Magnetism and Matter (Chap. 9)

The long and interesting history of the science of magnetism…

Pre-History

- Stone Age – Tools were made of stone
- Bronze Age (3500 to 1100 BC) – Tools of bronze (Cu – Sn alloy)
- Iron Age (1200 to 600 BC) – Tools of iron (Fe)

Ancient History

- Thales of Miletus (624 – 546 BC) described a force in iron ores from Magnesia in Greece; the two main forms of iron ore are hematite and magnetite.

Fe_2O_3 **Fe_3O_4**

Middle Ages

- Lodestones were used to magnetize compass needles. (Europe or China?) William Gilbert published *De Magnete* in the year 1600.

19th Century

- Michael Faraday found that most materials are diamagnetic (1845).

Demo
Lodestone and compass need

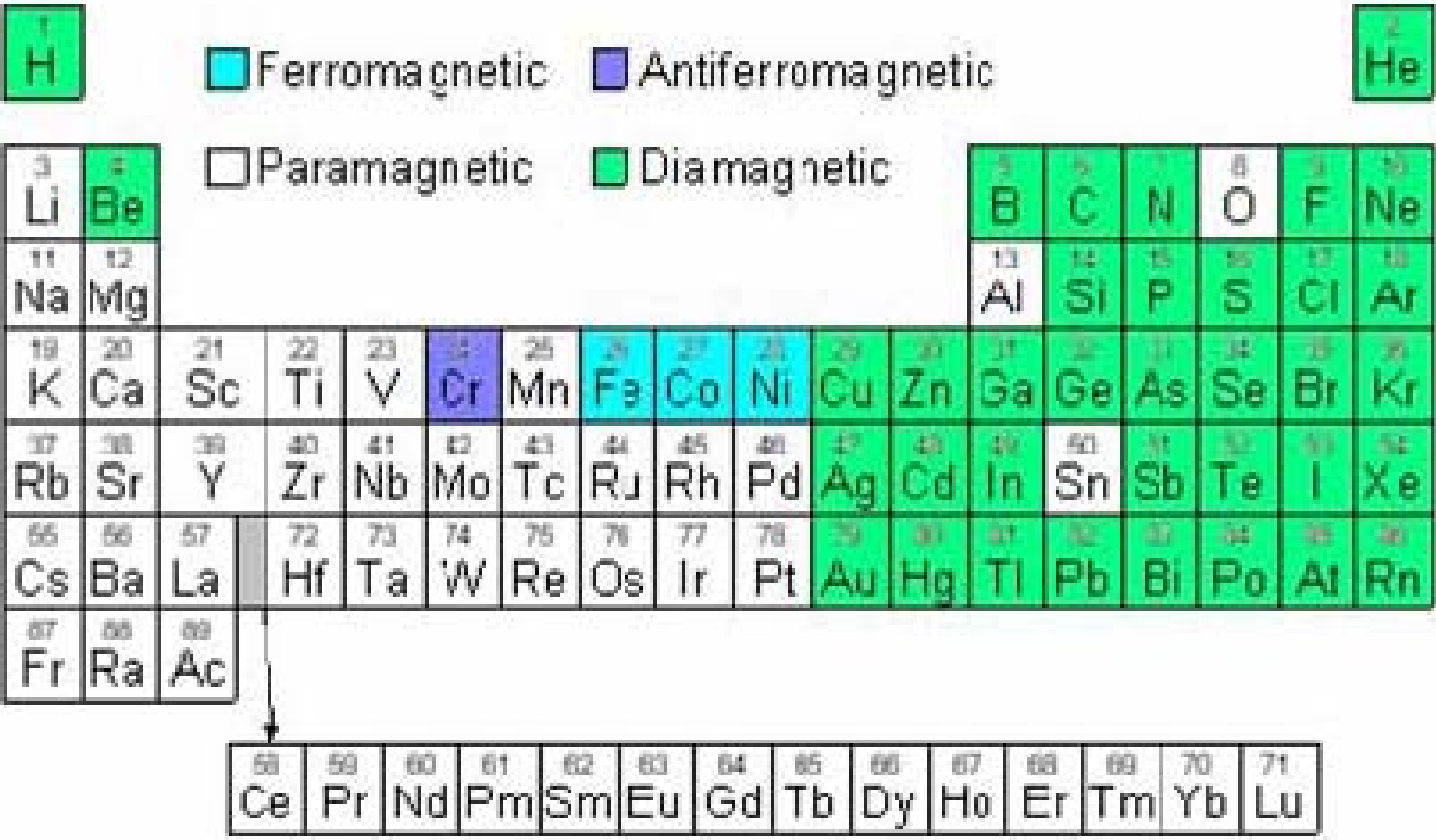
We will study three kinds of magnetism

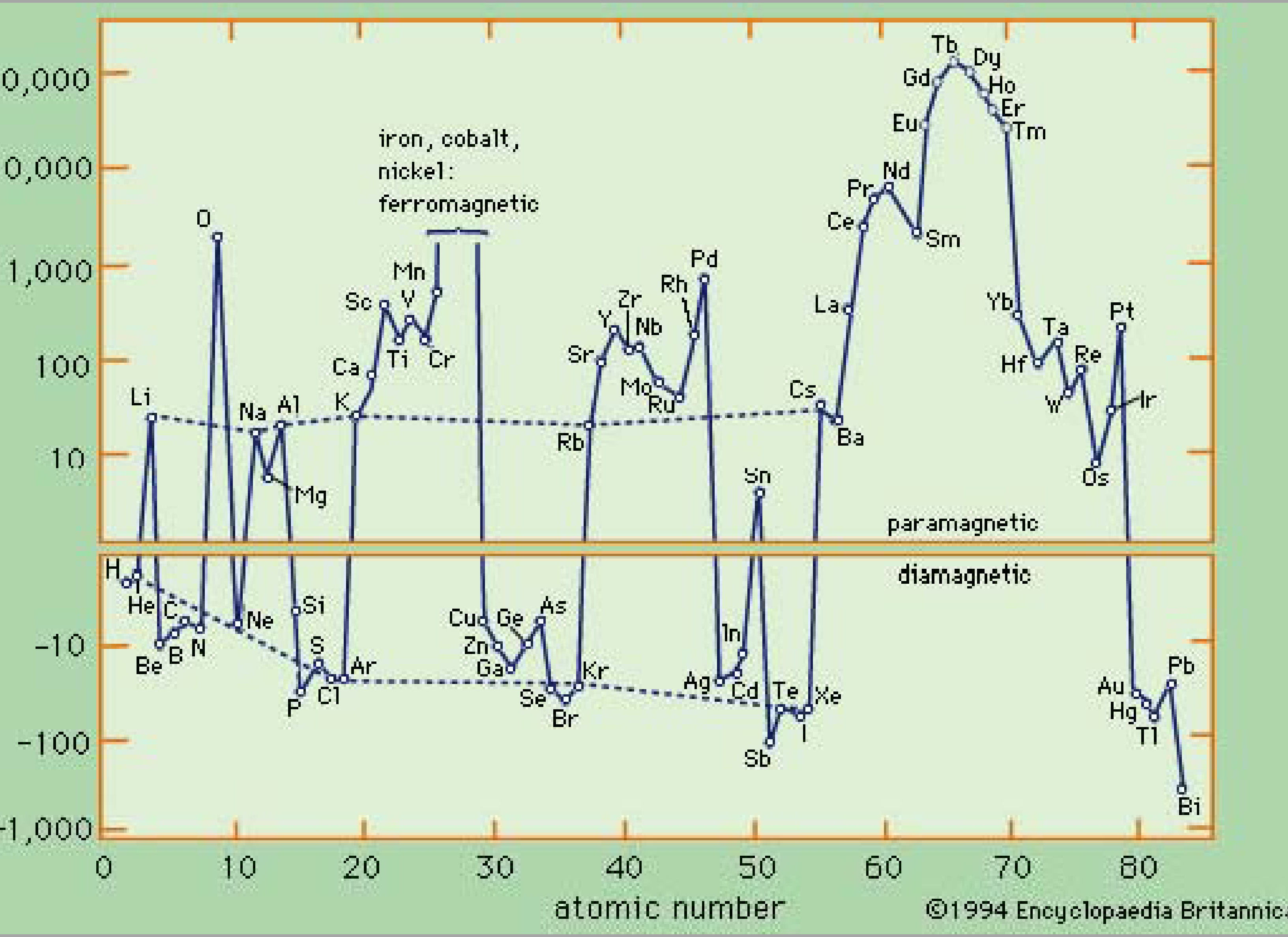
Ferromagnetism
- Fe, Co, Ni; some alloys
- Microscopic domains have nonzero magnetization.
- A macroscopic sample of ferromagnetic material may have a permanent magnetization.

Paramagnetism
- Placed in a magnetic field, the material has magnetization in the same direction as **B**.
- A paramagnetic material is attracted (weakly) to a magnet pole.

Diamagnetism
- Placed in a magnetic field, the material has magnetization in the direction opposite to **B**.
- A diamagnetic material is repelled (weakly) from a magnet pole.

(There are two other, more subtle, kinds of magnetism in matter: antiferromagnetism and ferrimagnetism.)


Ferromagnetic
Antiferromagnetic
Paramagnetic
Diamagnetic
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Ac
Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu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atomic number
iron, cobalt, nickel: ferromagnetic
paramagnetic
diamagnetic
H
He
Li
Be
B
C
N
O
Ne
Na
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Al
Si
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S
Cl
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Os
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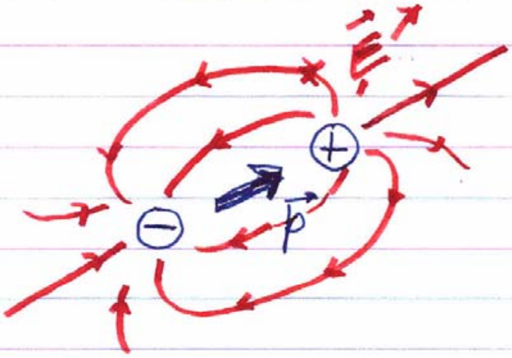
Chapter 9 - Magnetic Materials

The Magnetic Dipole 9.1/5

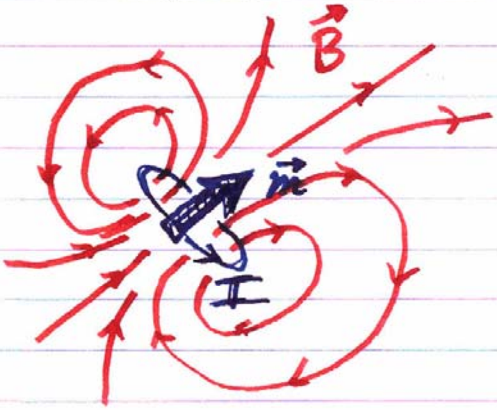
↳ and comparison to the electric dipole; in some ways similar, but also different.

ELECTRIC
DIPOLE



"two poles"

MAGNETIC
DIPOLE



"tiny current loop"

- The asymptotic fields are isomorphic.
- Each dipole experiences a torque if placed in a uniform field.

Notation $\vec{m}$ = dipole moment of an atom

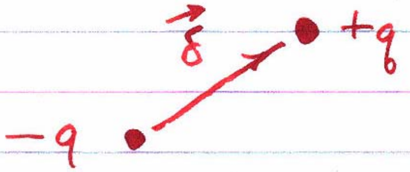
$\vec{M}(\vec{x})$ = "magnetization" = moment density

$$\vec{M}(\vec{x}) = n(\vec{x}) \langle \vec{m} \rangle_{AVG}$$

The Magnetic Dipole

↳ compared to the electric dipole

ELECTRIC DIPOLE

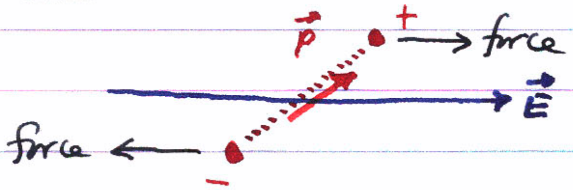


$$\vec p = q\vec\delta$$

or

$$\vec p = \int \vec x\,\rho(\vec x)\,d^3x$$

TORQUES

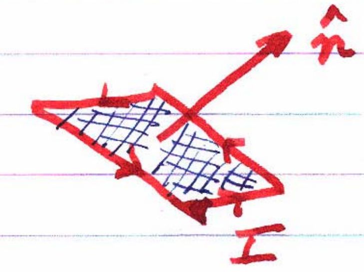


$$\vec N = \vec p \times \vec E$$

The torque acts in the direction toward alignment with $\vec E$.

$$N = pE\sin\theta$$

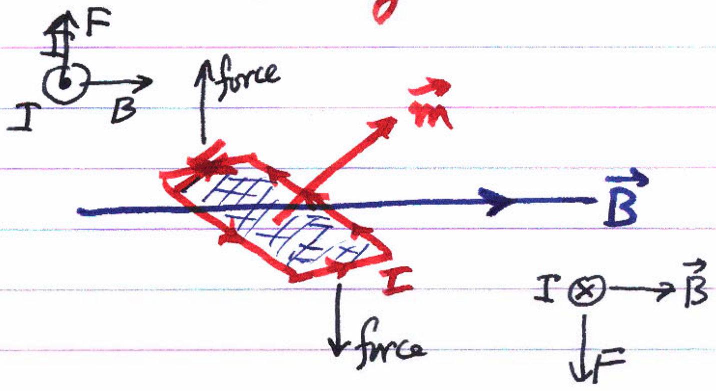
MAGNETIC DIPOLE



$$\vec m = IA\hat n$$

or

$$\vec m = \frac{1}{2}\int \vec x \times \vec J(\vec x)\,d^3x$$



$$\vec N = \vec m \times \vec B$$

The torque acts in the direction toward alignment with $\vec B$.

$$N = mB\sin\theta$$

Paramagnetism

◆ The atoms of the material have a *permanent magnetic dipole* moment **m**, even when there is no applied field. But the dipoles point in random directions so ⟨**m**⟩ = 0.

◆ When a magnetic field is applied, the dipoles align partially with the field, so ⟨**m**⟩ ∝ **B**. The torque twists them toward alignment.

Section 9.1
Equation 9.6

◆ Note that the susceptibility of a paramagnetic material is approximately proportional to 1/T.

$$\mathbf{M} = n m_0 \langle \cos\theta \rangle \hat{\mathbf{k}} = \frac{n m_0^2}{3kT}\mathbf{B}.$$

Diamagnetism

- The atoms of the material have no *permanent magnetic dipole moment.* That is, **m** = 0 when there is no applied field.

- When a magnetic field is applied, the atom develops a magnetic moment in the direction opposite to the magnetic field – an *induced dipole* moment.

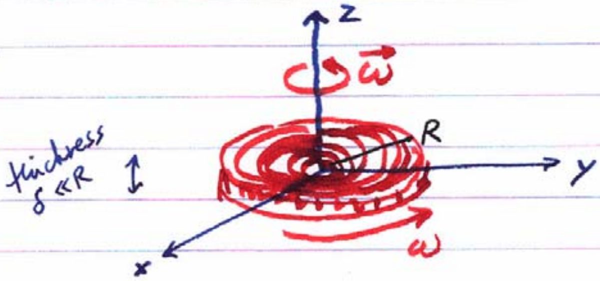
- *Why?*

Section 9.1
Equation 9.5

- Note that the susceptibility of a diamagnetic material is approximately independent of temperature.

$$\delta\mathbf{m} = -\frac{er}{2}(\delta v)\hat{\mathbf{k}} = -\frac{e^2r^2}{4m_e}B\hat{\mathbf{k}}.$$

QUIZ QUESTION



A uniformly charged disk is spinning as shown.

Charge density $\sigma = 1\ C/m^2$

Angular velocity $\omega = \frac{2\pi}{1\ \text{sec}} = 2\pi$ hz

Radius $R = 0.1$ m

Calculate the magnetic dipole moment (and don't forget the units).