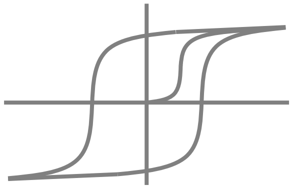
Chapter 6 Magnetic Materials

6.1 Magnetization **M** & Magnetization Current

6.2 Ferromagnetism

6.3* The Fundamental Magnetic Properties of Superconductors

6.4 Magnetic Circuit Theorem

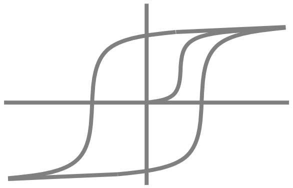


6.2 Ferromagnetism

◈ Ferromagnetism

✷ Ferromagnetic materials differs from diamagnetic and paramagnetic in three important ways.

- $$\frac{B'}{B_0}=10^2\sim10^3$$
- Relation between B & H is not a simple portion, M/H is very big but not a constant
- Shows a very large M without external field, permanently magnetized
- Iron, cobalt, nickel, and gadolinium, room T



6.2 Ferromagnetism

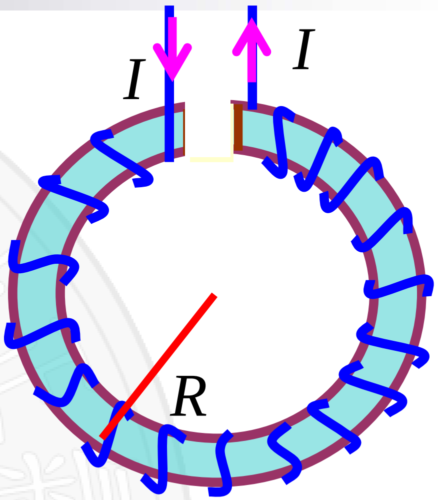
◇ Ferromagnetism

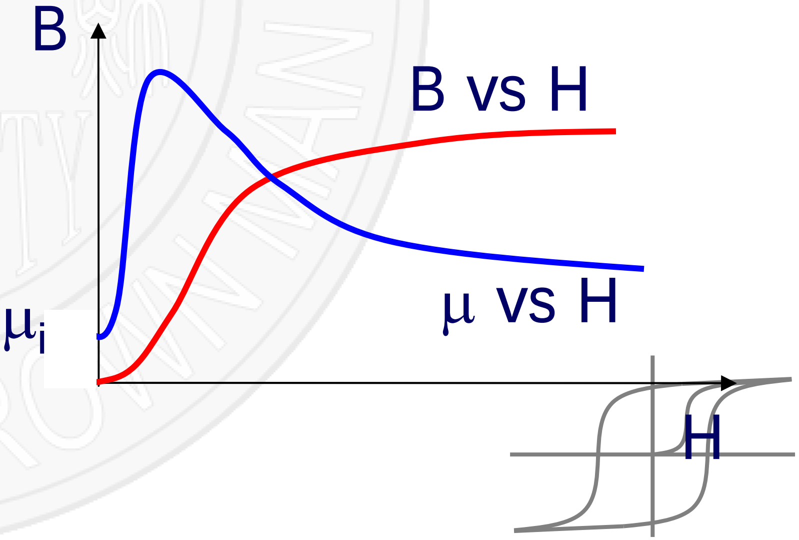
- Relation ***B*** to H is not simple.
- Show the relation by Curve of B & H
- Magnetization curve of the material
- Initial Magnetization Curve
- Permeability

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

- Initial permeability

$$\mu_i = \frac{dB}{dH}$$





6.2 Ferromagnetism

◈ Ferromagnetism

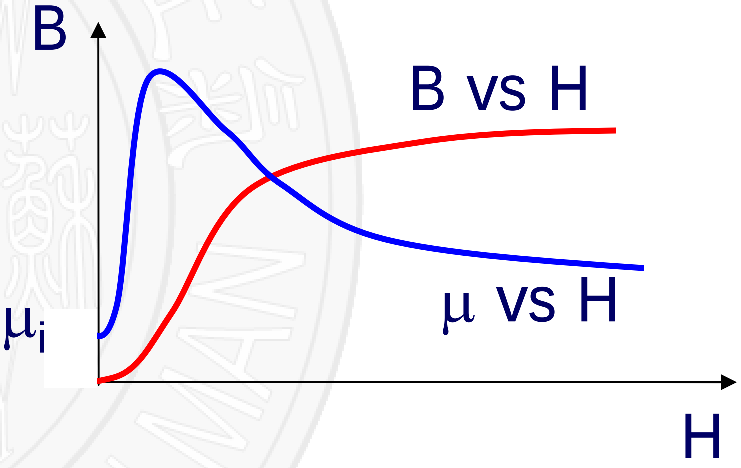
Example 6.4 Ferromagnetic material is on initially magnetized state, if B=1.01Tesla, H=150A/m, find μ and μ_r

Solution:

From initial magnetized state

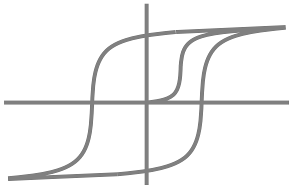
Permeability

$$\mu = \frac{B}{H} = \frac{1.01}{150} = 6.73 \times 10^{-3} (Tm/A)$$



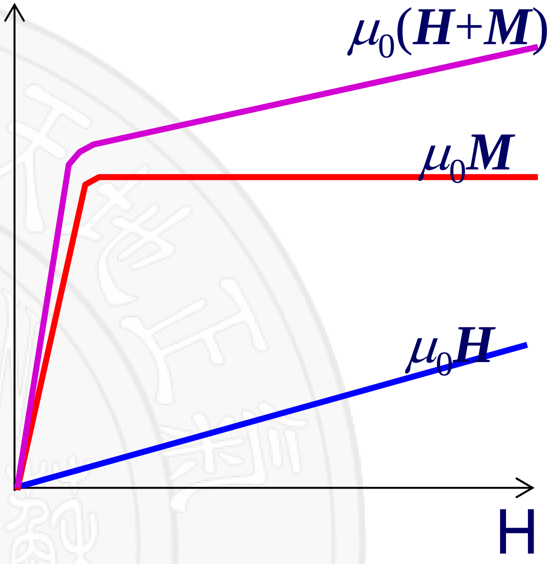
Relative Permeability

$$\mu_r = \frac{\mu}{\mu_0} = \frac{6.73 \times 10^{-3}}{4\pi \times 10^{-7}} = 5356$$



6.2 Ferromagnetism

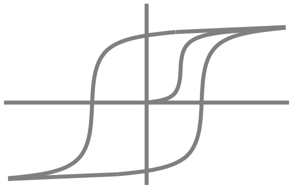
◈ Ferromagnetism



✷ With the increase of H, M approach to a constant

—— Saturated state

- Magnetic Domains
- The electrons in the metallic ions are paired off.
- half spinning one way , half the other way magnetically neutral
- Ferromagnetic elements are exceptions, uncompensated electrons

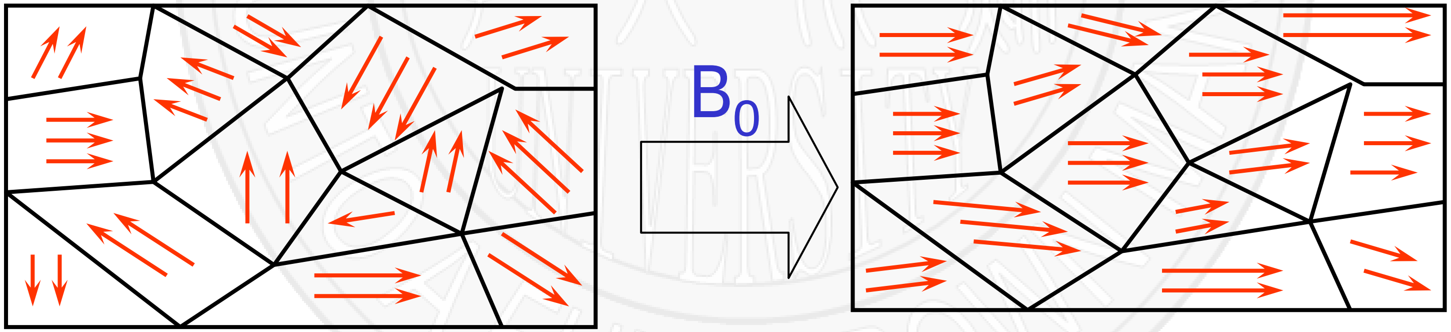


6.2 Ferromagnetism

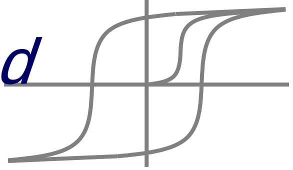
◇ Ferromagnetism

✷ Magnetically *saturated*, unpaired electrons are spinning with their axes in the direction of the magnetizing field.

- Exchanging interactions make up domains 10^{-12} m^3
- $N=nV=10^{28}\times 10^{-12}=10^{16}$molecules



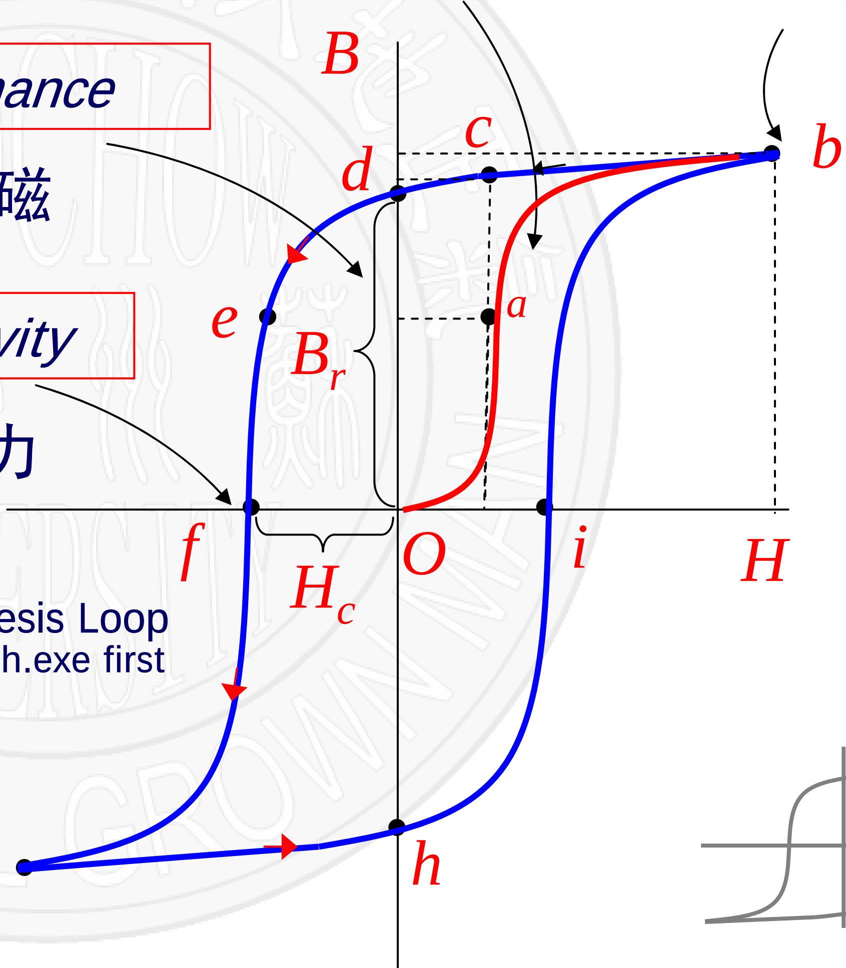
Magnetically *saturated*



6.2 Ferromagnetism

- Ferromagnetism
  - Hysteresis Loop

The area of the Hysteresis loop shows the energy dissipation, when magnetized. The fatter, the more dissipations of energy



Initial magnetization

saturation magnetization

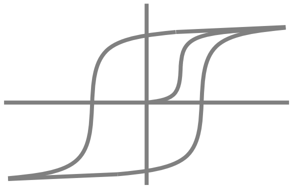
Remanance

剩磁

coercivity

矫顽力

Hysteresis Loop
Run flash.exe first



6.2 Ferromagnetism

◈ Ferromagnetism

Different magnetic properties are important for different applications.

- Soft magnetic material

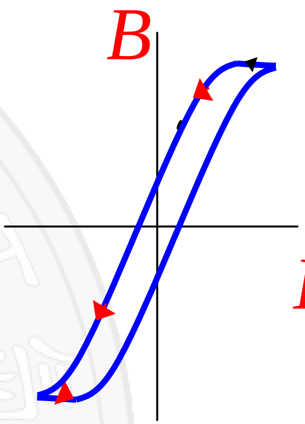
  Very thin, smaller area, smaller dissipation, smaller *remanance.*

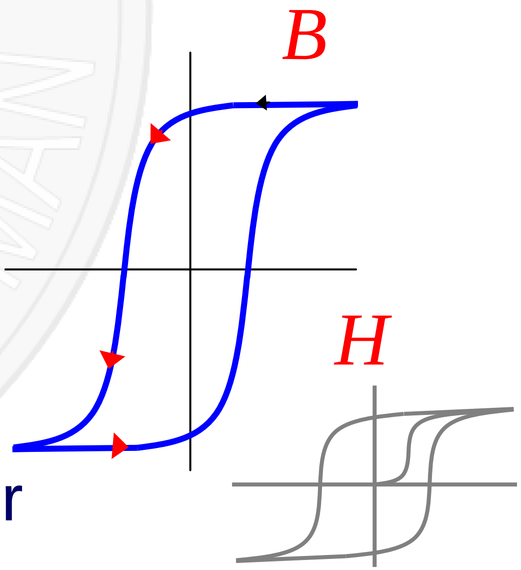
  Be used in transformer, motor, relay

- Hard magnetic material

  Very fat, bigger area, bigger dissipation, bigger *remanance.*

  Be used in permanent magnet, speaker, earphone, magnetoelectric galvanometer





6.2 Ferromagnetism

Ferromagnetism

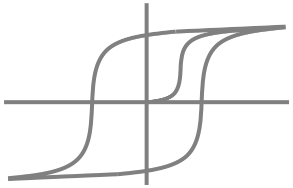
How to demagnetize ?

- Heating

  Critical Temperature : Curie Temperature

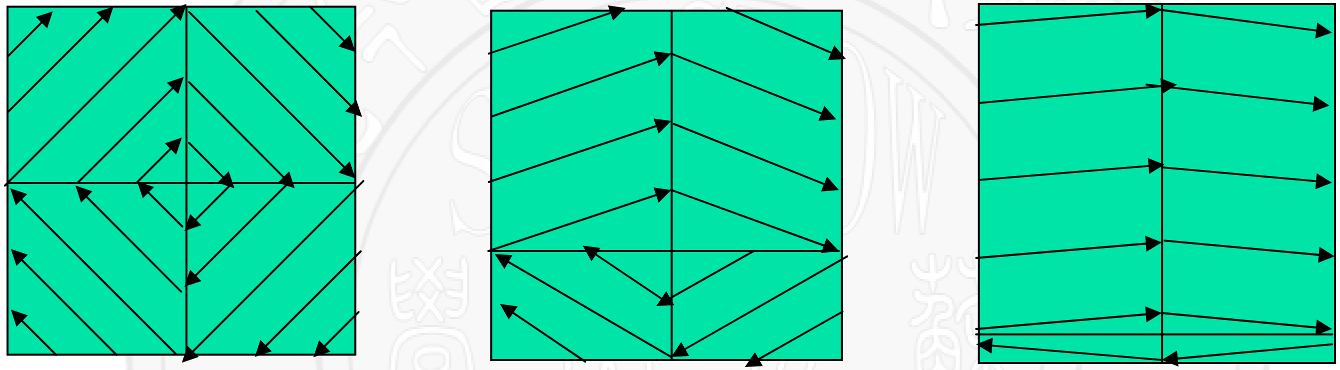
  Electric cooker, warning alarm

- Beating
- Opposite direction magnetic field
- To be placed in alternating decreasingly magnetic field



6.2 Ferromagnetism

- Ferromagnetism
  - Magnetostriction



  - Curie Temperature

Show Curie temperature

    - $T<T_c$, Ferromagnetic
    - $T>T_c$, paramagnetic

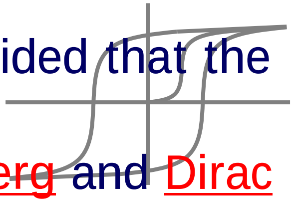
6.2 Ferromagnetism

In physics, the **exchange interaction** is a quantum mechanical effect which increases or decreases the expectation value of the energy or distance between two or more identical particles when their wave functions overlap. For example, the exchange interaction results in identical particles with spatially symmetric wave functions appearing "closer together" than would be expected of distinguishable particles, and in identical particles with spatially antisymmetric wave functions appearing "farther apart".

Although one might naively expect such an interaction to result from a force, the exchange interaction is a purely quantum mechanical effect without any analog in classical mechanics. It is the result of the fact that the wave function of indistinguishable particles is subject to exchange symmetry, that is, the wave function describing two particles that cannot be distinguished must be either unchanged (symmetric) or inverted in sign (antisymmetric) if the labels of the two particles are changed.

For example, if the expectation value of the distance between two particles in a spatially symmetric or antisymmetric state is calculated, the exchange interaction may be seen.

Both bosons and fermions can experience the exchange interaction provided that the particles in question are indistinguishable.



Exchange interaction effects were discovered independently by Heisenberg and Dirac in 1926.