

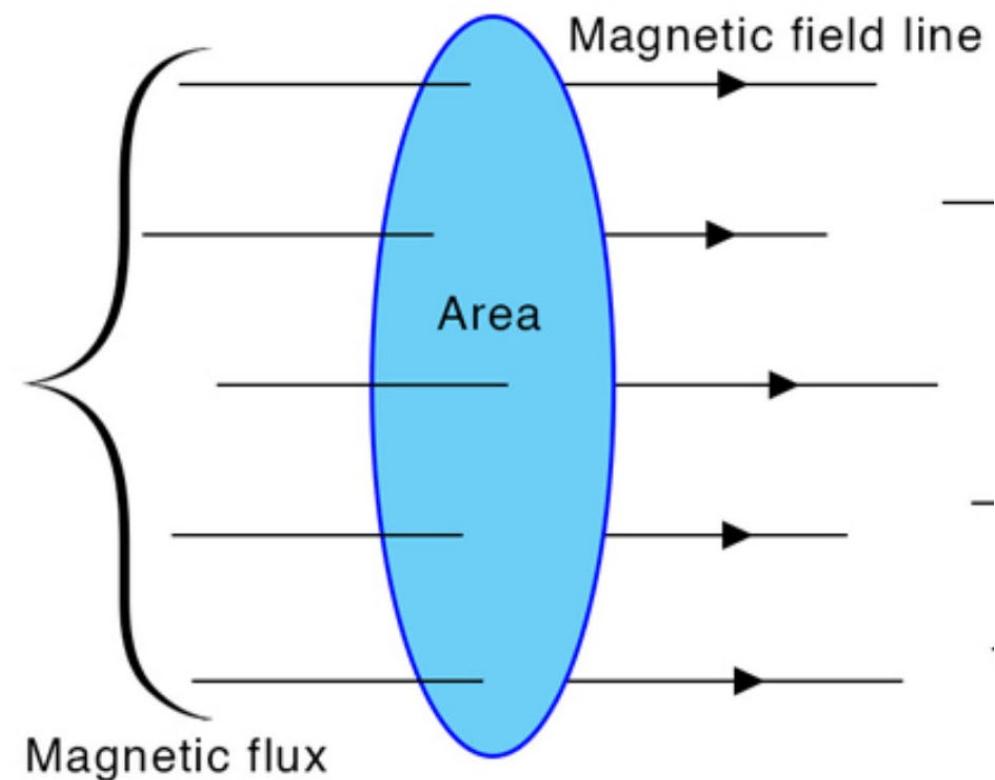
Permeability & ferromagnetic materials



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Refresher on magnetic flux

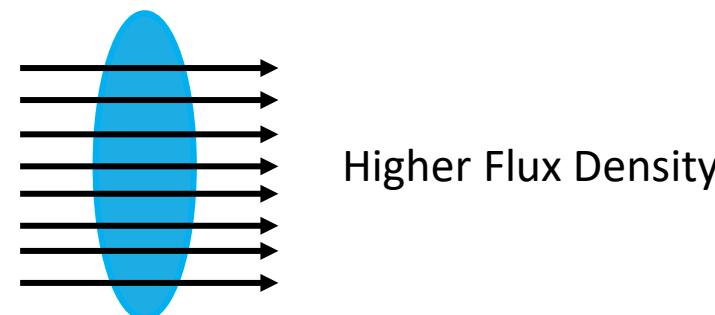
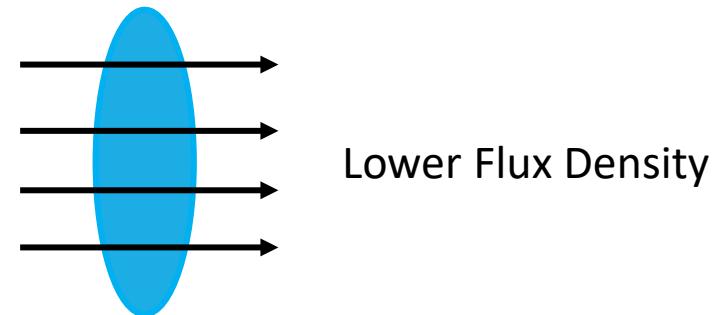
- If we have a given area (say a circle) we can work out how much magnetism is going through it
- The amount of magnetism going through this area is referred to as “flux” which has the symbol Phi “ Φ ”
- This has the equation:
$$\phi = BAc\cos\theta$$



Refresher on Flux Density

- Flux density is how compact all the field lines are in an area
- Flux density has the symbol B
- It also has the unit T (Tesla)
- It has the formula:

$$B = \frac{\phi}{A}$$



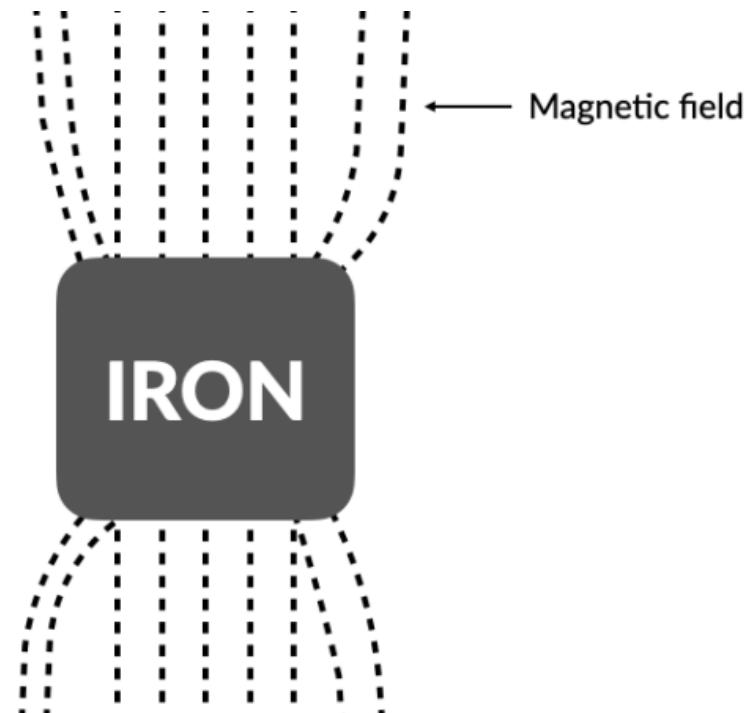
What is permeability

Definition: The ability of a material to support the formation of a magnetic field within itself.

Symbol: Represented by μ (Greek letter "mu").

Formula: $B = \mu H$

where B is magnetic flux density and H is magnetic field strength.



Types of permeability

- **Absolute Permeability (μ)** – Measured in Henries per meter (H/m).
- **Relative Permeability (μ_r)** – Ratio of a material's permeability to that of free space (μ_0).
- **Permeability of Free Space (Vacuum):** $\mu_0 = 4\pi \times 10^{-7}$ H/m.

Relative permeability

- $\mu_r = \frac{\mu}{\mu_0}$
- Air ($\mu_r \approx 1$)
- Iron ($\mu_r \approx 1000-5000$)
- Soft Ferrites ($\mu_r \approx 10-1000$)

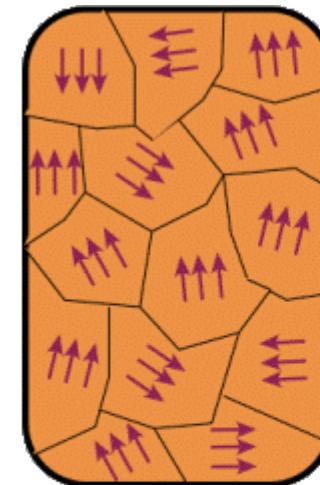
Material	Magnetic Permeability (H/m)
Air	$1.25663753 \times 10^{-6}$
Bismuth	1.25643×10^{-6}
Copper	1.256629×10^{-6}
Iron (pure)	6.3×10^{-3}
Nickle	$1.26 \times 10^{-4} - 7.54 \times 10^{-4}$
Carbon Steel	1.26×10^{-4}
Hydrogen	1.2566371×10^{-6}
Water	1.256627×10^{-6}
Wood	$1.25663760 \times 10^{-6}$

Your Turn

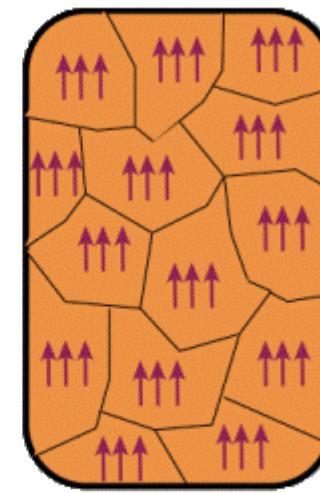
- Complete question 1 to 10 on the worksheet
- $B = \mu H$
- $\mu_r = \frac{\mu}{\mu_0}$

Ferromagnetic Materials

- They are materials that exhibit strong magnetic properties due to magnetic domain alignment.
- Magnetic domain alignment refers to the process in which the microscopic magnetic regions (domains) within a material orient themselves in the same direction under the influence of an external magnetic field.



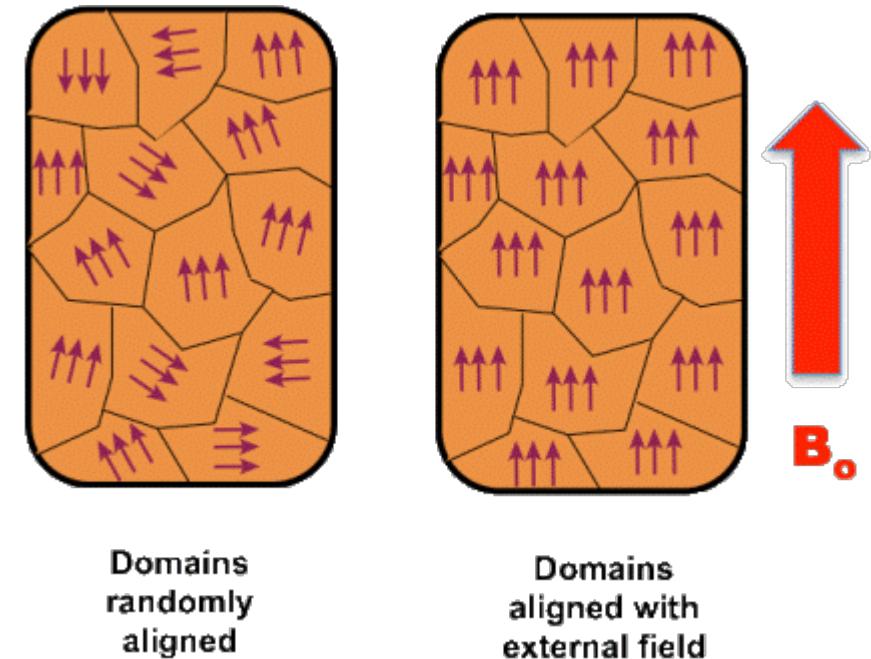
Domains randomly aligned



Domains aligned with external field

Ferromagnetic Materials Properties

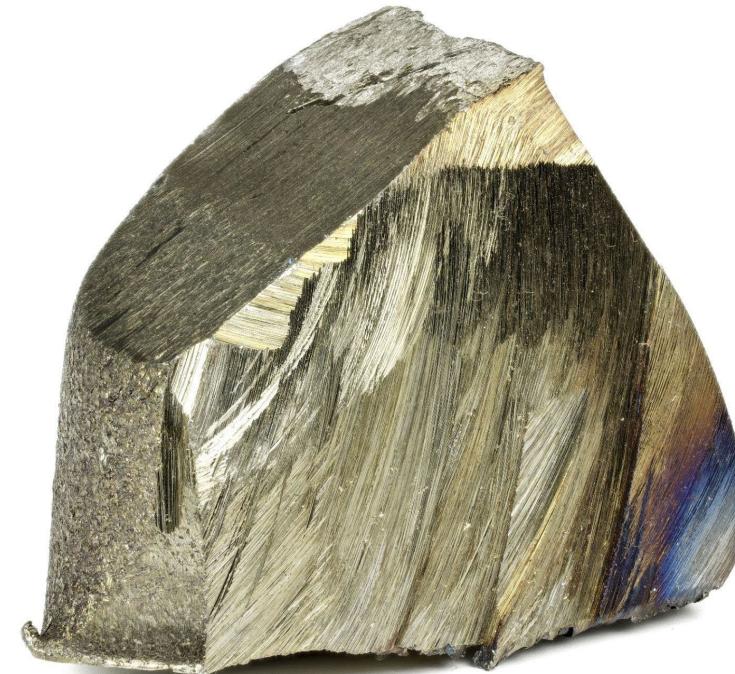
- High permeability (easily magnetized).
- Exhibit hysteresis (retain magnetism after an external field is removed).
- Can be permanently magnetized.



Examples of Ferromagnetic materials

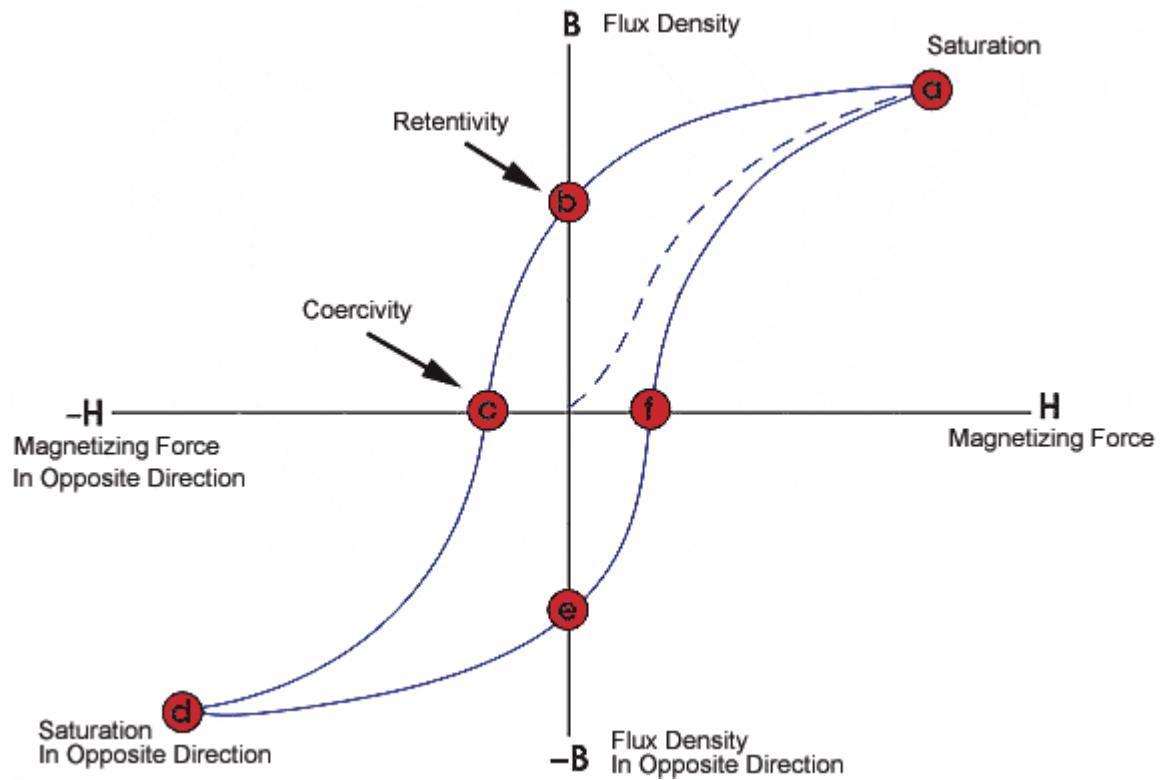
- Iron (Fe)
- Nickel (Ni)
- Cobalt (Co)
- Steel (an alloy mainly of iron)

- Used in transformers, electromagnets, and electric motors.



Hysteresis Loop

- Describes the relationship between the magnetic field strength (H) and the magnetic flux density (B) in a ferromagnetic material as it is magnetized and demagnetized
- This relationship can be mapped out on a graph like the one on the left



Key points of Hysteresis Loop

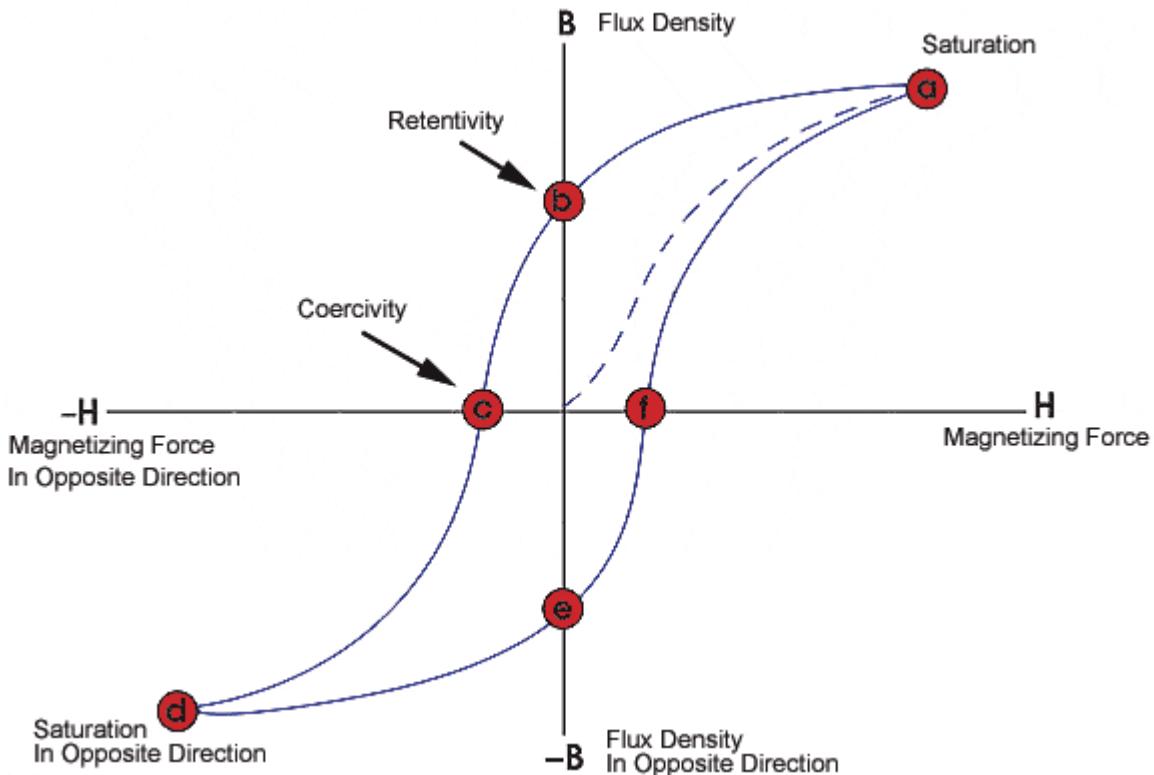
Magnetization (Increasing Field Strength): As an external magnetic field is applied, magnetic domains align, increasing the material's magnetic flux density.

Saturation: When all magnetic domains are aligned, the material reaches saturation, and increasing the field doesn't increase flux density.

Removal of Field (Demagnetization): After the external field is removed, residual magnetization (remanence) remains in the material.

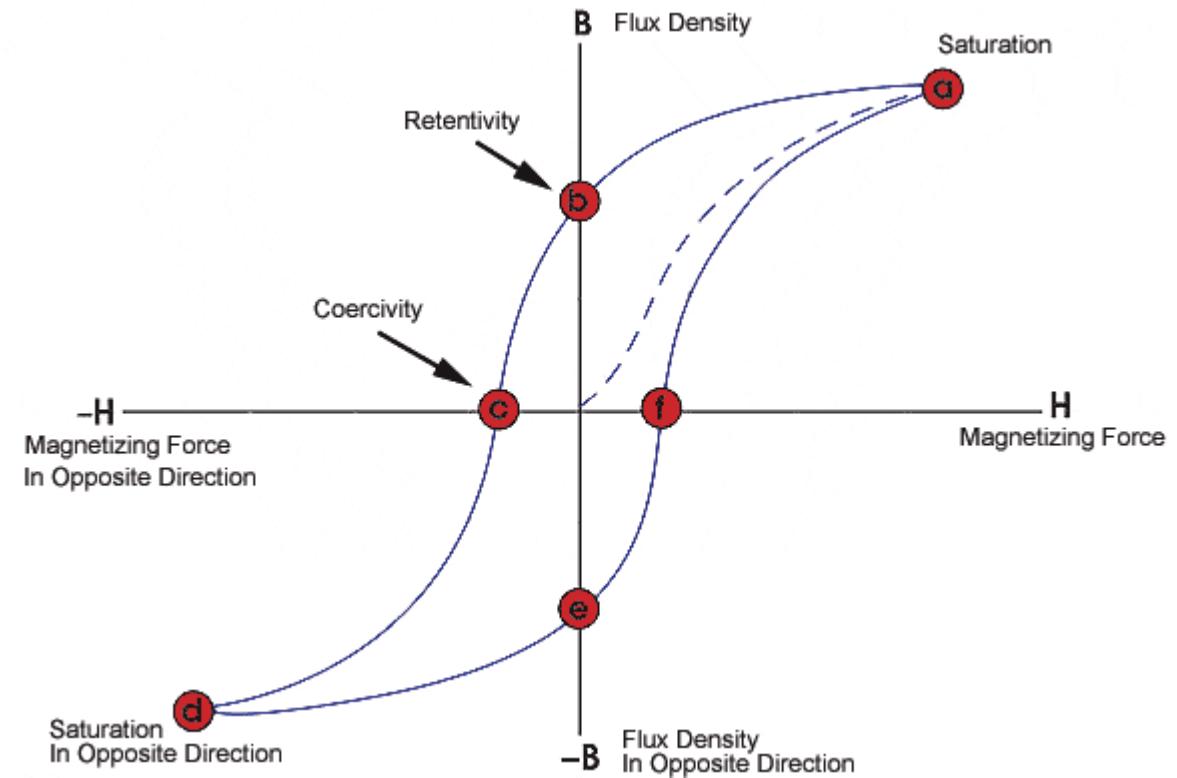
Coercivity (H_c): The magnetic field strength required to demagnetize the material is known as coercivity.

Reversing the Field: When the field is reversed, the flux density follows a different path, completing the loop.



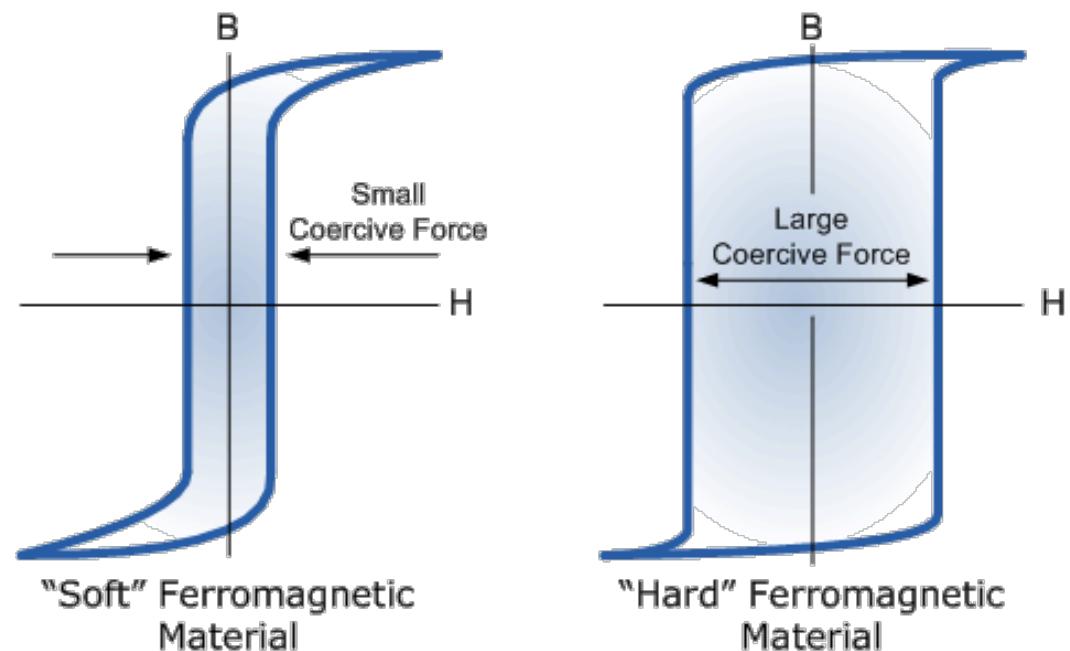
Energy Loss

- The area inside the hysteresis loop represents the energy loss due to hysteresis during one complete cycle of magnetization and demagnetization. This energy loss occurs primarily as heat within the material.
- As the external magnetic field changes, the domains in the material must move to realign with the changing field. Some energy is lost due to **friction** between these domain movements, which manifests as **heat**.



Soft vs Hard Hysteresis Loops

- The wideness of the loop shows us how much coercive force is needed
- Softer materials will be narrower
- Harder materials will be wider



Factors affecting energy loss

- Material: Hard magnetic materials (like permanent magnets) have larger hysteresis loops and higher energy losses because their domains are harder to move. Soft magnetic materials (like iron or steel) have smaller loops and lower energy losses.
- Frequency of Magnetization: The faster the material is cycled (i.e., the higher the frequency), the greater the energy loss.

Your Turn

- Please complete the rest of the questions on the worksheet