Magnetic Materials

Diamagnetic materials

Properties

- No permanent dipole or magnetic moment is present.
- The external magnetic field produces induced magnetic moment.
- Induced magnetic moment is always in opposite direction of the applied magnetic field.
- So magnetic induction in the specimen decreases.
- Magnetic susceptibility is small and negative.
- Repels magnetic lines of force.

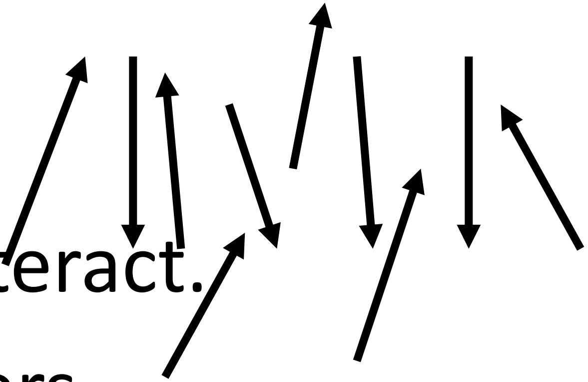
- Diamagnetic susceptibility is independent of temperature and applied magnetic field strength.
- Relative permeability is less than one.
- Examples: Bi, Zn, gold, H_2O, alkali earth elements (Be, Mg, Ca, Sr), superconducting elements in superconducting state.

Paramagnetic materials

Properties

- Possess permanent dipoles.
- In the absence of external mag. Field all dipoles are randomly oriented so net magnetic moment is zero.
- In presence of magnetic field the material gets feebly magnetized.
- i.e. the material allows magnetic lines of force to pass through it.
- The orientation of magnetic dipoles depends on temperature and applied field.
- Susceptibility is small and positive.

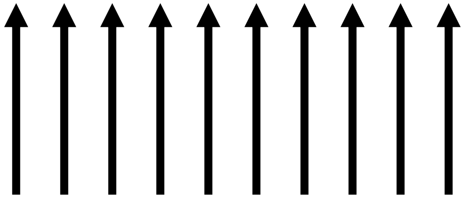
- Susceptibility is independent of applied mag. field & depends on temperature $\chi = \frac{C}{T}$
- C is Curie constant
- Spin alignment is random.
- The magnetic dipoles do not interact.
- These materials are used in lasers.
- Paramagnetic property of oxygen is used in NMR technique for medical diagnose.
- Examples: alkali metals (Li, Na, K, Rb), transition metals, Al, Pt, Mn, Cr etc.



Ferromagnetic Materials

Properties

- Possess net magnetic moment
- Possess spontaneous magnetization.
- Material shows magnetic properties even in the absence of external magnetic field.
- Spontaneous magnetization is because of interaction between dipoles called EXCHANGE COUPLING.
- When placed in external mag. field it strongly attracts magnetic lines of force.
- All spins are aligned parallel & in same direction.

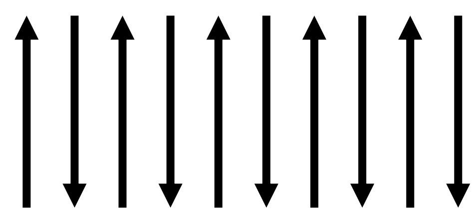


- Susceptibility is large and positive. $\chi = \frac{C}{T - \theta}$
- C is Curie constant & θ is Curie temperature.
- When temp is greater than curie temp then the material gets converted in to paramag.
- They possess the property of HYSTERESIS.
- Material gets divided into small regions called domains.
- Examples: Fe, Co, Ni.

Antiferromagnetic Material

Properties

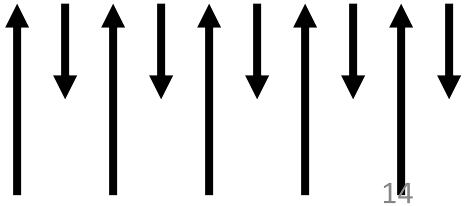
- The spin alignment is in antiparallel manner.
- So net magnetic moment is zero.
- Susceptibility is small and positive. $\chi = \frac{C}{T + \theta}$
- Initially susceptibility increases with increase in temperature and beyond Neel temperature the susceptibility decreases with temperature.
- At Neel temperature susceptibility is maximum.
- Examples: FeO, MnO, Cr_2O_3 and salts of transition elements.



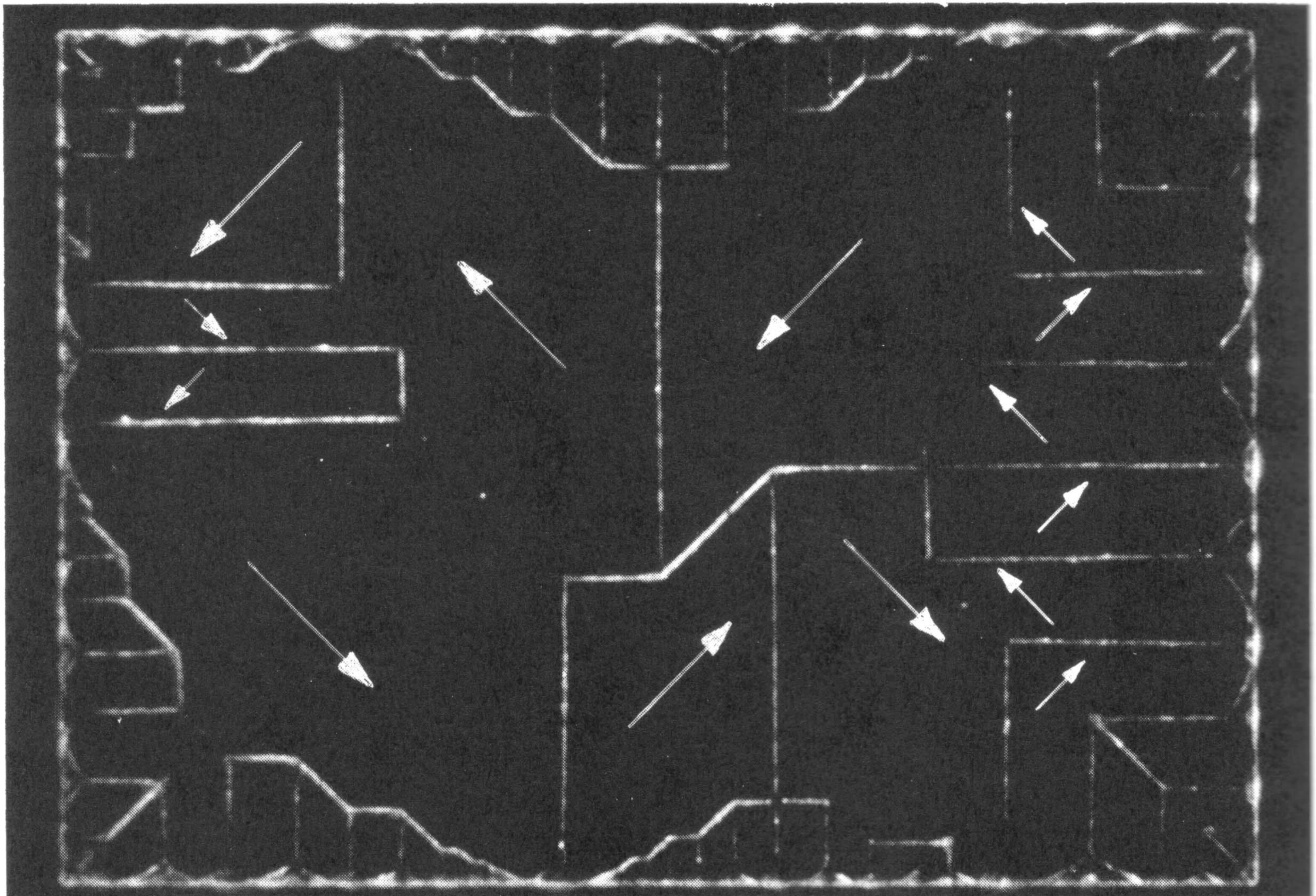
Ferrimagnetic Materials

Properties

- Special type of antiferromagnetic material.
- The spin alignment is antiparallel but different magnitude.
- So they possess net magnetic moment.
- Also called ferrites.
- Susceptibility is very large and positive.
- Examples: ferrous ferrite, nickle ferrite

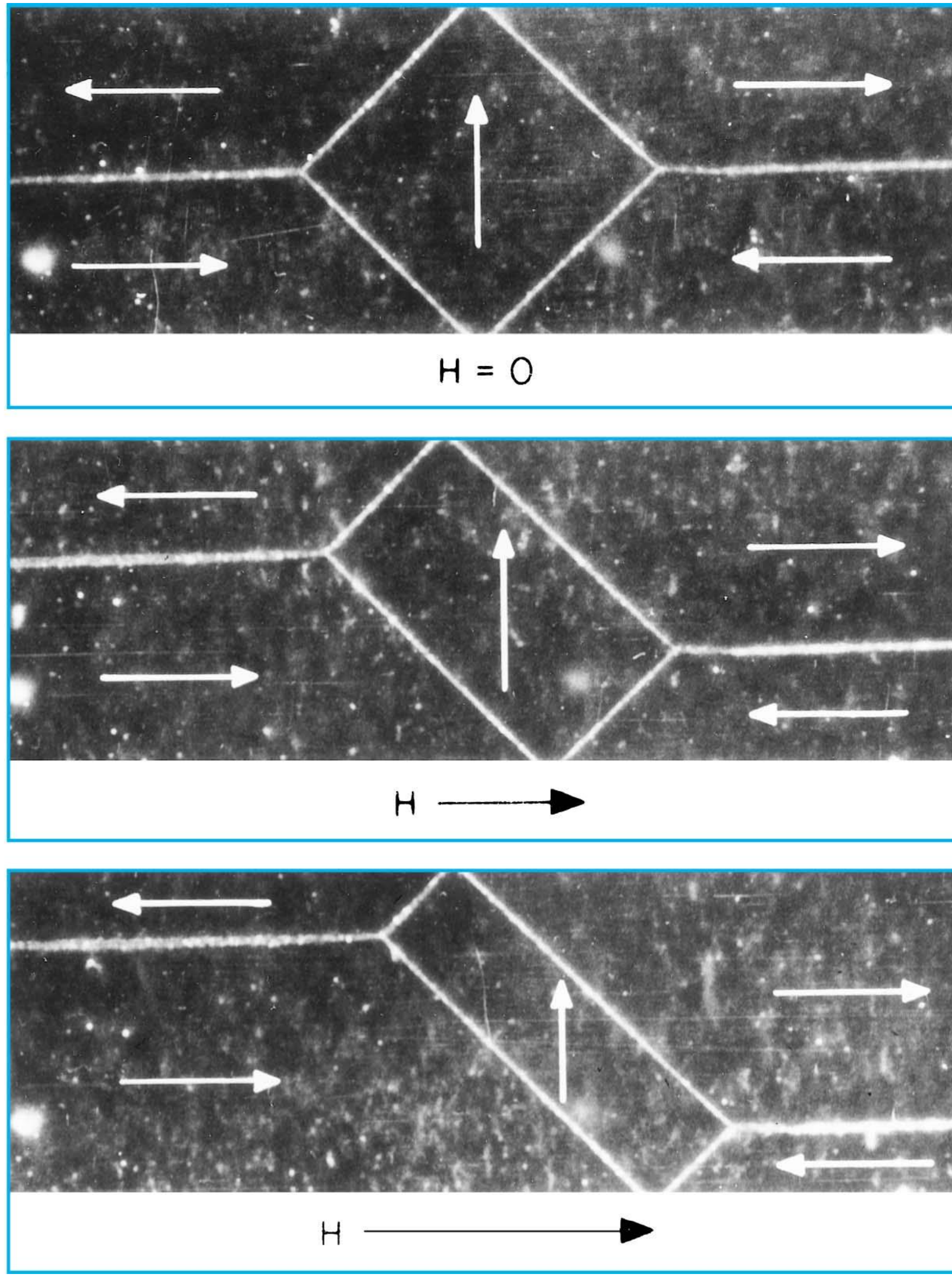


Domain Theory of Ferromagnetic Materials



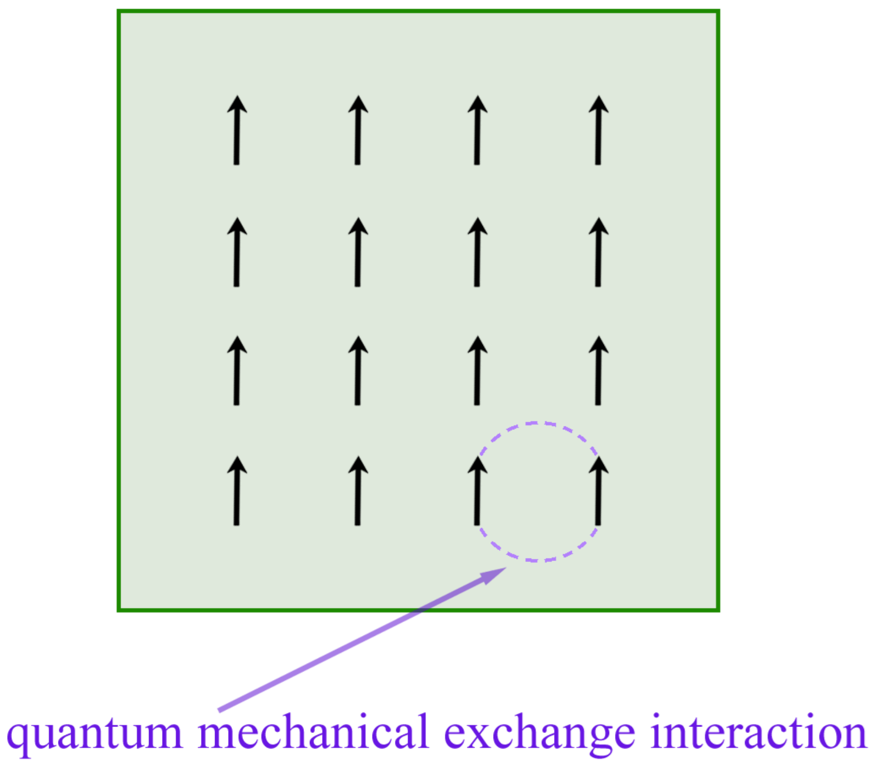
Lots and lots of domains in Ferro- (or Ferri-) Magnets

Photomicrographs of an iron single crystal, showing magnetic domains and their change in shape as a magnetic field (*H*) is applied. The magnetization direction of each domain is indicated by an arrow. Those domains that are favorably oriented with the applied field grow at the expense of the unfavorably oriented domains. (Photomicrographs courtesy of General Electric Research Laboratory.)



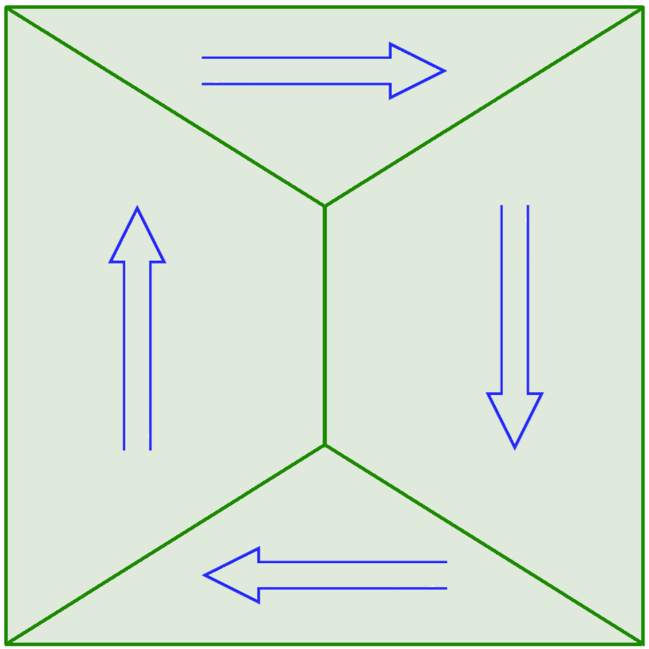
Domains form for a reason in ferro- and ferrimagnetic materials.
They are not random structures.

Ferromagnetism



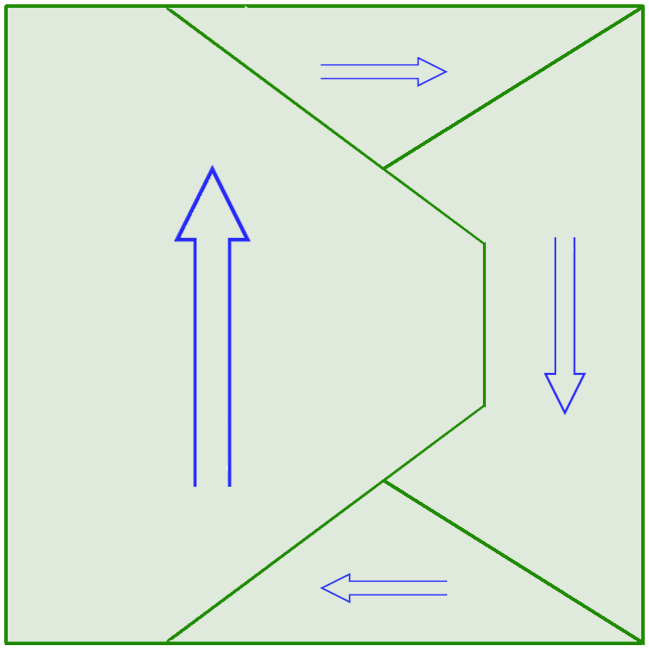
- Materials that retain a magnetization in zero field
- Quantum mechanical exchange interactions favour parallel alignment of moments
- Examples: iron, cobalt

Magnetic domains



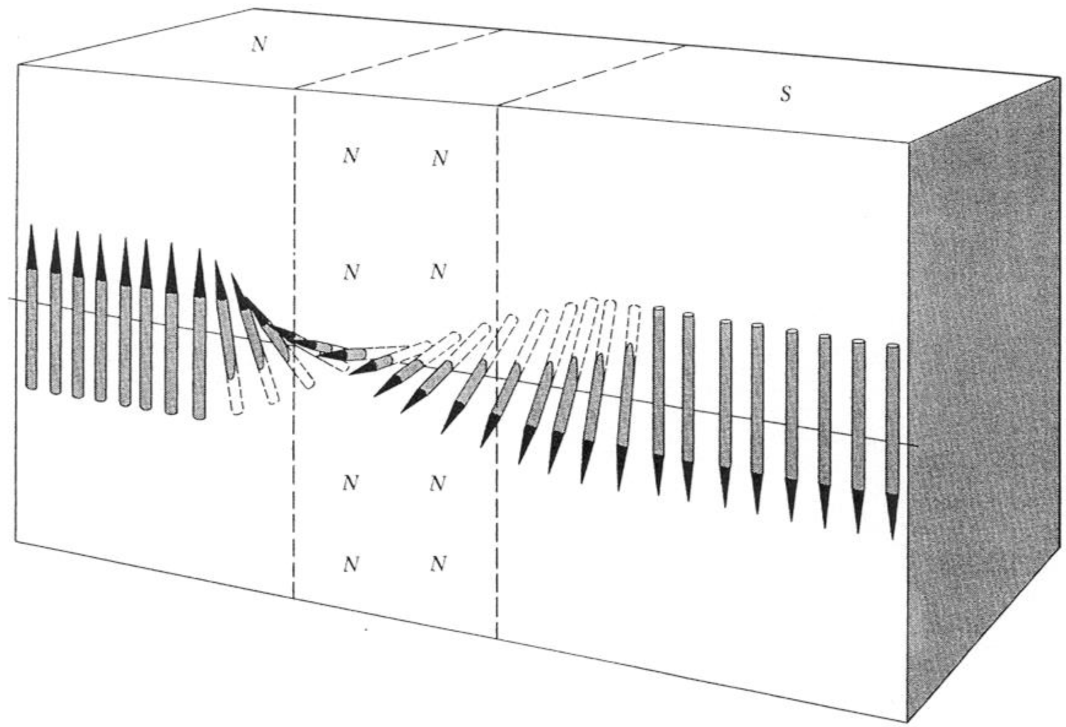
- Ferromagnetic materials tend to form magnetic domains
- Each domain is magnetized in a different direction
- Domain structure minimizes energy due to stray fields

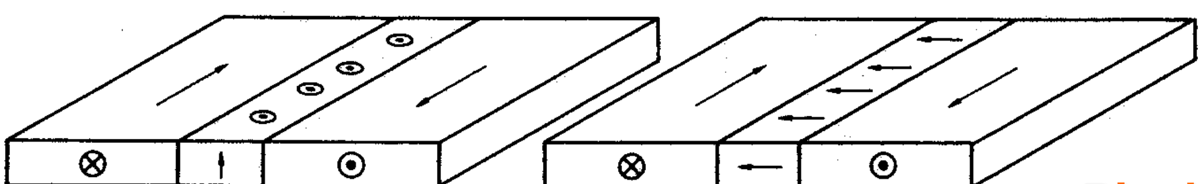
Magnetic domains



- Applying a field changes domain structure
- Domains with magnetization in direction of field grow
- Other domains shrink

Bloch Wall





Bloch Wall and Nèel Wall

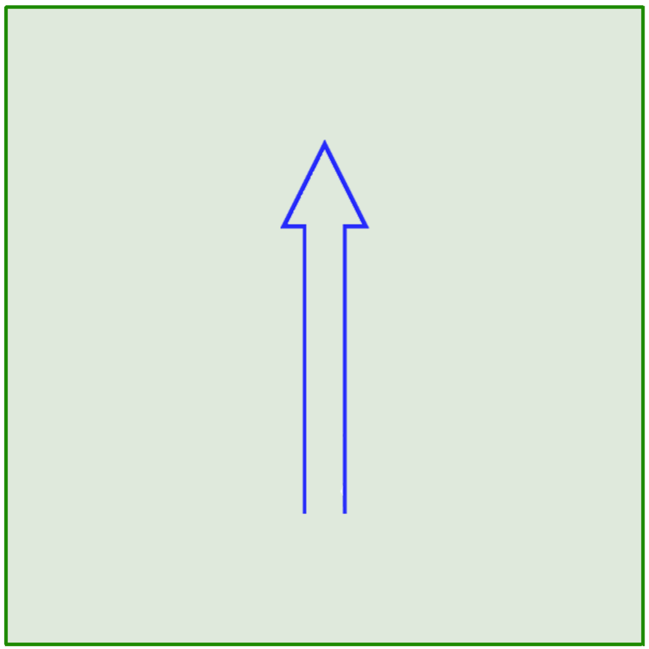
Figure 40 A Bloch wall and a Néel wall in a thin film. The magnetization in the Bloch wall is normal to the plane of the film and adds to the wall energy a demagnetization energy $\sim M_s^2 \delta d$ per unit length of wall, where δ is the wall thickness and d the film thickness. In the Néel wall the magnetization is parallel to the surface; the addition to the wall energy is negligible when $d \ll \delta$. The addition to the Néel wall energy when $d \gg \delta$ is the subject of Problem 7. (After S. Middelhoek.)

Two ways for aligning of magnetic domains:

1. Growth of favorably oriented domains (initially)

2. Rotation of domains (finally)

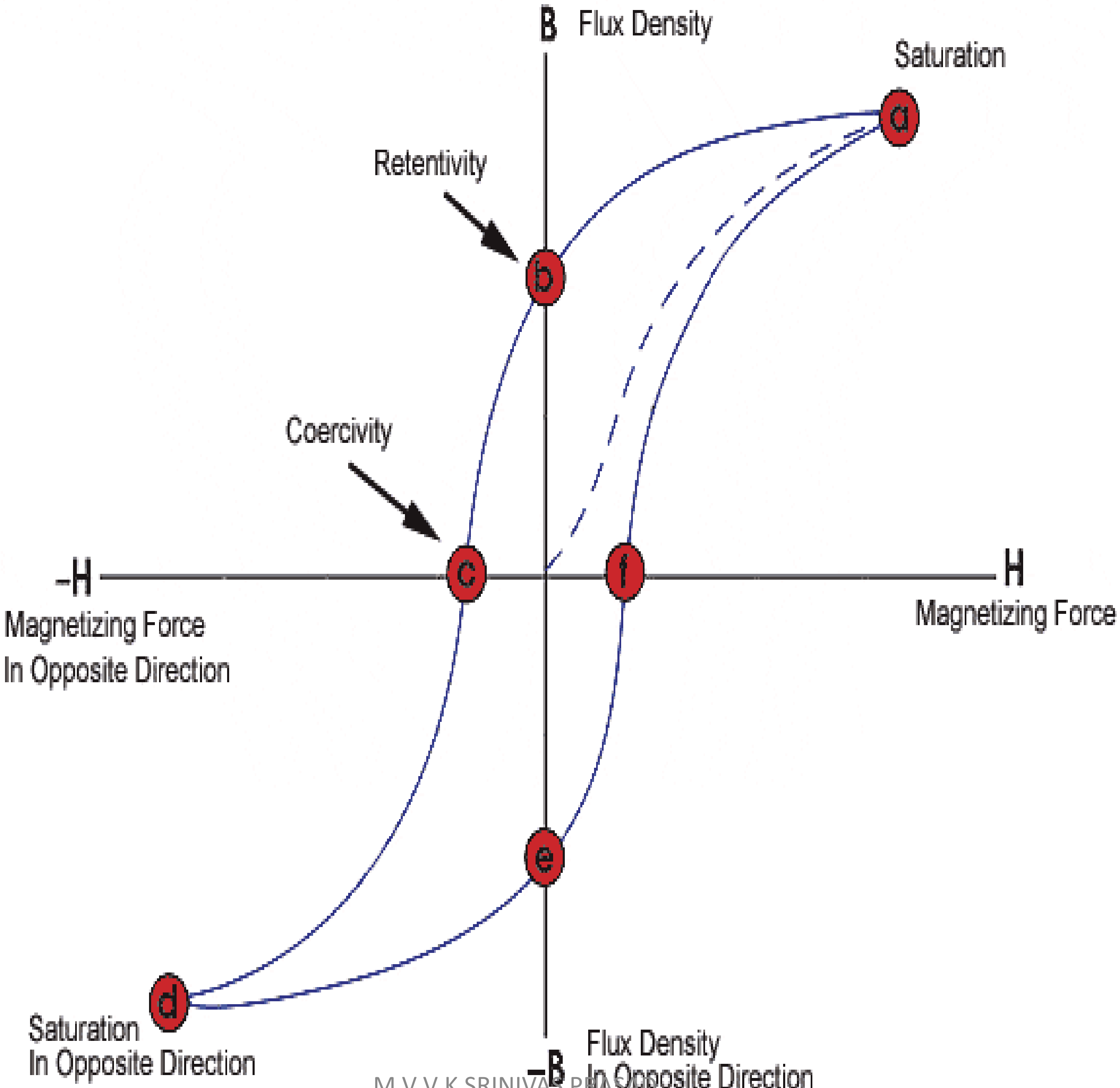
Magnetic domains



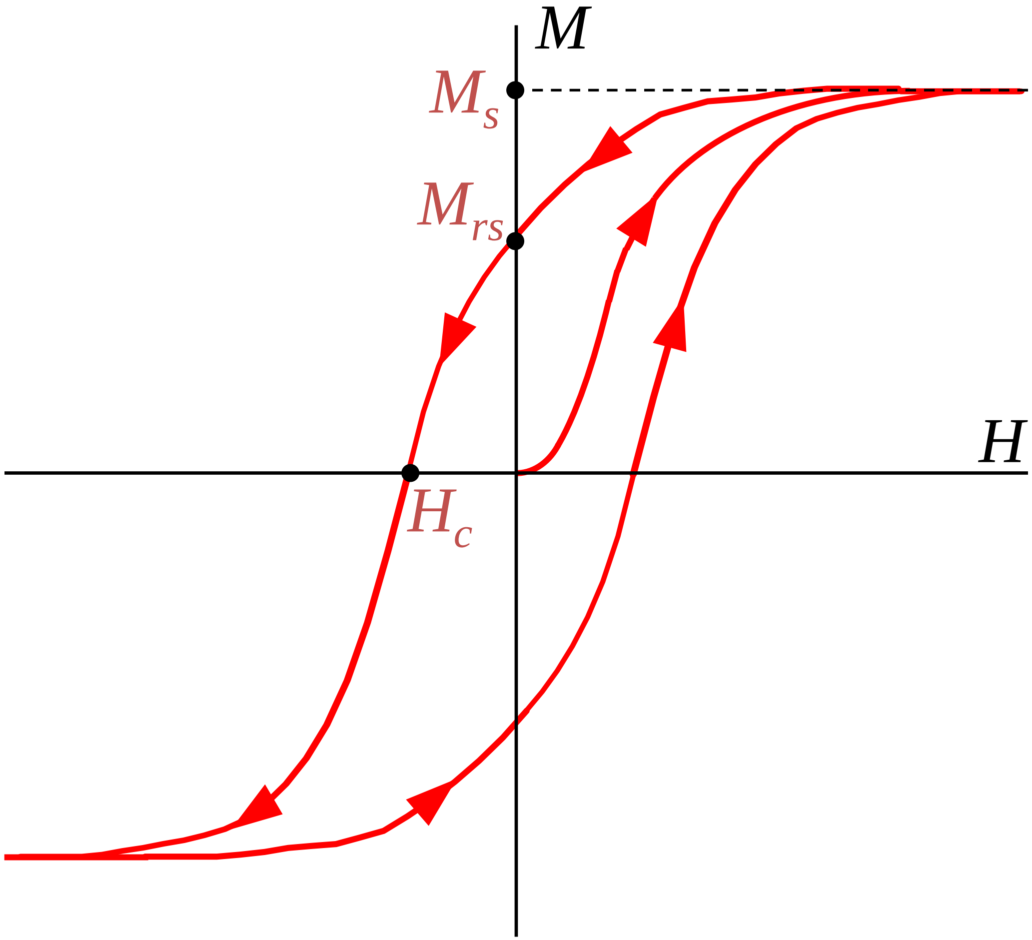
- Applying very strong fields can saturate magnetization by creating single domain

Hysteresis Curve

- Means lagging or retarding of an effect behind the cause of the effect.
- Here effect is B & cause of the effect is H.
- Also called B H curve.
- Hysteresis in magnetic materials means lagging of magnetic induction (B) or magnetization (M) behind the magnetizing field (H).


B Flux Density
Saturation
a
Retentivity
b
Coercivity
c
f
-H
H
Magnetizing Force
In Opposite Direction
Magnetizing Force
e
d
Saturation
In Opposite Direction
-B
Flux Density
In Opposite Direction

Ferromagnetism: Magnetic hysteresis

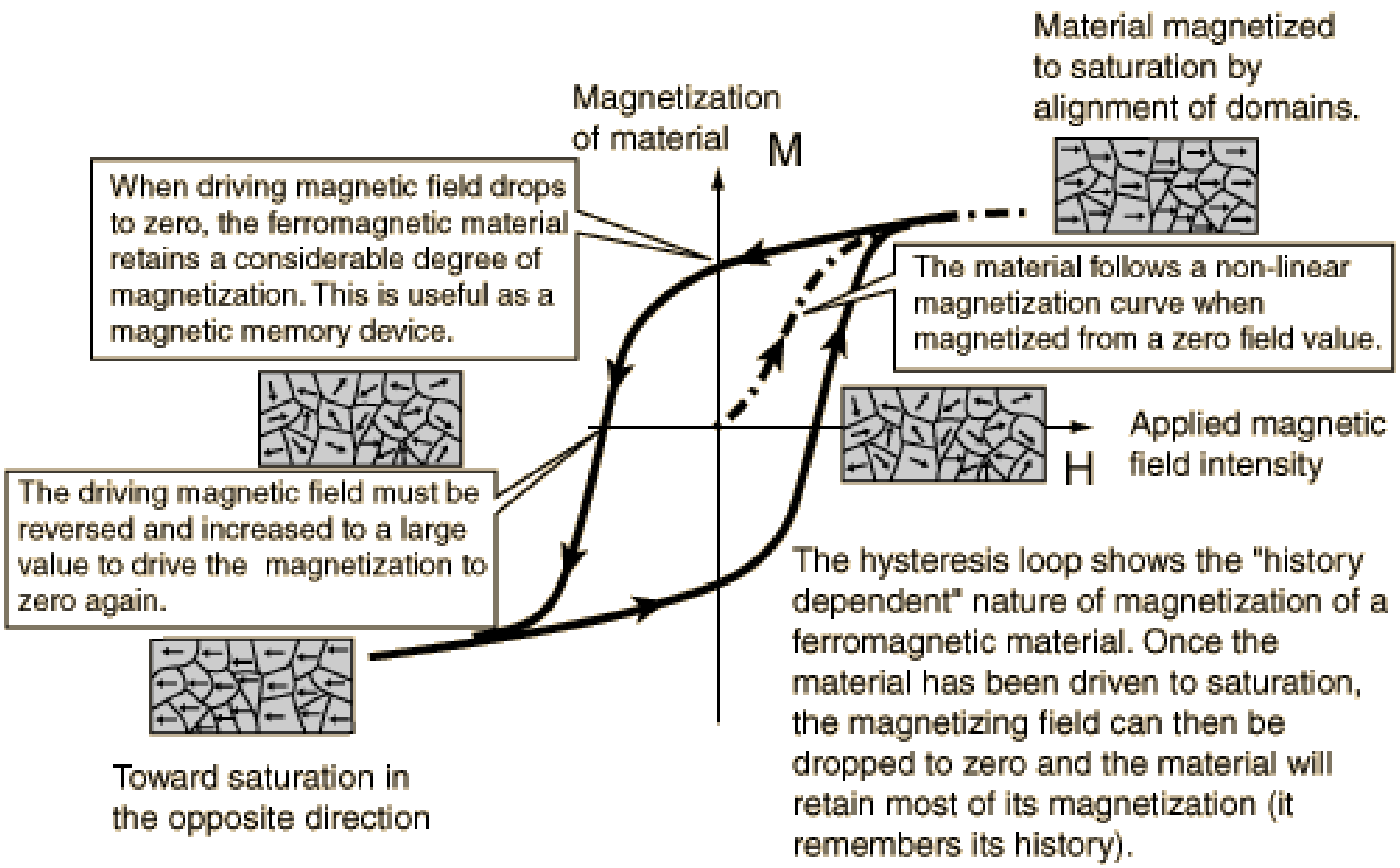


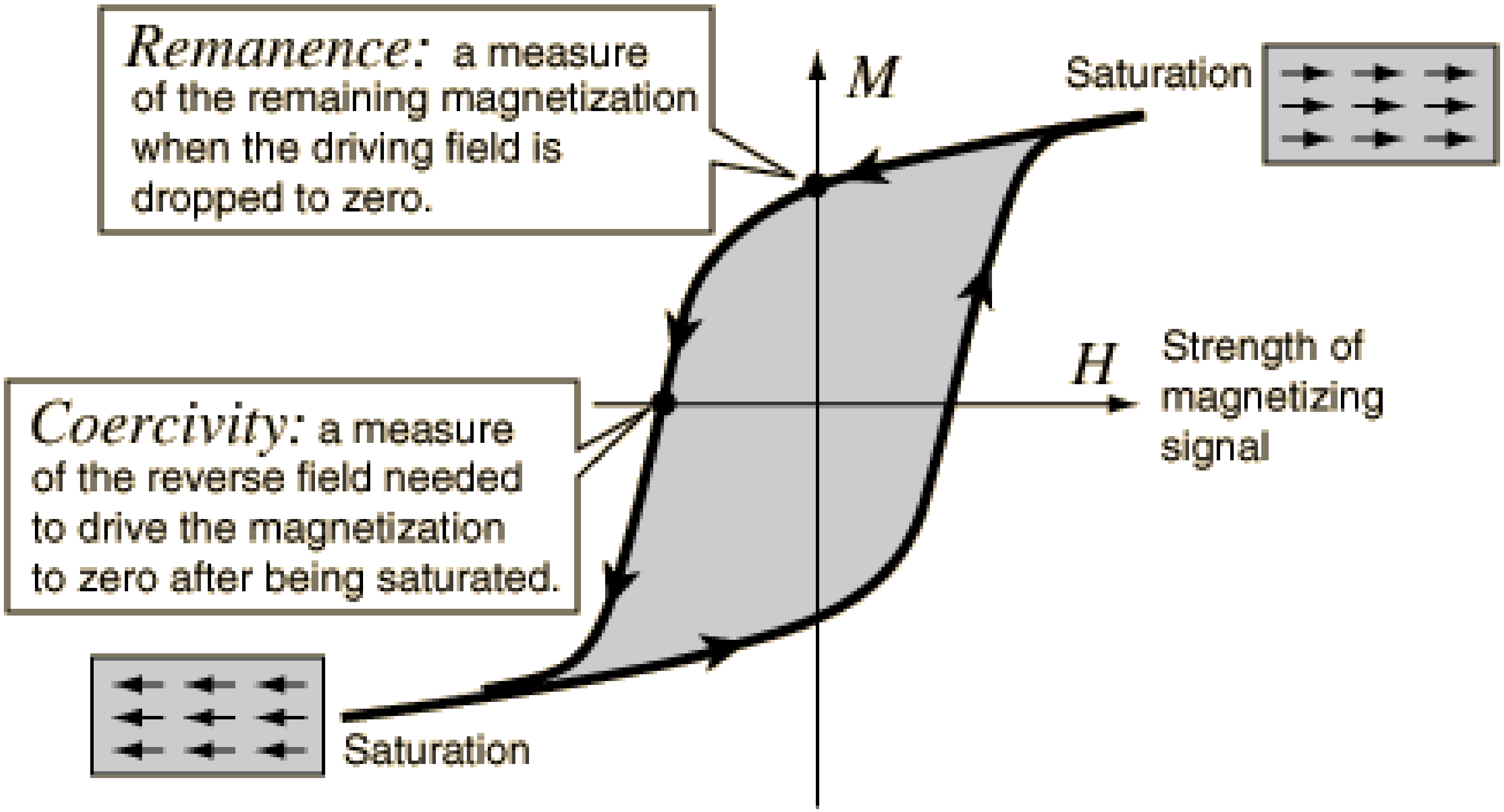
M_s – Saturation magnetization

M_{rs} – Saturation remanent magnetization

H_c – Coercive force *(the field needed to bring the magnetization back to zero)*

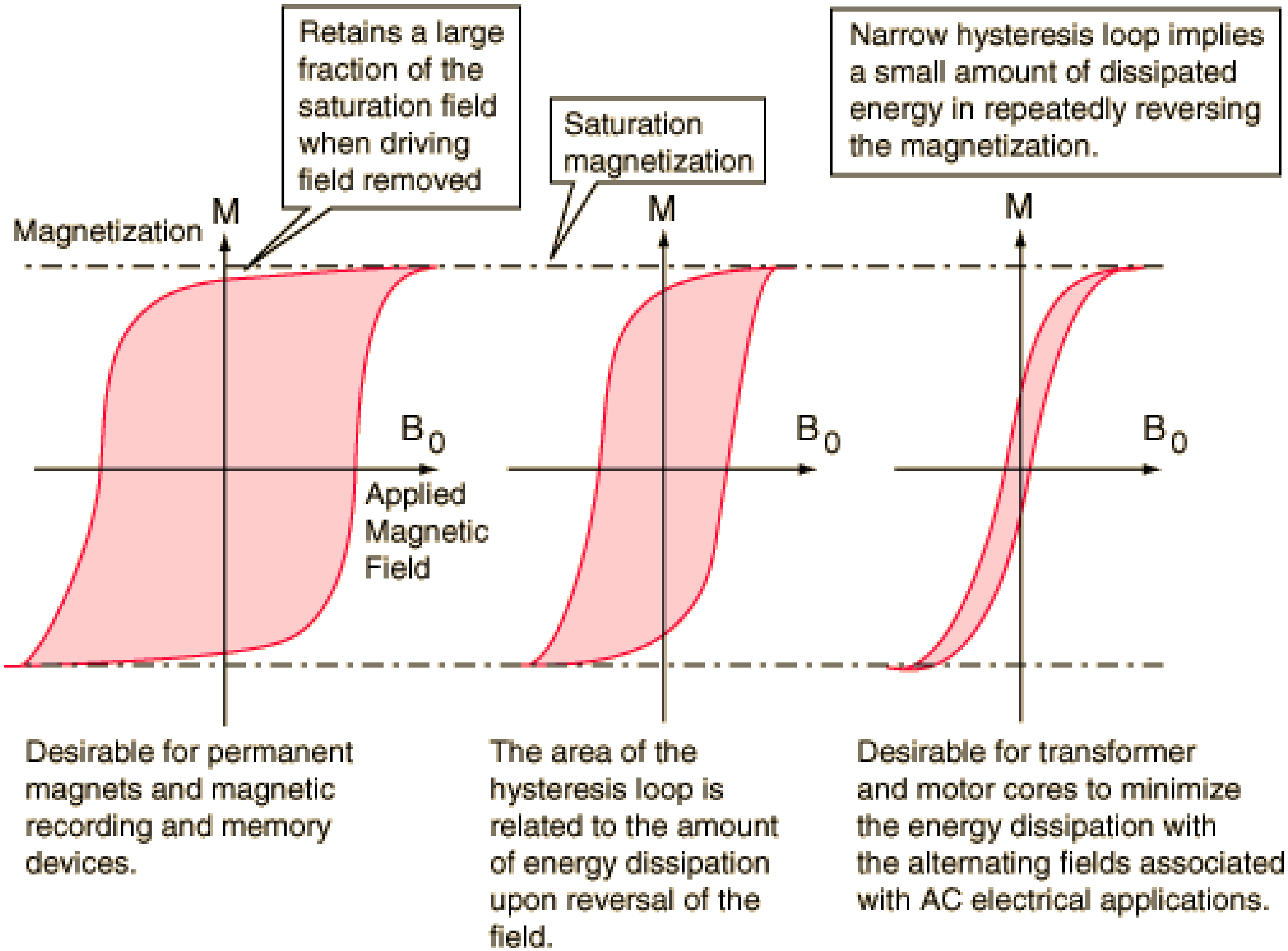
Hysteresis, Remanence, & Coercivity of Ferromagnetic Materials





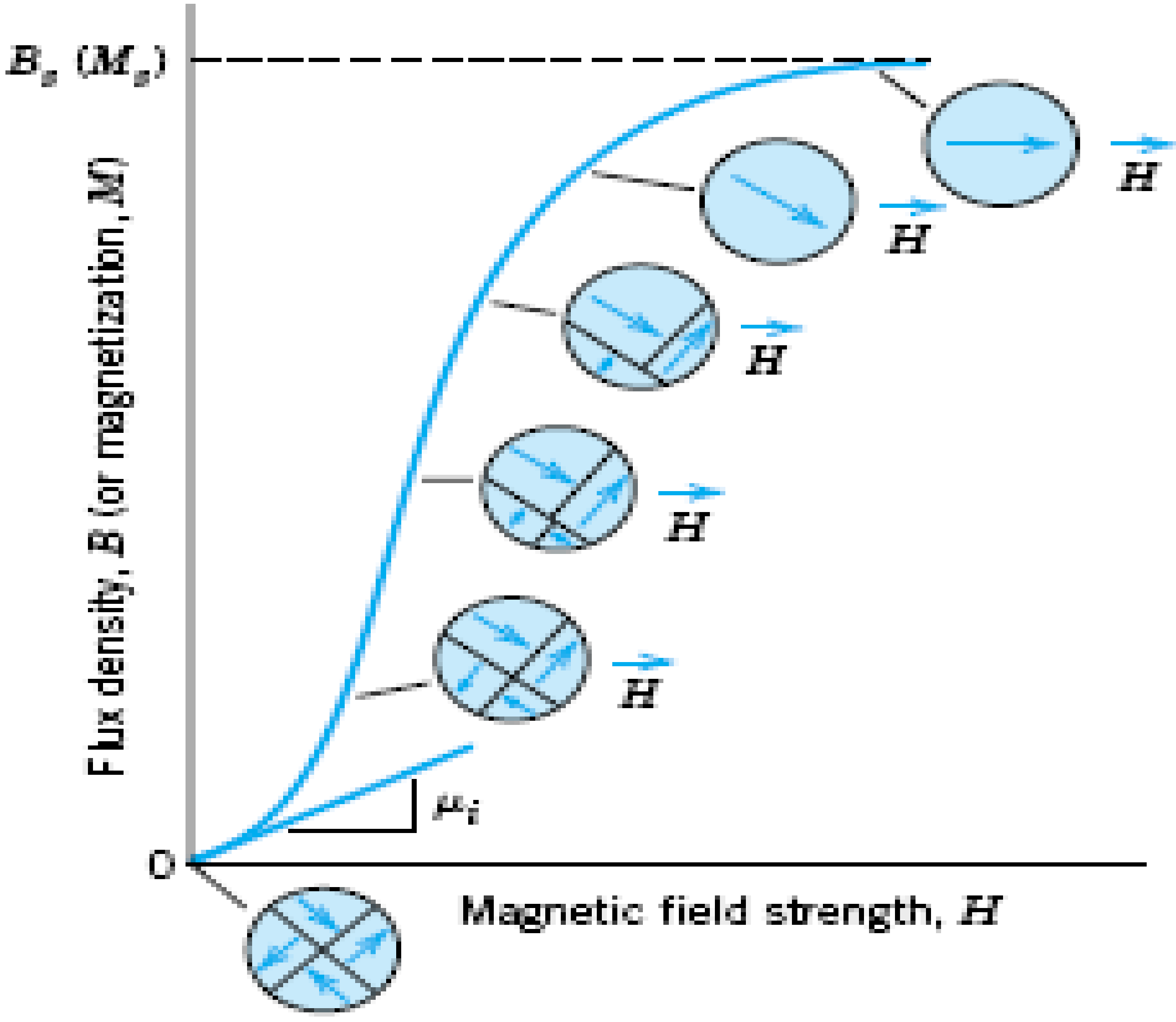
remanent magnetization = M_0

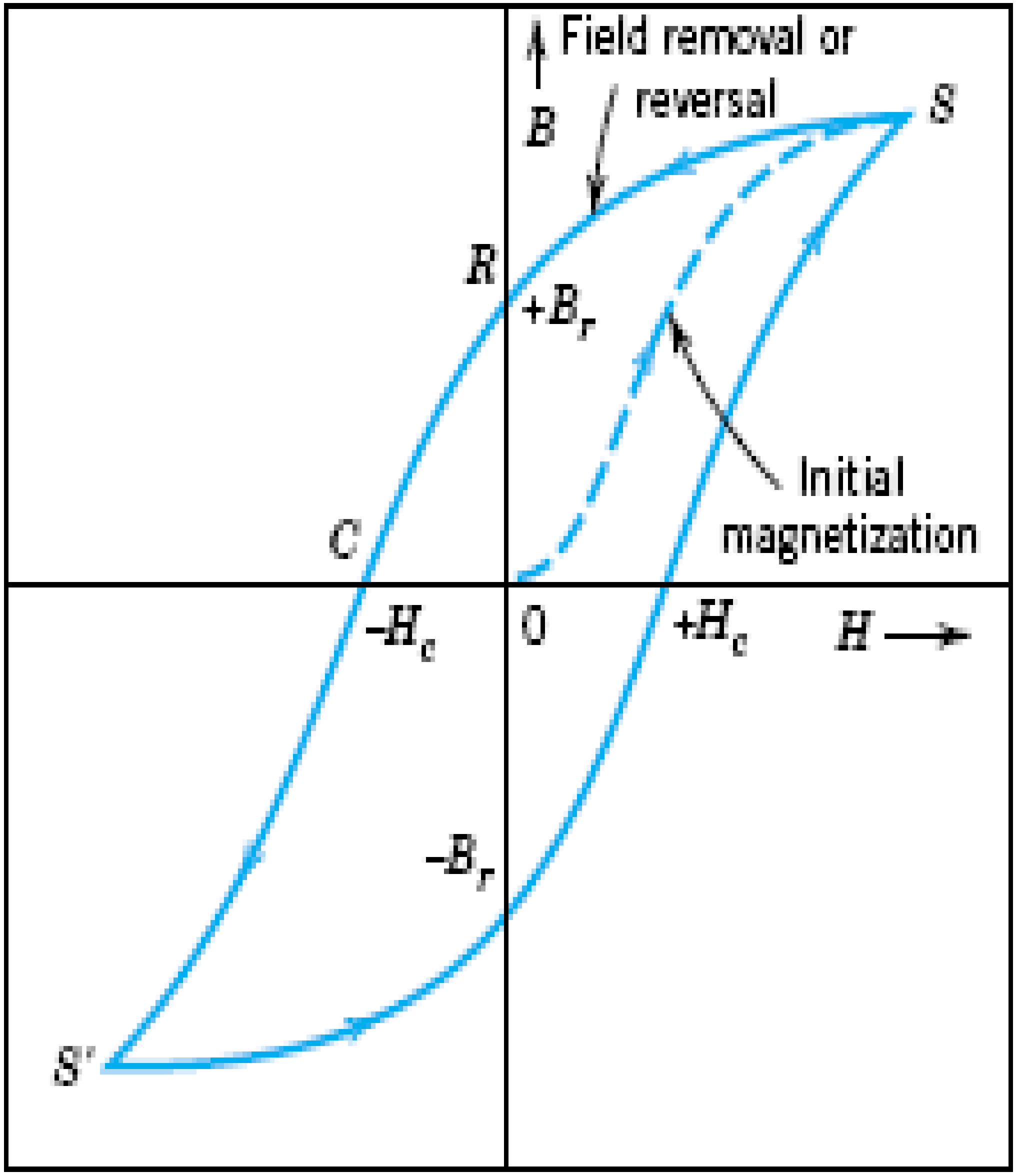
coercivity = H_c



"hard" ferromagnetic material has a large M_0 and large H_c.

"soft" ferromagnetic material has both a small M_0 and H_c.


B_s (M_s)
Flux density, B (or magnetization, M)
H
H
H
H
H
μ_i
0
Magnetic field strength, H
H = 0


Field removal or
reversal
B
S
R
$+B_r$
Initial
magnetization
C
$-H_c$
0
$+H_c$
H
$-B_r$
S'

Hard Magnetic Material	**Soft Magnetic Material**
Have large hysteresis loss.	Have low hysteresis loss.
Domain wall moment is difficult	Domain wall moment is relatively easier.
Coercivity & Retentivity are large	Coercivity & Retentivity are small.
Cannot be easily magnetized & demagnetized	Can be easily magnetized & demagnetized.
Magneto static energy is large.	Magneto static energy is small.
Have small values of permeability and susceptibility	Have large values of susceptibility and permeability.
Used to make permanent magnets.	Used to make electromagnets.
Iron-nickel-aluminum alloys, copper-nickle-iron alloys, copper–nickel– cobalt alloys	Iron- silicon alloys, ferrous- nickel alloys, ferrites, garnets.