Magnetism and Matter

- Known facts about magnets
  - magnetic materials tend to point in the north-south direction
  - magnetic poles repel and unlike ones attract
  - Cutting a bar magnet in two leads to two smaller magnets.
  - Magnetic poles cannot be isolated.

- When a bar magnet of dipole moment **m** is placed in a uniform magneticfield **B**,
  - the force on it is zero
  - the torque on it is **m × B**
  - Its potential energy is **–m.B**, where we choose the zero of energy atthe orientation when **m** is perpendicular to **B**.

- Consider a bar magnet of size *l* and magnetic moment **m**, at a distance*r* from its mid-point, where *r* >>*l*, the magnetic field **B** due to this baris,

  B = ($\mu_0 m/2\pi r^3$) [along the axis]

  = - ($\mu_0 m/4\pi r^3$) [along the equator]

	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's law for magnetism states that the net magnetic flux throughany closed surface is zero

  $\phi_B = \Sigma B. \Delta S = 0$

- The earth's magnetic field resembles that of a (hypothetical) magneticdipole located at the centre of the earth. The pole near the geographicnorth pole of the earth is called the north magnetic pole. Similarly, thepole near the geographic South Pole is called the south magnetic pole.This dipole is aligned making a small angle with the rotation axis ofthe earth. The magnitude of the field on the earth's surface $\approx 4 \times 10{-}5$ T.

- Three quantities are needed to specify the magnetic field of the earthon its surface – the horizontal component, the magnetic declination,and the magnetic dip. These are known as the elements of the earth'smagnetic field.

- Consider a material placed in an external magnetic field B0. Themagnetic intensity is defined as,

  $H = B_0/\mu_0$

- The magnetisation M of the material is its dipole moment per unit volume.The magnetic field B in the material is,

  $B = \mu_0 (H + M)$

- For a linear material $M = \chi H$. So that $B = \mu H$ and χ is called themagnetic susceptibility of the material. The three quantities, χ, therelative magnetic permeability μr, and the magnetic permeability μ are
  related as follows:

  $\mu = \mu_0 \mu_r$

  $\mu_r = 1+ \chi$

- Magnetic materials are broadly classified as: diamagnetic, paramagnetic,and ferromagnetic. For diamagnetic materials χ is negative and smalland for paramagnetic materials it is positive and small. Ferromagnetic materials have large χ and are characterised by non-linear relationbetween B and H. They show the property of hysteresis.

Sample Examples

- A short bar magnet placed with its axis at 30º with anexternal field of 800 G experiences a torque of 0.016 Nm. (a) what isthe magnetic moment of the magnet? (b) What is the work done inmoving it from its most stable to most unstable position? (c) The barmagnet is replaced by a solenoid of cross-sectional area 2×10^{-4} $m^2$and 1000 turns, but of the same magnetic moment. Determine thecurrent flowing through the solenoid.

  Solution

  (a) $\tau = m B \sin \theta$, $\theta = 30º$, hence $\sin\theta = 1/2$.

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

  $m = 160 \times 2/800 = 0.40\ A\ m^2$

  (b) the most stable position is $\theta = 0º$ and the mostunstable position is $\theta = 180º$. Work done is given by

  $W = U_m (\theta = 180°) - U_m (\theta = 0°) = 2\ m\ B = 2 \times 0.40 \times 800 \times 10^{-4} = 0.064\ J$

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

  $0.40 = 1000 \times I \times 2 \times 10^{-4} I = 0.40 \times 10^4/(1000 \times 2) = 2A$

- The earth's magnetic field at the equator is approximately0.4 G. Estimate the earth's dipole moment.

  Solution

  $B = (\mu_0 m/4\pi r^3)$

  We are given that *BE* ~ 0.4 G = 4×10^{-5} T. For *r*, we take the radius of the earth 6.4×10^6 m. Hence,

  $m = 4 \times 10^{-5} \times (6.4 \times 10^6)^3/(\mu_0/4\pi)$

  $\pi = 4 \times 10^2 \times (6.4 \times 10^6)^3 (\mu_0/4\pi = 10^{-7})$

  $= 1.05 \times 10^{23}$ A m^2

  This is close to the value 8×10^{22}A m^2quoted in geomagnetic texts.