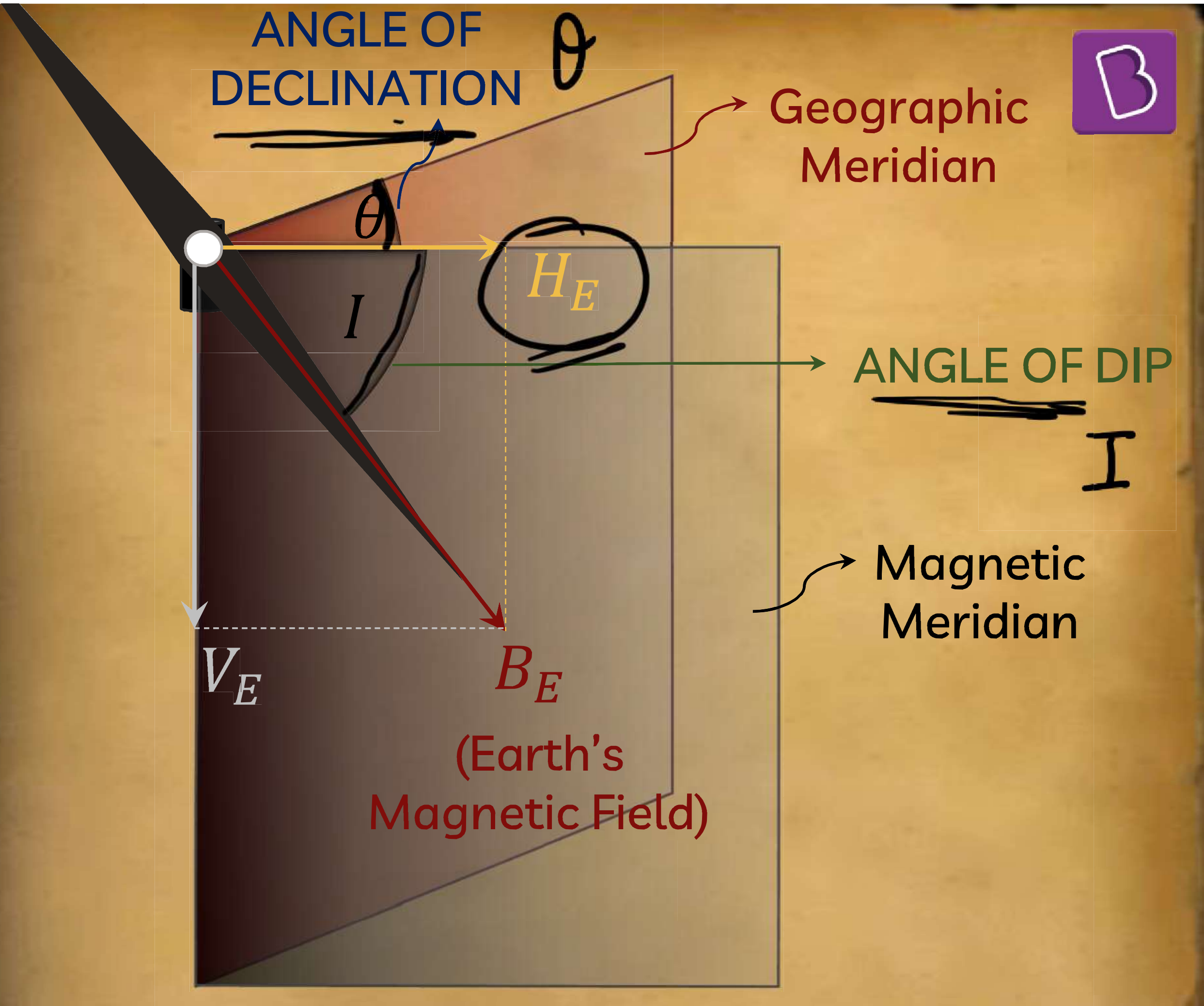
EARTH'S MAGNETISM



$H_E = B_E \cos I$

$V_E = B_E \sin I$

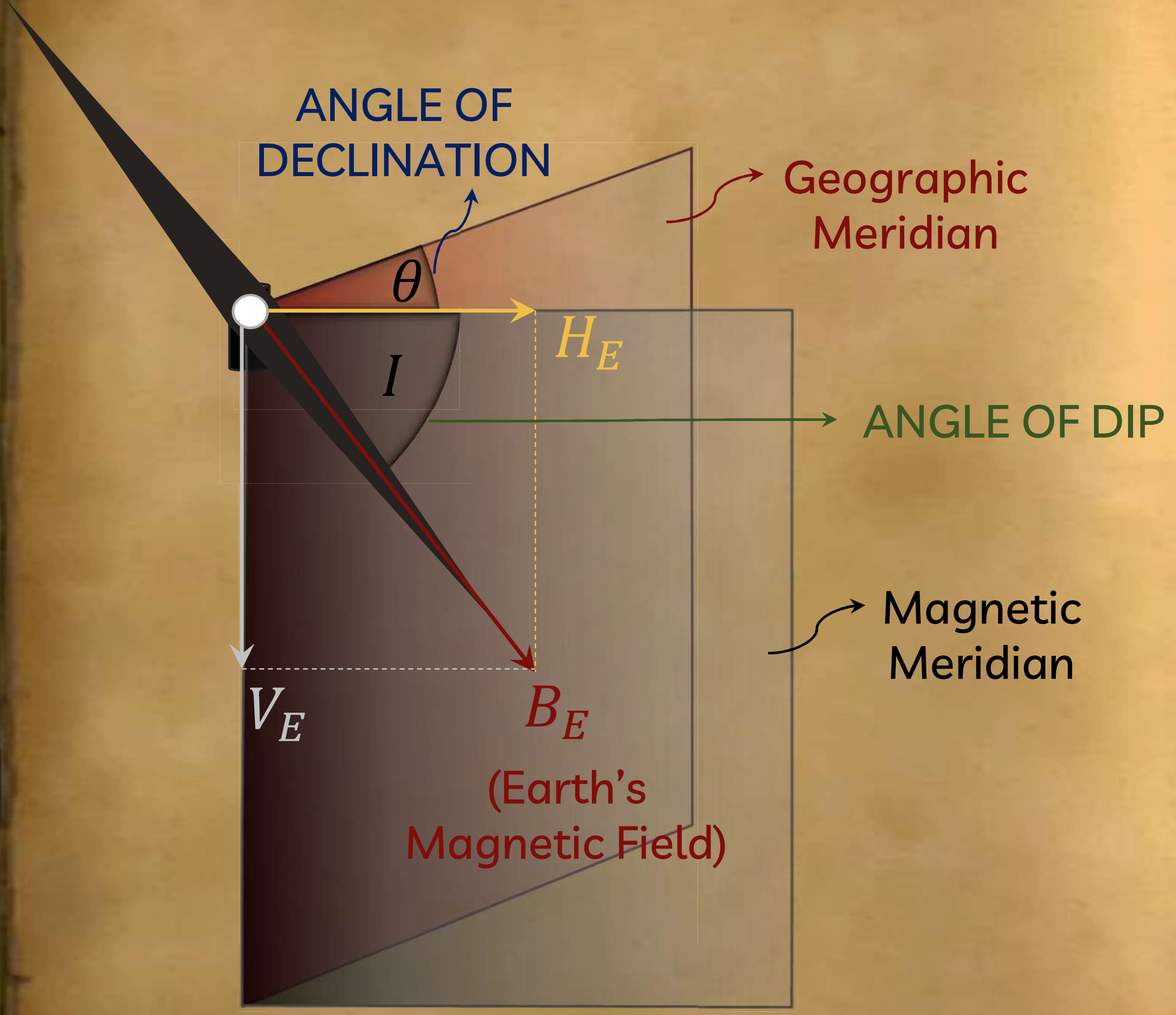




$\boxed{H_E} = B_E \boxed{\cos I}$ ✓

B_E ✓

EARTH'S MAGNETISM



Horizontal component of earth's magnetic field

$$H_E = B_E \cos I$$

Vertical component of earth's magnetic field

$$V_E = B_E \sin I$$

$$\boxed{\tan I = V_E / H_E}$$

EARTH’S MAGNETISM

Components of earth magnetic field

- **Angle of declination or magnetic declination :**

  The angle between true north (the line towards geographic north pole) and the direction towards which the compass points (horizontal component of the magnetic field) is called magnetic declination. → θ

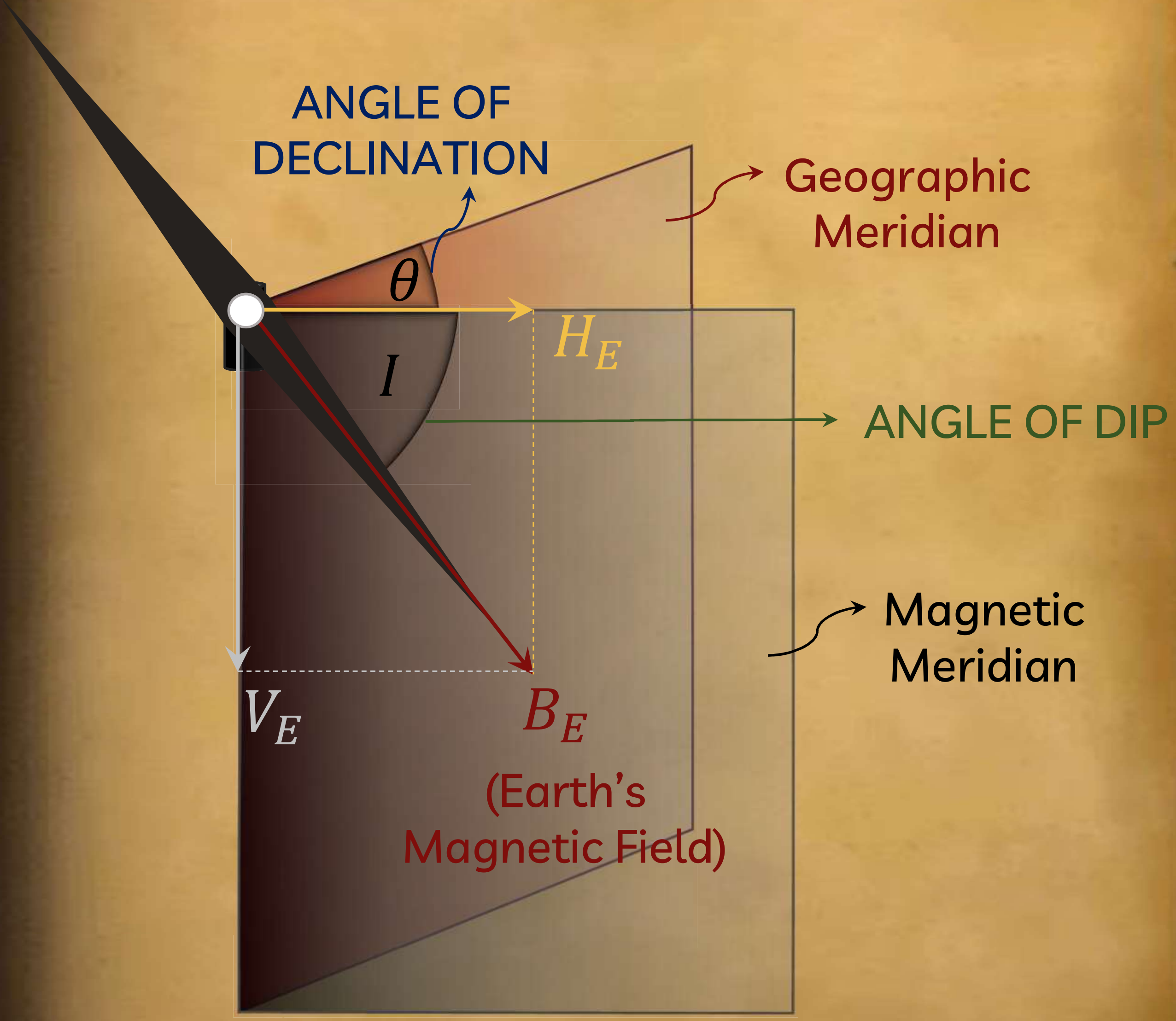
- **Angle of dip or inclination :**

  Angle that is made by the earth’s magnetic field lines with the horizontal.

- **Horizontal component of earth’s magnetic field (H_E) :**

  It is the projection of earth’s magnetic field on surface of earth

  ✓
  $$\boxed{H_E} = B_E \boxed{\cos I}$$



PROBLEM

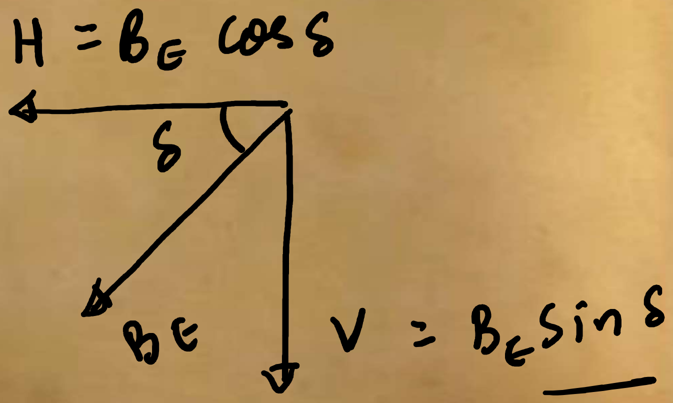
The relations amongst the three elements of earth's magnetic field, namely horizontal component H, vertical component V and dip δ are, (B_E =Total magnetic field)

a. $V = B_E, H = B_E \tan\delta$

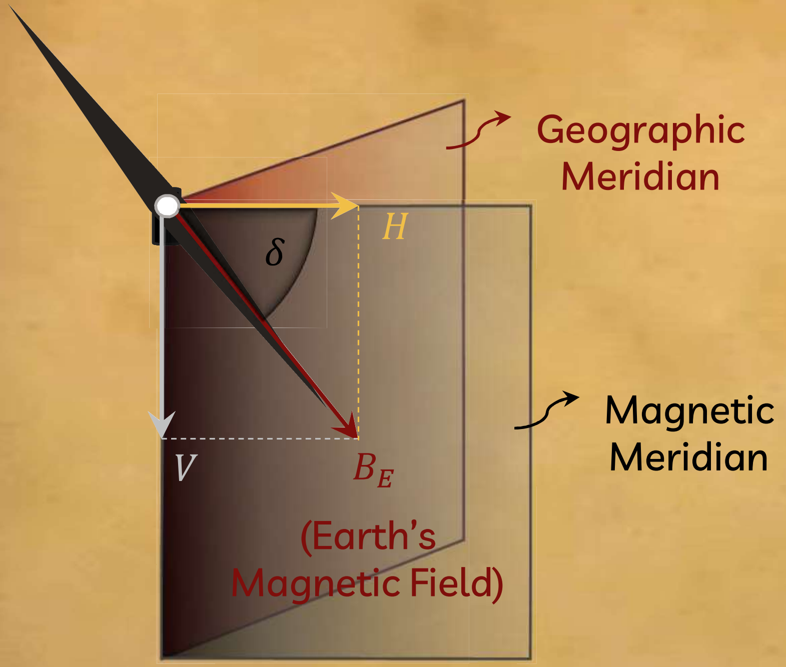
b. $V = B_E\ tan\delta, H = B_E$

[✓ c.] $V = B_E\ sin\ \delta\ , H = B_E cos\delta$

d. $V = B_E\ cos\ \delta\ \ , H = B_E\ sin\ \delta$



SOLUTION



Vertical component:

$$V = B_E \sin\delta$$

Horizontal component:

$$H = B_E \cos\delta$$

Therefore, option c is the correct answer.

PROBLEM

At a point ***A*** on the Earth's surface, the angle of dip $\delta = \underline{\boxed{+}25^\circ}$. At a point ***B*** on the Earth's surface the angle of dip, $\delta = \boxed{-}25^\circ$. We can interpret that:

a. A is located in the northern hemisphere and B is located in the southern hemisphere

b. A and B are both located in the southern hemisphere

c. A and B are both located in the northern hemisphere

d. A is located in the southern hemisphere and B is located in the northern hemisphere

Hint

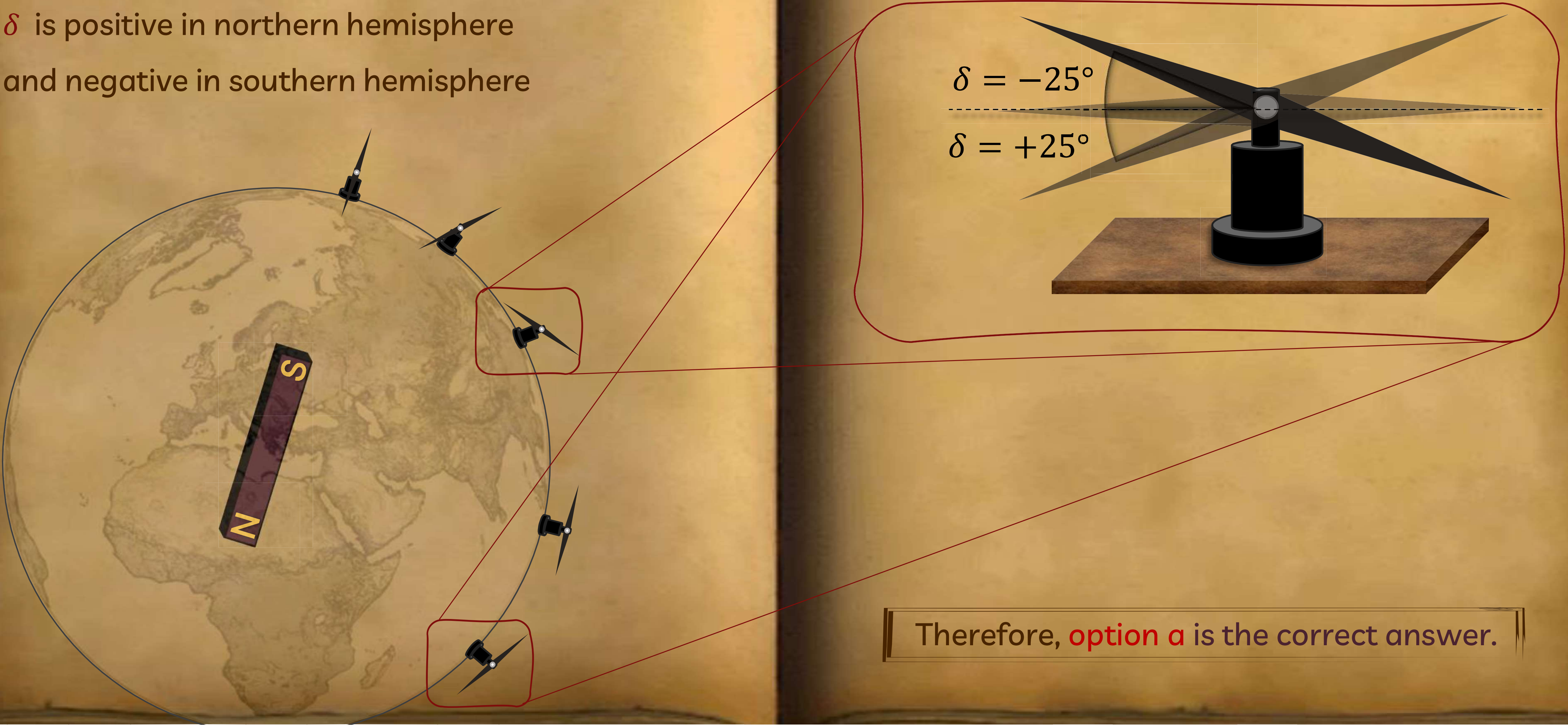
- Angle of dip is the angle made by the earth's magnetic field lines with the horizontal.
- We know that the angle of dip is 0° at thee equator and it is 90° at the magnetic poles of the earth.
- If the dip is in clockwise direction we take it as negative and if it is in anti-clockwise direction we take it as positive.

SOLUTION

At equator: $\delta = 0^\circ$

At magnetic poles, $\delta = 90^\circ$

δ is positive in northern hemisphere and negative in southern hemisphere



Therefore, option a is the correct answer.

PROBLEM

A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It

a. will become rigid showing no movement.

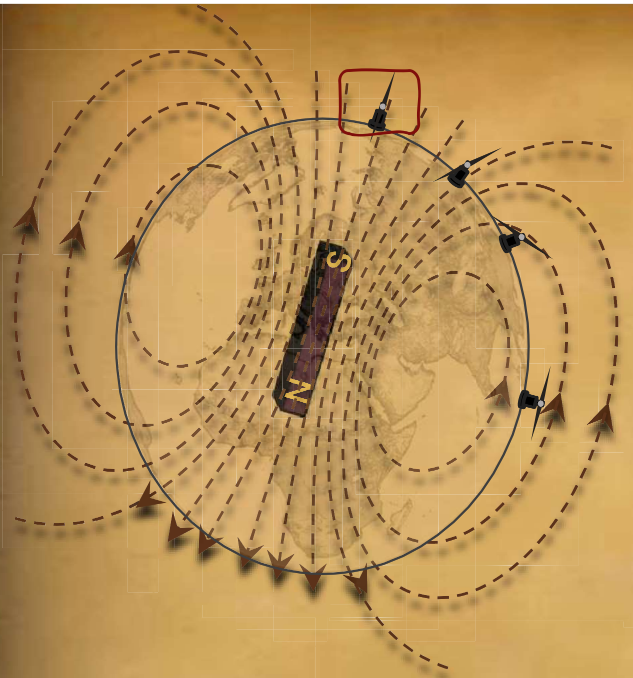
b. will stay in any position.

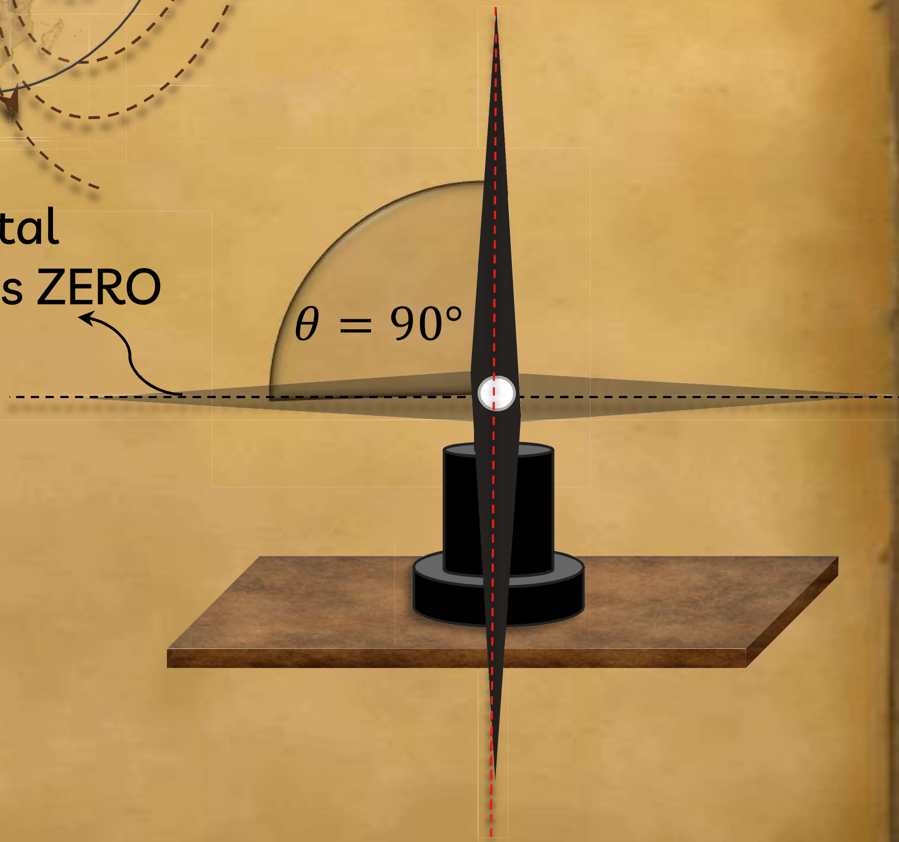
c. will stay in north – south direction only.

d. will stay in east – west direction only.

SOLUTION

If a compass needle that is allowed to move in a horizontal plane is taken to a geomagnetic pole, it will stay in any position as the horizontal component of the earth's magnetic field becomes zero at the geomagnetic pole.



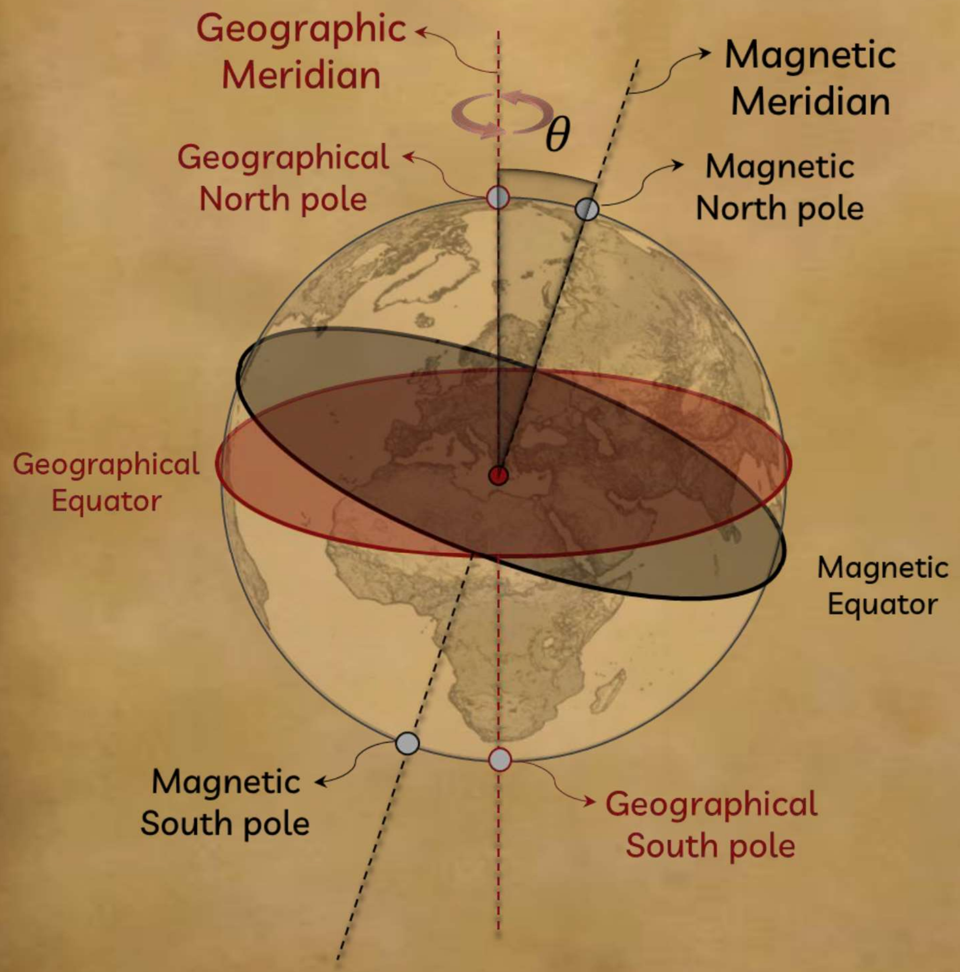


Horizontal component is ZERO

Therefore, option b is the correct answer.

RECAP

Earth's magnetism

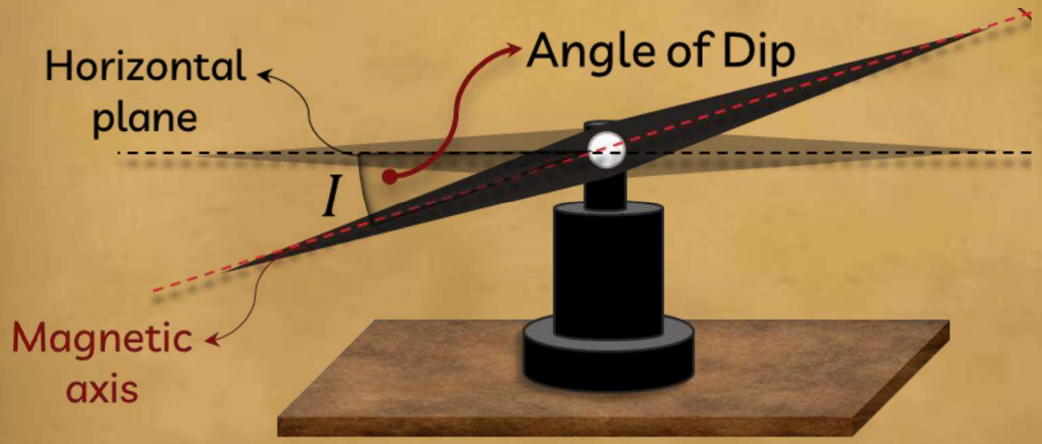


Angle of Declination

The angle between true north (the line towards geographic north pole) and the direction towards which the compass points (horizontal component of the magnetic field) is called magnetic declination.

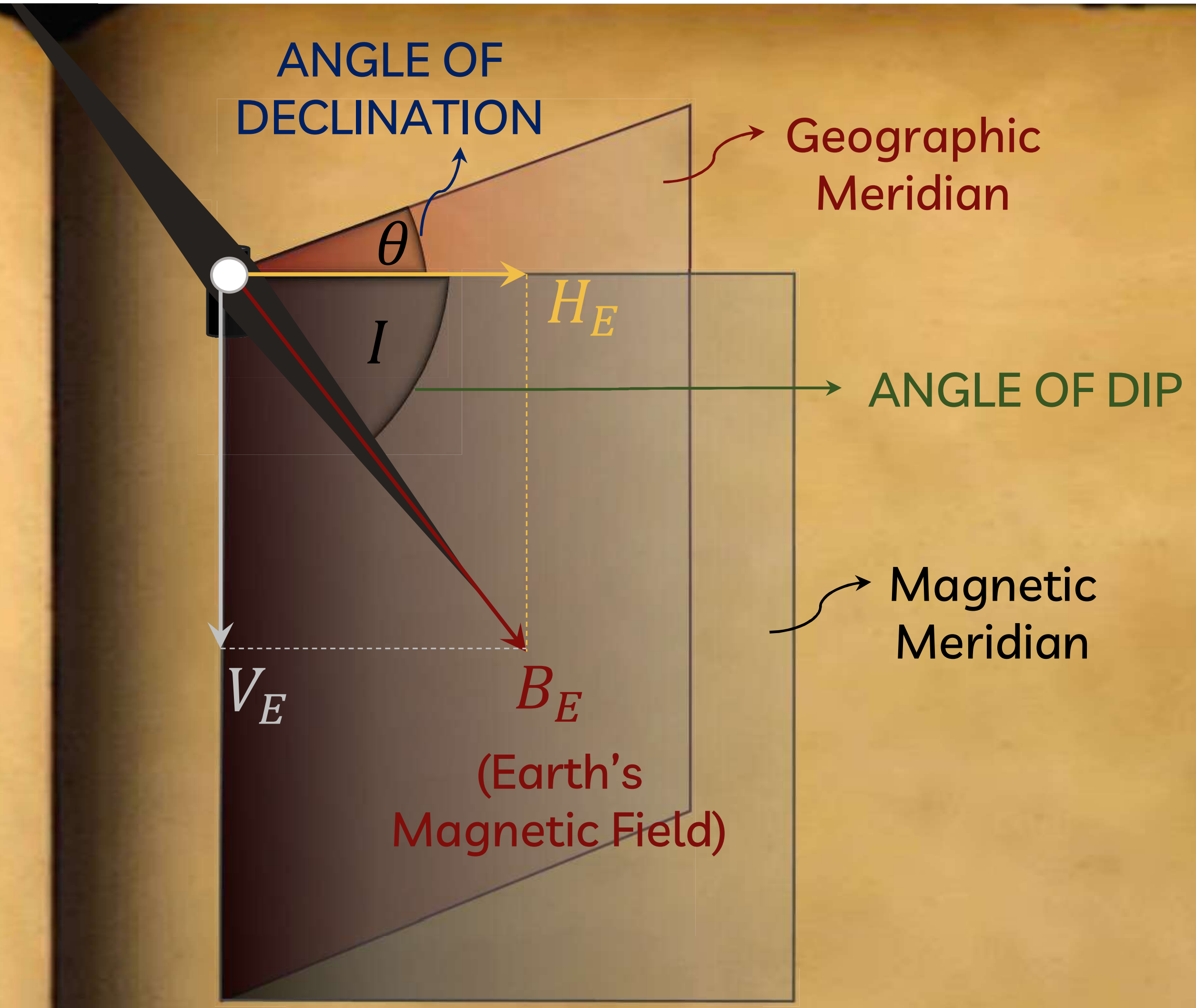
Angle of dip

Angle that is made by the Earth's magnetic field lines with the horizontal.



RECAP

Earth's magnetism



Horizontal component of Earth's magnetic field

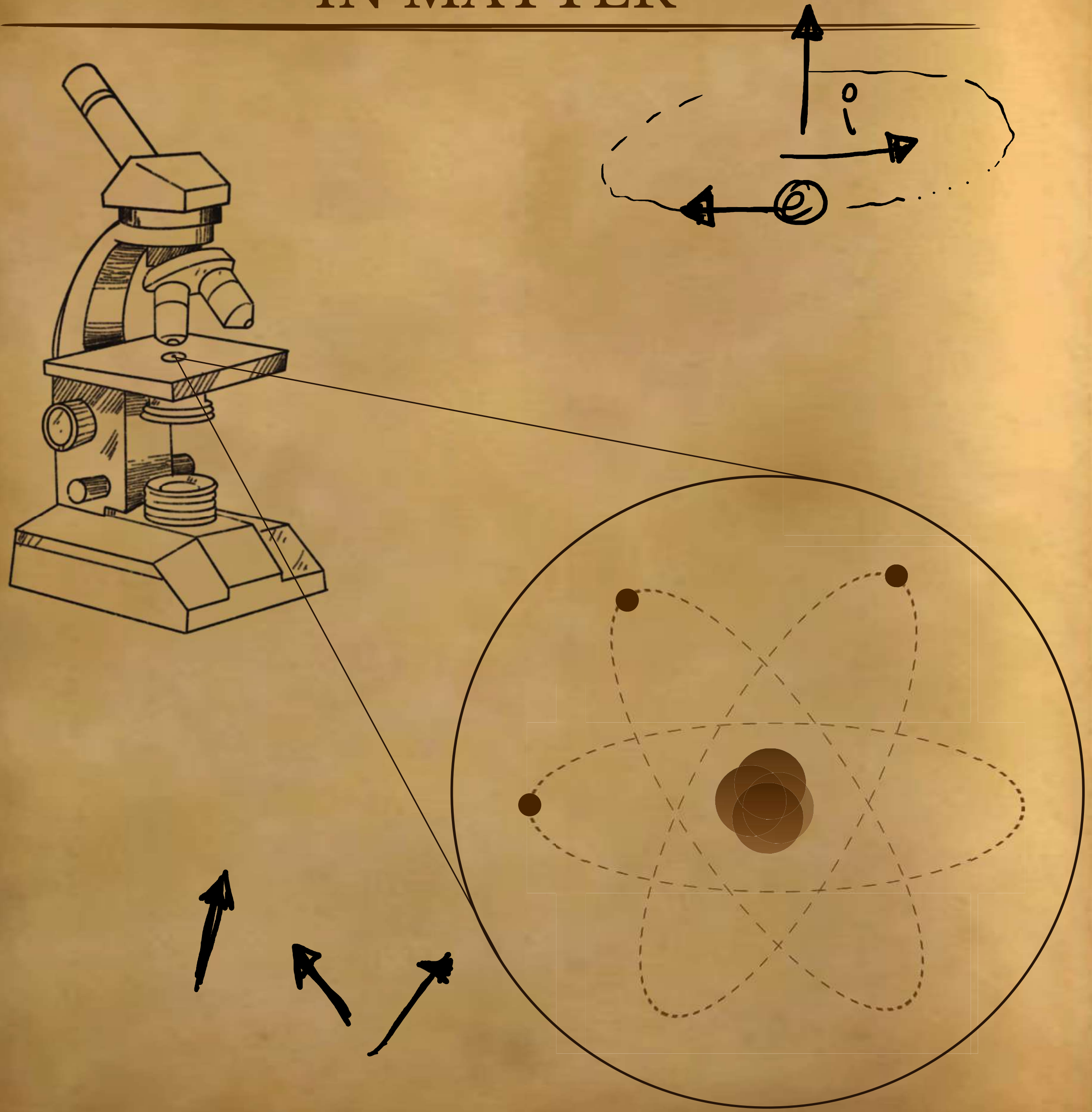
$$H_E = B_E \cos I$$

Vertical component of Earth's magnetic field

$$V_E = B_E \sin I$$

$$\tan I = V_E / H_E$$

CAUSE OF MAGNETISM IN MATTER



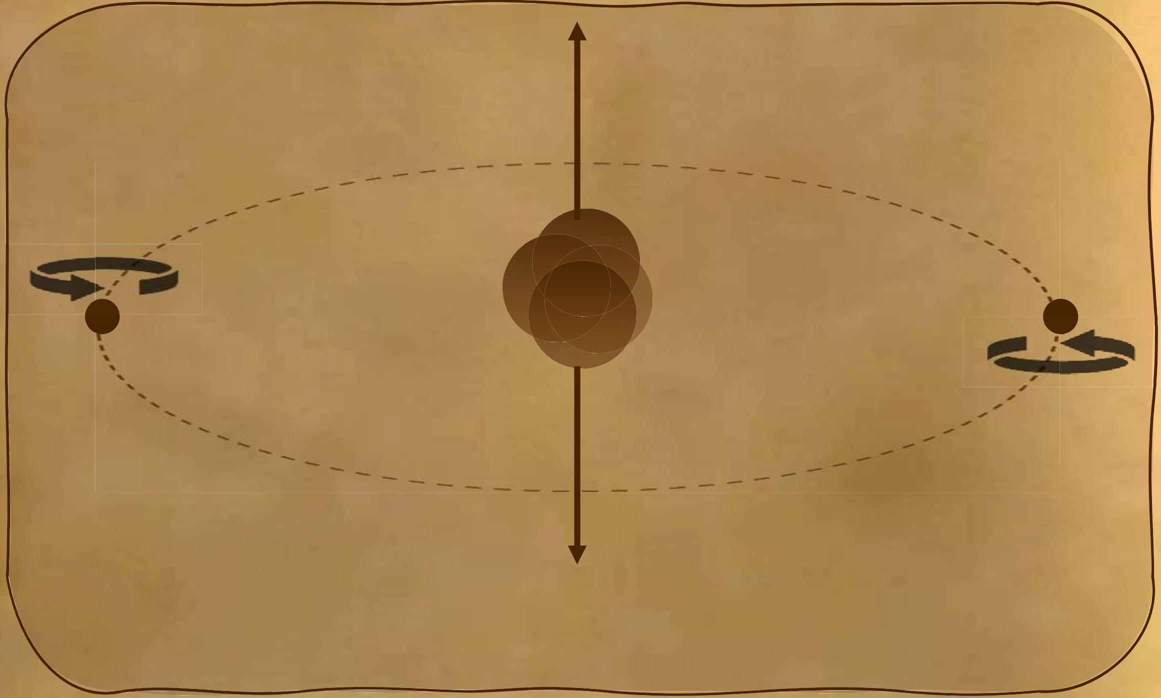
Magnetic moment of an atom is due to:

- **Orbital motion of e^-** — Major contributing factor
- **Magnetic moment due to spin angular momentum of an e^-**
- **Magnetic moment of nucleus**

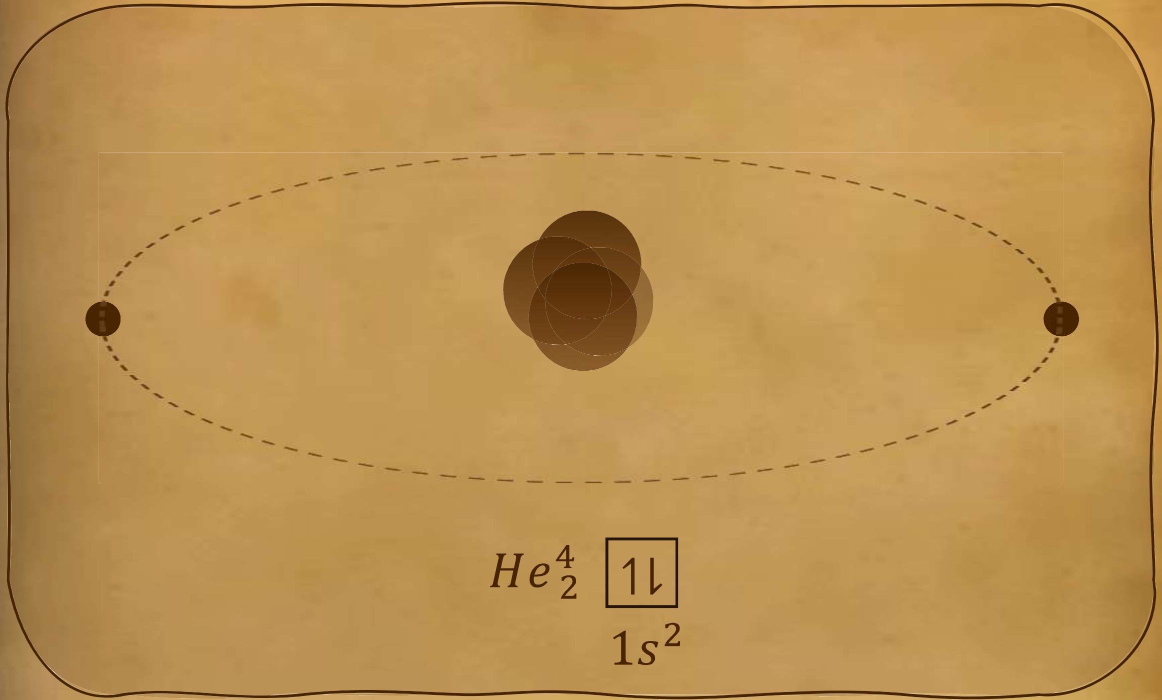
Net moment of an atom is a resultant of magnetic moments due to all e^-.

CAUSE OF MAGNETISM IN MATTER

BOARDS



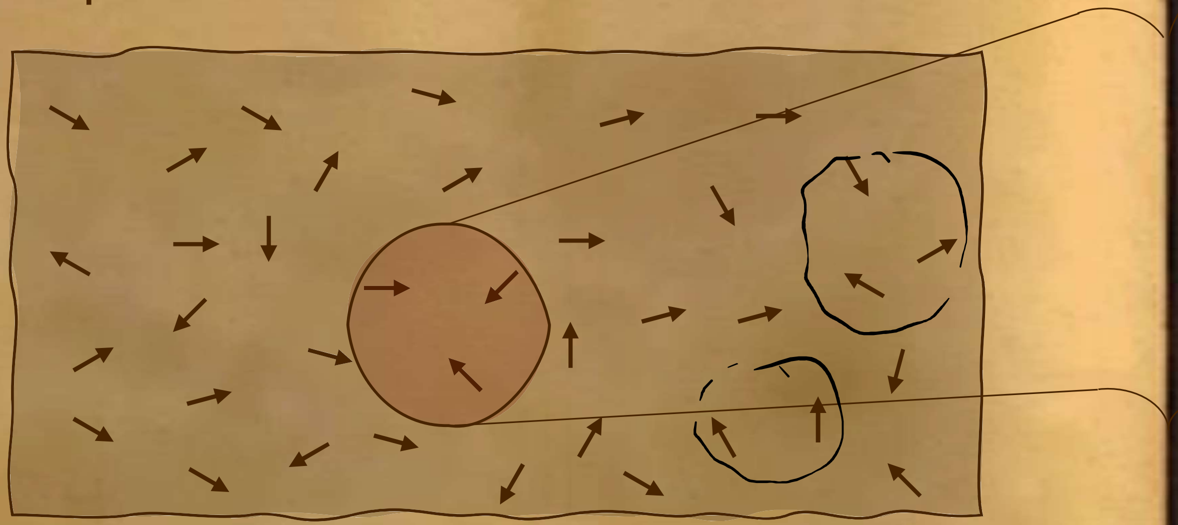
- In some elements, the resultant magnetic moment due to electrons gets cancelled.
- In case of Helium, all the e^- are paired. So, their magnetic moment is Zero.



- These materials are known as DIAMAGNETIC MATERIALS.
- In some other materials, moment does not get cancelled due to presence of unpaired e^-.
- These materials are known as PARAMAGNETIC & FERROMAGNETIC MATERIALS.

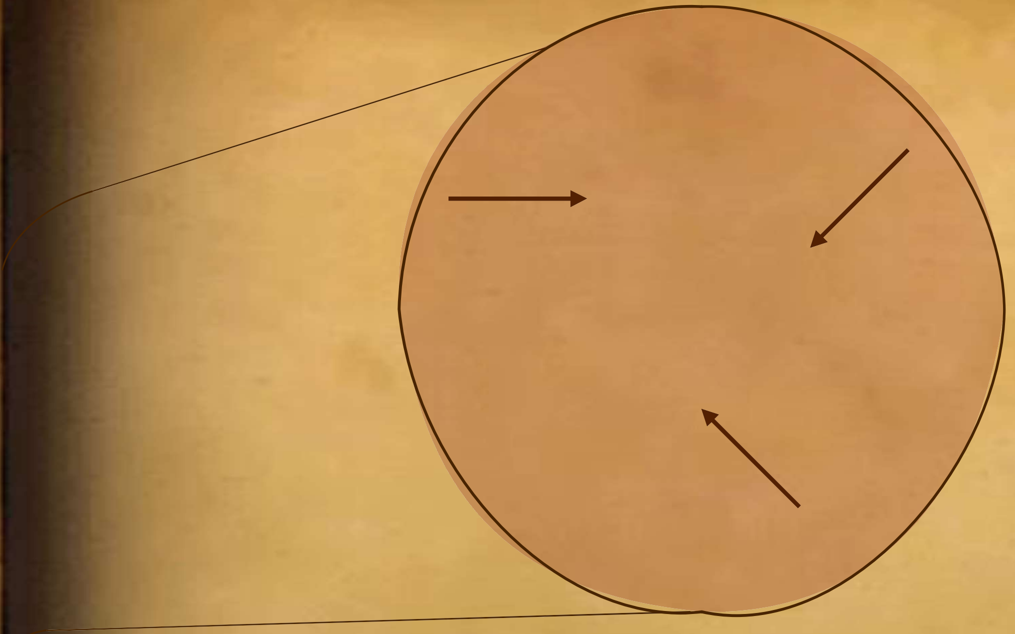
CAUSE OF MAGNETISM IN MATTER

- In a specimen of matter -



Random alignment of dipoles

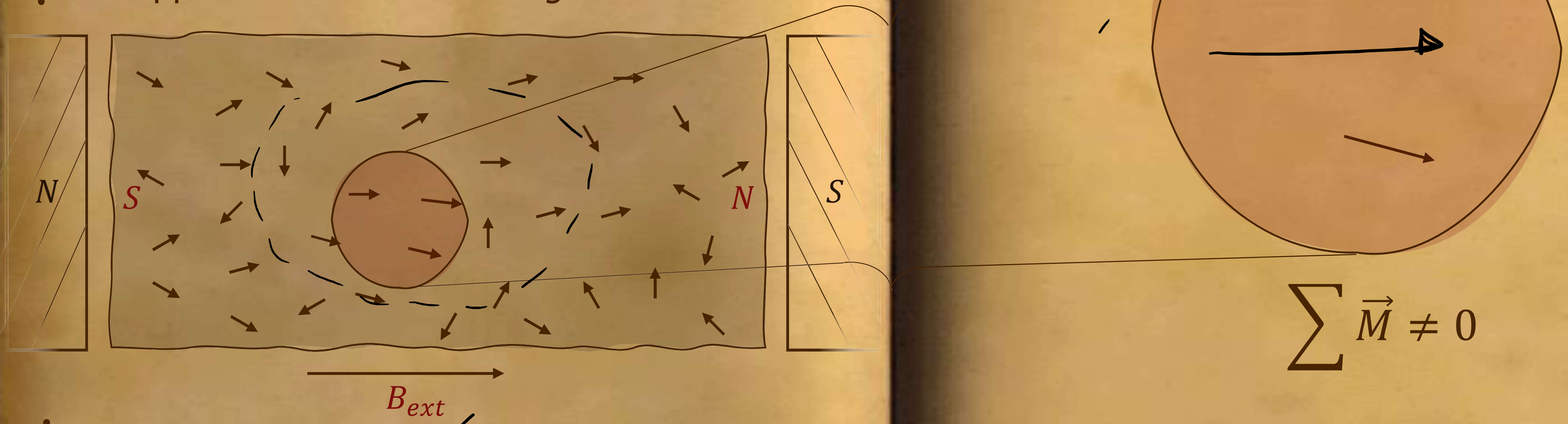
- Net magnetic moment ($\vec{M}$) is ZERO.



$$\sum \vec{M} = 0$$

CAUSE OF MAGNETISM IN MATTER

- On application of external magnetic field -



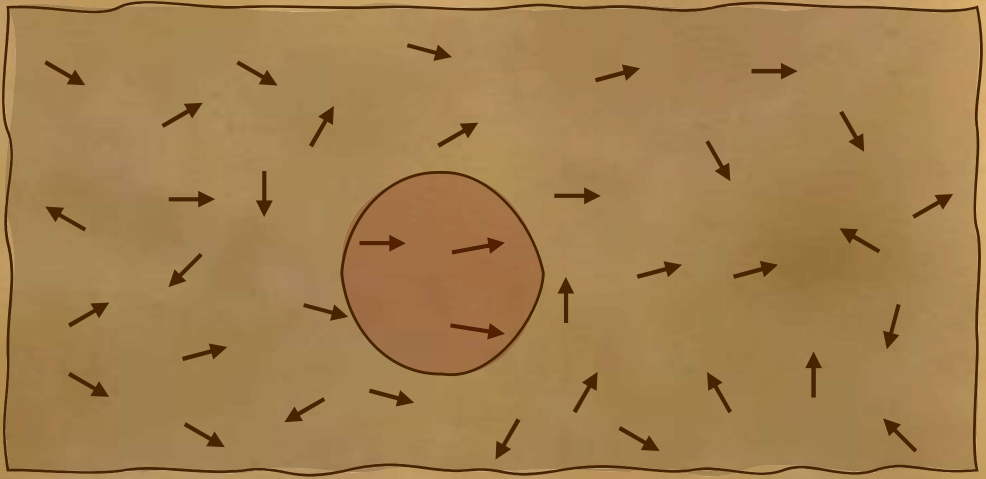
$$\sum \vec{M} \neq 0$$

- The matter is now magnetised
- Matter adds its own magnetic field.
- Net magnetic field inside > External magnetic field

MAGNETISATION & MAGNETIC INTENSITY

MAGNETISATION VECTOR ($\vec{I}$)

- It's defined as NET MAGNETIC MOMENT per unit volume

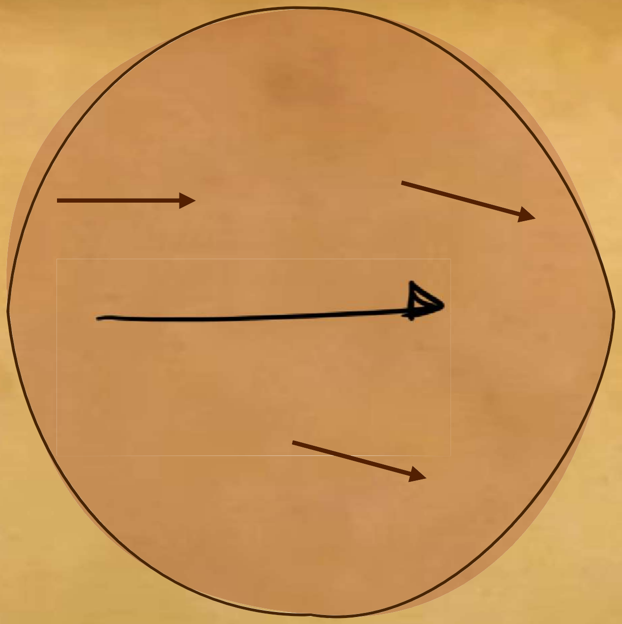


$$\vec{I} = \frac{\sum \vec{M}_{net}}{V}$$

$$\vec{M} = m\,2\vec{l}$$

$$\vec{M} = I\vec{A}$$

- S.I. Unit is *Ampere* m^{-1}



- Once the matter is magnetised, magnetic dipoles align themselves in the direction of magnetic field.
- Net magnetic moment is the sum of magnetic moments of these magnetic dipoles per unit volume.

PROBLEM

For a bar magnet with pole strength m, length $2l$ and cross sectional area A, calculate the value of magnetisation vector I.

(a) $\frac{m}{Al}$

(b) $\frac{m}{A}$

(c) $\frac{2m}{A}$

(d) $\frac{m}{2A}$

SOLUTION

NEET

$$M = m \times 2l$$

$$\boxed{I} = \frac{M}{V}$$

$$I = \frac{m \times \cancel{2l}}{A \times \cancel{2l}} = \boxed{\frac{m}{A}}$$

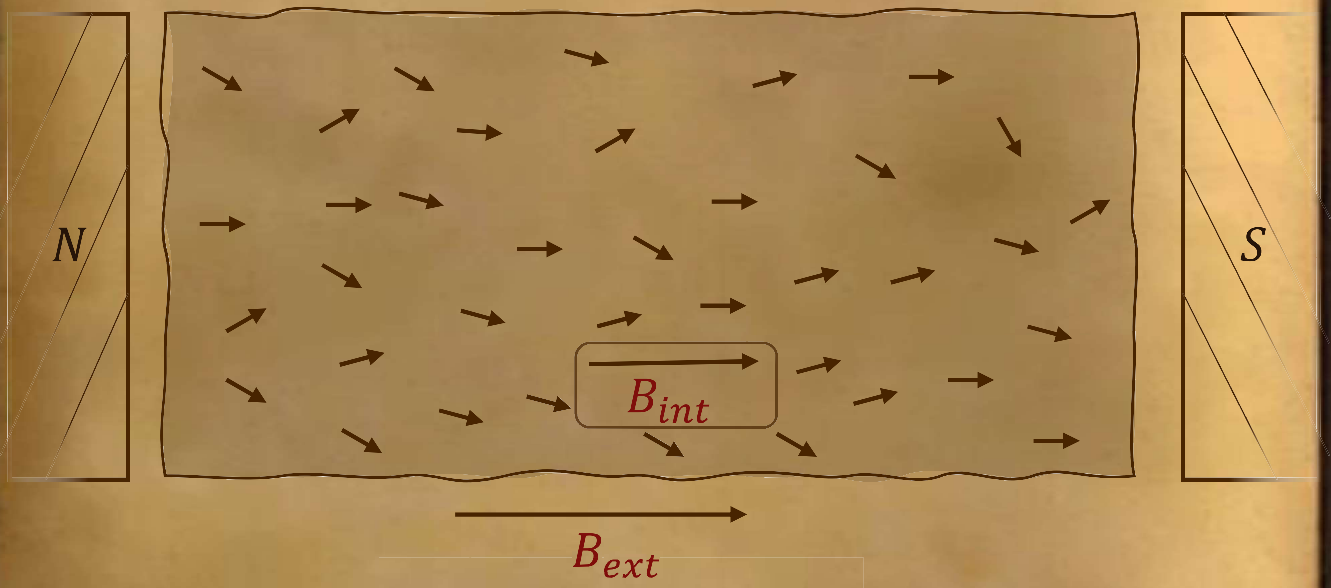
Therefore, option b is the correct answer.

MAGNETISATION & MAGNETIC INTENSITY

MAGNETIC INTENSITY ($\vec{H}$)

- Net magnetic field inside matter:

$$\vec{B}_{net} = \vec{B}_{ext} + B_{int}$$



$$B_{net} \propto (H + I)$$

$$B_{net} = \mu_0 (H + I)$$

$$\vec{B}_{net} = \mu_0 \vec{H} + \mu_0 \vec{I}$$

Factors affecting B_{net} inside matter

- **Internal factor :**

  Due to alignment of dipoles ($\vec{I}$)

- **External factor :**

  Like a current carrying coil or external magnetic field ($\vec{H}$)

MAGNETISATION & MAGNETIC INTENSITY

MAGNETIC INTENSITY ($\vec{H}$)

- It is defined as the ABILITY of a magnetic field to MAGNETIZE A MATERIAL medium

$B_{net} \propto (H + I)$

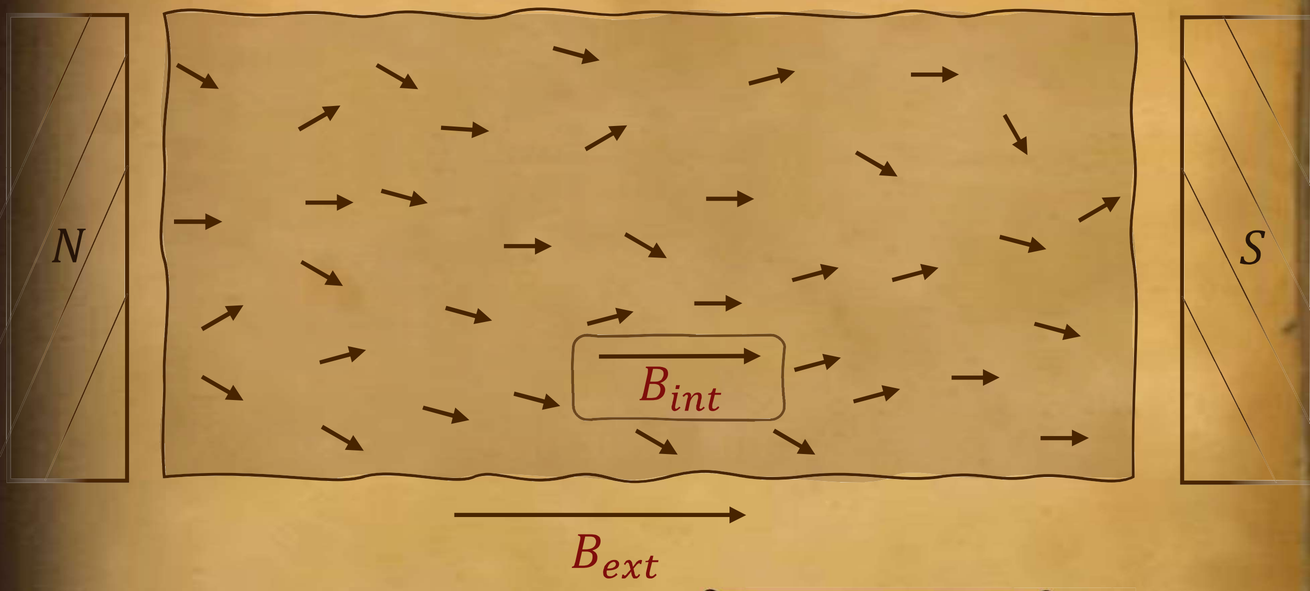
- $\vec{H}$ is defined as:

$$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{I}$$

- S.I. unit of $\vec{H}$ is *Ampere* m^{-1}

RELATION BETWEEN $\vec{I}$ & $\vec{H}$

- Internal factor is proportional to external factor



$$\vec{I} \propto \vec{H}$$

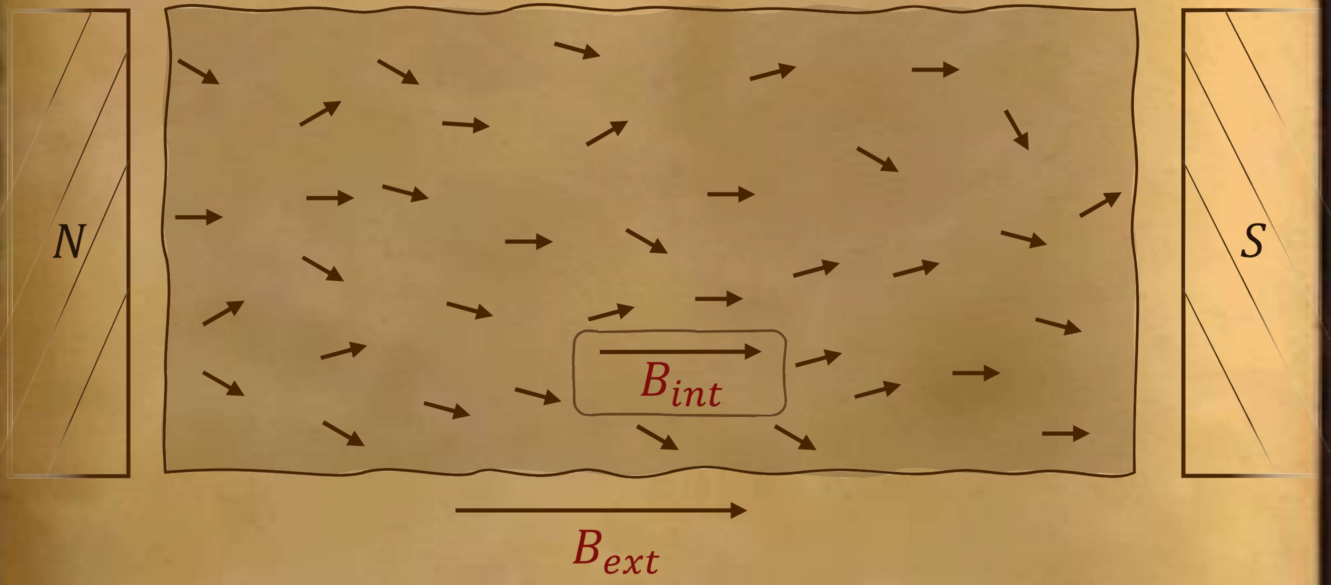
$$\vec{I} = \chi\vec{H}$$

χ = Magnetic susceptibility (Dimensionless constant)

Magnetic susceptibility (χ) of a material is defined as the ratio of $\vec{I}$ & $\vec{H}$

- χ indicates how much a substance gets magnetized when placed in external magnetic field.

PERMEABILITY



$$B_{net} = \mu_0(H + I)$$

$$B_{net} = \mu_0 H + \mu_0 \chi H$$

$$\vec{B}_{net} = \mu_0(1+\chi)\vec{H}$$

$$\vec{I} = \chi\vec{H}$$

$$\vec{B}_{net} = \mu_0(1+\chi)\vec{H}$$

$$\vec{B}_{net} = \mu\vec{H}$$

Permeability of material

$$\mu = \mu_0(1+\chi)$$

$$\vec{B}_{net} = \mu\,\vec{H}$$

$$=$$

PERMEABILITY

NEET

$$\mu = \mu_0(1 + \chi)$$

- If there is no material ($\vec{I} = 0$)

$$\vec{B}_0 = \mu_0 \vec{H}$$

Permeability of vacuum

- If there is a material ($\vec{I} \neq 0$)

$$\vec{B}_m = \mu_0 \vec{H} + \mu_0 \vec{I}$$

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

$$\vec{B}_m = \mu \vec{H}$$

RELATIVE PERMEABILITY

- Factor by which magnetic field increases when a material is introduced.

$$\mu_r = \frac{\vec{B}_m}{\vec{B}_0}$$

$$\mu_r = \frac{\mu_m \cancel{\vec{H}}}{\mu_0 \cancel{\vec{H}}}$$

$$\mu_r = \frac{\mu_m}{\mu_0}$$

PROBLEM

A solenoid has a material of relative permeability 400. If solenoid has 1000 turns per meter and carries a current of $2\ A$. Find

1) H
2) B_{net}
3) I

SOLUTION

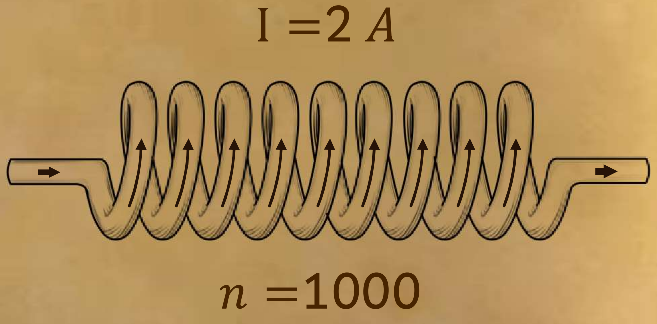
BOARDS

- $B_0 = \mu_0 n\mathrm{I}$

$B_0 = \mu_0 H$

$\Rightarrow H = n\mathrm{I}$

$\therefore H = 2 \times 1000 = 2 \times 10^3\ Am^{-1}$



- $B_m = \mu_m H$

$\mu_r = \dfrac{\mu_m}{\mu_0} \qquad \Rightarrow B_m = \mu_r \mu_0 H$

$\Rightarrow B_{net} = 400 \times 4\pi \times 10^{-7} \times 2 \times 10^3$

$\therefore B_{net} = 1.0048\ T$

- $I = \chi H$

$\mu_r = 1 + \chi$

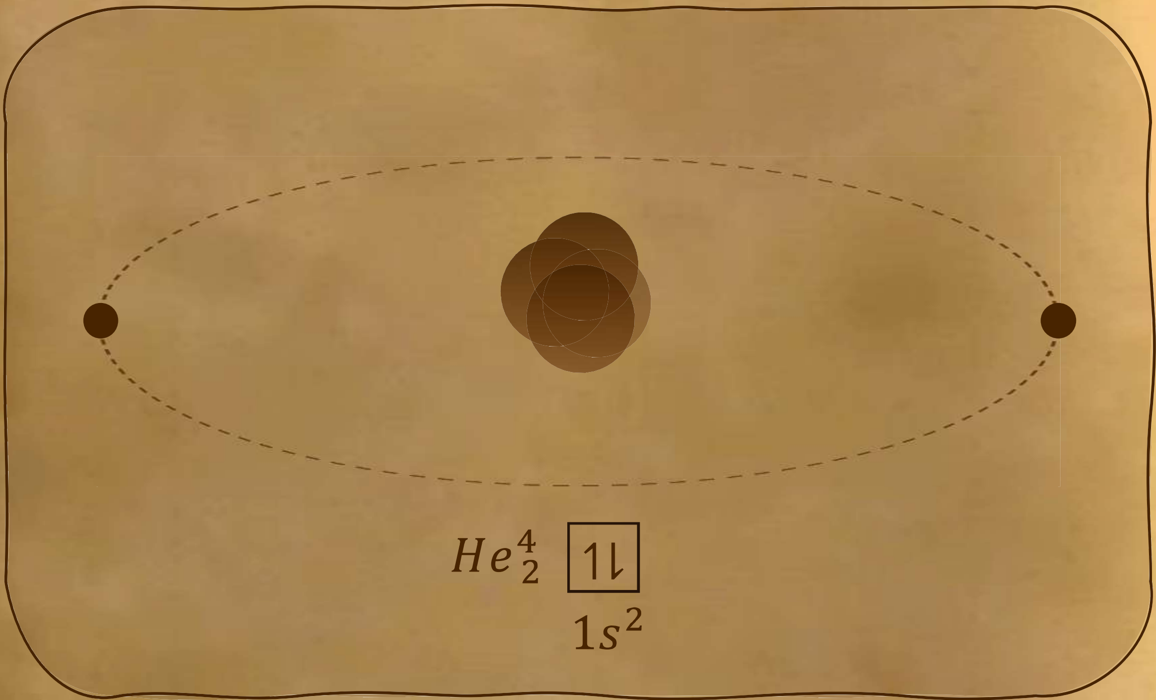
$\chi = 400 - 1 = 399$

$I = 399 \times 2 \times 10^3 = 7.98 \times 10^5\ Am^{-1}$

DIAMAGNETISM

RECAP

- In some elements, the resultant magnetic moment due to electrons gets CANCELLED.



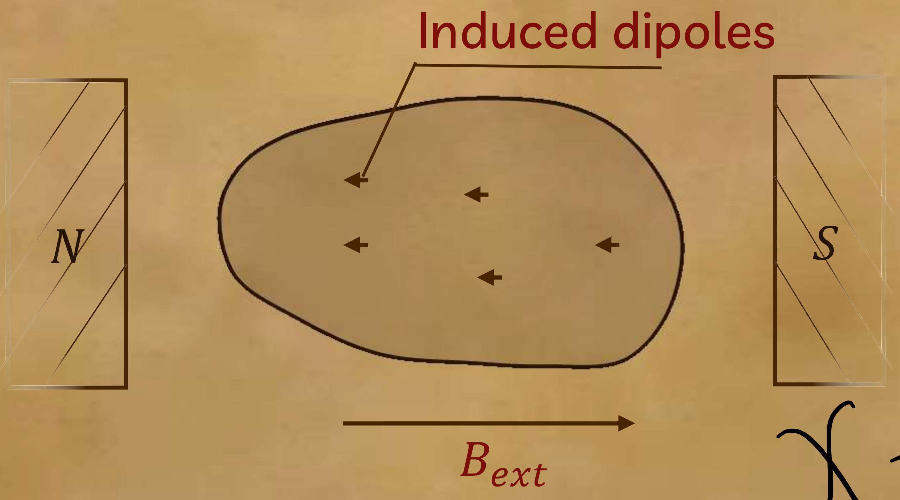
- In case of Helium, all the e^- are paired. So, their magnetic moment is Zero.

- These materials are known as DIAMAGNETIC MATERIALS.

- Diamagnetic materials do not have atomic dipoles

DIAMAGNETISM

- Dipoles are INDUCED in any substance on application of external magnetic field. (Lenz's law)

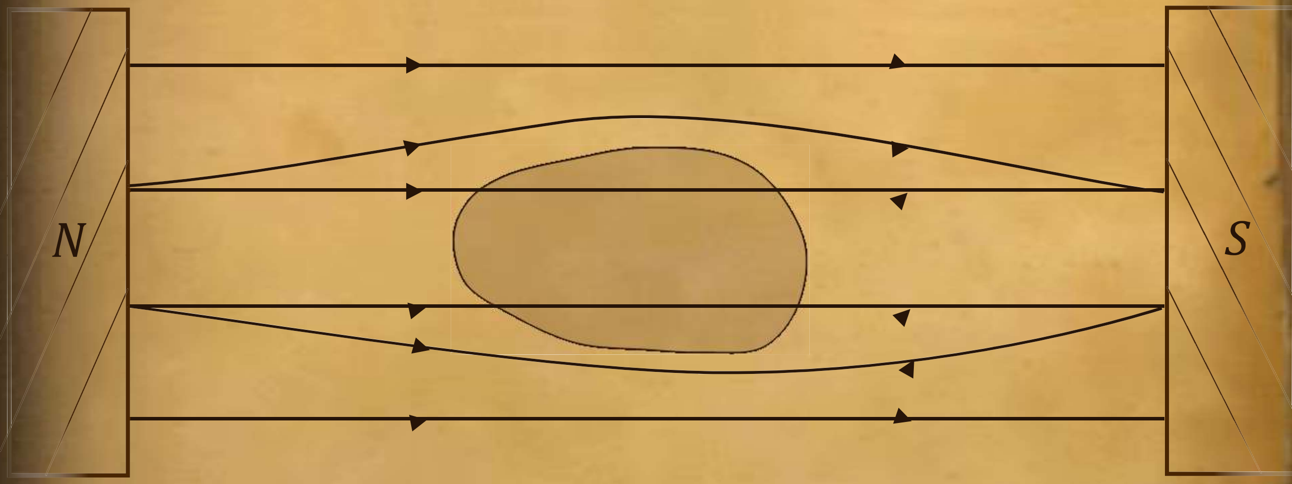


$\chi \rightarrow -ve$

- This induction is VERY SMALL.
- In diamagnetic substances, these induced dipoles cause a WEAK REPULSION.
- Magnetic susceptibility is SMALL and NEGATIVE.

χ is –ve and $\mu_r < 1$ $\mu_r = 1 + \chi$

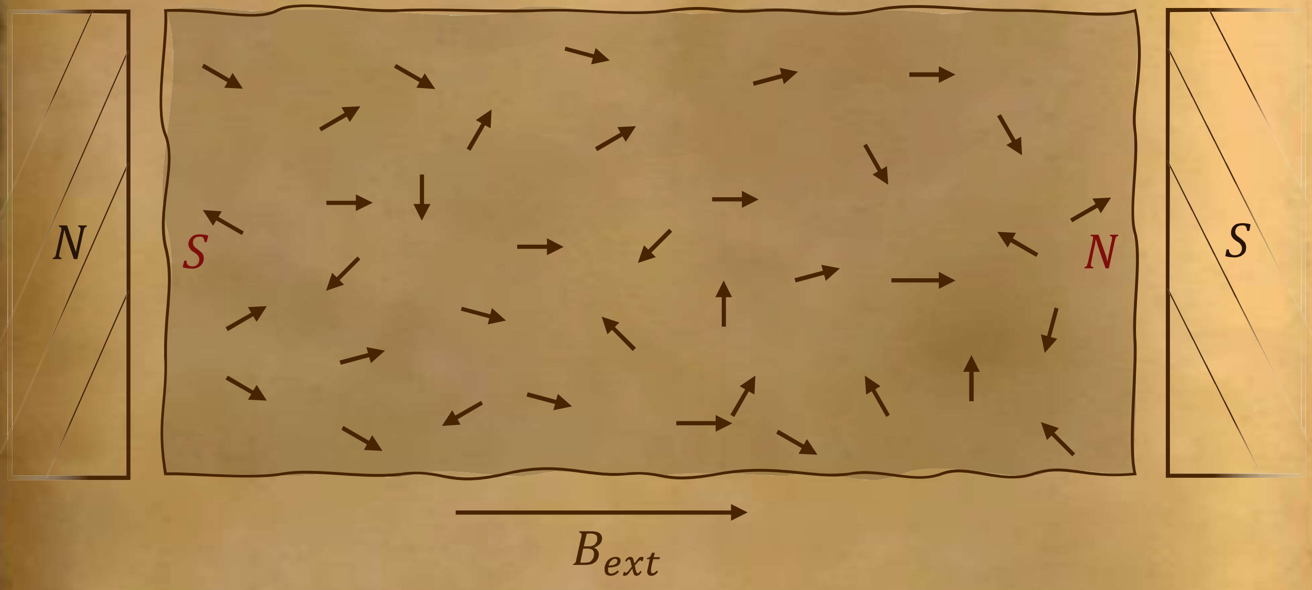
- Magnetic field lines are REPELLED from diamagnetic substances



- **Examples:** N_2 (At STP), Water, $NaCl$, Cu

PARAMAGNETISM

- Atomic dipoles are REALIGNED in the presence of external magnetic field.

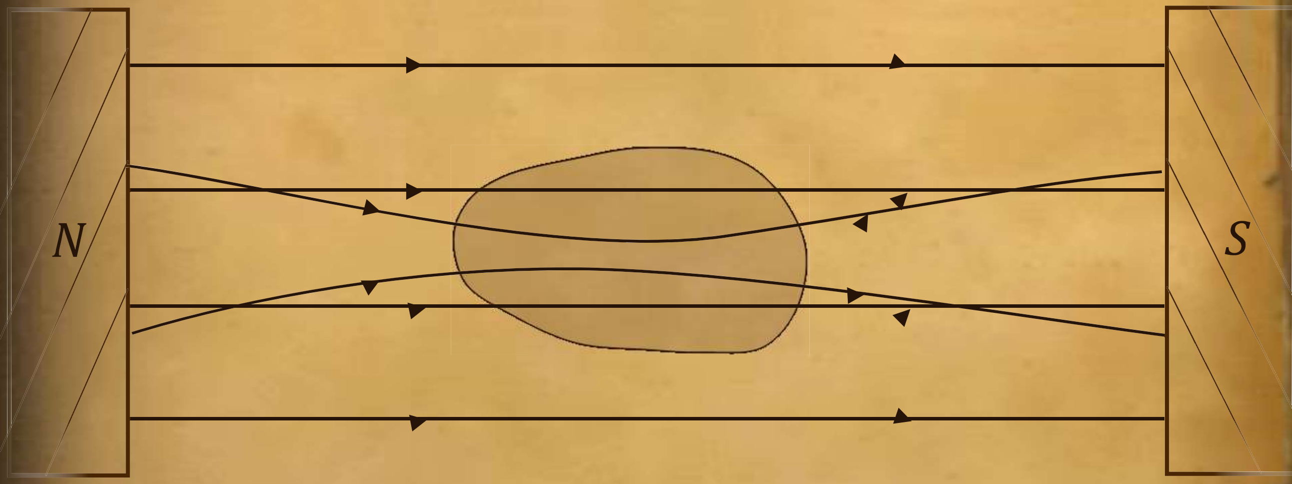


- The alignment is PARTIAL.
- In paramagnetic substances, there is a WEAK ATTRACTION in external magnetic field.
- Magnetic susceptibility is SMALL and POSITIVE.

χ is +ve and $\mu_r \geq 1$

$$\mu_r = 1 + \chi$$

- Magnetic field lines get denser inside paramagnetic substances.

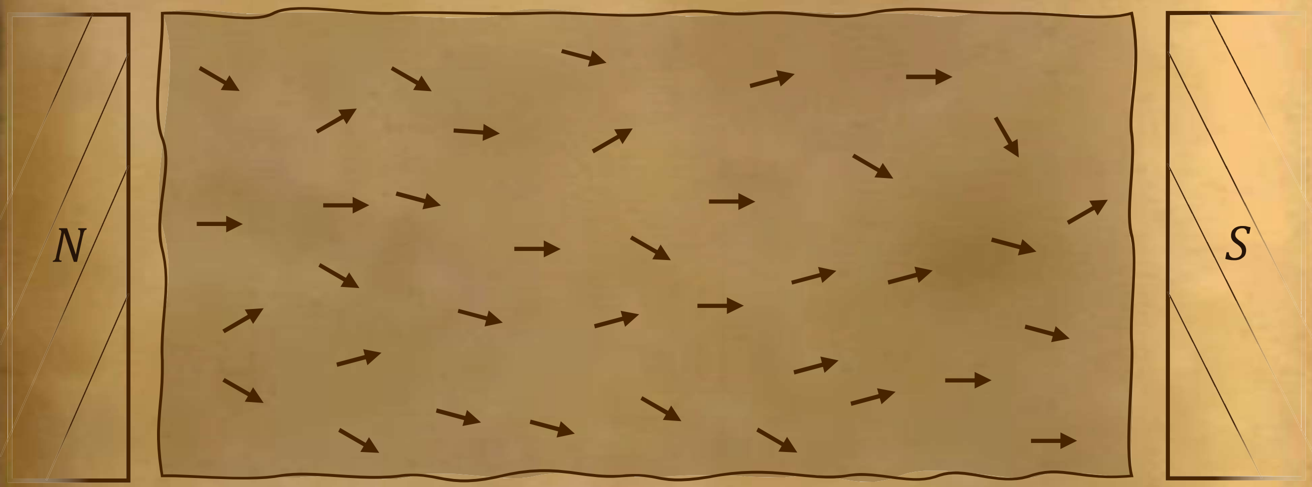


- **Examples:** O_2 (at STP) , FeO, Al, Na, Ca

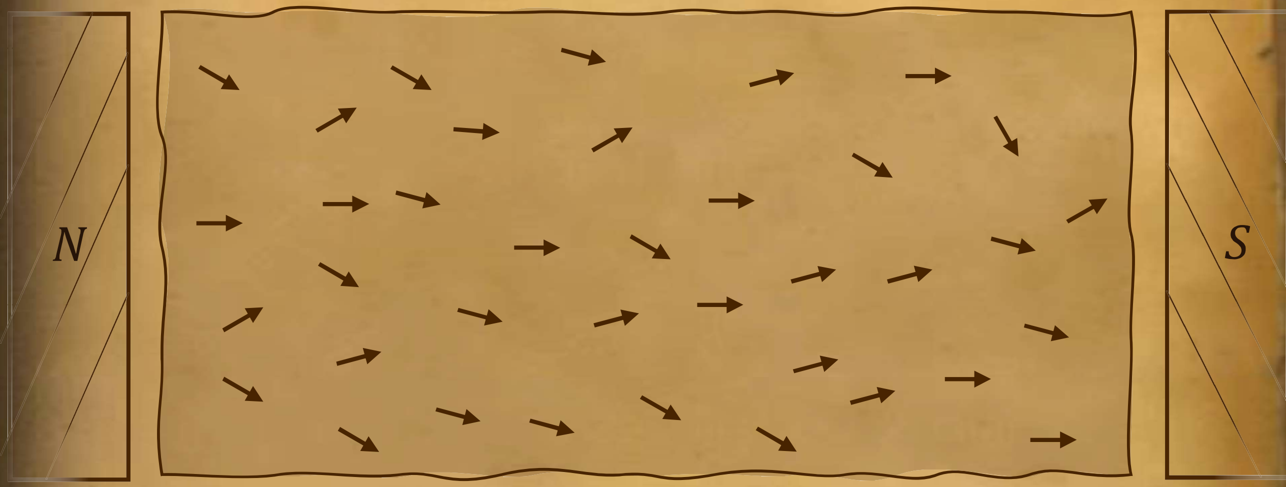
PARAMAGNETISM

CURIE'S LAW

- Magnetisation ($\vec{I}$) of a paramagnetic substance is inversely proportional to absolute temperature (T).



At normal temperature

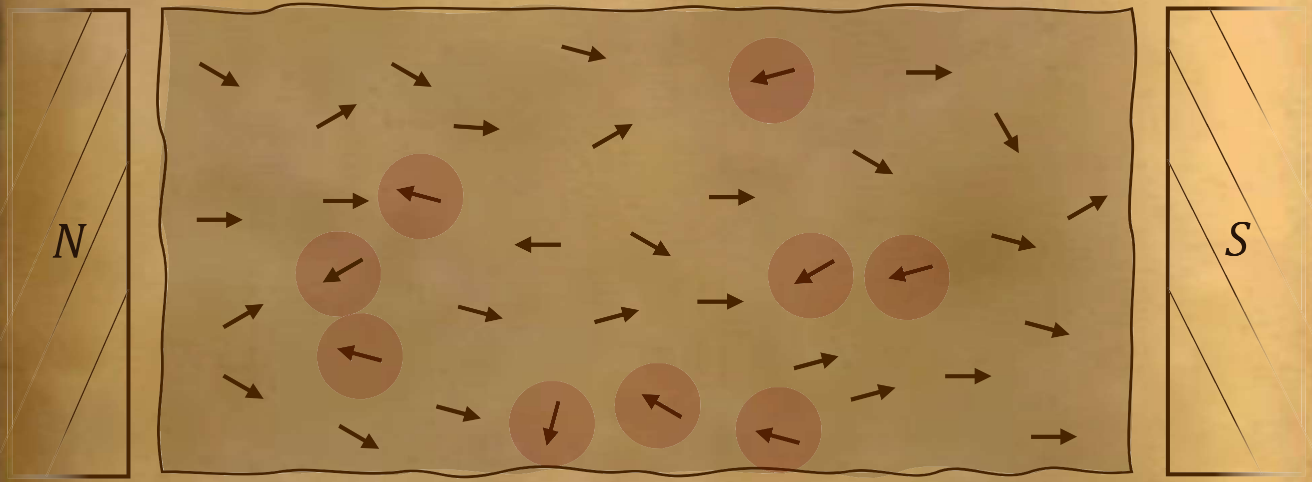


At higher temperature

PARAMAGNETISM

CURIE'S LAW

- Magnetisation ($\vec{I}$) of a paramagnetic substance is inversely proportional to absolute temperature (T)



When temperature is increased, magnetisation reduces

$$I \propto \frac{B_0}{T}$$

$$B_0 = \mu_0 H$$

$$I = \chi H$$

$$I = \boxed{C}\frac{B_0}{T}$$

Curie's constant

$$I = \chi H$$

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

$$B_0 = \mu_0 H$$

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

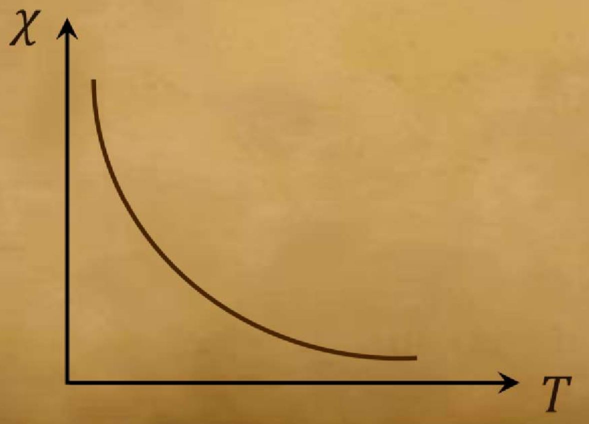
χ = Magnetic susceptibility

μ_o = Permeability of free space

C = Curie's constant

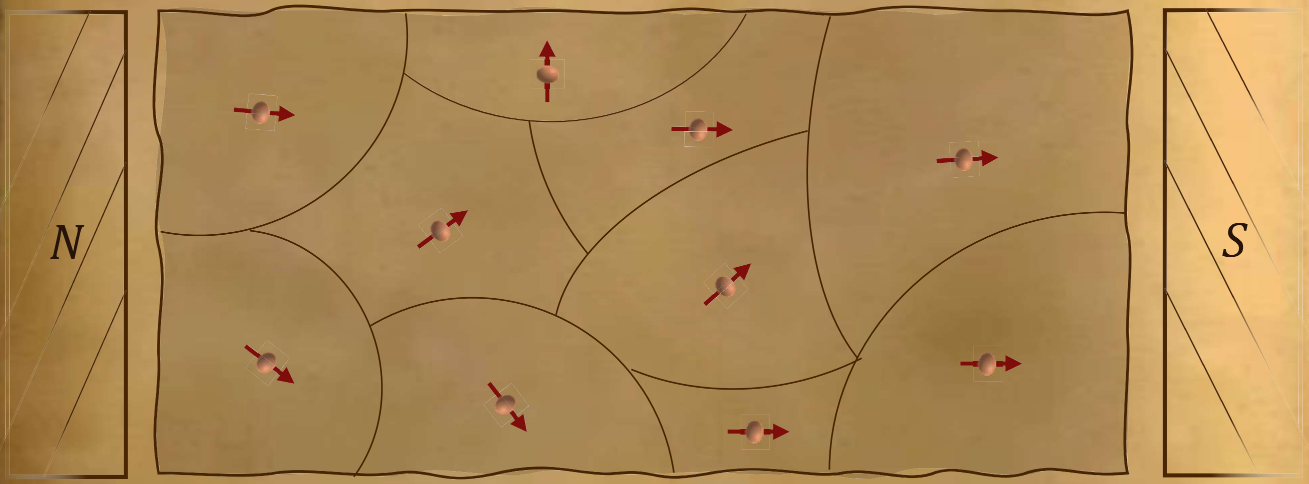
T = Absolute temperature

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



FERROMAGNETISM

- In ferromagnetic substances, atomic dipoles interact with each other to align in same direction. These small volumes are called DOMAINS.



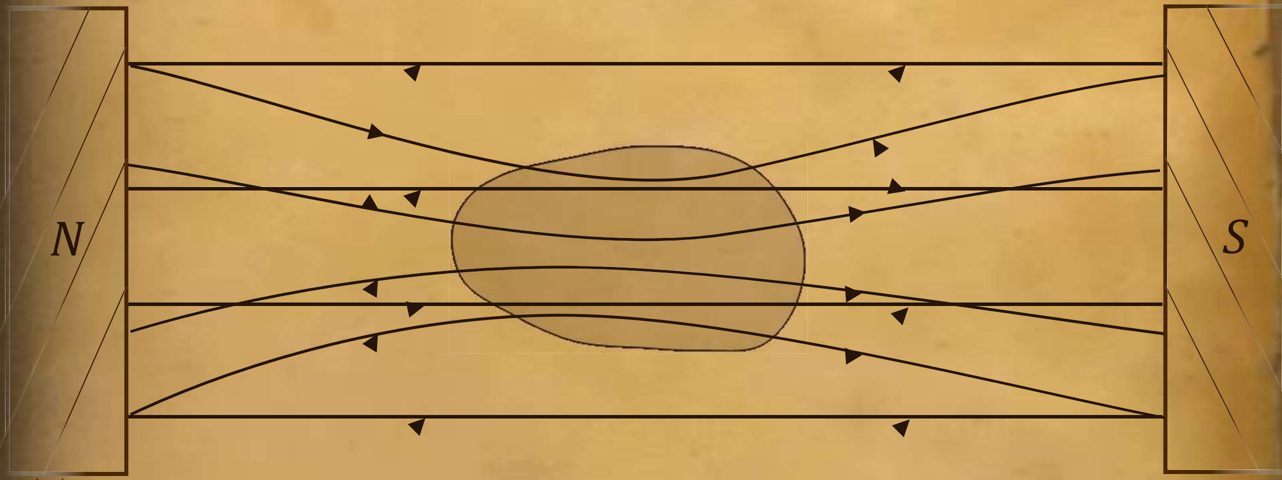
- On application of external magnetic field, these domains align themselves in the direction of magnetic field.

- Domains usually are of $1\ mm$ size & contain around 10^{11} atoms

- Domains aligned in the direction of magnetic field also grow in size. (Domain Growth)

$\mu_r = 1 + \chi$

- Magnetic susceptibility (χ) is +ve and very large, $\mu_r \gg 1$.
- Ferromagnetic substances are strongly attracted in external magnetic field

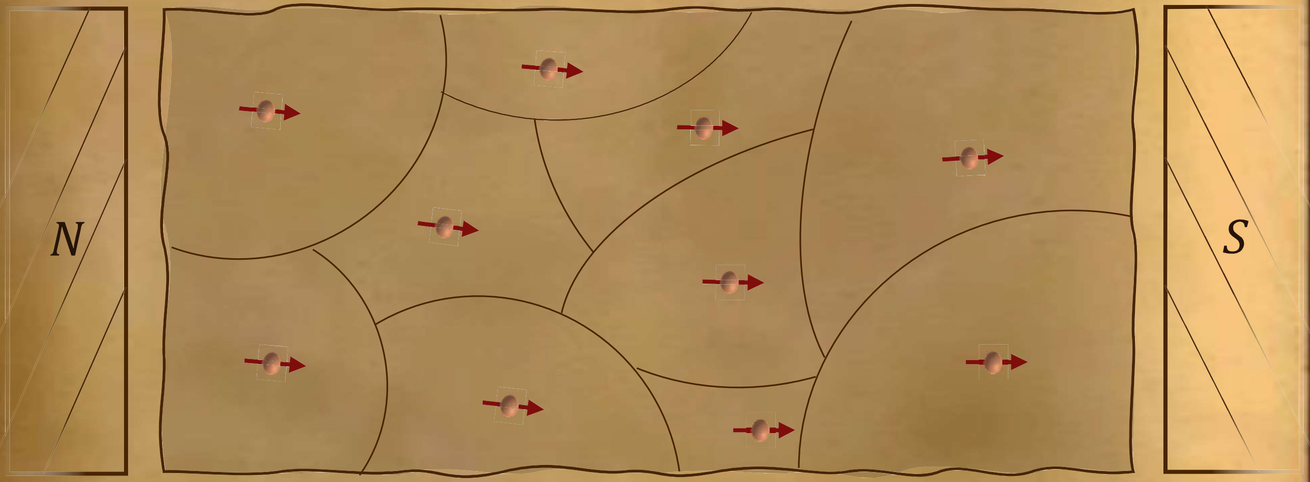


On removal of external magnetic field

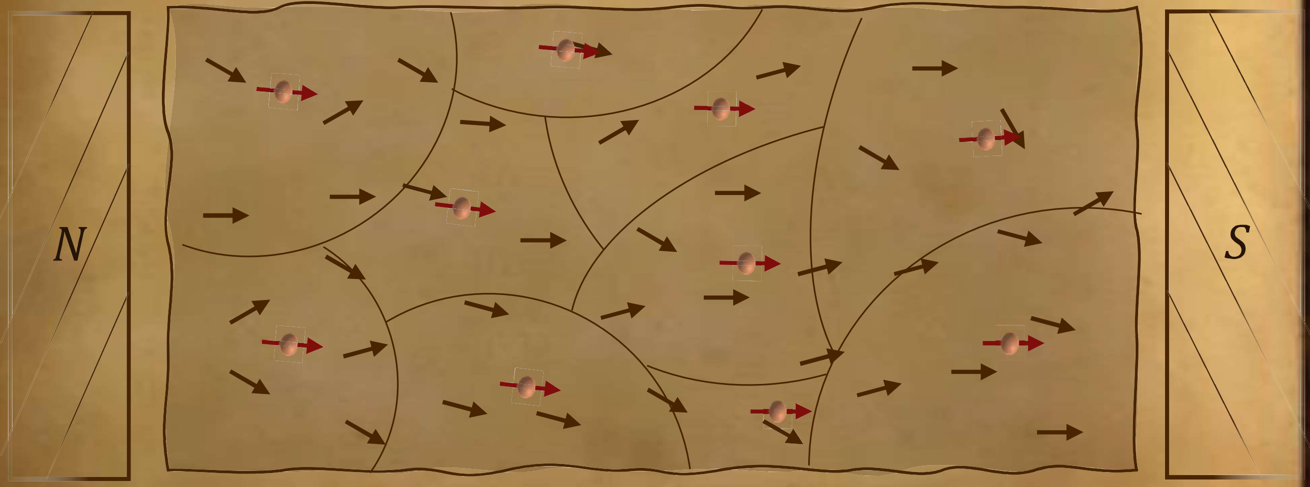
- Magnetisation persists:
  Hard ferromagnetic materials
  (Ex. Alnico)
- Magnetisation disappears:
  Soft ferromagnetic materials
  (Ex. Soft iron)

FERROMAGNETISM

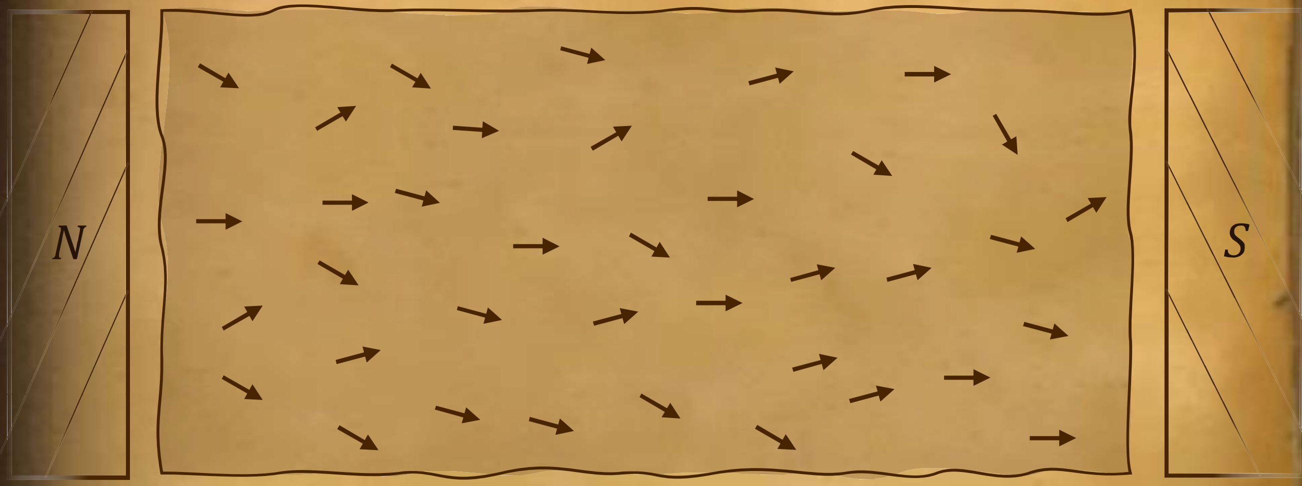
CURIE TEMPERATURE



At normal temperature



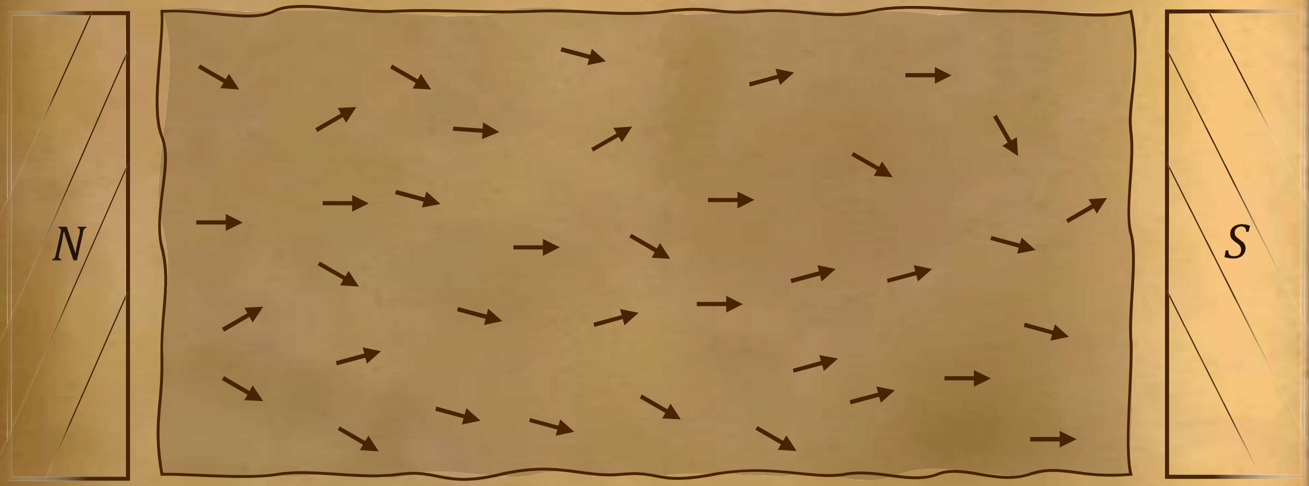
At higher temperature



- On increasing temperature, ferromagnetic property DECREASES.
- At a certain temperature, materials lose their ferromagnetic properties and become PARAMAGNETIC.
- The domain structure disintegrates.
- This transition temperature is called CURIE TEMPERATURE (T_C).

FERROMAGNETISM

CURIE TEMPERATURE



- On increasing temperature, ferromagnetic property DECREASES.
- At a certain temperature, materials lose their ferromagnetic properties and become PARAMAGNETIC.
- The domain structure disintegrates.

- The susceptibility above Curie temperature in paramagnetic state is given by :

$$\chi = C\,\frac{\mu_0}{T - T_C}$$

χ = Magnetic susceptibility

μ_o = Permeability of free space

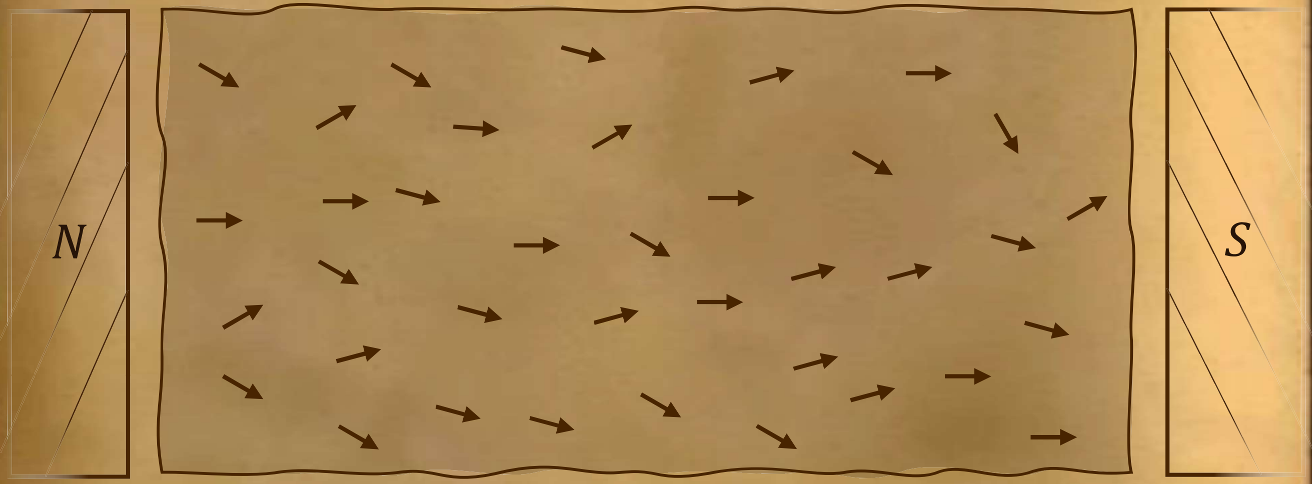
C = Curie's constant

T = Absolute temperature

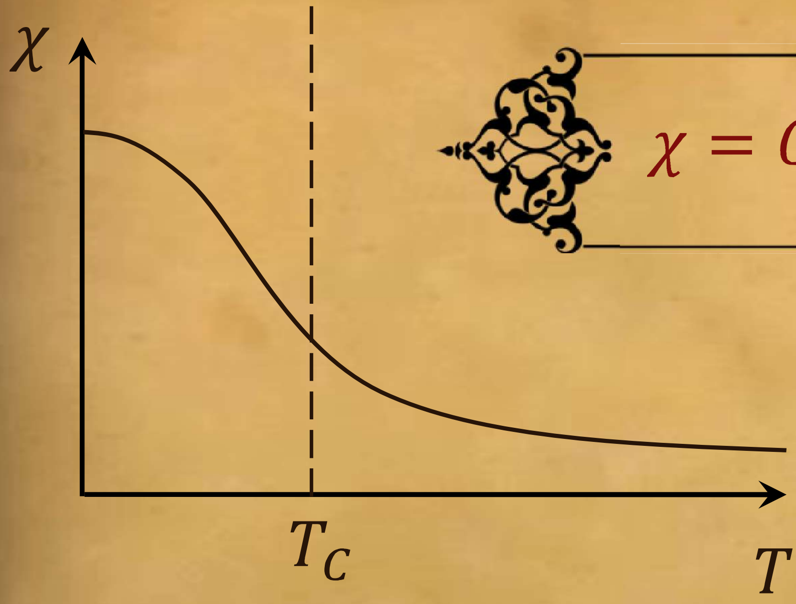
T_c = Curie temperature

FERROMAGNETISM

CURIE TEMPERATURE



- On increasing temperature, ferromagnetic property DECREASES.
- At a certain temperature, materials lose their ferromagnetic properties and become PARAMAGNETIC.
- The domain structure disintegrates.



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

Material	$T_C\ (K)$
Cobalt	1394
Nickel	631
Iron	1043
Alnico	973-1123

CLASSIFICATION OF MATERIALS

BASED ON MAGNETIC PROPERTIES

BOARDS

$$\mu_r = 1 + \chi$$

DIAMAGNETIC :

- Susceptibility (χ) is negative.
- Permeability of material (μ) is less than permeability of vacuum (μ_0)

$\underline{\mu_r < 1}$

- Relative permeability (μ_r) is between 0 and 1.

PARAMAGNETIC :

- Susceptibility (χ) is small and positive.
- Permeability of material (μ) is slightly greater than permeability of vacuum (μ_0).
- Relative permeability (μ_r) is slightly greater than 1.

FERROMAGNETIC :

- Susceptibility (χ) is large and positive.
- Permeability of material (μ) is greater than permeability of vacuum (μ_0).
- Relative permeability (μ_r) is greater than 1.

$$\mu = \mu_0(1 + \chi)$$

Diamagnetic	Paramagnetic	Ferromagnetic
$-1 \leq \chi \leq 0$	$0 < \chi < \varepsilon$	$\chi \gg 1$
$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$
$0 \leq \mu_r \leq 1$	$1 < \mu_r < 1 + \varepsilon$	$\mu_r \gg 1$

- ε is a small positive number introduced to quantify paramagnetic materials.

PROBLEM

The magnetic susceptibility is negative for

(a) Ferromagnetic materials only.

(b) Paramagnetic and ferromagnetic materials

[✓ (c)] Diamagnetic material only.

(d) Paramagnetic material only.

SOLUTION

Susceptibility (χ) is large and positive for ferromagnetic materials, it is small and positive for paramagnetic materials, and it is negative only for diamagnetic materials.

Therefore, option c is the correct answer.

PROBLEM

If a diamagnetic substance is brought near north or south pole of a bar magnet, it is

(a) Attracted by the poles.

[✓ (b)] Repelled by the poles.

(c) Repelled by the north pole and attracted by the south pole.

(d) Attracted by the north pole and repelled by south pole.

SOLUTION

NEET

Diamagnetic substances do not have any unpaired electrons. Also, they magnetize in the opposite direction of the magnetic field. These substances are repelled in an external magnetic field.
Hence it will get repelled by the poles .

Therefore, option b is the correct answer.

PROBLEM

The magnetic moment of a diamagnetic atom is,

(a) Much greater than one.

(b) 1

(c) Between zero and one.

(d) Equal to zero.

SOLUTION

In diamagnetic materials, all the electrons are paired so their magnetic moment is equal to zero.

Therefore, option d is the correct answer.

PROBLEM

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

(a) Anti ferromagnetism.

(b) No magnetic property.

(c) Diamagnetism.

(d) Paramagnetism.

SOLUTION

NEET

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

When $T > T_C$, χ becomes positive and small.

Therefore, option d is the correct answer.

PROBLEM

If the magnetic dipole moment of an atom of diamagnetic material, paramagnetic material and ferromagnetic material is denoted by μ_d, μ_p, μ_f respectively. Then,

(a) $\mu_d \neq 0$ and $\mu_f \neq 0$

(b) $\mu_p = 0$ and $\mu_f \neq 0$

(c) $\mu_d = 0$ and $\mu_p \neq 0$

(d) $\mu_d \neq 0$ and $\mu_p = 0$

$\mu_d = 0$; $\mu_p \neq 0$

$\mu_f \neq 0$

SOLUTION

NEET

Only diamagnetic substances have zero atomic dipole number.

$\mu_d = 0,\ \mu_p \neq 0,\ \mu_f \neq 0$

Therefore, option c is the correct answer.

PROBLEM

A thin diameter rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched ON, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from,

(a) The current source.

(b) The magnetic field.

(c) The lattice structure of the material of the rod.

(d) The induced electric field due the changing magnetic field.

SOLUTION

NEET

In this case, as the electromagnet is connected to battery (source of emf), the magnetic field is produced in it. Force due to this magnetic field pushes the rod upwards and so gravitational potential energy is stored. This stored energy will require work which will come from current source or battery which is connected to electromagnet.

Therefore, option a is the correct answer.

Quick Recap

Diamagnetic	Paramagnetic	Ferromagnetic
$-1 \leq \chi \leq 0$	$0 < \chi < \varepsilon$	$\chi \gg 1$
$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$
$0 \leq \mu_r \leq 1$	$1 < \mu_r < 1 + \varepsilon$	$\mu_r \gg 1$

CURIE'S LAW

- Magnetisation ($\vec{I}$) of paramagnetic substance is inversely proportional to absolute temperature (T).

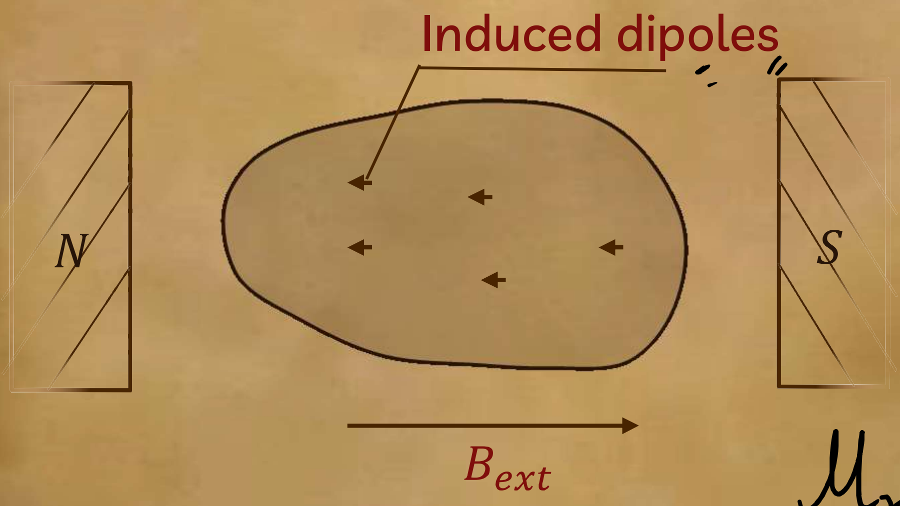
$$\chi = C\frac{\mu_0}{T}$$

- The susceptibility above Curie temperature in paramagnetic state is given by :

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

RECAP

Diamagnetism

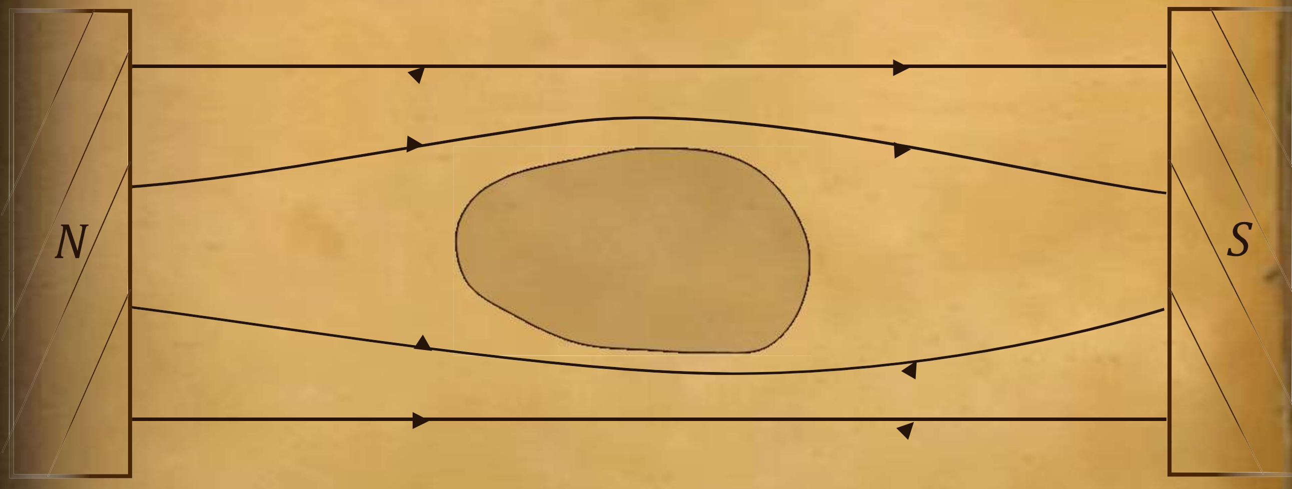


$\mu_r = 1 + \chi$

- This induction is VERY SMALL.
- In diamagnetic substances, these induced dipoles cause a WEAK REPULSION.

Magnetic susceptibility is SMALL and NEGATIVE.

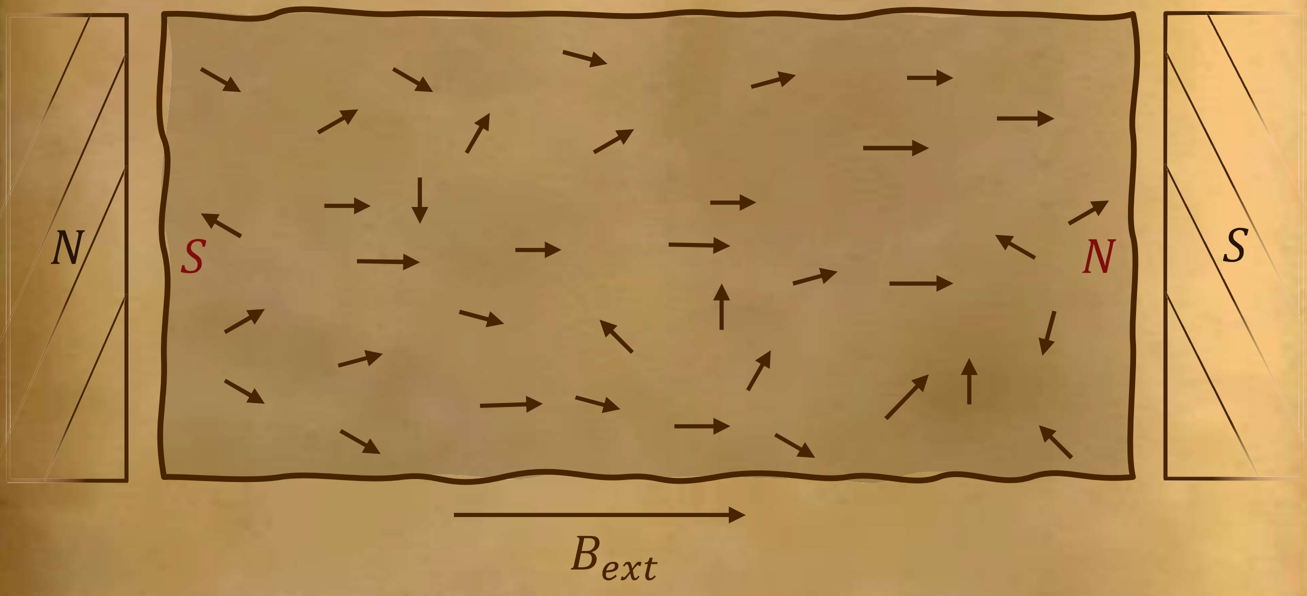
χ is –ve and $\mu_r < 1$



- Magnetic field lines are REPELLED from diamagnetic substances

RECAP

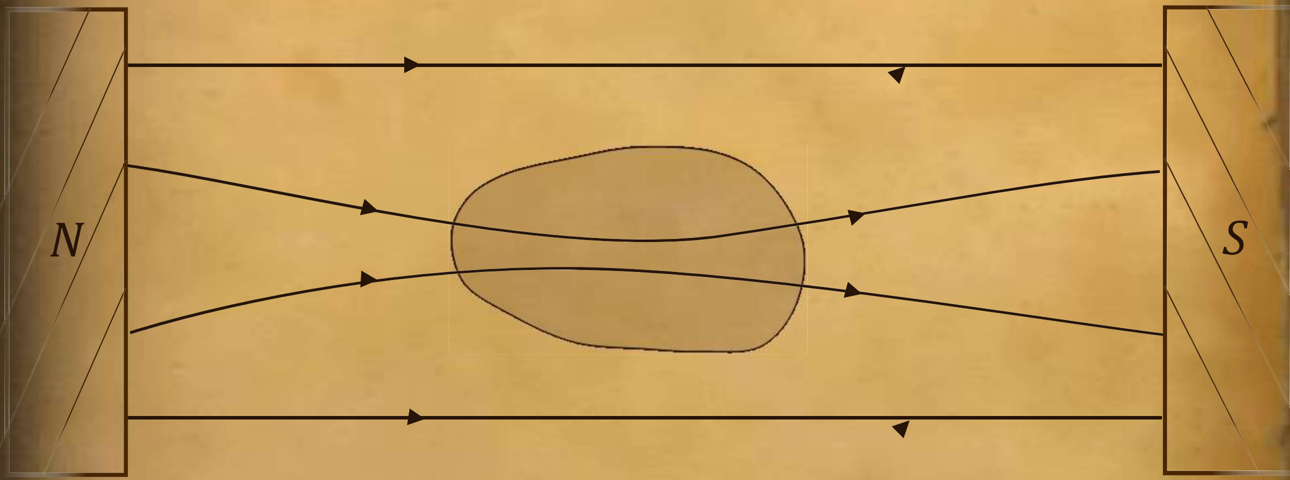
Paramagnetism



- The alignment is PARTIAL.
- In paramagnetic substances, there is a WEAK ATTRACTION in external magnetic field.
- Magnetic susceptibility is SMALL and POSITIVE.

χ is +ve and $\mu_r > 1$

- Magnetic field lines get denser inside paramagnetic substances.

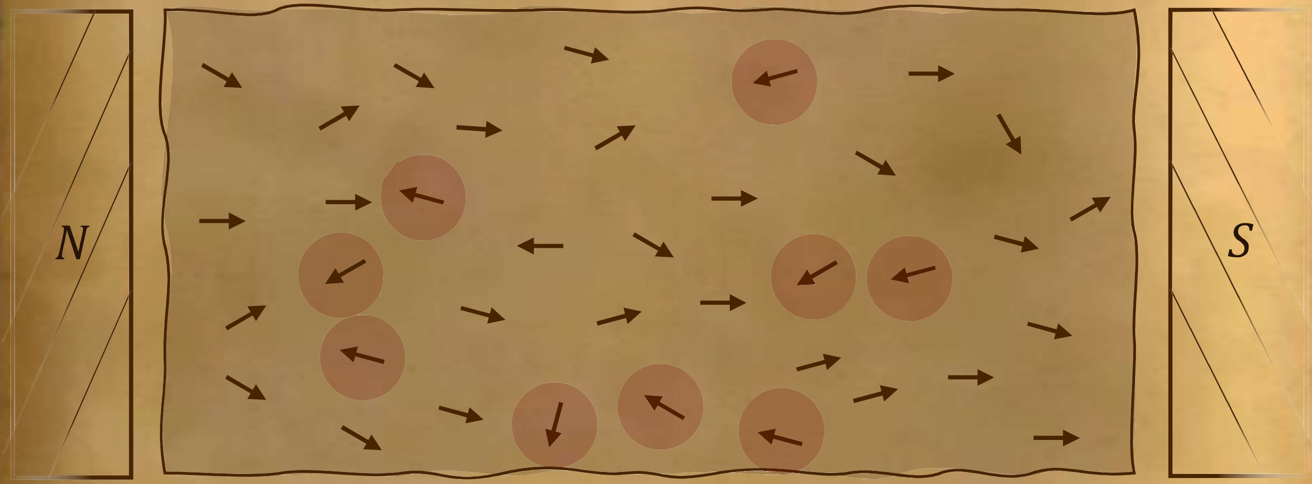


RECAP

Paramagnetism

Curie's Law

- Magnetisation ($\vec{I}$) of a paramagnetic substance is inversely proportional to absolute temperature (T)



When temperature is increased, magnetisation reduces.

$$I \propto \frac{B_0}{T}$$

χH

$\mu_0 H$

$$I = \boxed{C}\frac{B_0}{T}$$

Curie's constant

$$\boxed{\downarrow\chi = C\frac{\mu_0}{T\uparrow}}$$

χ = Magnetic susceptibility

μ_o = Permeability of free space

C = Curie's constant

T = Absolute temperature

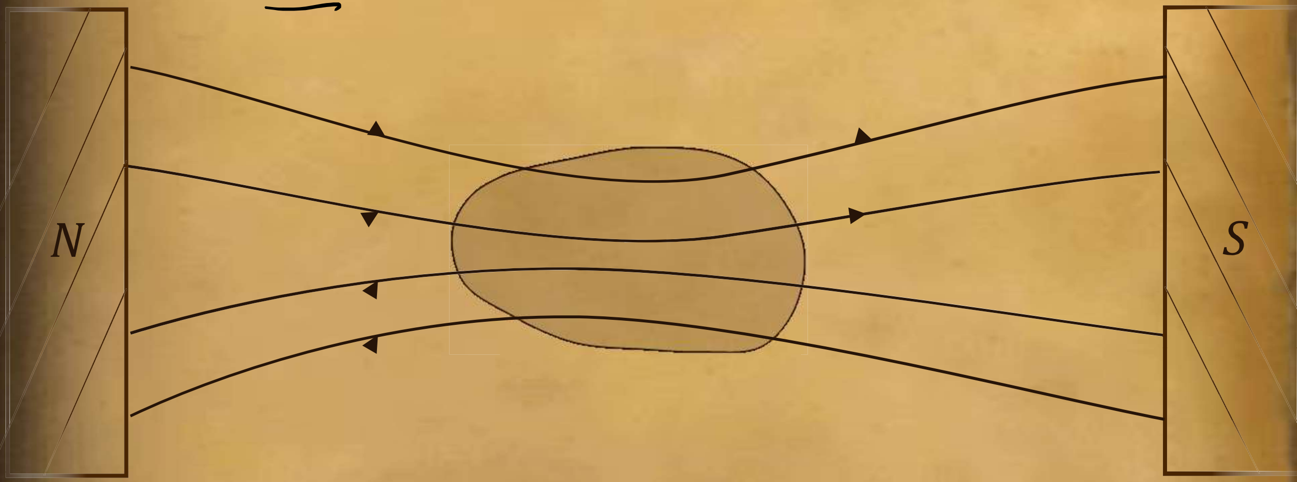
RECAP

Ferromagnetism

- In ferromagnetic substances, atomic dipoles interact with each other to align in same direction. These small volumes are called DOMAINS.

- On application of external magnetic field, these domains align themselves in the direction of magnetic field.
- Domains usually are of $1\ mm$ size & contain around 10^{11} atoms

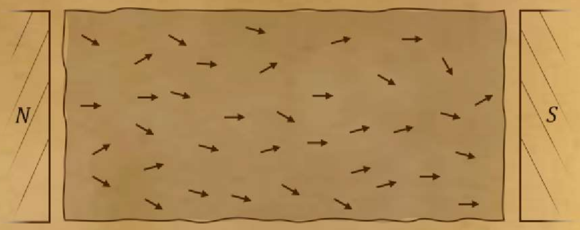
- Domains aligned in the direction of magnetic field also grow in size. (Domain Growth)
- Magnetic susceptibility (χ) is +ve and very large, $\mu_r \gg 1$.



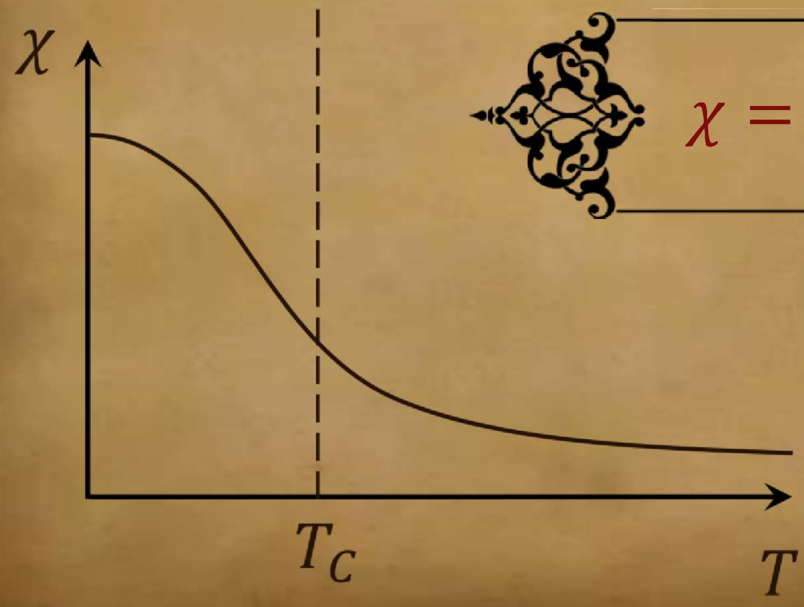
RECAP

Ferromagnetism

Curie's Law



- At a certain temperature, materials lose their ferromagnetic properties and become PARAMAGNETIC.
- The domain structure disintegrates.
- The susceptibility above Curie temperature in paramagnetic state is given by :



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

Classification of materials based on magnetic properties

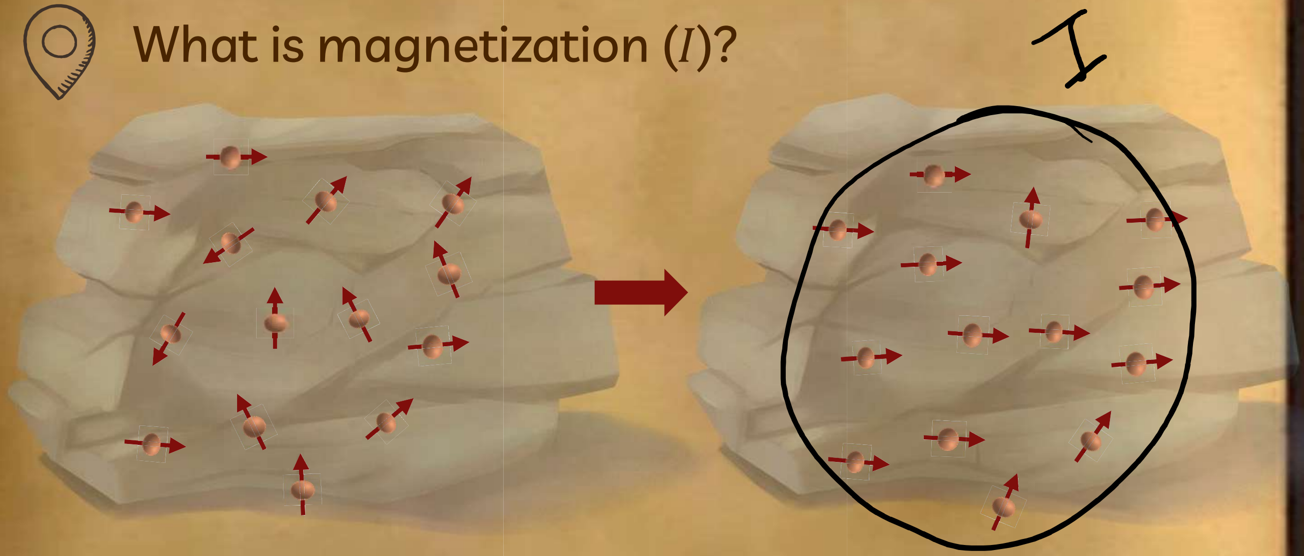
$$\mu = \mu_0(1 + \chi)$$

Diamagnetic	Paramagnetic	Ferromagnetic
$-1 \le \chi \le 0$	$0 < \chi < \varepsilon$	$\chi \gg 1$
$\mu < \mu_0$	$\mu > \mu_0$	$\mu \gg \mu_0$
$0 \le \mu_r \le 1$	$1 < \mu_r < 1 + \varepsilon$	$\mu_r \gg 1$

- ε is a small positive number introduced to quantify paramagnetic materials.

I-*H* CURVE

What is magnetization (I)?

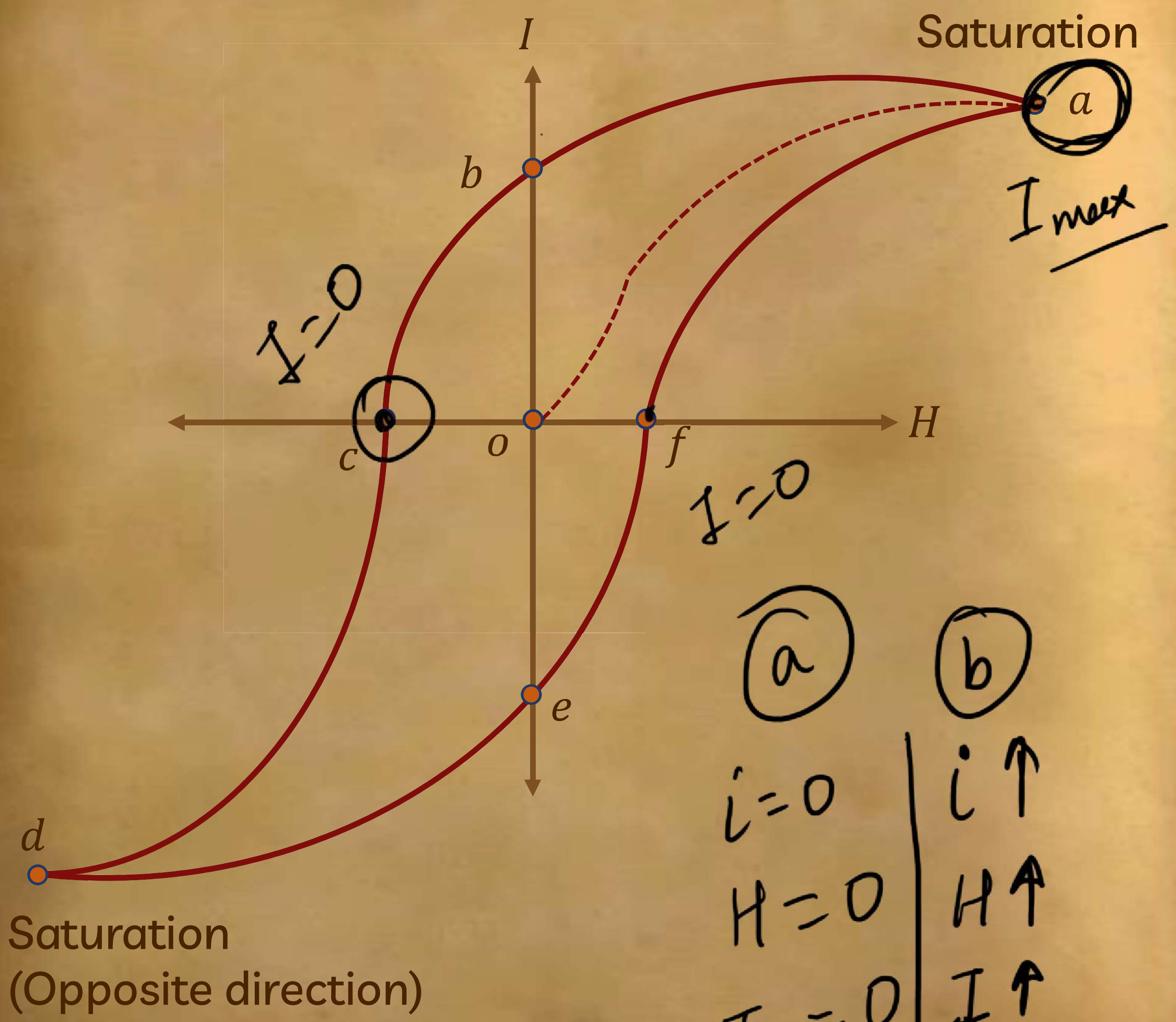


What is magnetic intensity (H)?

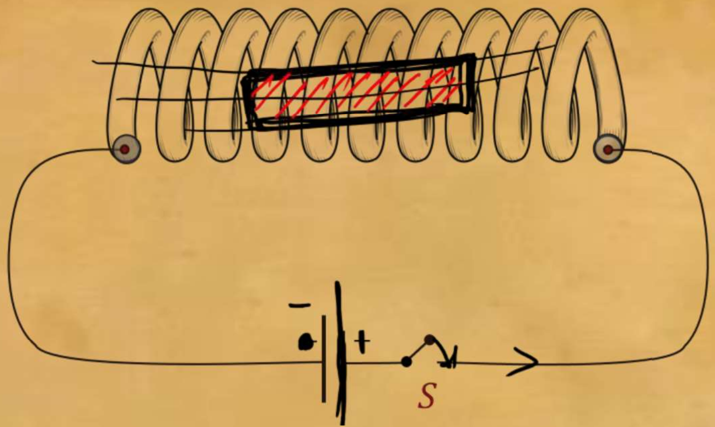
Hysteresis loop (Hysteresis Curve)

- A hysteresis loop (also known as a hysteresis curve) is a four-quadrant graph that shows the relationship between the induced magnetic flux density (B) and the magnetizing field (H).
- Hysteresis is characterized as a lag of magnetic flux density behind the magnetic field strength.

I-H CURVE



ⓐ	ⓑ
i=0	i↑
H=0	H↑
I=0	I↑



- Hysteresis loop (Hysteresis Curve)
- It is the path $(a \to b \to c \to d \to e \to f \to a)$ in which a ferromagnetic substance is taken through a cycle of magnetisation and de-magnetisation.

Magnetised (a) ⟶ De-magnetised (c)

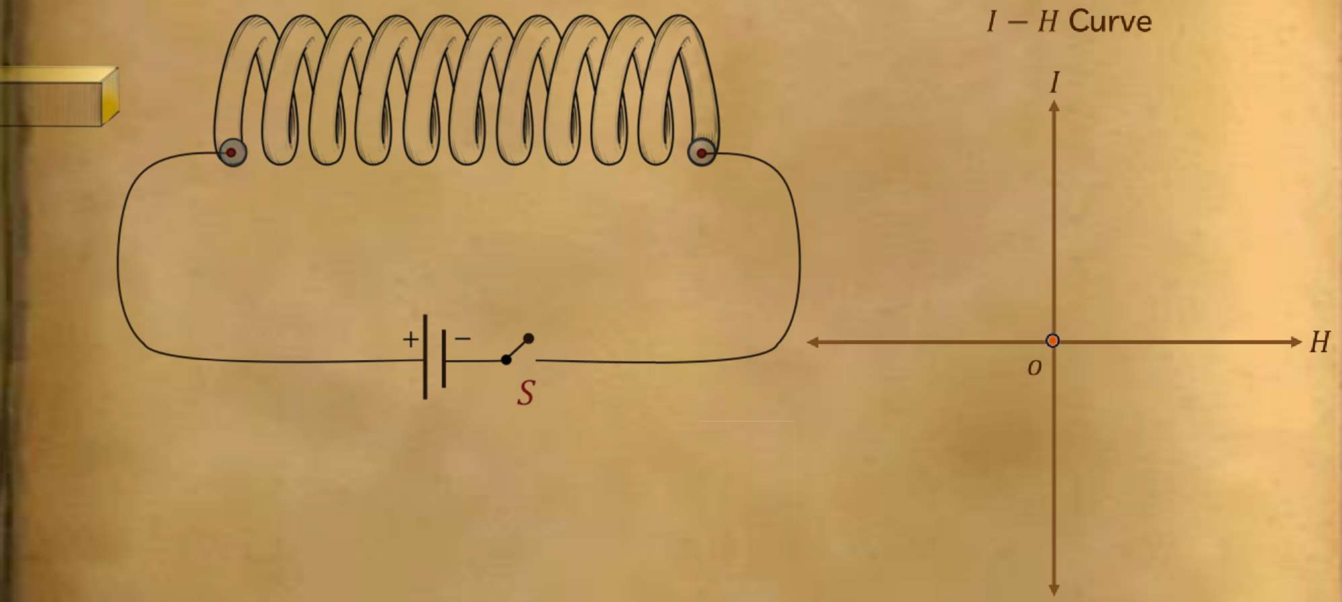
↓

Magnetised (d) ⟶ De-magnetised (f)

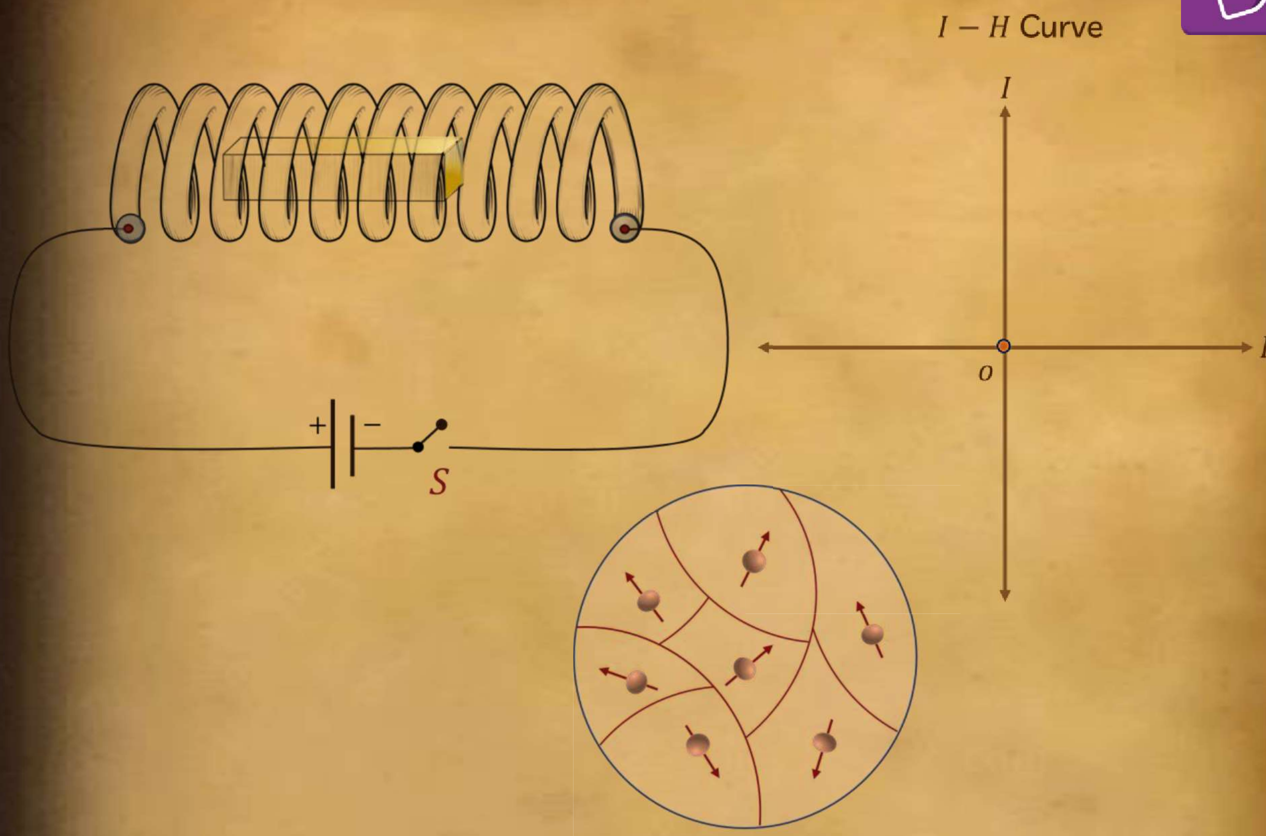
↑

Magnetised (a)

FORMATION OF $I-H$ CURVE



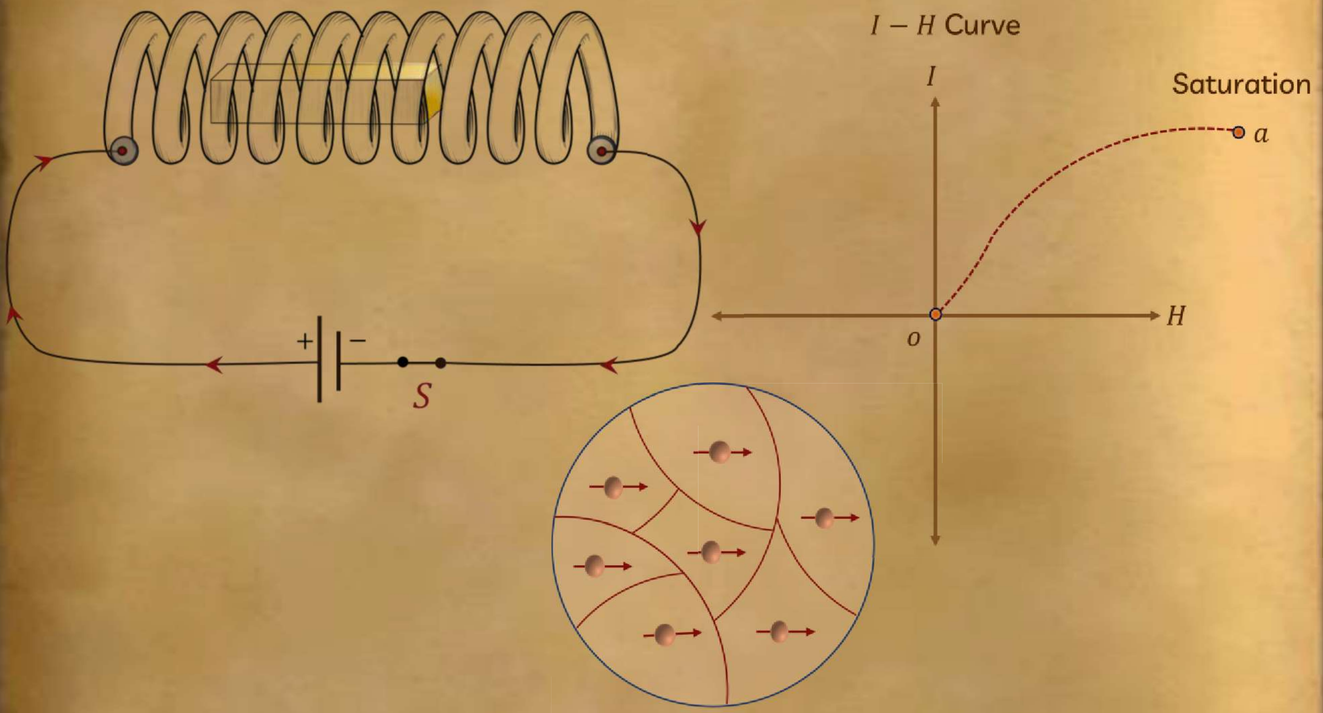
- At, $i = 0, H = 0, I = 0$
- In the given circuit, because of zero current, no magnetic intensity and the magnetization will develop.



o. Domains are in random orientations

- At, $i = 0, H = 0, I = 0$
- In the given circuit, because of zero current, no magnetic intensity and the magnetization will develop.

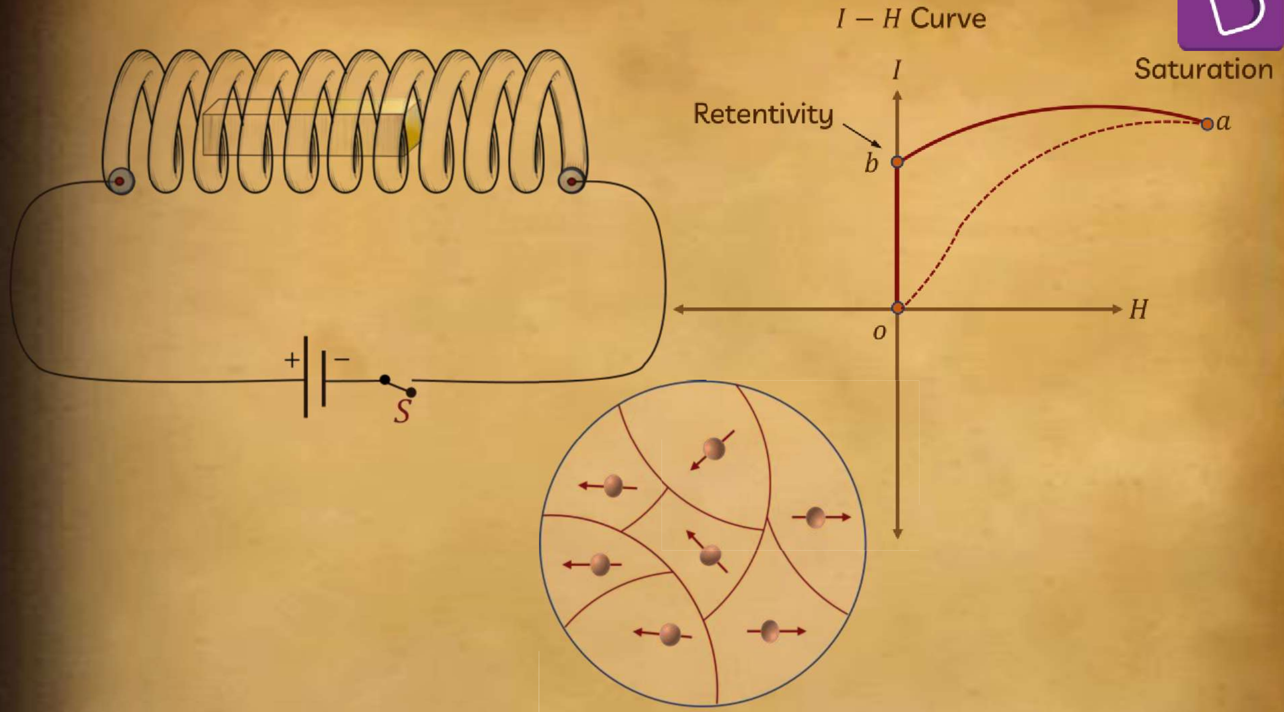
FORMATION OF $I - H$ CURVE



$a.$ Magnetic saturation
(in the positive direction)

- At, $i \neq 0, H(\uparrow), I(\uparrow)$

- When the bar is inside the coil and charges are now commencing to flow, shallowly magnetic intensity and magnetization will develop in a material.



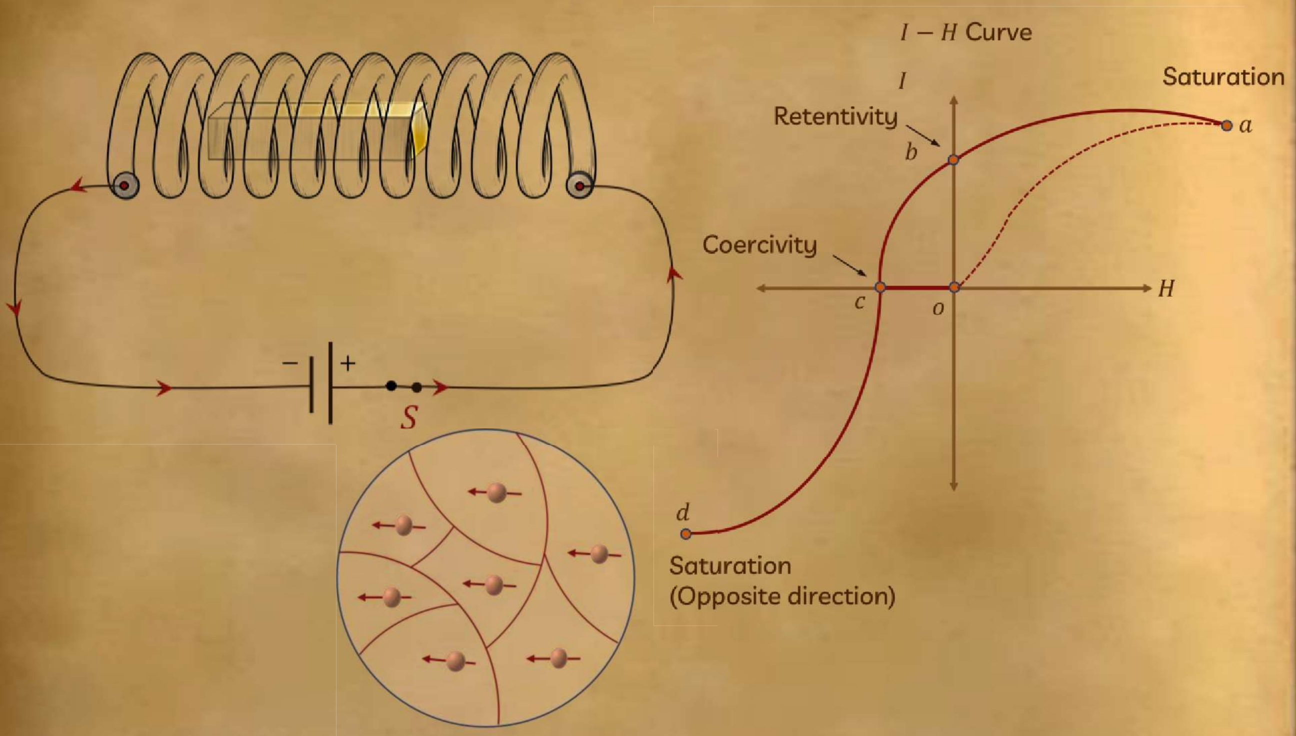
$b.$ Retentivity in domains

- At, $i = 0, H = 0,\ I\ (\downarrow) \neq 0$

Retentivity:

- It is the capacity of a substance to retain its magnetism even when the magnetizing field has ceased to act.

FORMATION OF $I - H$ CURVE

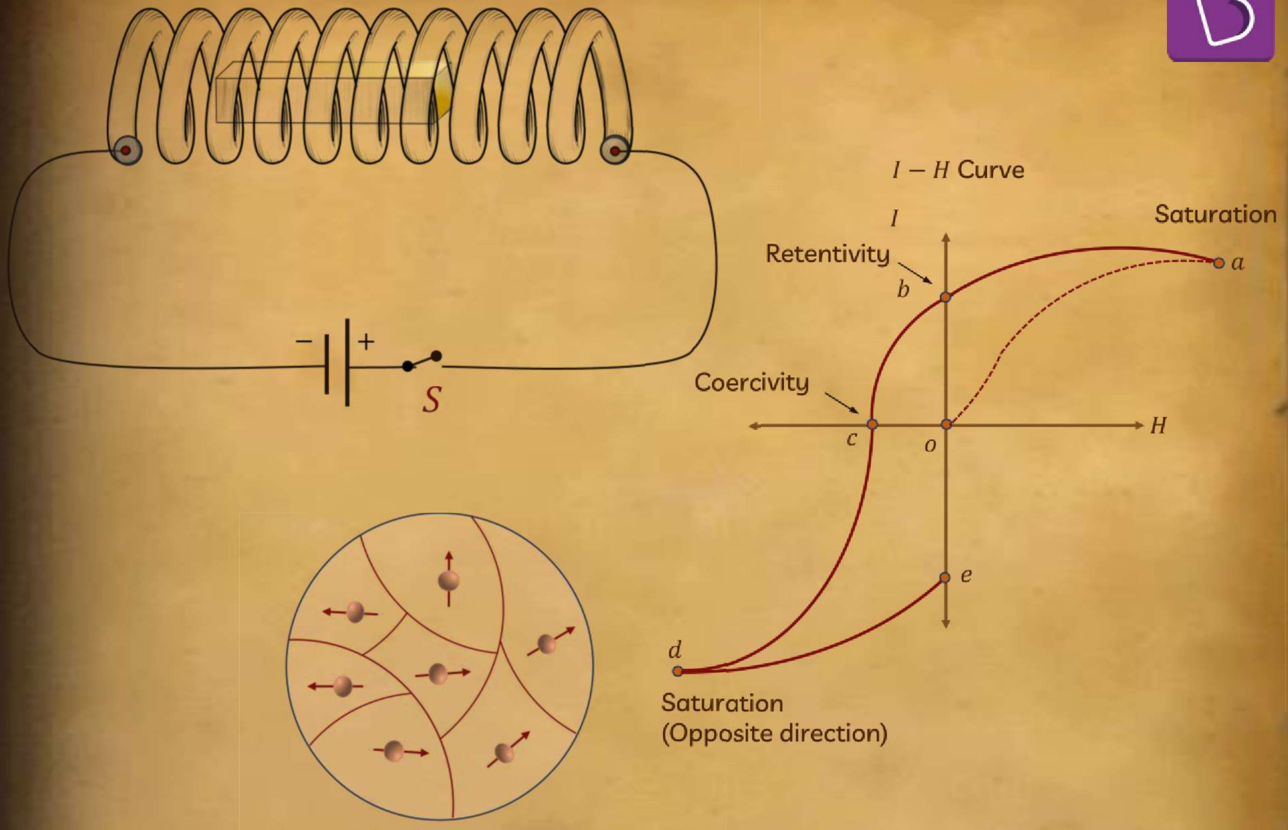


d. Magnetic Saturation (in the negative direction)

- At, $i = -i, H = (\uparrow), I = (\uparrow)$, opposite direction
- Now, due to negative current, dipoles are aligned in the opposite direction. Hence, the curve becomes negative.

Coercivity:

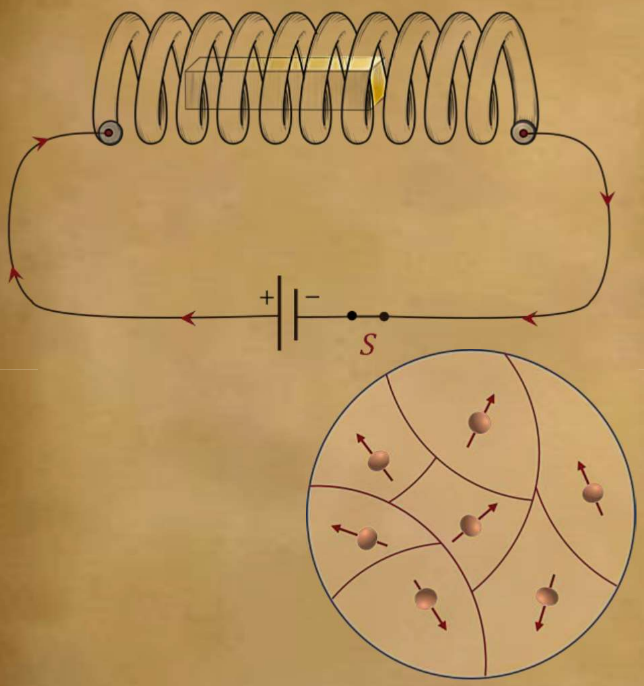
It is an amount of magnetic intensity required to demagnetize a material.



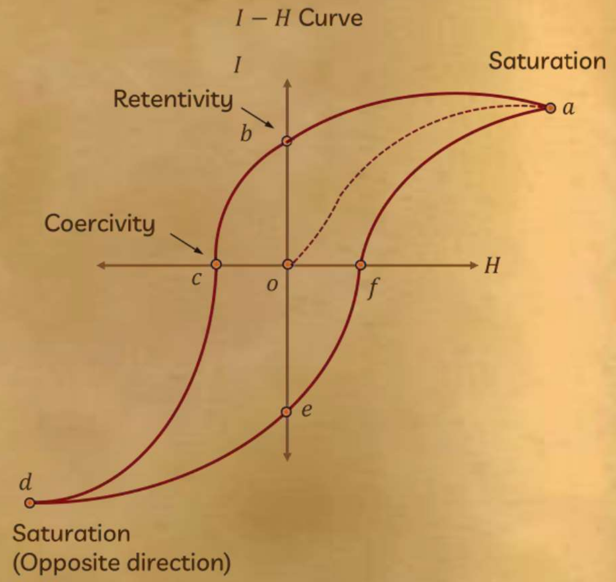
e. Retentivity (in the negative direction)

- At, $i = 0, H = 0, \ I \neq 0 \ (\uparrow)$
- Here, the current is zero, but still, some magnetization characteristic is present in the dipoles, which never allows them to regain their random orientations.

FORMATION OF $I - H$ CURVE



f. Dipoles regain its natural positions



- At, $i = +i, H = 0,\ I\ (\downarrow) \neq 0,$ œį šffiffiċ ræffįċ ãtiffįh

- Again, change the polarity of the battery to demagnetize the dipoles.

$B - H$ AND $I - H$ CURVES FOR THE MAGNETIC MATERIALS

Relationship between Magnetic field (B) and Magnetization (M):

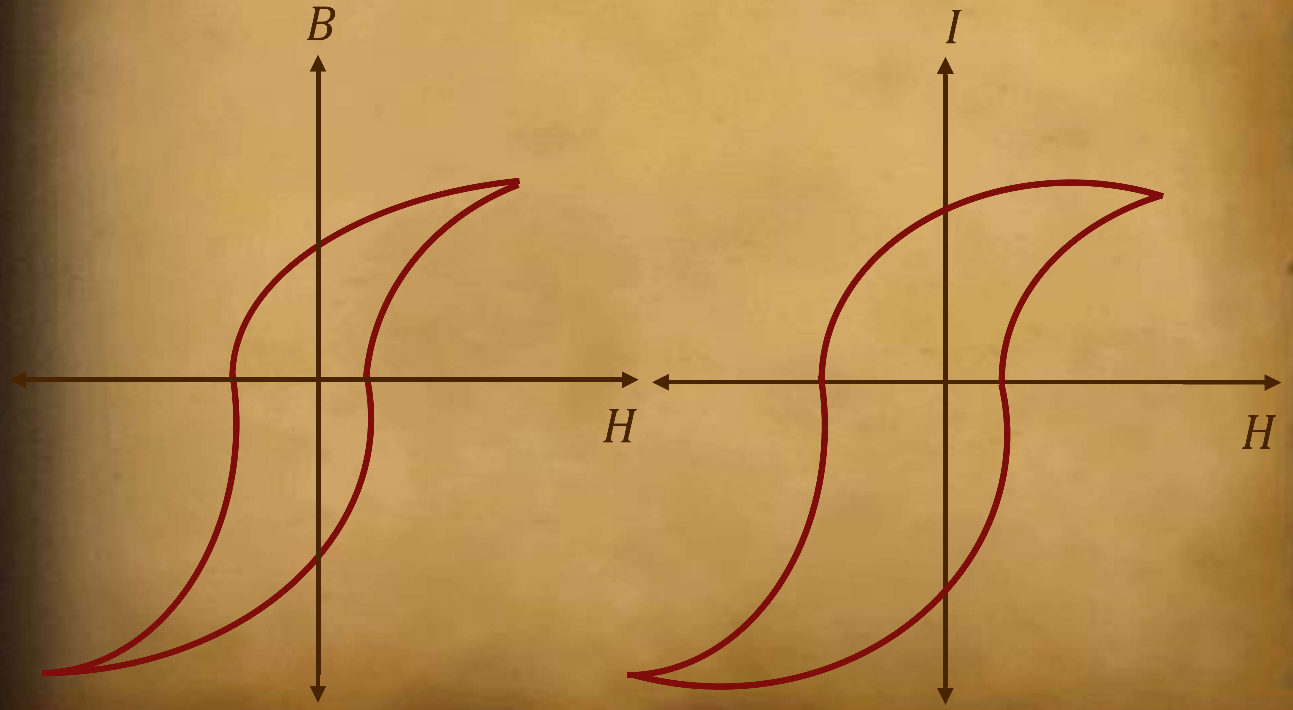
$$\vec{B} = \mu_o(\vec{H} + \vec{I})$$

$\vec{H}$ = Magnetic field strength

$\vec{I}$ = Magnetization vector

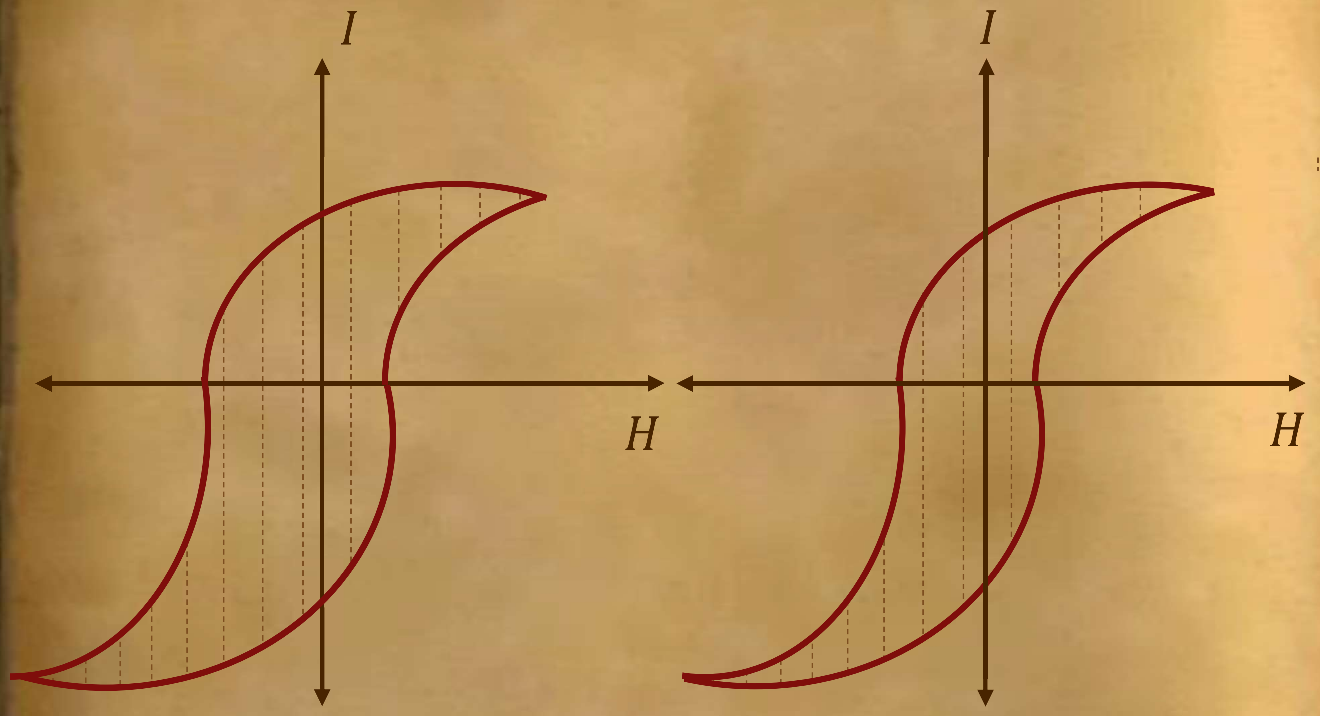
μ_o = Permeability of free space

$\vec{B}$ = Magnetic field vector



HYSTERESIS LOSS

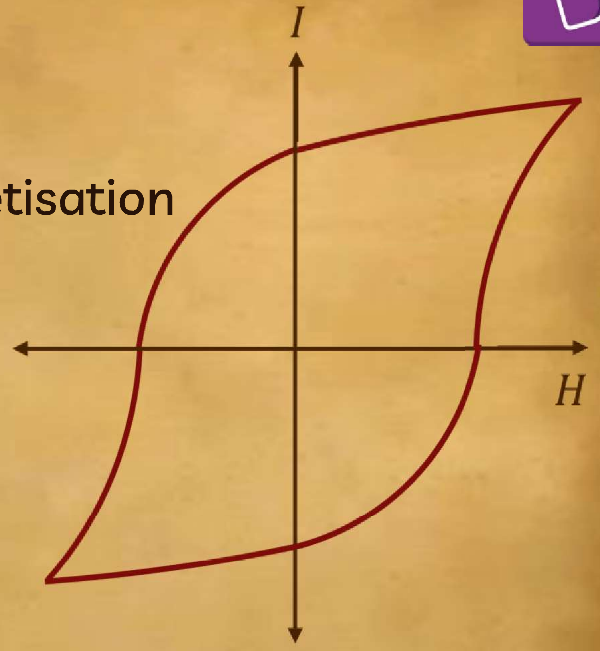
BOARDS



The area enclosed by the hysteresis loop $\propto$ Energy supplied per unit volume of material in each cycle which is lost as heat.

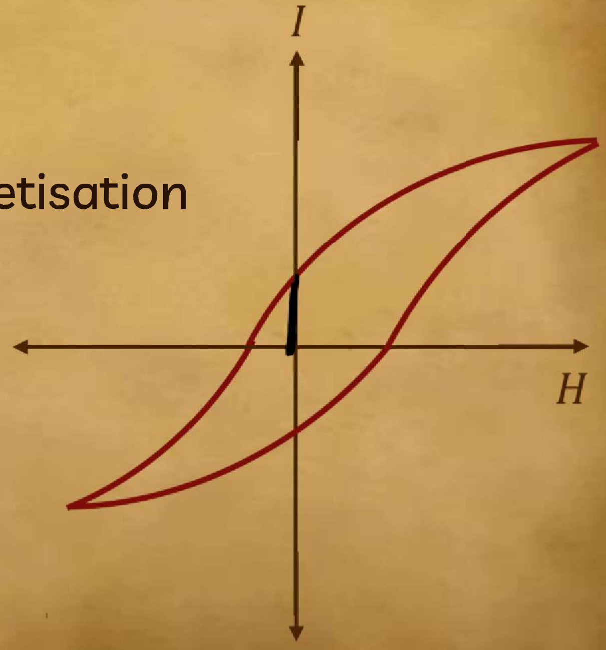
For permanent magnet

- High saturation magnetisation
- High Retentivity
- High Coercivity



For electromagnet

- High saturation magnetisation
- Low Retentivity
- Low Coercivity



PROBLEM

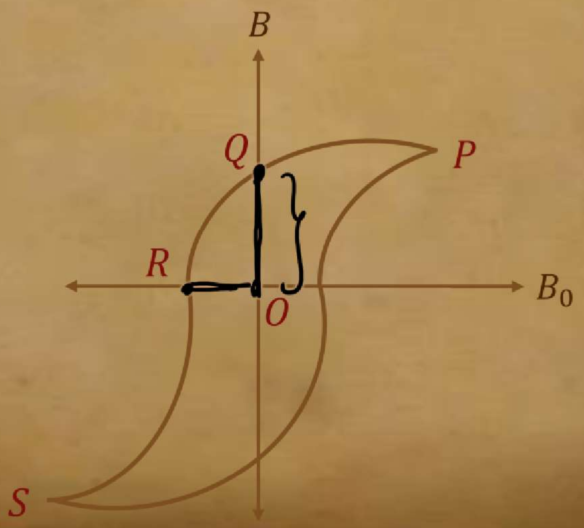
The figure illustrates how B, the flux density inside a sample of unmagnetized ferromagnetic material varies with B_0, the magnetic flux density in which the sample is kept. For the sample to be suitable for making a permanent magnet.

a. OQ should be large, OR should be small.

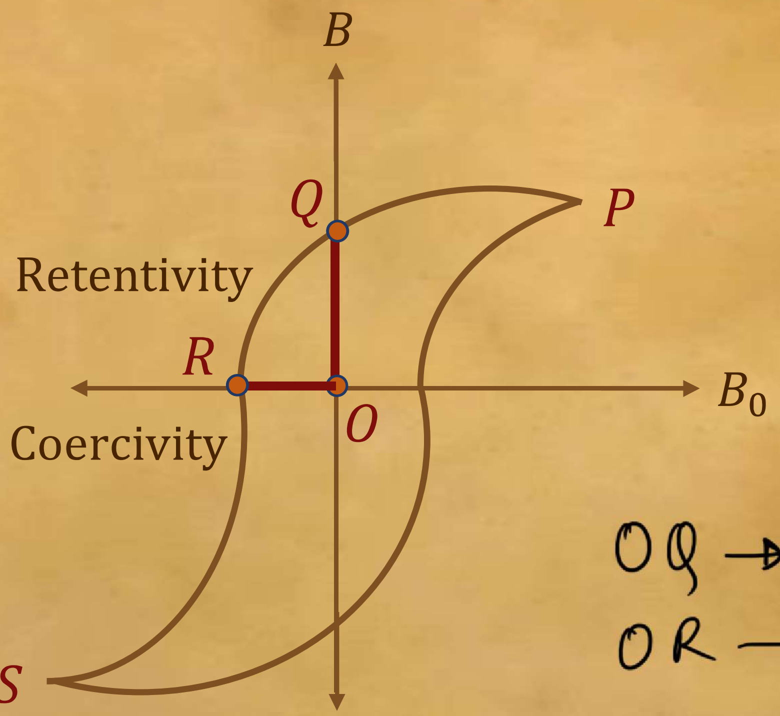
b. Both OQ and OR should both be large.

c. OQ should be small and OR should be large.

d. Both OQ and OR should both be small.



SOLUTION



$OQ \rightarrow R \uparrow$

$OR \rightarrow Co \uparrow$

Both OQ and OR should be large

Therefore, option b is the correct answer.

PROBLEM

Which material is better for use in a coil of the generator or the core of a transformer?

a. [✓ Soft iron]

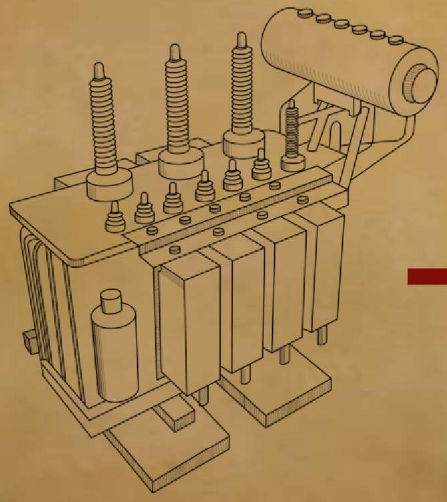
b. Mild steel

c. Stainless steel

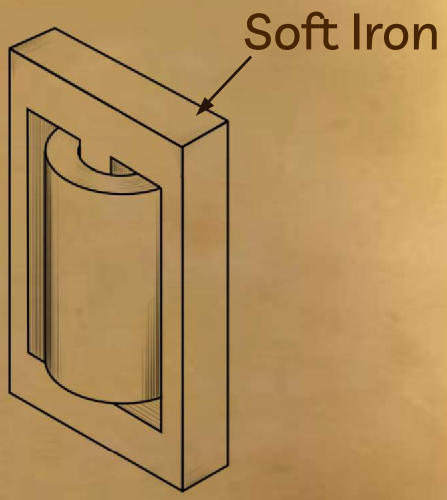
d. Hard iron

SOLUTION

NEET



Transformer



Transformer core

Material to be used in core of transformer should have :

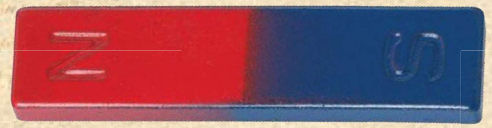
- Low Retentivity
- Low Coercivity
- Small Area of hysteresis loop

Soft Iron

Soft iron have the better combination of the properties required for the core of transformer.

Therefore, option a is the correct answer.

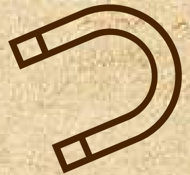
Magnetic Materials and Permanent Magnets



Session wise content

START

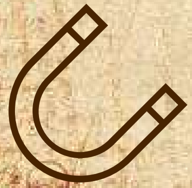
S1
Magnetic dipole moment due to bar magnet



S2
Earth's magnetism

S3
Magnetisation and magnetic intensity

S4
Classification of materials



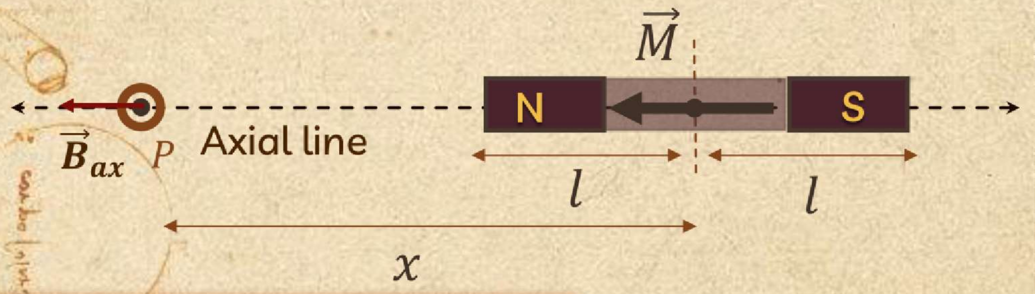
S5
Hysteresis

FINISH

Magnetic dipole

- Opposite poles of the magnet attract and similar poles repel similar to the case of electric charges.
- Magnetic moment of solenoid : $M = NIA$
- Magnetic dipole moment : $\vec{M} = q_m 2\vec{l}$ (Along the vector joining south pole to north pole)
- Magnetic field due to magnetic dipole:

At axial point



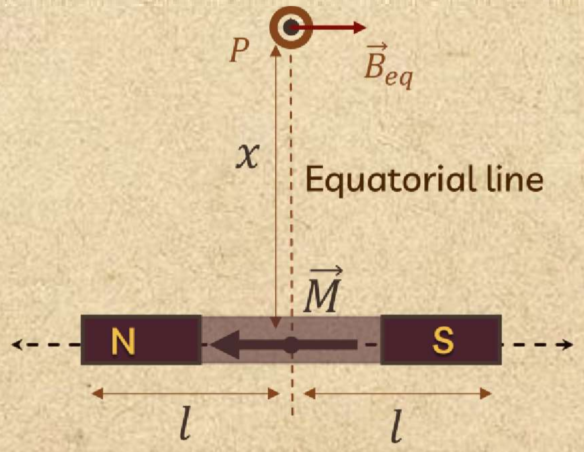
$$\boxed{\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}x}{(x^2 - l^2)^2}}$$

Direction of $\vec{B}_{ax}$ is along $\vec{M}$.

For short magnets, $x \gg l$

$$\boxed{\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}}{x^3}}$$

At equatorial point

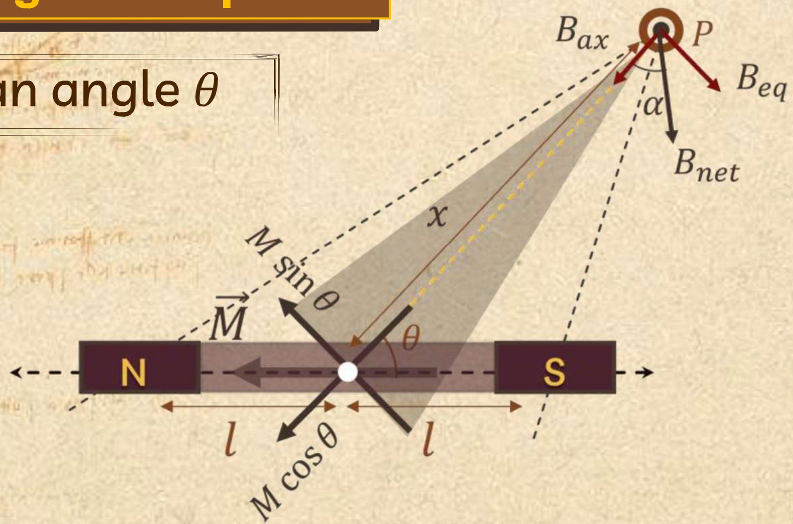


$$\boxed{\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{-\vec{M}}{x^3}}$$

Direction of $\vec{B}_{eq}$ is opposite to $\vec{M}$.

Magnetic dipole

At an angle θ



$$\vec{B}_{ax} = \left(\frac{\mu_0}{4\pi}\right)\frac{2\vec{M}\cos\theta}{x^3}$$

$$\vec{B}_{eq} = \left(\frac{\mu_0}{4\pi}\right)\frac{(-\vec{M}\sin\theta)}{x^3}$$

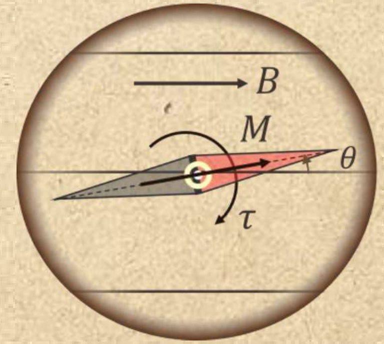
$$|\vec{B}_{net}| = \left(\frac{\mu_0}{4\pi}\right)\frac{|\vec{M}|}{x^3}\sqrt{1+3\cos^2\theta}$$

$$\tan\alpha = \frac{\tan\theta}{2}$$

Magnetic dipole in uniform magnetic field

- **Torque on a magnetic dipole:**

$$\vec{\tau}_{net} = \vec{M}\times\vec{B} = MB\sin\theta$$



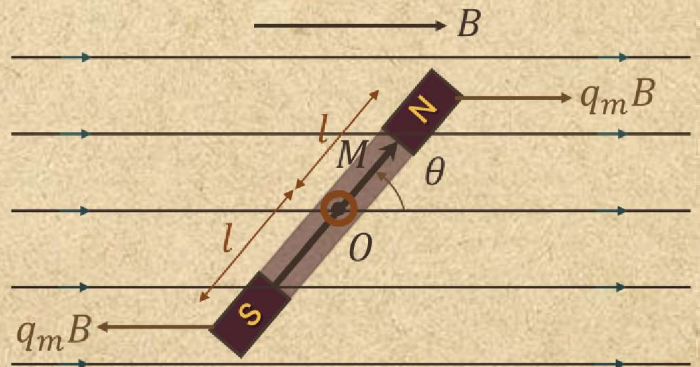
- **Torque in deflection of magnetic needle in uniform magnetic field:**

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

τ is restoring torque and θ is the angle between $\vec{M}$ and $\vec{B}$

$-ve$ sign implies that the restoring torque is opposite to deflecting torque.

Potential energy

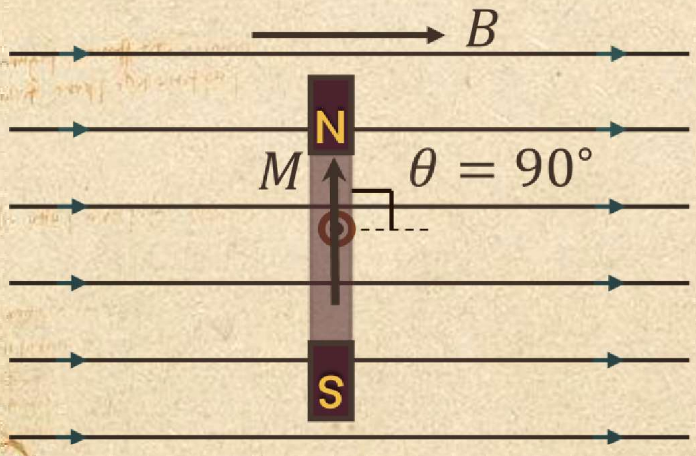


$$U = -\vec{M}\cdot\vec{B} = -|\vec{M}||\vec{B}|\cos\theta$$

(Taking zero potential at $\theta = 90°$)

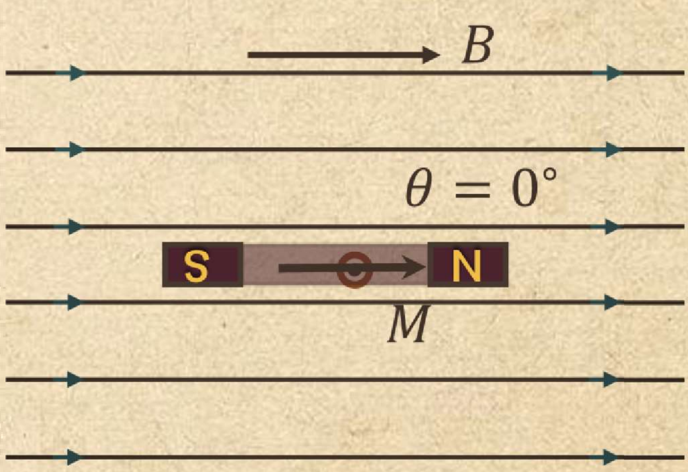
Potential energy of magnetic dipole

Case 1: $\theta = 90^\circ$



$$U = -|\vec{M}||\vec{B}|\cos 90^\circ = 0$$

Case 2: $\theta = 0^\circ$

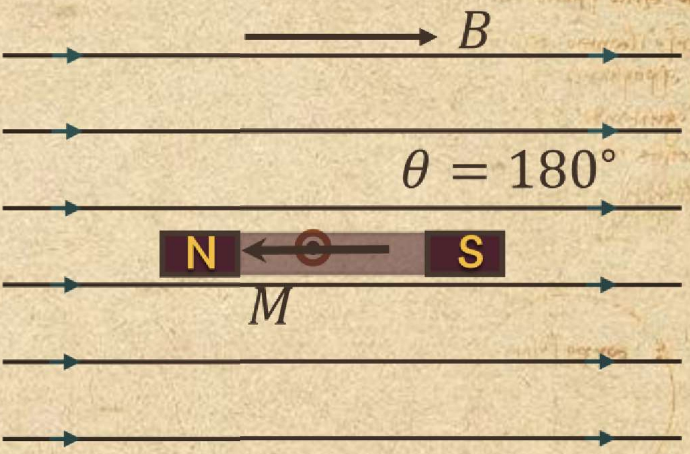


(Stable equilibrium)

$$U = -|\vec{M}||\vec{B}|\cos 0^\circ = -|\vec{M}||\vec{B}|$$

Potential energy is minimum.

Case 3: $\theta = 180^\circ$



(Unstable equilibrium)

$$U = -|\vec{M}||\vec{B}|\cos 180^\circ = |\vec{M}||\vec{B}|$$

Potential energy is maximum.

Work done by external force

$$W_{external} = \Delta U$$

Taking zero potential at $\theta = 90^\circ$

Earth's magnetism

- **Angle of declination (θ):**

  The angle between true north (the line towards geographic north pole) and the direction towards which the compass points (horizontal component of the magnetic field) is called magnetic declination.

- **Angle of dip or inclination (I) :**

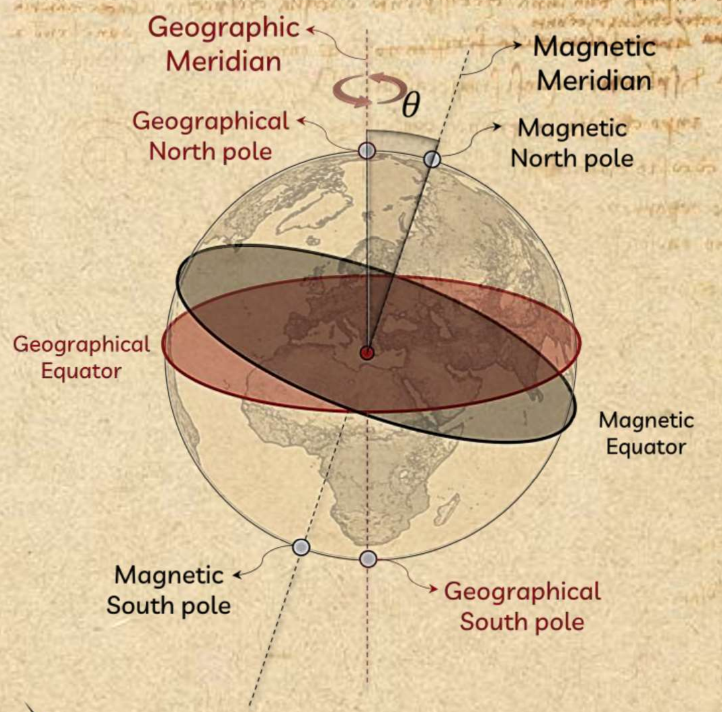
  Angle that is made by the earth's magnetic field lines with the horizontal.

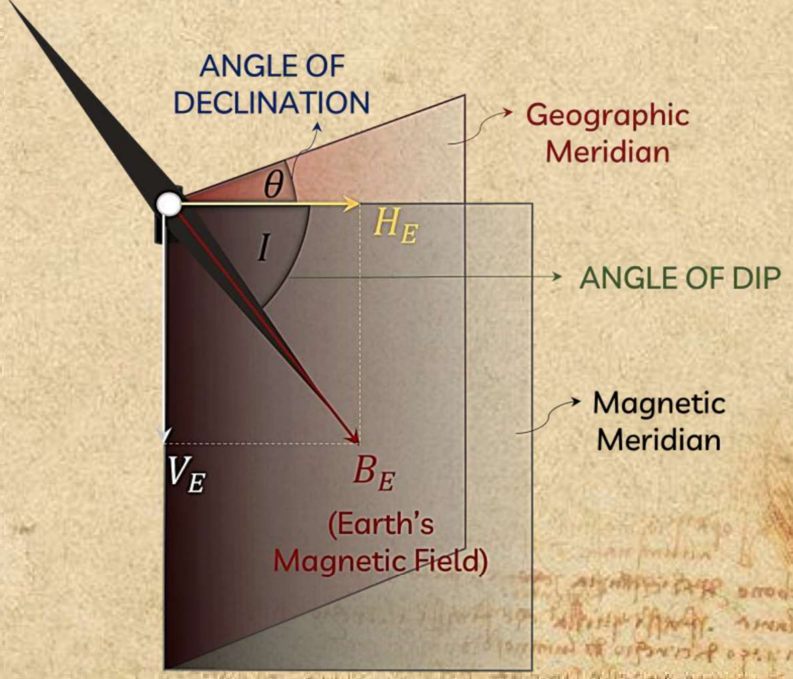
  Horizontal component of Earth's magnetic field:

$$H_E = B_E \cos I$$

  Vertical component of earth's magnetic field:

$$V_E = B_E \sin I \qquad \boxed{\tan I = V_E / H_E}$$





Cause of magnetism in matter

- **Orbital motion of e^-** (Major contributing factor)
- **Magnetic moment due to spin angular momentum of an e^-**
- **Magnetic moment of nucleus**

Magnetisation

MAGNETISATION VECTOR ($\vec{I}$)

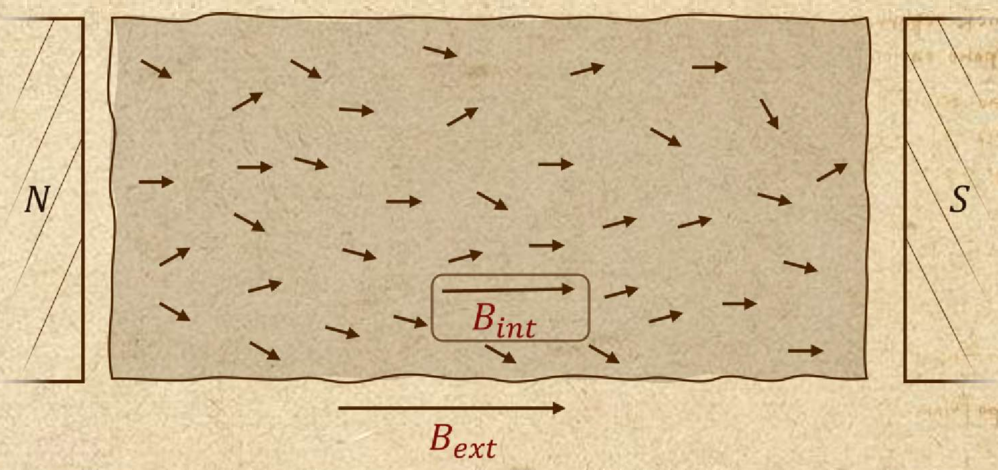
It's defined as net magnetic moment per unit volume.

$$\boxed{\vec{I} = \frac{\sum \vec{M}_{net}}{V}}$$

S.I. Unit is $Ampere\ m^{-1}$

Net magnetic field inside matter $\vec{B}_{net} = \vec{B}_{ext} + B_{int}$

$$\boxed{\vec{B}_{net} = \mu_0 \vec{H} + \mu_0 \vec{I}}$$



MAGNETIC INTENSITY ($\vec{H}$)

It is defined as the ability of a magnetic field to magnetize a material medium

$$\boxed{\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{I}}$$

RELATION BETWEEN $\vec{I}$ & $\vec{H}$

$\vec{I} \propto \vec{H}$

$$\boxed{\vec{I} = \chi \vec{H}}$$

χ = Magnetic susceptibility

PERMEABILITY (μ)

$\vec{B}_{net} = \mu_0 \vec{H} + \mu_0 \vec{I}$ $\mu = \mu_0(1 + \chi)$ = Permeability

$$\boxed{\vec{B}_{net} = \mu_0(1 + \chi)\vec{H} = \mu \vec{H}}$$

If there is no material

($\vec{I} = 0$)

$\vec{B}_0 = \mu_0 \vec{H}$

If there is a material

($\vec{I} \neq 0$)

$\vec{B}_m = \mu \vec{H}$

Relative permeability: $\mu_r = \dfrac{\mu_m}{\mu_0}$

Classification of materials

Diamagnetism

- Susceptibility (χ) is negative.
- Permeability of material (μ) is less than permeability of vacuum (μ_0).
- Relative permeability (μ_r) is between 0 and 1.

$$-1 \le \chi \le 0$$
$$\mu < \mu_0$$
$$0 \le \mu_r \le 1$$

Paramagnetism

- Susceptibility (χ) is small and positive.
- Permeability of material (μ) is slightly greater than permeability of vacuum (μ_0).
- Relative permeability (μ_r) is slightly greater than 1.

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

Ferromagnetism

- Susceptibility (χ) is large and positive.
- Permeability of material (μ) is greater than permeability of vacuum (μ_0).
- Relative permeability (μ_r) is greater than 1.

$$\chi \gg 1$$
$$\mu \gg \mu_0$$
$$\mu_r \gg 1$$

Curie's law

Magnetisation ($\vec{I}$) of a paramagnetic substance is inversely proportional to absolute temperature (T)

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

The susceptibility above Curie temperature in paramagnetic state is given by :

$$\boxed{\chi = C\frac{\mu_0}{T - T_C}}$$

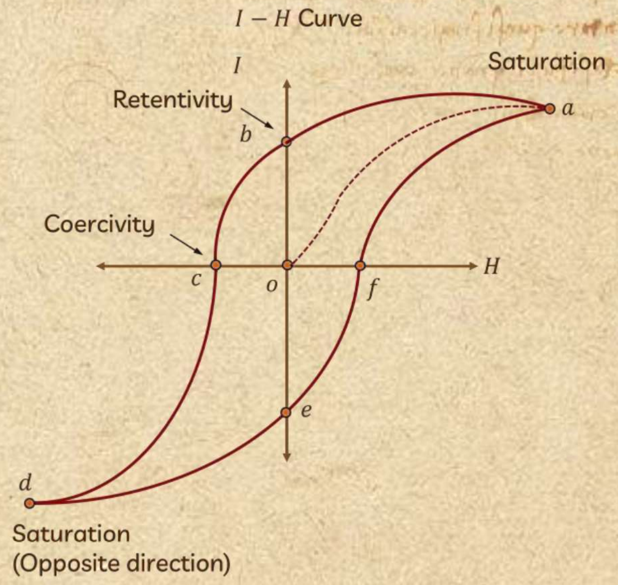
Hysteresis

Hysteresis is characterized as a lag of magnetic flux density behind the magnetic field strength.

A hysteresis loop (also known as a hysteresis curve) is a four-quadrant graph that shows the relationship between the induced magnetic flux density (B) and the magnetizing field (H).

Retentivity is the capacity of a substance to retain its magnetism even when the magnetizing field has ceased to act.

Coercivity is an amount of magnetic intensity required to demagnetize a material.

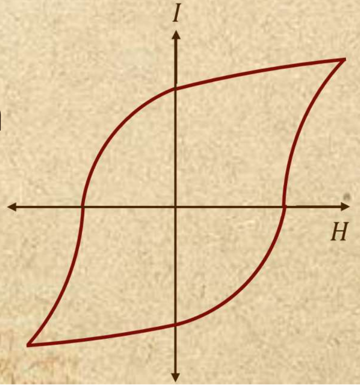


HYSTERESIS LOSS

The area enclosed by the hysteresis loop $\propto$ Energy supplied per unit volume of material in each cycle which is lost as heat

For permanent magnet

- High saturation magnetisation
- High Retentivity
- High Coercivity



For electromagnet

- High saturation magnetisation
- Low Retentivity
- Low Coercivity