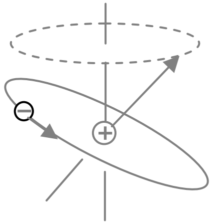
Chapter 6 Magnetic Materials

6.1 Magnetization M & Magnetization Current

6.2 Ferromagnetism

6.3* The Fundamental Magnetic Properties of Superconductors

6.4 Magnetic Circuit Theorem



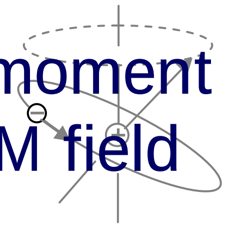
6.1 Magnetization & M's Current

- Magnetic Field: Created by
  - Current due to Motion of Free Charges
  - The Motion of Electrified Bodies
  - The Motion of Electrified Bodies (electron and proton) in Atom

Spinning and Going around atom

Purpose on Computation of Magnetic Field due to Magnetization Current.

Magnetic Materials ≃ Dielectrics, possess magnetic moment oriented properly(maybe magnetized) and creates M field



6.1 Magnetization & M's Current

Classification

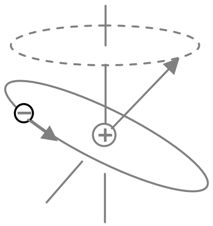
- ♦Diamagnetic Materials
- ♦Paramagnetic Materials
- ♦Ferromagnetic Materials

◈ Paramagnetic Materials:

The Resultant Magnetic Moment due to orbital and spinning motion of electrons is not zero.

The Magnetic Field created by Magnetization I', B'

- $B' << B_0$ (By conduction current), $B' \uparrow\uparrow B_0$
- B (total) $\approx B_0$ B is a little bigger than B_0



6.1 Magnetization & M's Current

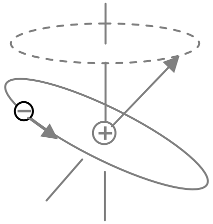
Diamagnetic Materials:

- The Resultant Magnetic Moment due to orbital and spinning motion of electrons is zero.

- The Magnetic Field created by Magnetization I', B'

  - $B' << B_0$ (By conduction current), $B' \uparrow\downarrow B_0$

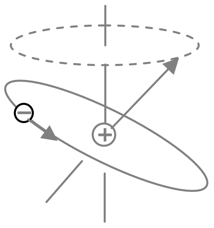
  - B (total) $\approx B_0$ B is a little smaller than B_0



6.1 Magnetization & M's Current

◈ Ferromagnetic Materials:

- The Resultant Magnetic Moment due to Exchanging interaction is very strong.
- The Magnetic Field created by Magnetization I', B'
  - $B' >> B_0$ (By conduction current), $B' \uparrow\uparrow B_0$
  - B (total) $>> B_0$,

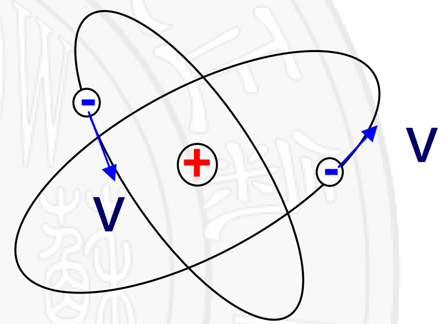


6.1 Magnetization & M's Current

◈ Paramagnetic Material in Micro-view

- The Resultant Magnetic Moment due to orbital and spinning motion of electrons is not zero.

- Placed it in B_0

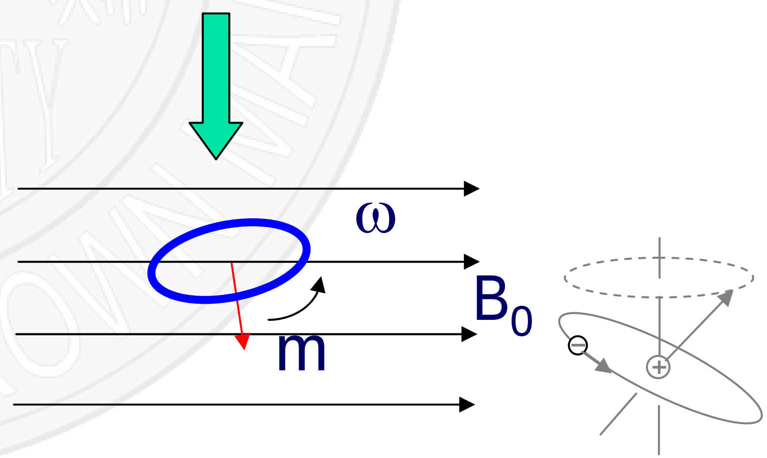


Torque on current-carrying ring

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

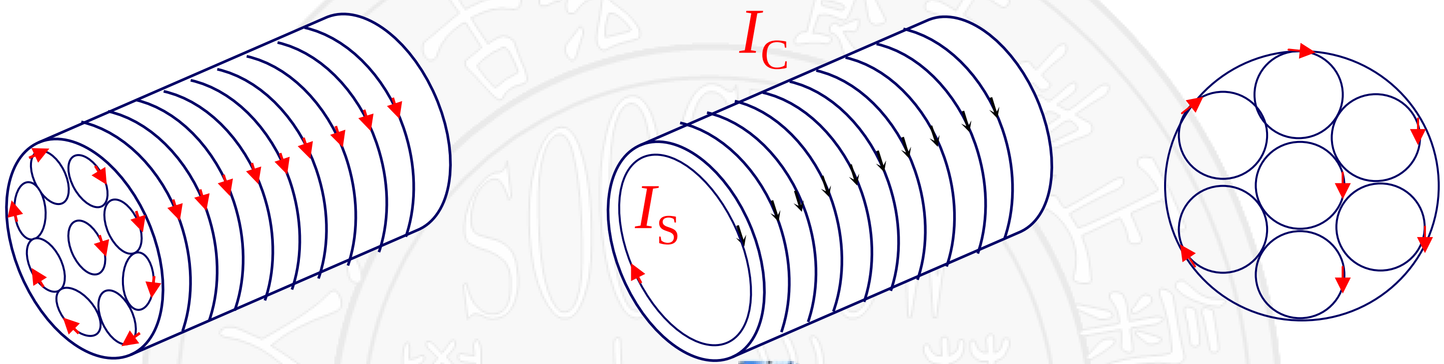
Magnetization current I'
appears on the surface

I'→B'



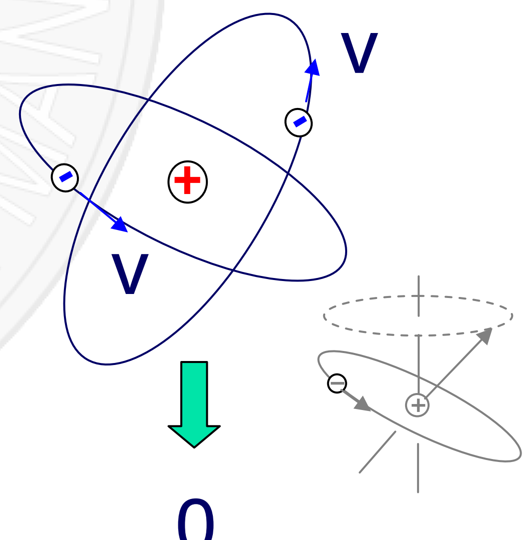
6.1 Magnetization & M's Current

- Paramagnetic Material in Micro-view



Magnetization current
Run flash.exe first

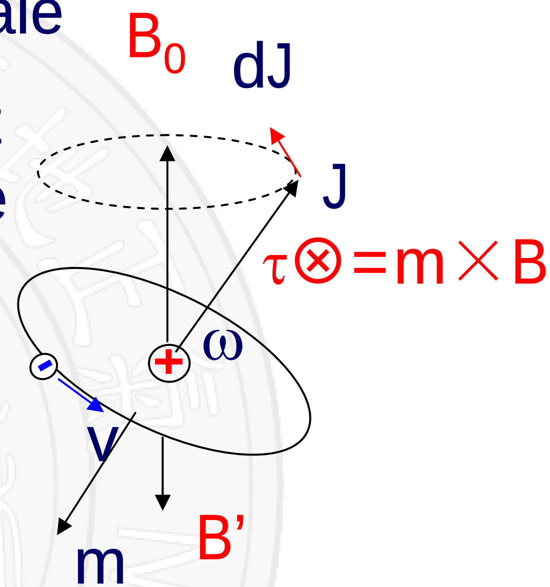
- Diamagnetic Material in Micro-view



- The Resultant Magnetic Moment due to orbital and spinning motion of electrons is zero.

6.1 Magnetization & M's Current

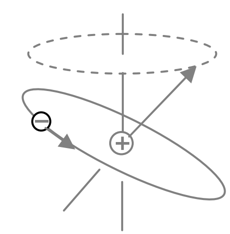
- No magnetic properties in atom scale
- But Because of induction, a current appears in the direction to oppose the changes of flux



$$\vec{J} = \vec{r} \times m\vec{v}$$

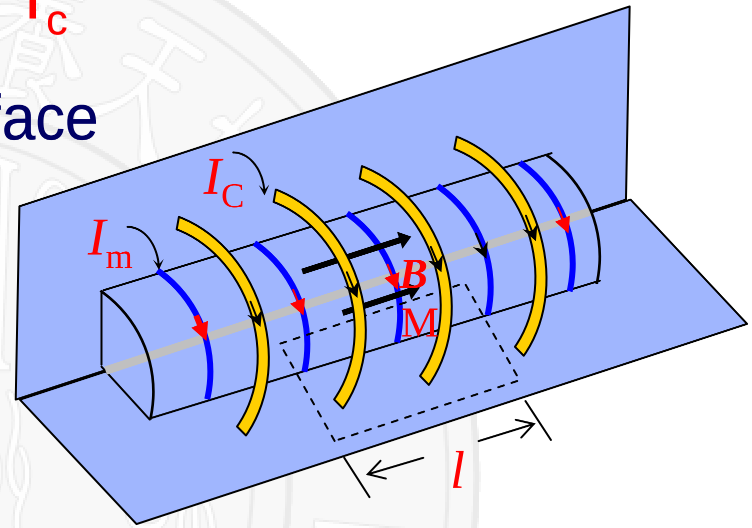
$$d\vec{J} = \vec{\tau}dt$$

The *The Relation of magnetization M to magnetization Current*



6.1 Magnetization & M's Current

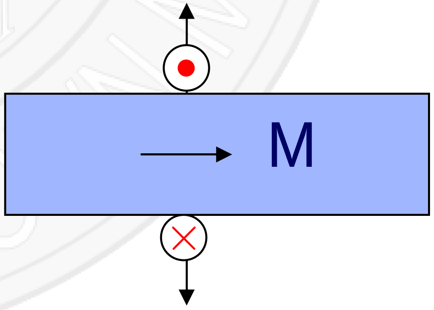
- M & magnetization current I_c
  - I_m :Total Current on the surface
  - S: The cross-sectional area
  - I_mS : Total moment
  - Sl : Total volume

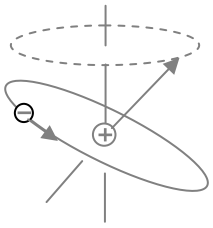


Paramagnetic material

$$M = \frac{\sum m}{V} = \frac{I_m S}{Sl} = \frac{I_m}{l} = i_m$$

$$\vec{i}_m = \vec{M} \times \vec{n}$$





6.1 Magnetization & M's Current

$$\oint \vec{M} \cdot d\vec{l} = Ml = i_m l = I_m$$

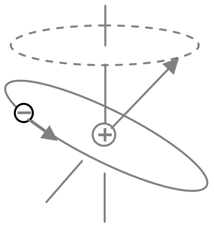
◈ Ampere's circuital Law in magnetic material

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \sum I$$

$$\oint \frac{\vec{B}}{\mu_0} \cdot d\vec{l} = \sum I = \sum I_C + \sum I_m$$

$$\oint \frac{\vec{B}}{\mu_0} \cdot d\vec{l} = \sum I_C + \oint \vec{M} \cdot d\vec{l}$$

$$\oint \left(\frac{\vec{B}}{\mu_0} - \vec{M}\right) \cdot d\vec{l} = \sum I_C$$



6.1 Magnetization & M's Current

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

H: Magnetic intensity

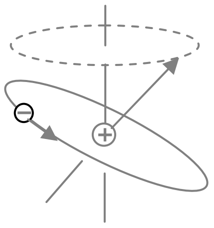
- Ampere's circuital Law in magnetic material

$$\oint \vec{H} \cdot d\vec{l} = \sum I_C$$

- Linear and isotropic—homogenous materials

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

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



6.1 Magnetization & M’s Current

- Linear and isotropic—homogenous materials

$$\vec{B} = \mu_0 (1 + \chi_m) \vec{H} = \mu_r \mu_0 \vec{H}$$

χ_m *magnetic susceptibility*

$\mu(\mu_r\mu_0)$ permeability, μ_r relative permeability

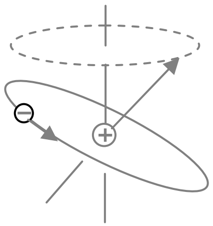
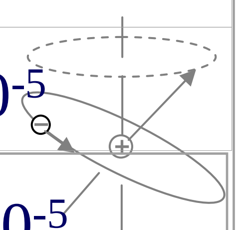


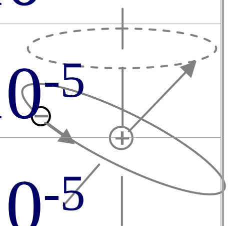
Table 6.1 Magnetic susceptibilities of paramagnetic and diamagnetic materials

Materials	Temperature, ° C	$\chi_m=\mu_r-1$
	Paramagnetic	
Iron ammonium alum	-269	4830×10^{-5}
Iron ammonium alum 铁铵明矾	-183	213×10^{-5}
Oxygen, liquid	-183	152×10^{-5}
Iron ammonium alum	+20	66×10^{-5}
Uranium（铀）	20	40×10^{-5}
Platinum（铂,白金）	20	26×10^{-5}
Aluminum	20	2.2×10^{-5}



6.1 Magnetization & M's Current

Sodium	20	0.72×10^{-5}
Oxygen gas	20	0.19×10-5
	Diamagnetic	
Bismuth	20	-16.6×10^{-5}
Mercury	20	-2.9×10^{-5}
Sliver	20	-2.6×10^{-5}
Carbon(diamond)	20	-2.1×10^{-5}
Lead	20	-1.8×10^{-5}
Rock salt	20	-1.4×10^{-5}
Copper	20	-1.0×10^{-5}

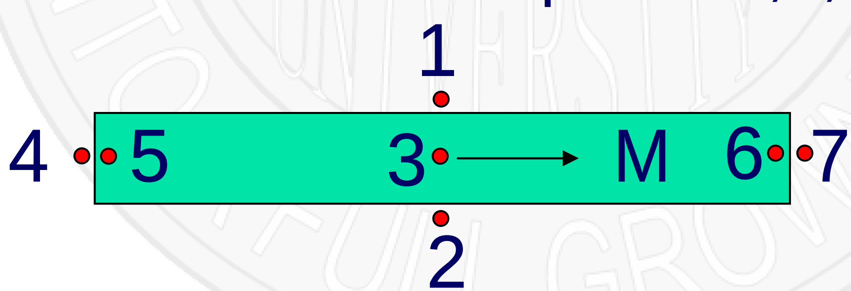


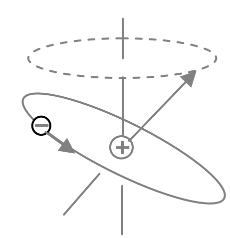
6.1 Magnetization & M's Current

- Paramagnetic susceptibilities decrease with increasing temperature because of the disorienting effect of thermal motion;

- Diamagnetic susceptibilities are nearly independent of temperature.

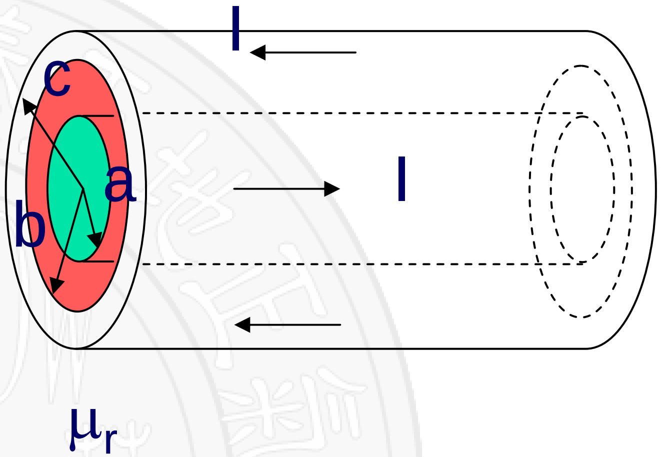
Example 6.1 A bar magnet with Magnetization M, Find the induction B and H at the points 1,2,3,4,5,6,7





6.1 Magnetization & M's Current

Example 6.2 Find B and H distribution



Example 6.3 A ring magnet with Magnetization M, Find the induction B and H at the points 1,2,3