# Supplemental Podcast: Magnetic Material

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# Learning Goals

- Magnetic Material
  - The Bohr Magneton
  - Types of Magnetism:
    - Paramagnetism
    - Diamagnetism
    - Ferromagnetism

# 28.9: Magnetic Material

- **Determine the Bohr Magneton**

  - Hydrogen atom

$$\mu = IA = I\pi r^2$$

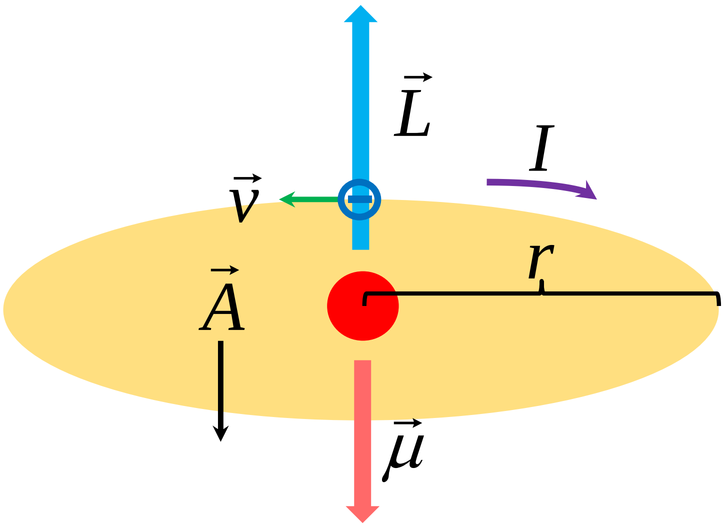
$$I = \frac{q_e}{T} = \frac{q_e v_e}{2\pi r}$$

  - Accordingly the magnetic moment is:

$$\vec{\mu} = I\vec{A} = \frac{q_e \vec{v}_e}{2\pi r}\pi r^2 = \frac{q_e \vec{v}_e r}{2}$$

  - This can be rewritten in terms of the angular momentum:

$$\vec{L} = m\vec{v} \times \vec{r} \qquad \vec{\mu} = \frac{q_e}{2m_e}\vec{L}$$



## 28.9: Magnetic Material

- For completeness I must now incorporate some quantum mechanics, in that the orbital angular momentum is quantized, so it can only have discreet values that are a multiple, *n* :

$$L = n\frac{h}{2\pi} = n\hbar$$

- where $h$ is a fundamental physical constant of nature, called Planck's constant, and it has a numerical value of:

$$h = 6.626\cdot 10^{-34}\, J\cdot s$$

- The resultant quantized dipole moment is:

$$\mu = \frac{q_e}{2m_e}n\hbar$$

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- If $n$ = 1, this is dipole moment of Hydrogen, which is called the **Bohr magneton**, denoted as $\mu_B$:

$$\mu_B = 9.274 \cdot 10^{-24}\, A \cdot m^2 = 9.274 \cdot 10^{-24}\, J/T$$

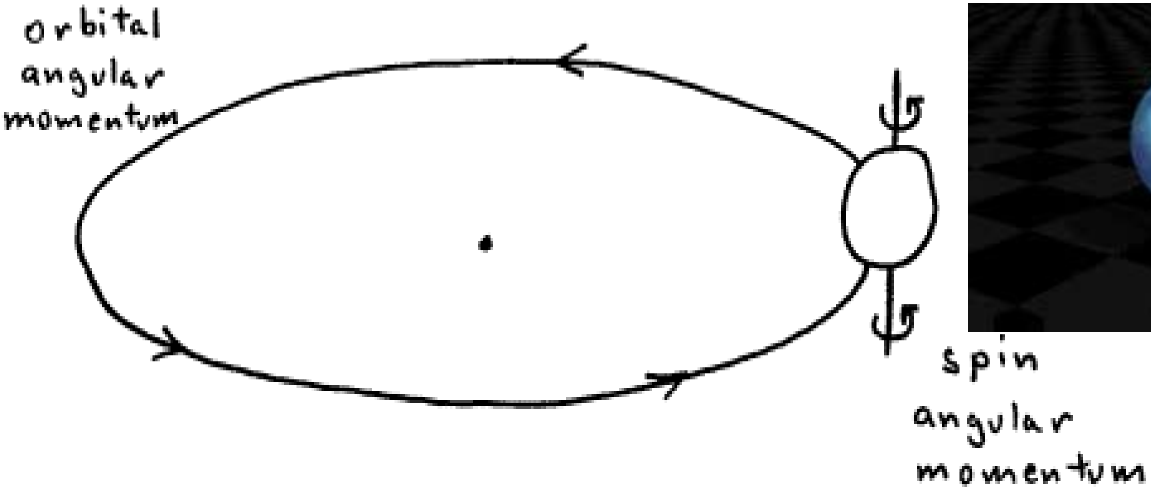
- The associated potential energy is correlated to the alignment of the Bohr magneton with an external magnetic field:

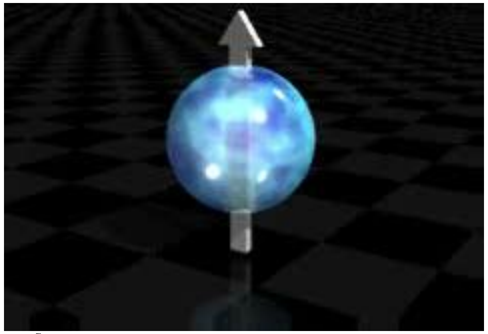
$$U = -\vec{\mu}_B \cdot \vec{B}$$

- I have also mentioned that the electrons themselves act as if they spin on its on axis like a spinning top, which also must be factored into the total angular momentum.

# 28.9: Magnetic Material

- This is called spin and there are only two states, “spin-up” and “spin-down”. I have also discussed a method to determine the spin state of conducting electrons (see Hall Effect).



# 28.9: Magnetic Material

- **Types of magnetism**
  - The atomic configuration of electrons in material governs its magnetic properties.
  - The configuration is determined by Hund’s rules: gives ground state of atoms with many electrons.
  - The pairing of electrons is key: more unpaired electrons = higher magnetic moment

Paramagnetism | Diamagnetism | Ferromagnetism

# 28.9: Magı

- **Paramagnet**
  - The dens ıgnetic field is actually tı gnetization:
  - A new fiel l can be defined:
  - where $\chi_m$ n an external magnetic ceptibility, which is defined

| Material | $\chi_m = K_m - 1\ (\times 10^{-5})$ |
|---|---|
| **Paramagnetic** | |
| Iron ammonium alum | 66 |
| Uranium | 40 |
| Platinum | 26 |
| Aluminum | 2.2 |
| Sodium | 0.72 |
| Oxygen gas | 0.19 |
| **Diamagnetic** | |
| Bismuth | −16.6 |
| Mercury | −2.9 |
| Silver | −2.6 |
| Carbon (diamond) | −2.1 |
| Lead | −1.8 |
| Sodium chloride | −1.4 |
| Copper | −1.0 |

# 28.9: Magnetic Material

- The relative permeability or $K_m$ is ratio between the permeability of the material, $\mu$, and the permeability of free space:

$$K_m = \mu_r = \frac{\mu}{\mu_0}$$

- The magnetic susceptibility is positive when any point in the material is greater by a factor of the relative permeability.
- These types of material are called **paramagnetic**. The magnetic field from the external magnetic field and the magnetic field generated by each dipole moment sum together:

$$\vec{B} = B_0 + \mu_0 \vec{M}$$

# 28.9: Magnetic Material

- The field caused by the external magnetic field within the material, $B_0$, is:

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

- If the material is linear the total magnetic field is proportional to the *H*-field:

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

- Accordingly, the total magnetic field can be written as:

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

- In order to determine if a material is paramagnetic, you simply have to measure the magnetization as a function of applied external magnetic field.

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

# 28.9: Magnetic Material

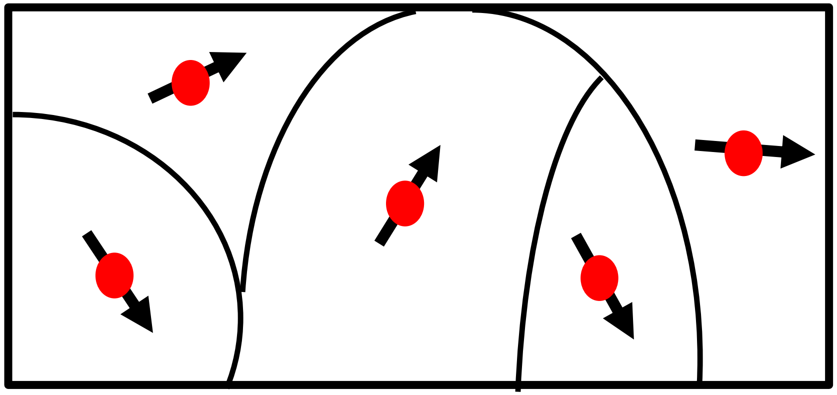
- **Diamagnetism**
  - If paramagnetism is the alignment of dipole moments to enhance the total magnetic field, **diamagnetism** is the exact opposite.
  - The dipole moments align antiparallel to the magnetic field; hence reducing the total magnetic field.
  - These materials exhibit a negative susceptibility and a relative permeability less than unity.
  - You have already seen this effect demonstrated via a type II superconductor, since it was able to suspend a magnet above it.

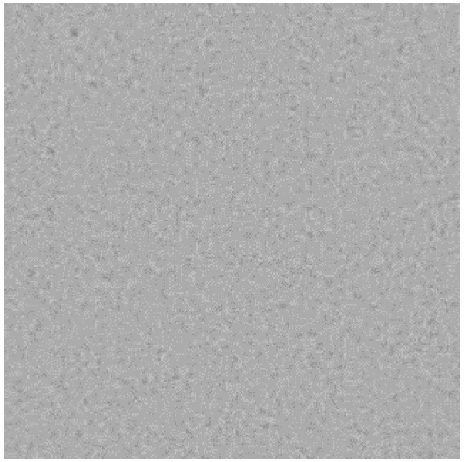
# 28.9: Magnetic Material

- **Ferromagnetism**
  - The most familiar type of magnetism is known as **ferromagnetism**, which has a name bearing iron in it.
  - These materials are comprised of tiny regions – approximately a square micrometer in size – called **magnetic domains**.
  - These are essentially a region in the material where all of the dipole moments tend to align in one preferential direction. They also interact with adjacent as well as remote domains, and try to configure themselves parallel to each other.

# 28.9: Magnetic Material

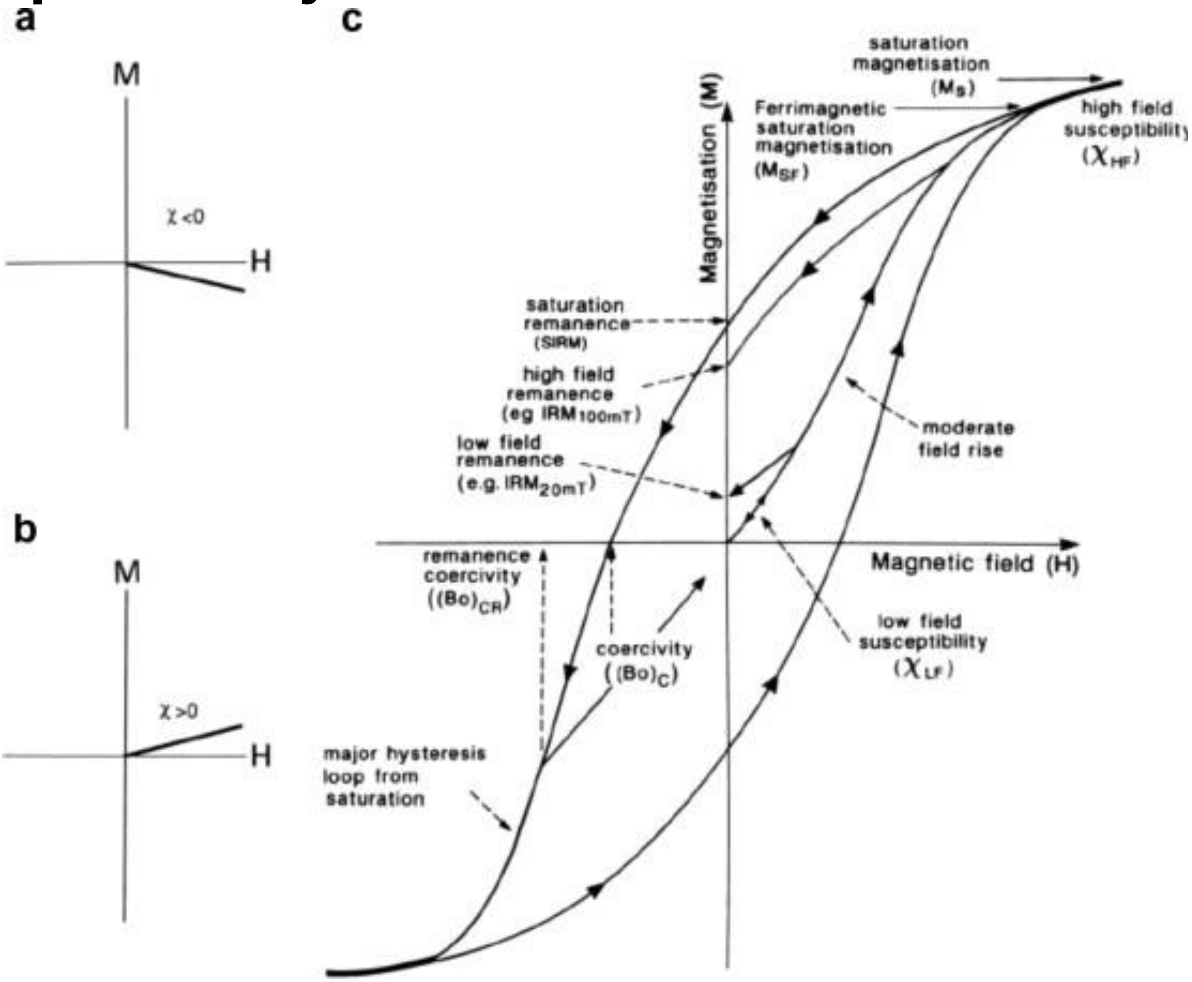
- **Magnetic Domains**





# 28.9: Magnetic Material

- **M-H Loops and Hysteresis**



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