Ferromagnetism (Q1)

- Ferromagnetic materials have atoms with large magnetic moments and interactions between internal dipole moments that can maintain alignment without external field
  - Iron, nickel, cobalt, iron oxide, cobalt oxide
- Magnetic moments align within regions called **domains**, but domains have random directions if no applied mag. field

- Applying an external $\mathbf{B}$ to the ferromagnetic material causes growth of domains aligned with external field

- Material becomes magnetized

- Very large effect - internal field thousands of times larger than applied field
  - Iron (98.8% pure): $\frac{B_{\text{int}}}{B_{\text{app}}} = 5000$
  - Iron (99.95% pure): $\frac{B_{\text{int}}}{B_{\text{app}}} = 200,000$

- Two classes of ferromagnetic materials
  - Magnetically **soft**: Domain alignment disappears when applied field removed; no "memory", or hysteresis (pure iron)
  - Magnetically **hard**: some domain alignment remains when applied field removed; has “memory” (hysteresis). (Iron alloys, iron oxide)
- Magnetically hard ferromagnetic material can make a permanent magnet

Magnetization and Magnetization Curve

- Magnetization $\mathbf{M}$: Magnetic dipole moment per unit volume:
  \[
  \mathbf{M} = \frac{\sum\mathbf{m}_i}{\text{Volume}}
  \]
- Magnetization curve Plot $\mathbf{M}$ as a function of $B_{\text{applied}}$
  - “Soft” material

Applications of Ferromagnetic Magnetization

- Electromagnet with core:
  - Magnetic Recording:
    - Core (soft iron)

- Residual magnetization allows for permanent magnet, or for information storage
- Residual magnetism can be lost at high temperature (Curie temperature)
Magnetic Data Storage

- "Hard" drive:

- "Floppy" Disk:
  - Magnetic Specifications. Sony MFD-2HD:
    Residual Magnetic Flux Density: 75 mT
    Squareness: 0.7
  - Videotape, credit cards, ...

Permanent Magnets

- Ferromagnetic material with residual magnetization

- Lines of $\mathbf{B}$ emerge from “North pole” of magnet and return into “South pole.”

As with charges, like poles repel, unlike poles attract (but never find isolated magnetic poles; only dipoles)

Magnetic compass is a permanent magnet on a pivot

Magnetic Field Intensity $\mathbf{H}$ and Susceptibility

- Magnetic Field Intensity $\mathbf{H}$ is basically the “applied” magnetic field divided by $\mu_0$:
  \[
  \mathbf{H} \equiv \frac{\mathbf{B}}{\mu_0} - \mathbf{M}
  \]

- Unit of $\mathbf{H}$: A/m

- For most materials, the magnetization $\mathbf{M}$ is related to $\mathbf{H}$ by the magnetic susceptibility $\chi_m$:
  \[
  \mathbf{M} = \chi_m \mathbf{H}
  \]

- Magnetic susceptibility (dimensionless) is positive for paramagnetic materials, negative for diamagnetic. It is usually <<1 (see text Table 29.2), but is large for ferromagnetic materials. It has a complicated temperature dependence. (Q2)