

### 3.15 Magnetic Fundamentals

#### References:

Jiles, Introduction to Magnetism and Magnetic Materials

#### Magnetic quantities and units

$H$  = magnetic field, A/m –represents energy gradient, or torque on a dipole

$B$  = magnetic flux density, T or Wb/m<sup>2</sup> –number of magnetic field lines per unit area

$M$  = magnetization, A/m –the magnetic moment, the response of a material to a field.

$H$  comes from a current: current  $i$  produces tangential field  $H = i/2 \pi r$  at radius  $r$  or from a magnetic material.

$B$  depends on  $H$ : in free space  
but inside a material

or  
or  
or

$$\begin{aligned} B &= \mu_0 H \\ B &= \mu_0 (H + M) \\ B &= \mu_0 \mu_r H \\ M &= H(\mu_r - 1) \\ M &= \chi H \end{aligned}$$

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ Henry/m}$$

$\mu_r$  = relative permeability

$$\chi = (\mu_r - 1) = \text{susceptibility}$$

$M$  and  $B$  both indicate how a material responds to a field  $H$ . Lines of  $B$  are continuous.

Note the same relation expressed in cgs units:

$$B \text{ (Gauss)} = H \text{ (Oersted)} + 4\pi M \text{ (emu/cc)}$$

where

$$1 \text{ Oe} = (1000/4\pi) \text{ A/m} = 79.6 \text{ A/m}$$

$$1 \text{ G} = 10^{-4} \text{ T}$$

$$1 \text{ emu/cc} = 1 \text{ kA/m}$$

#### Different types of materials

Diamagnet: atom has no net magnetic moment, but a field induces a small moment opposite to the field. Susceptibility is negative ( $\mu_r < 1$ )

Paramagnet: atoms have a net moment but the spin directions are randomly arranged. An applied field can give weak alignment, hence a small susceptibility that varies with  $1/T$ . ( $\mu_r > 1$ )

Ferromagnets have spontaneous magnetization, a large permeability which depends on the history of the sample, and nonlinear, hysteretic behavior.

#### Origin of magnetic behavior

Angular momentum of electrons produces magnetization due to moving charges.

Magnetization comes from 1) electron spin, 2) electron orbital motion.

Contributions from paired electrons cancel out, so strong magnetic effects are found in materials with unpaired electrons.

One electron has a moment of  $1 \mu_B$  (Bohr magneton) =  $9.27 \cdot 10^{-24} \text{ Am}^2$

Stern-Gerlach and Zeeman experiments indicate the quantization of the magnetization in atoms.

We expect large magnetic effects in transition metals (unfilled 3d) and rare earths (unfilled 4f) because these can have a large net spin.

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