International Magnetics Association
Permanent Magnet Tutorial

# Permanent Magnets-The Basics

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Spontaneous Materials
Indianapolis, IN
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## Some Perspective

Roughly 90 % of the useful information
about permanent magnets
can be learned in 25 minutes.
The remaining 10%
takes a lifetime to learn.

Anonymous

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## Outline

- The three magnetic vectors: B, H and M
- Hysteresis Loops
- The basic magnetic parameters: $M_s$, $B_r$, $H_{ci}$, $H_c$, $(BH)_{max}$, $H_s$, and $\mu_r$
- Loadline
- The effects of temperature
  - reversible
  - irreversible

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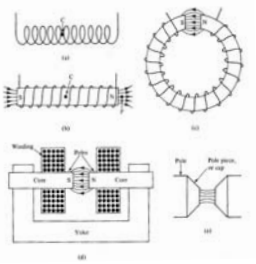
## Magnetic Field, H

- The magnetic field created by passing current through a wire.
- Units: Oersted (Oe), Ampere-turn/meter (A/m)



Source: Cullity

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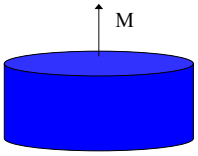
## Magnetization, M

- The magnetic state of a material, representing the sum of all the individual magnetic moments per unit volume.
- Magnetic moments arise from unpaired electron spins, usually in the 3d or 4f shells.
- Units: Gauss (G) for $4\pi M$
  Tesla (T) for $\mu_0 M$
- $B_i$ is also in use, intrinsic induction

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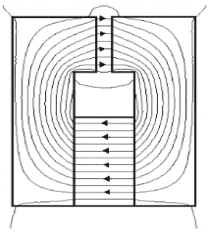
## Flux Density or Induction, B

- The total concentration of magnetic flux in a region
- A combination of Magnetic Field and Magnetization
- Units: Gauss (G)
  Tesla (T)



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## How are H, M and B related?

Induction, B is a combination of H and M.

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$B = H + 4\pi M$ CGS units

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## How are H, M and B related?

Induction, B is a combination of H and M.

$B=H + 4\pi M$ CGS units

$B= \mu_0 H+ \mu_0 M$ SI units

$\mu_0=4\ \pi \times 10^{-7}$ Tesla-m/A

$\mu_0 M=J$, Polarization

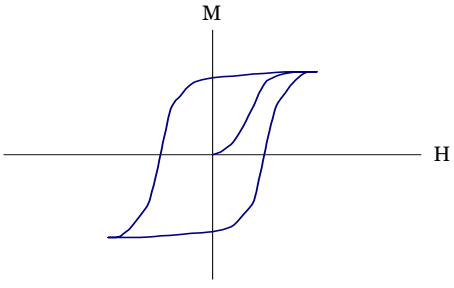


## Hysteresis

- A delayed response to a stimulus
- In this case, the stimulus is an applied magnetic field and the response is the magnetization or flux density

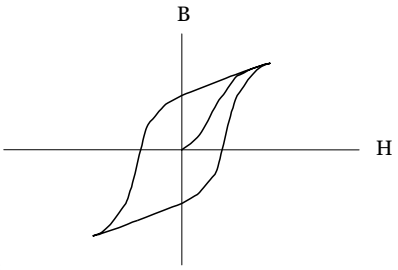


## Major Hysteresis Loop

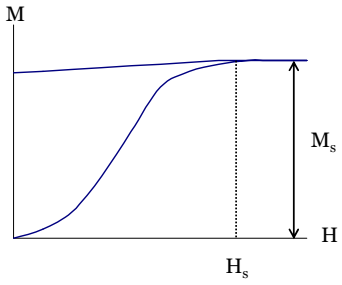





## Major Hysteresis Loop



## Initial Magnetization

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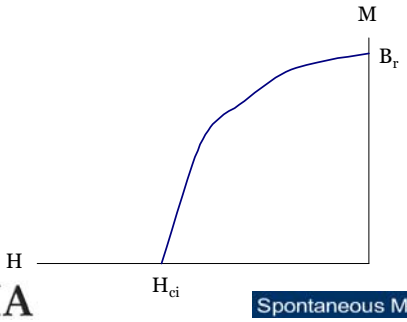
## Demagnetization Curve

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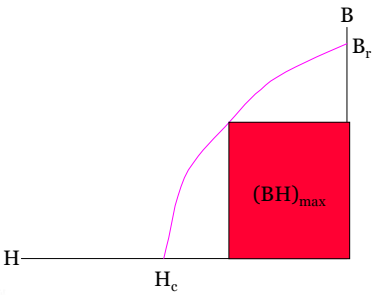
## Demagnetization Curve

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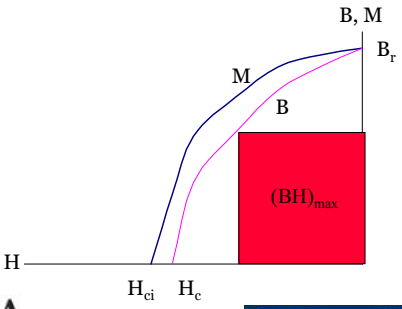
## Demagnetization Curves

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## Some Interesting Relationships

| CGS | SI |
|---|---|
| $B_r \geq H_c$ | $B_r \geq \mu_o H_c$ |
| $H_{ci} \geq H_c$ | $H_{ci} \geq H_c$ |
| $\frac{B_r^2}{4} \geq (BH)_{max}$ | $\frac{B_r^2}{4} \geq \mu_0 (BH)_{max}$ |

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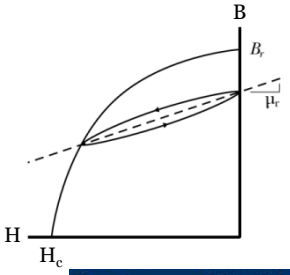
## Recoil Permeability, $\mu_r$

- The Minor loop

Typical $\mu_r$ Values

| | |
|---|---|
| Alnico 5-7 | 2.5 |
| Ferrite | 1.1 |
| $SmCo_5$ | 1.05 |
| NdFeB | 1.05 |

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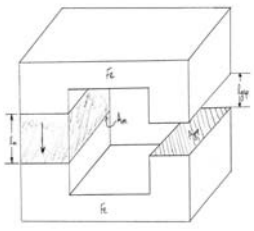
## Loadline

- Apply Maxwell's equations to a simple circuit

$$\Phi = B_m A_m = B_{gap} A_{gap}$$

$$H_m l_m = H_{gap} l_{gap}$$

$$B_{gap} = H_{gap}$$



C-frame

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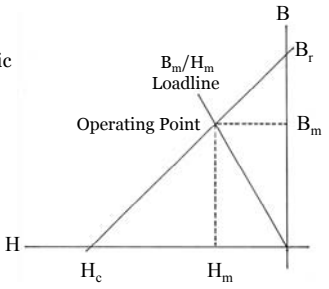
## Loadline

- Separate the geometric effects from the magnetic effects

$$\frac{B_m}{H_m} = \frac{l_m A_{gap}}{l_{gap} A_m}$$

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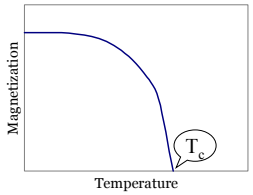
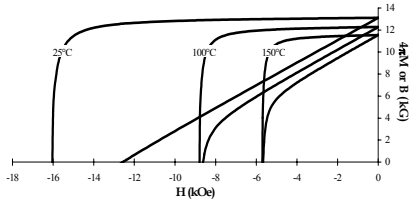
## Thermal Effects




For all ferromagnetic materials, the magnetization decreases as the temperature increases



## Demagnetization Curves at Various Temperatures






## Reversible Thermal Properties

- Temperature coefficient of $B_r$, $\alpha = \frac{1}{B_r}\left(\frac{\Delta B_r}{\Delta T}\right)\cdot 100\%$
  - Related to Curie Temperature
- Temperature coefficient of $H_{ci}$, $\beta = \frac{1}{H_{ci}}\left(\frac{\Delta H_{ci}}{\Delta T}\right)\cdot 100\%$
  - Related to Curie temperature and coercivity mechanism

Typically, a temperature range is specified

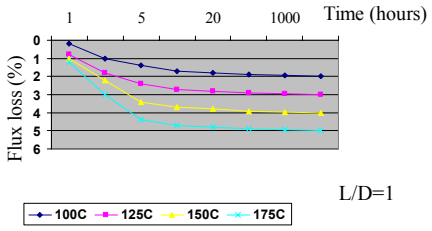
| Typical values (0 to 100°C) | | |
|---|---|---|
| Material | α (%/°C) | β (%/°C) |
| Ferrite | -0.2 | +0.2 |
| Alnico | -0.02 | +0.01 ($H_c$) |
| $SmCo_5$ | -0.04 | -0.3 |
| NdFeB | -0.09 | -0.5 |



## Irreversible Losses

- A flux loss observed after exposure to temperature
- Found to depend on three things: temperature, time and geometry (loadline)
- Recovered by remagnetization!

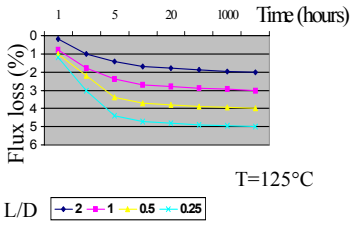
## Irreversible Losses




L/D=1




## Irreversible Losses


T=125°C

L/D 2 1 0.5 0.25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## Summary

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