Magnetic Domains & Ferrites

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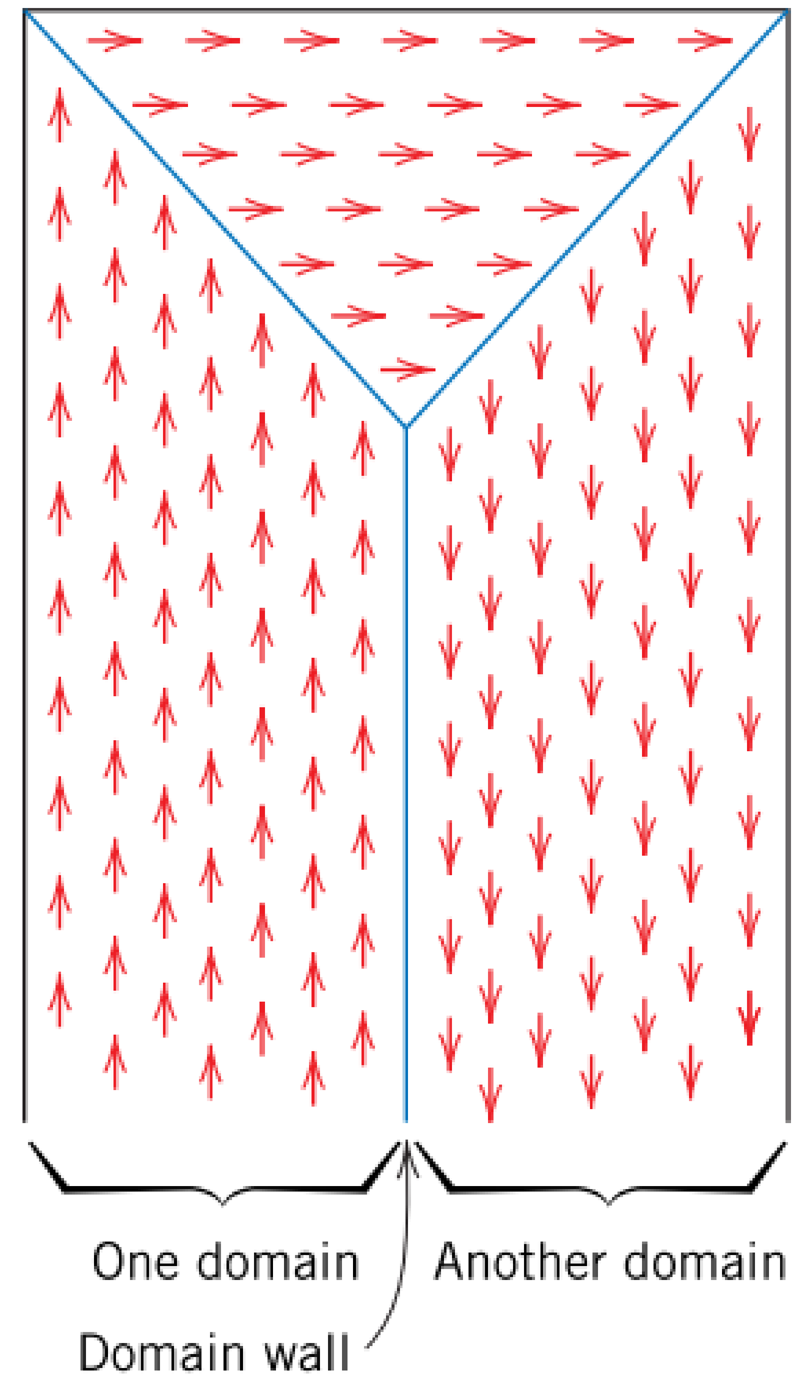
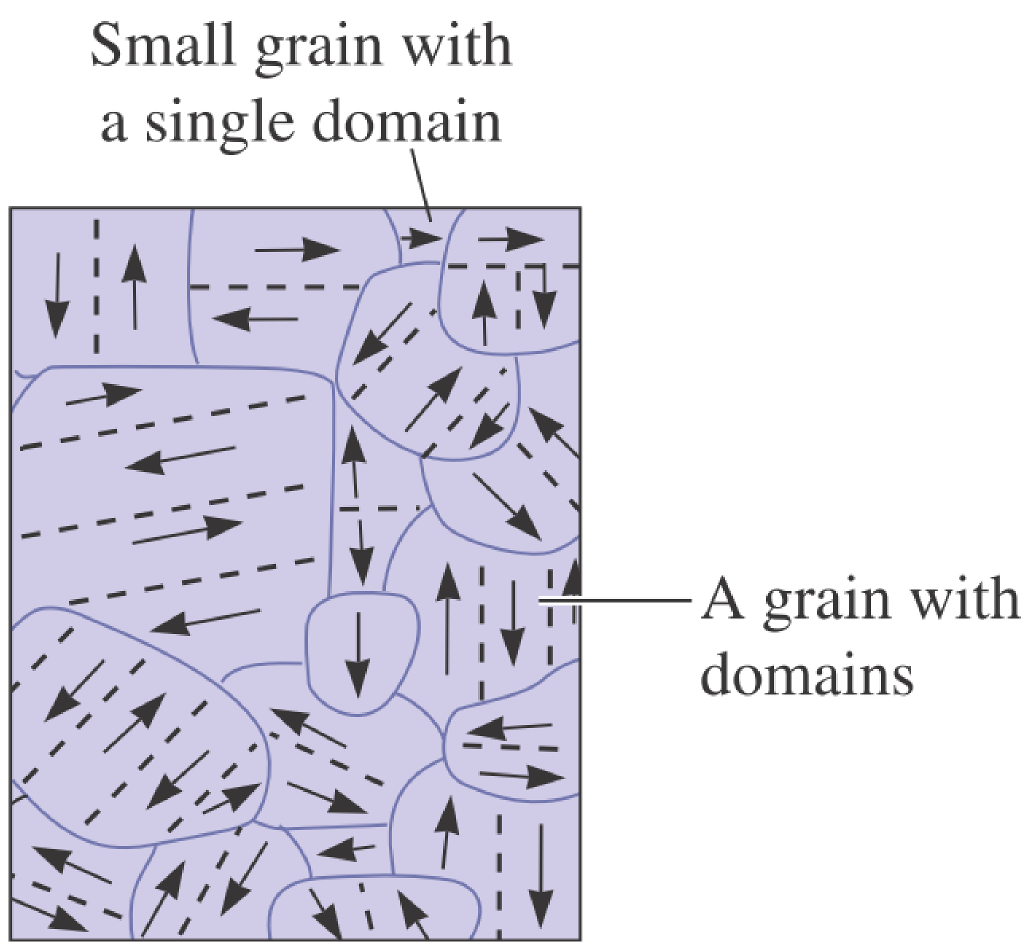
Magnetic Domains

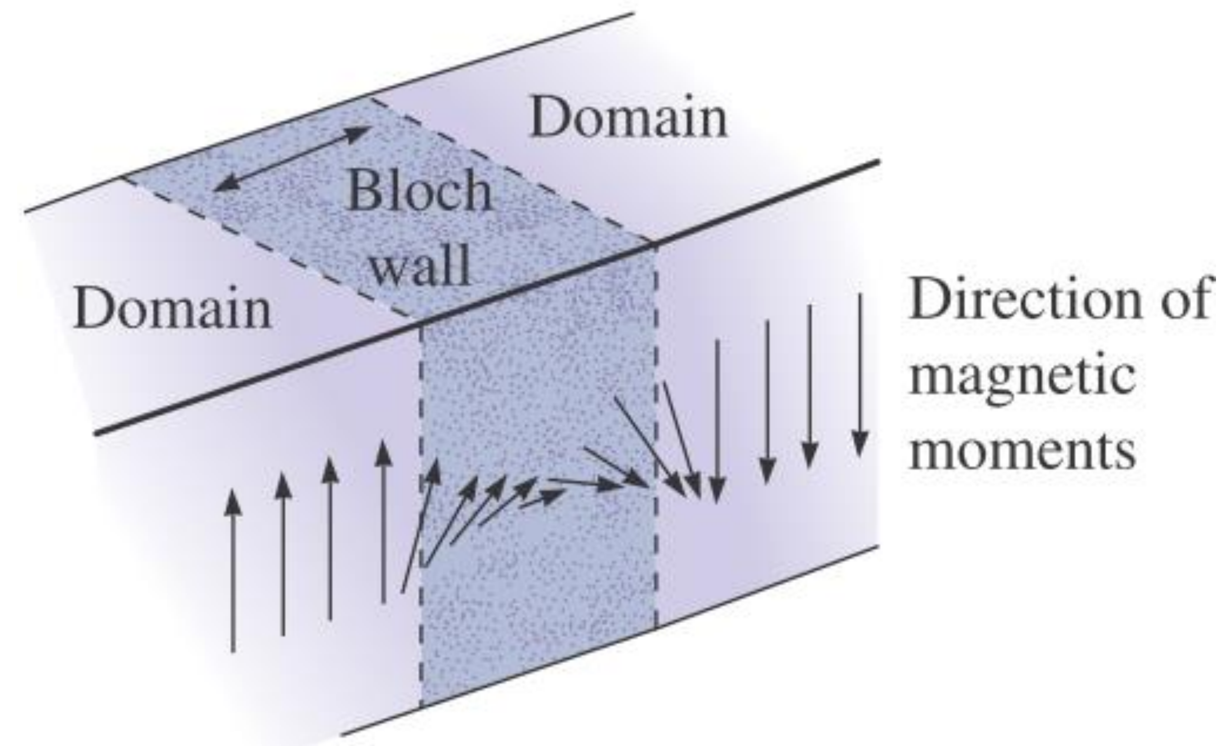
1. Regions where all magnetic dipole moments are aligned in the same direction.
2. Each domain is magnetized to its saturation magnetization.
3. Domains are microscopic in size.
4. Thus, in a macroscopic piece of material, there will be a large number of domains.
5. The magnitude of the **M** field for the entire solid is the vector sum of the magnetizations of all the domains.
6. For an unmagnetized specimen, the appropriately weighted vector sum of the magnetizations of all the domains is zero.



Magnetic domains

A grain can have a single domain but vice versa is not true.

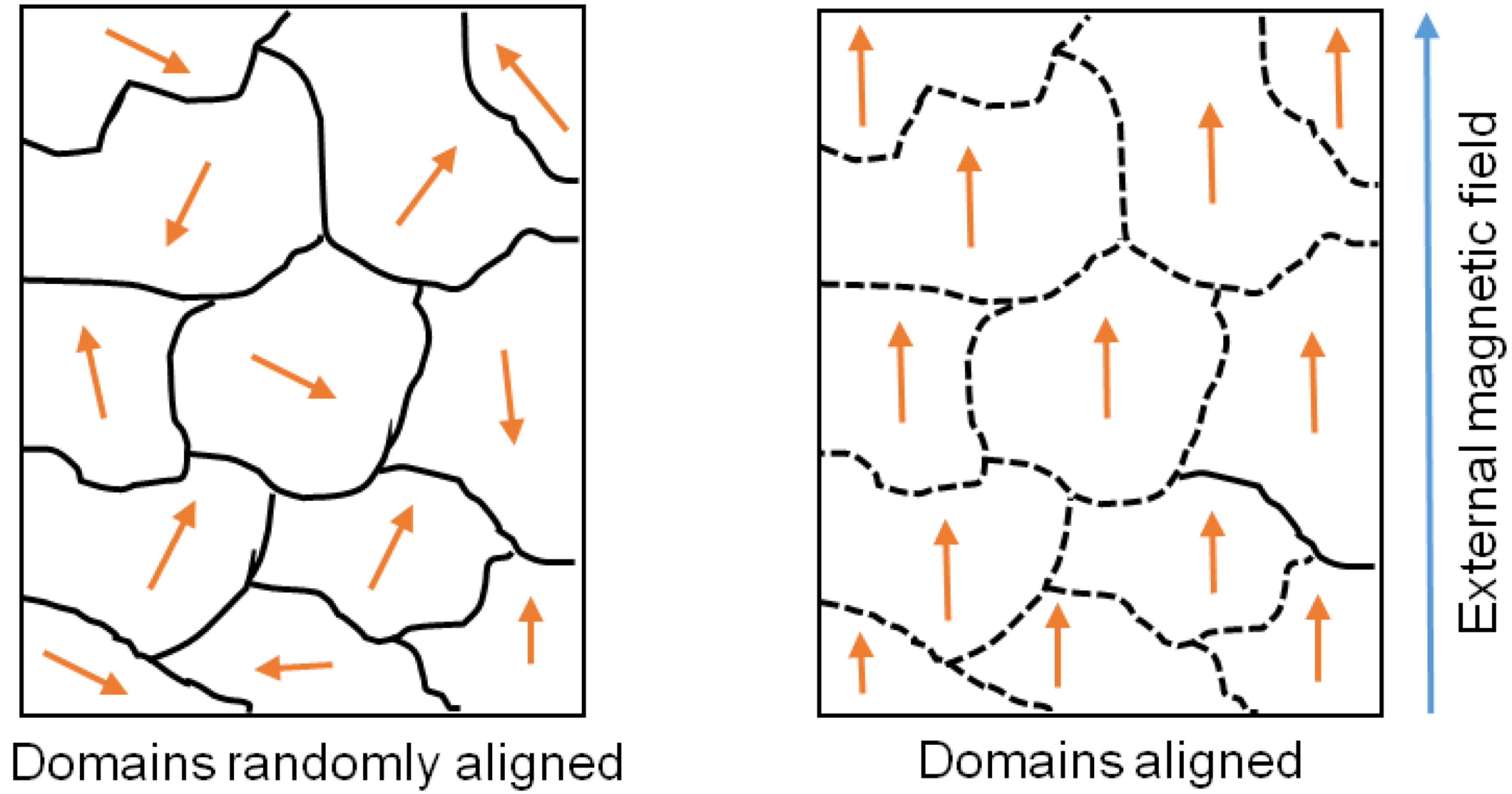




Domains are 50 μm thick while Bloch wall thickness ~ 100 nm.

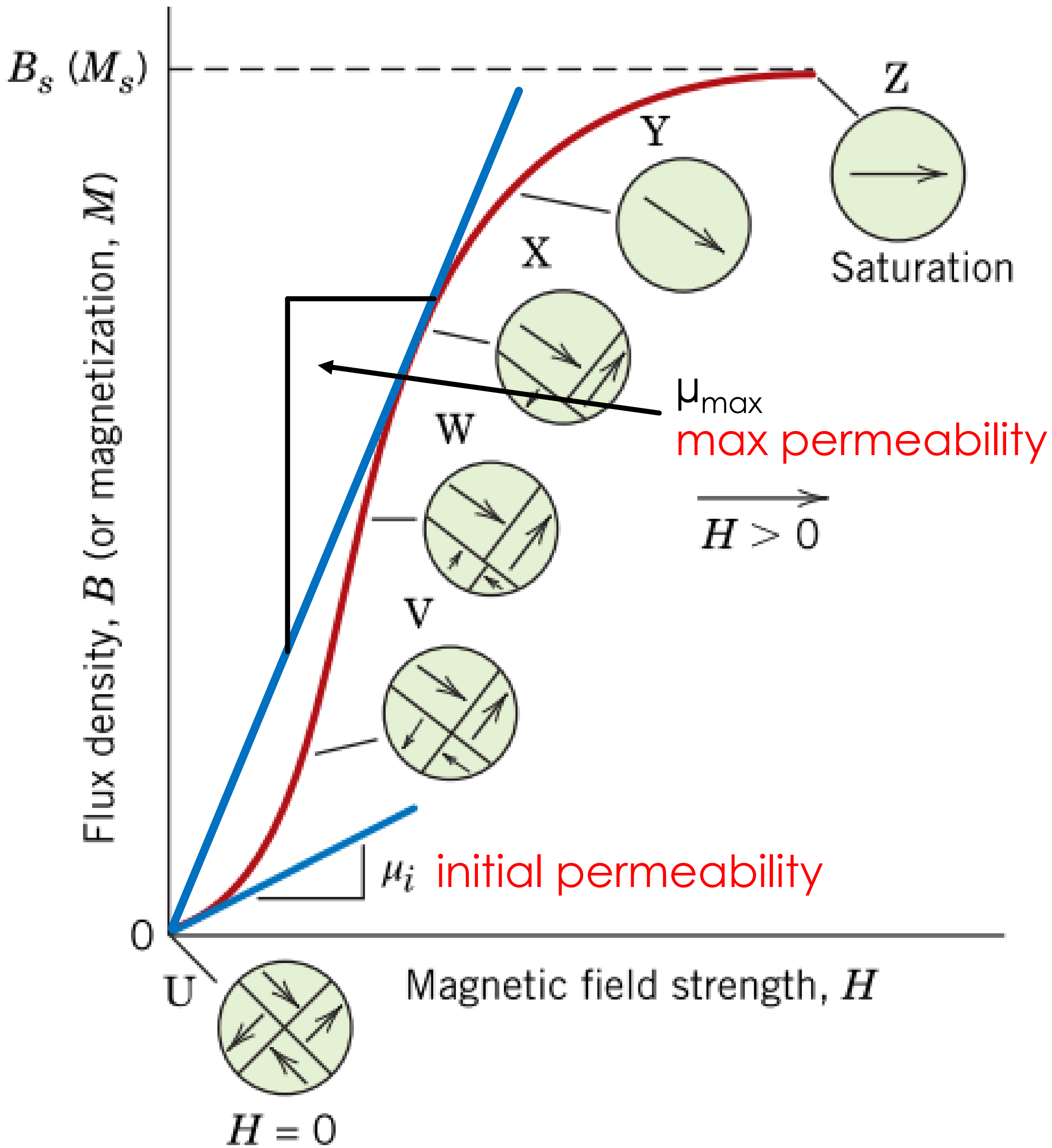
Magnetic domains

Domains can align in the direction of applied magnetic field.



$H = 0$ $H > 0$

Movement of domains in magnetic field



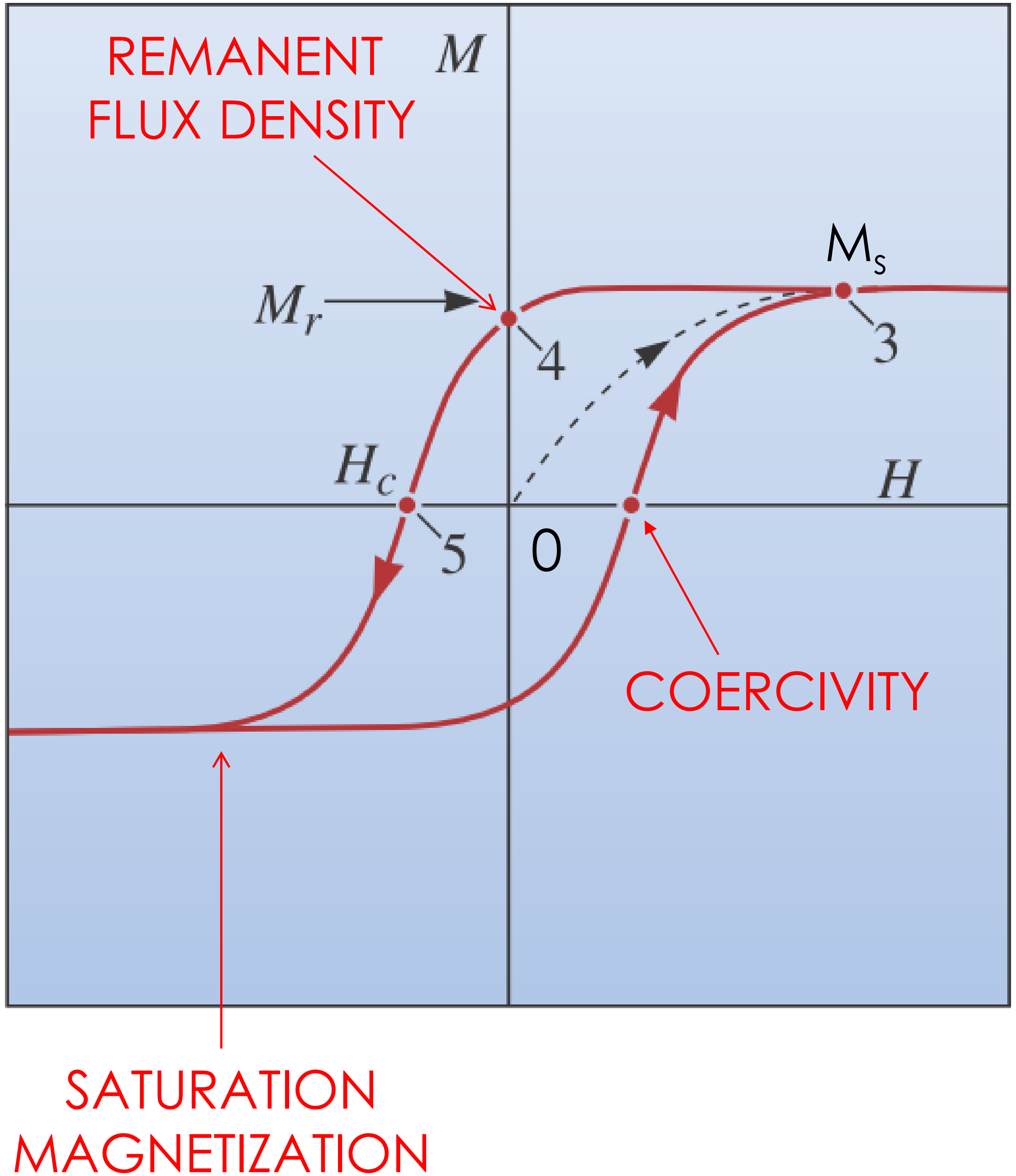
Saturation is achieved when this domain, by means of rotation, becomes oriented with $\vec{H}$

Domains grows in directions favorable to $\vec{H}$ at the expense of unfavorably oriented ones.

Domains change shape and size by the movement of domain boundaries.

Initially, moments are randomly oriented
Resultant $\vec{B} = 0$

Hysteresis loop



- $\vec{M}$ lags behind $\vec{H}$, or decreases at a lower rate.
- **Point 0:** H=0, M=0, domains are randomly aligned.
- **Point 3:** Saturation magnetization M_s (maximum possible magnetization).
- **Point 4:** at $\vec{H} = 0$; REMANENCE, or REMANENT FLUX DENSITY, M_r
- **Point 5:** To reduce the M to zero an H field of magnitude $-H_c$ must be applied in a direction opposite to that of the original field;
- H_c is called the COERCIVITY, or sometimes the COERCIVE FORCE.

Effect of temperature on magnetism

- Temperature can influence magnetic properties of materials.
- Rise in temperature $\rightarrow$ increases the thermal vibrations of atoms.
- Atomic magnetic moments are free to rotate; hence, the increased thermal motion of the atoms tends to randomize the directions of any moments that may be aligned.
- This decreases the magnetic moment of the material.

Effect of temperature on magnetism

Curie temperature (T_C)

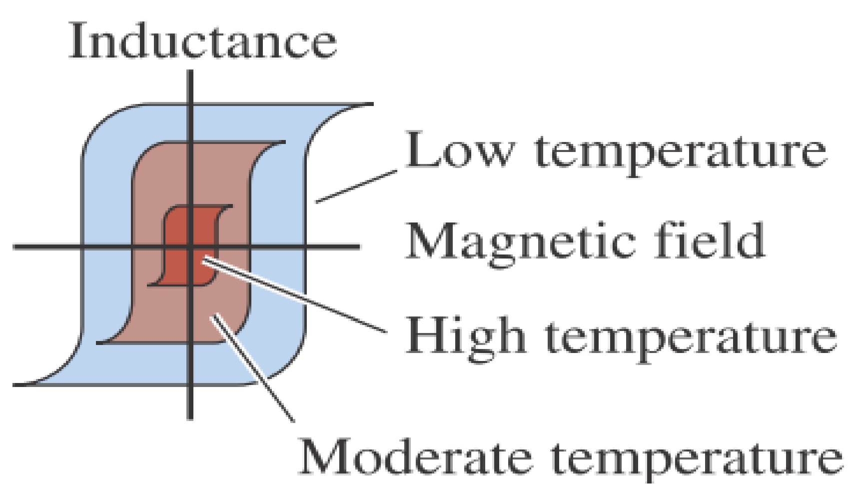
For temperatures above T_C both ferromagnetic and ferrimagnetic materials become paramagnetic.

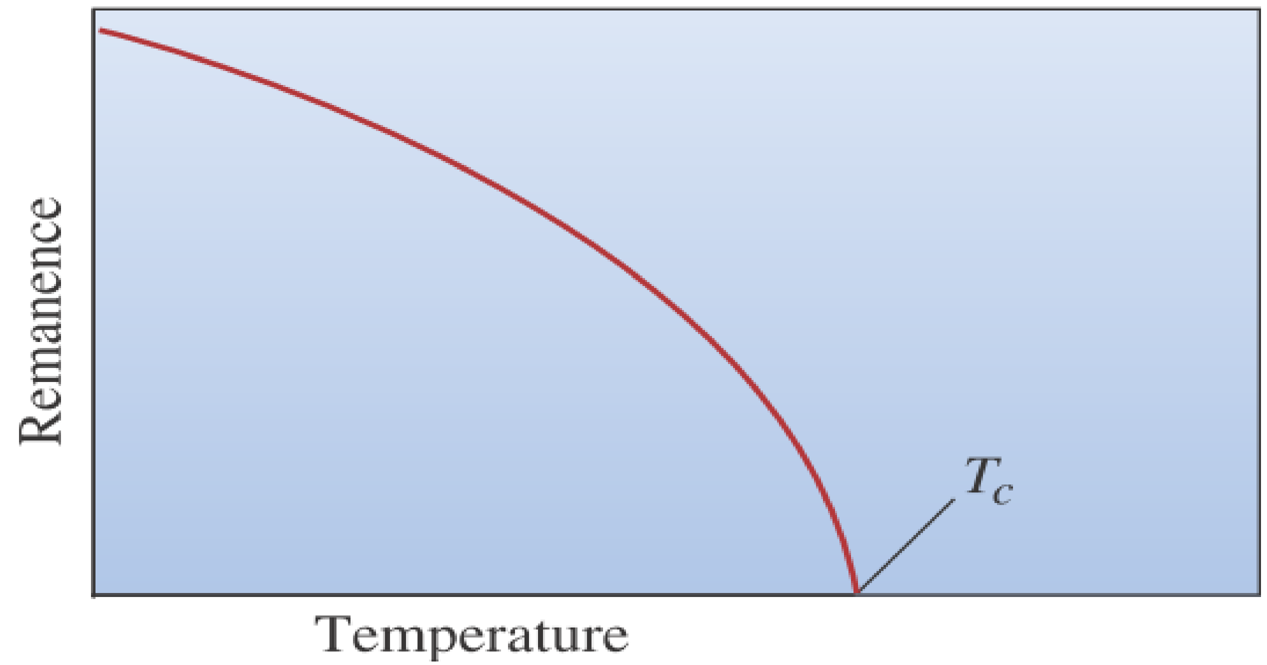
The mutual spin-coupling forces are completely destroyed.

Fe: 786 °C; Fe_3O_4: 585 °C

Neel temperature (T_N)

For temperatures about T_N, antiferromagnetic materials become paramagnetic.





Magnetic anisotropy

Shape of the magnetic hysteresis curve depends on

1. Whether the specimen is a single crystal or polycrystalline
2. Percentage of orientation if single polycrystalline
3. The presence of pores or second-phase particles
4. Temperature
5. If a mechanical stress is applied, the stress state.

Magnetic anisotropy

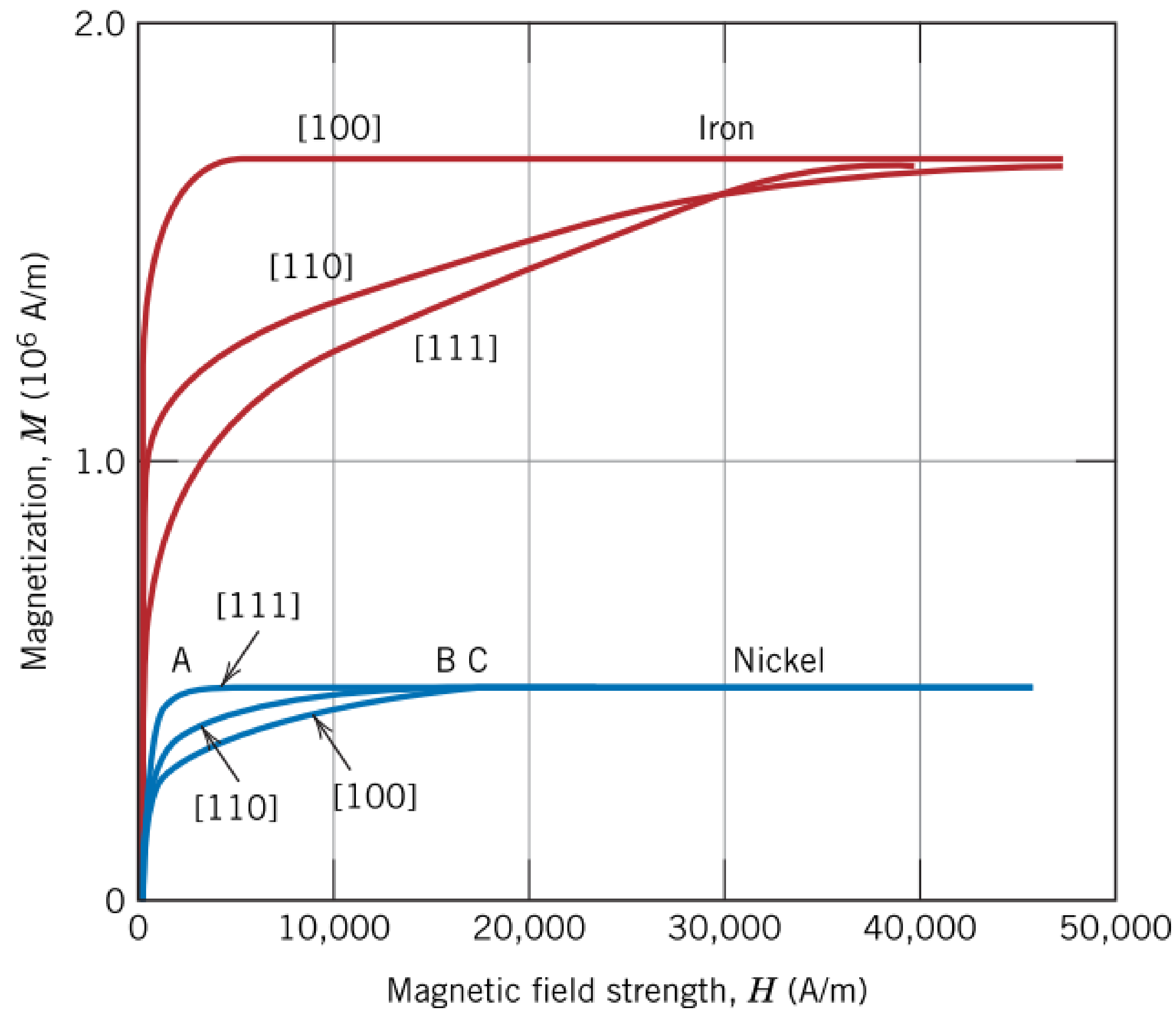
Dependence of magnetic behavior on crystallographic orientation

Direction of easy magnetization

- Crystallographic direction in which magnetization is easiest
- Saturation (of **M**) is achieved at the lower value of **H**
- Fe : [100]; Ni: [111]; Co: [0001]

Direction of hard magnetization

- Crystallographic direction in which magnetization is most difficult
- Saturation (of **M**) is achieved at the higher value of **H**
- Fe : [111]; Ni: [100]; Co: [10-10]/ [11-20]



Based on this, we can categorize into two types as soft ferrites and hard ferrites

Soft and hard ferrites

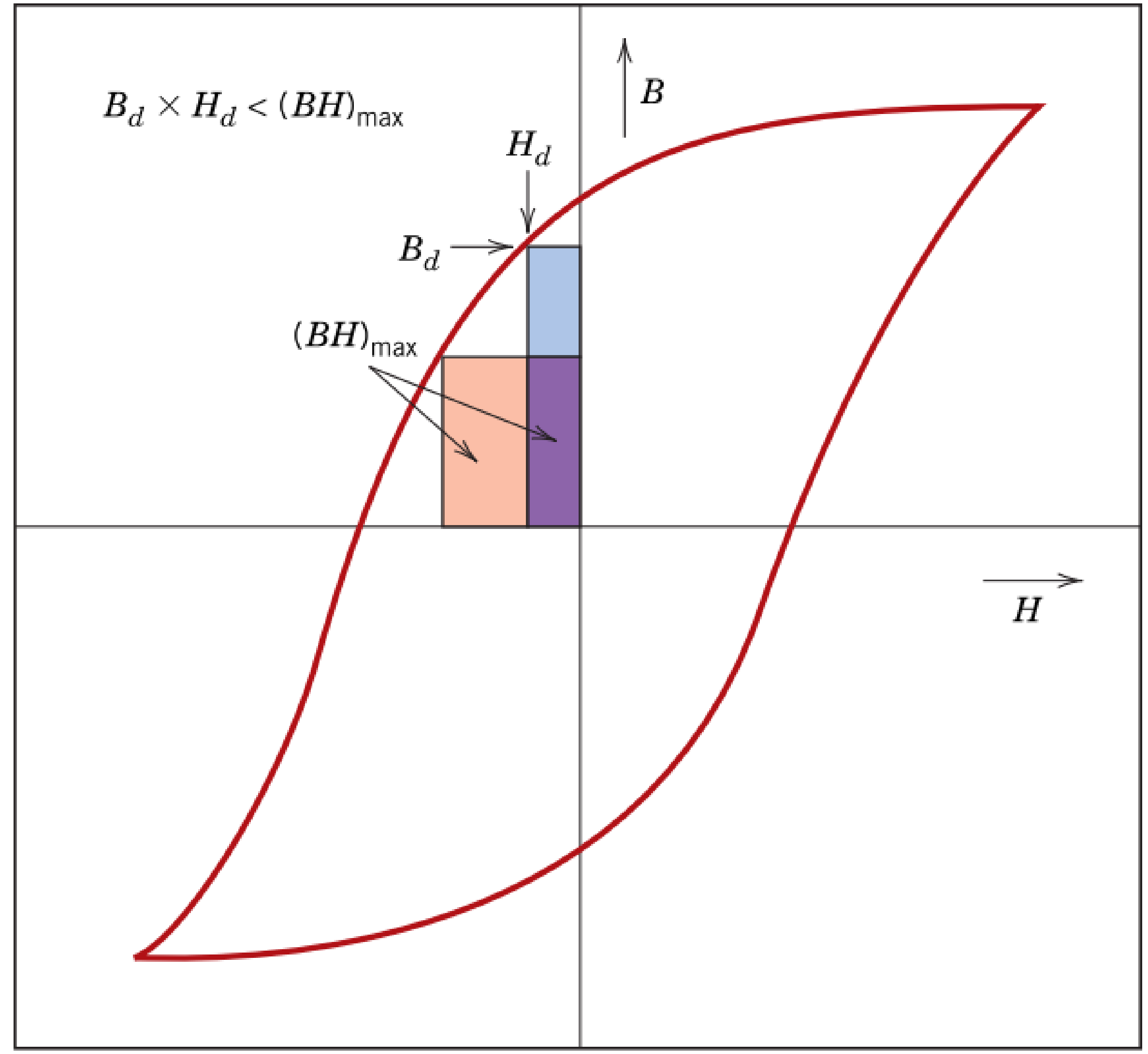
Both ferromagnetic and ferrimagnetic materials are classified as either SOFT or HARD on the basis of their hysteresis curve.

The area within a loop represents a magnetic energy loss per unit volume of material per magnetization - demagnetization cycle;

This energy loss is manifested as heat that is generated within the magnetic specimen and is capable of raising its temperature.

Demagnetization energy

- Energy required to demagnetize a magnet.
- $(BH)_{max}$ corresponds to the area of the largest B–H rectangle that can be constructed within the second quadrant of the hysteresis curve, its units are kJ/m^3.
- The value of $(BH)_{max}$ is representative of the energy required to demagnetize a permanent magnet.
- The larger $(BH)_{max}$, the harder the material in terms of its magnetic characteristics.



Question

1. What material would you prefer for hard disk of computer?

2. What material would you prefer for transformer coil that requires frequent magnetization - demagnetization cycle?

Hint: Hysteresis loop represents energy loss per unit volume of material per magnetization - demagnetization cycle

Answer

1. Hard ferrites

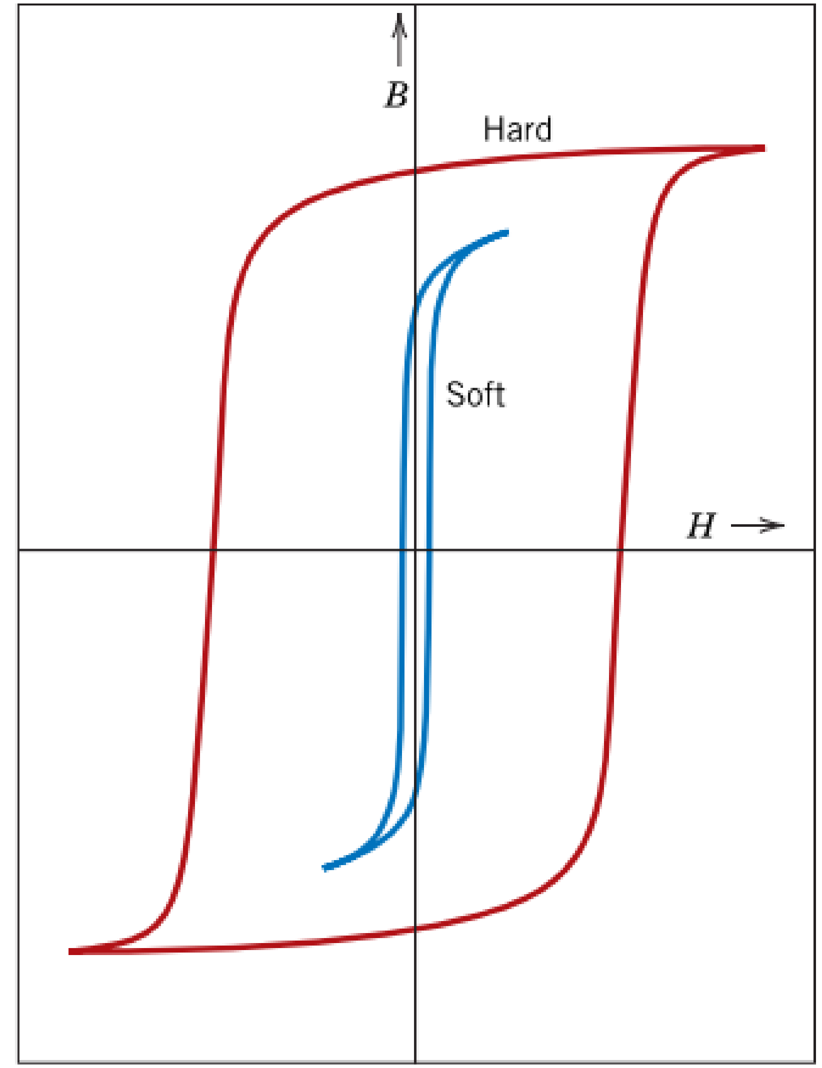
- Hard ferrites are difficult to demagnetize. So, there is no data loss even if accidently placed inside a magnetic field.

2. Soft ferrites

- Soft ferrites are used to make magnetic cores for transformers and inductors – minimization of core losses, energy dissipated in the transformer core when the alternating current changes direction.

Soft ferrites

	Soft Ferrites
1	Small remanence
2	High Initial permeability
3	Small coercive field
4	Small and thin hysteresis loop
5	Low power (or BH product)
6	Rapid response to high-frequency magnetic fields
7	Easy to demagnetize
8	Low hysteresis energy loss
9	Used in generators, motors, dynamos, and switching circuits

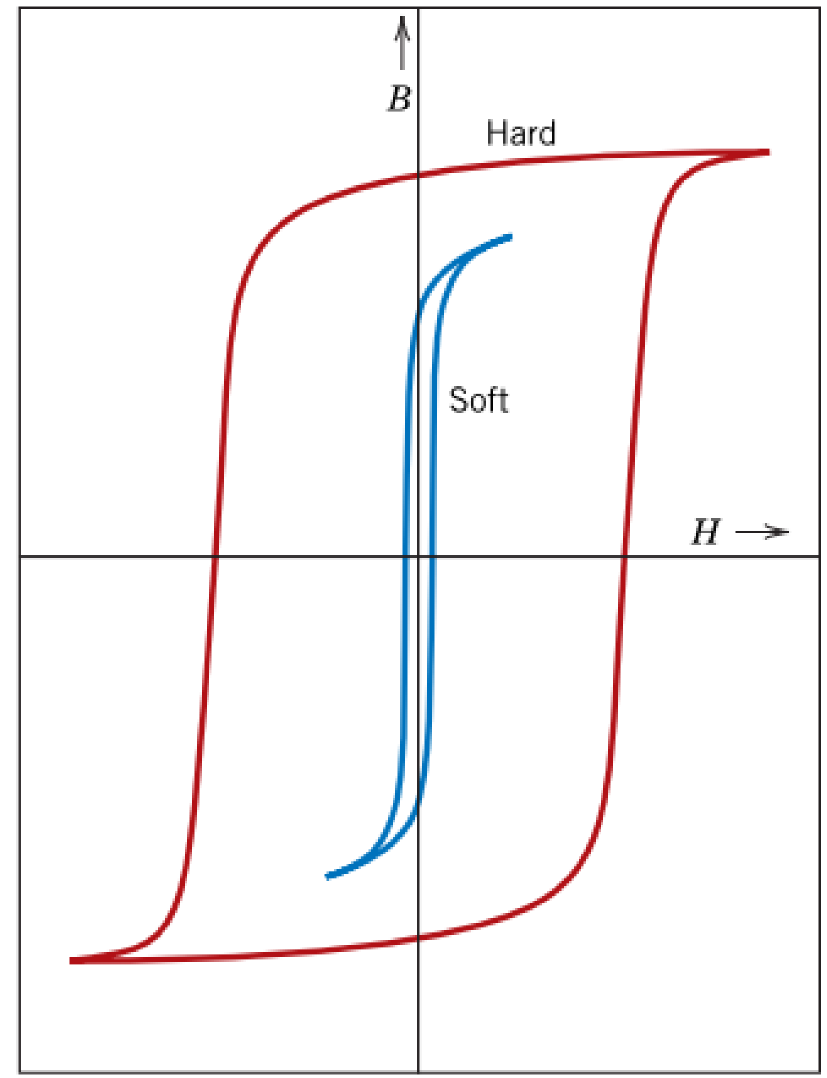


Typical soft ferrite materials

Material	*Composition (wt%)*	*Initial Relative Permeability μ_i*	*Saturation Flux Density B_s [tesla (gauss)]*	*Hysteresis Loss/Cycle [J/m^3 (erg/cm^3)]*	*Resistivity ρ ($\Omega \cdot m$)*
Commercial iron ingot	99.95 Fe	150	2.14 (21,400)	270 (2,700)	1.0×10^{-7}
Silicon–iron (oriented)	97 Fe, 3 Si	1,400	2.01 (20,100)	40 (400)	4.7×10^{-7}
45 Permalloy	55 Fe, 45 Ni	2,500	1.60 (16,000)	120 (1,200)	4.5×10^{-7}
Supermalloy	79 Ni, 15 Fe, 5 Mo, 0.5 Mn	75,000	0.80 (8,000)	—	6.0×10^{-7}
Ferroxcube A	48 $MnFe_2O_4$, 52 $ZnFe_2O_4$	1,400	0.33 (3,300)	~40 (~400)	2,000
Ferroxcube B	36 $NiFe_2O_4$, 64 $ZnFe_2O_4$	650	0.36 (3,600)	~35 (~350)	10^7

Hard ferrites

	Hard Ferrites
1	High remanence (stable domains)
2	Low initial permeability
3	High coercive field
4	Large and big hysteresis loop
5	High power (or BH product)
6	Slow response to high-frequency magnetic fields.
7	Difficult to demagnetize
8	High hysteresis energy loss
9	Used to make permanent magnets



Typical hard ferrite materials

Material	*Composition (wt%)*	*Remanence B_r [tesla (gauss)]*	*Coercivity H_c [amp-turn/m (Oe)]*	*$(BH)_{max}$ [kJ/m^3 (MGOe)]*	*Curie Temperature T_c [°C (°F)]*	*Resistivity ρ ($\Omega \cdot m$)*
Tungsten steel	92.8 Fe, 6 W, 0.5 Cr, 0.7 C	0.95 (9,500)	5,900 (74)	2.6 (0.33)	760 (1,400)	3.0×10^{-7}
Cunife	20 Fe, 20 Ni, 60 Cu	0.54 (5,400)	44,000 (550)	12 (1.5)	410 (770)	1.8×10^{-7}
Sintered alnico 8	34 Fe, 7 Al, 15 Ni, 35 Co, 4 Cu, 5 Ti	0.76 (7,600)	125,000 (1,550)	36 (4.5)	860 (1,580)	—
Sintered ferrite 3	$BaO–6Fe_2O_3$	0.32 (3,200)	240,000 (3,000)	20 (2.5)	450 (840)	$\sim 10^4$
Cobalt rare earth 1	$SmCo_5$	0.92 (9,200)	720,000 (9,000)	170 (21)	725 (1,340)	5.0×10^{-7}
Sintered neodymium–iron–boron	$Nd_2Fe_{14}B$	1.16 (11,600)	848,000 (10,600)	255 (32)	310 (590)	1.6×10^{-6}

Summary

1. Domains are microscopic in size.
2. Domain walls are nanometer in size.
3. The magnetic properties decreases with temperature due to randomization of the magnetic moments.
4. Ferro and ferrimagnetic materials becomes paramagnetic above a temperature called as Curie temperature.
5. Antiferromagnetic materials becomes paramagnetic above a temperature called as Neel temperature.
6. Magnetic properties are anisotropic.
7. Soft ferrites are easy to magnetize and demagnetize.
8. Hard ferrites are difficult to magnetize and demagnetize.