Basic Magnetics Bootcamp
Session I
Basics

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Spontaneous Materials

Spontaneous Materials

Basic Magnetics Bootcamp

- Welcome
- Background

I. Basics

- Things we already knew
  - Poles
  - Living on a magnet
  - Viewing magnetic fields
- Two simple tests
  - Does it stick to a magnet?
  - Does it remain magnetized?
- Magnetic Theory
  - Hysteresis
  - Units and Conversions

II. Magnetism: Electro- and Ferro-

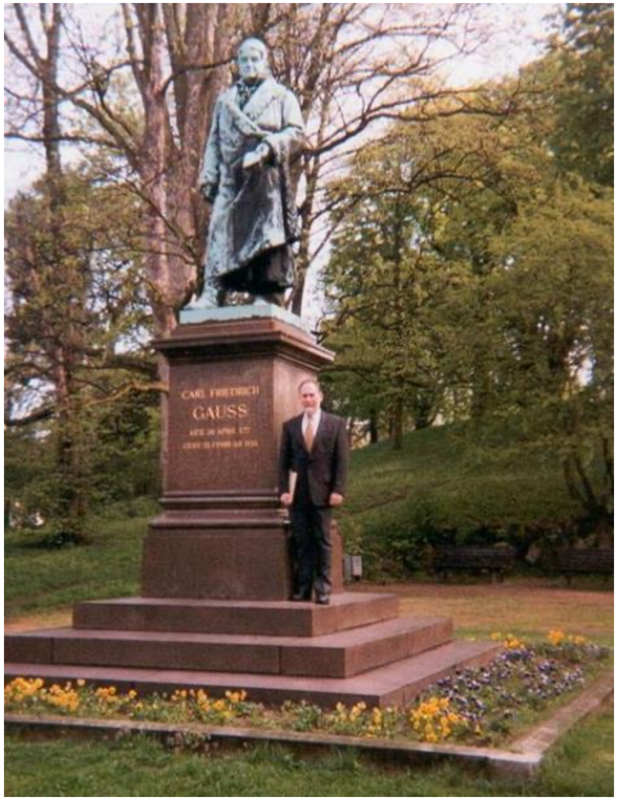
III. Processing: Mine to Magnets

IV. Thermal Properties of Permanent Magnets

Spontaneous Materials

Background

Background



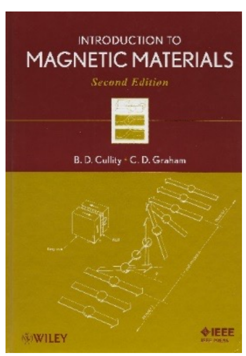
Stops along the way

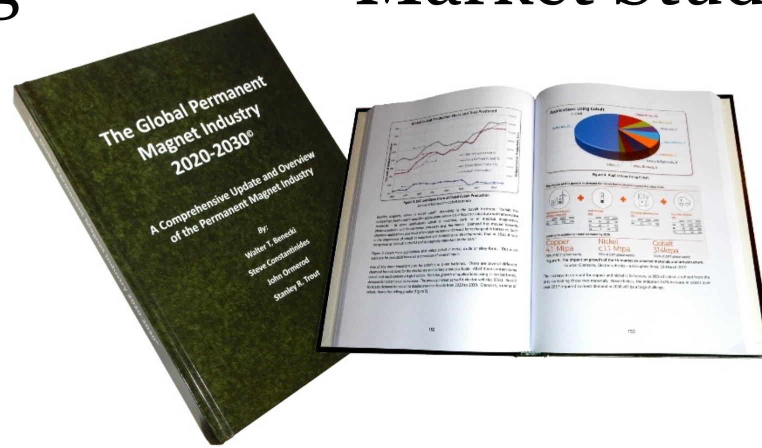
(Where I learned about magnets)

- Univ. of Pennsylvania
- Recoma
- Crucible
- Hitachi
- Magnequench
- Molycorp
- Consulting

What Spontaneous Materials Does

- Technical Training
- Material Selection
- Industry Reports
- Process Development
- Troubleshooting
- Magnetic Design Review
- Due Diligence
- Expert Witness
- Advice to Investors
- Market Studies





21 Years

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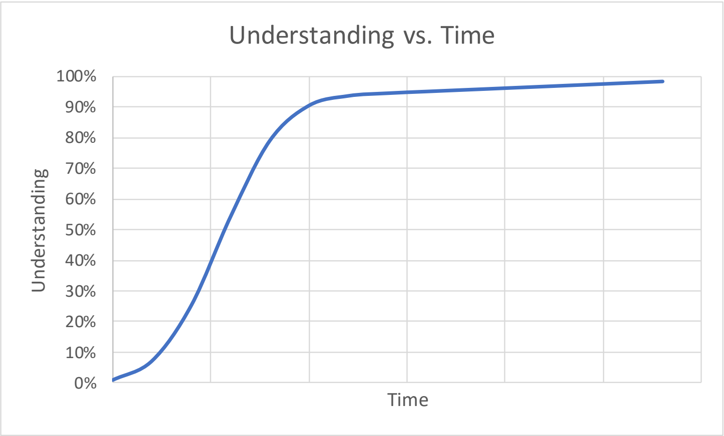
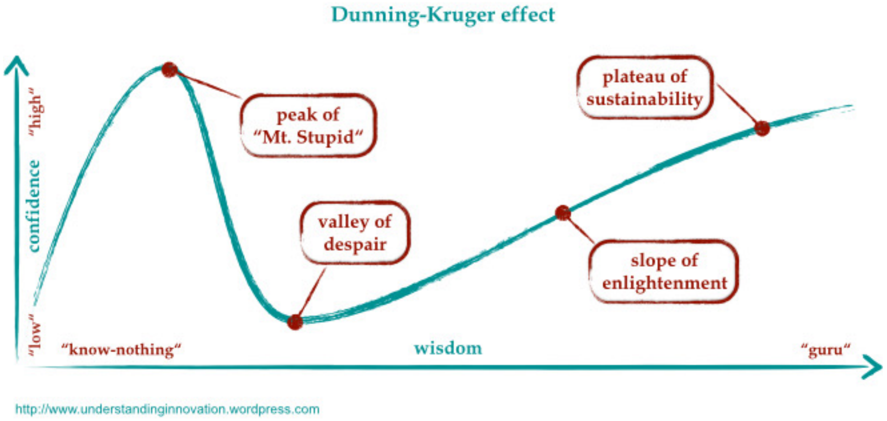
Some Perspective

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

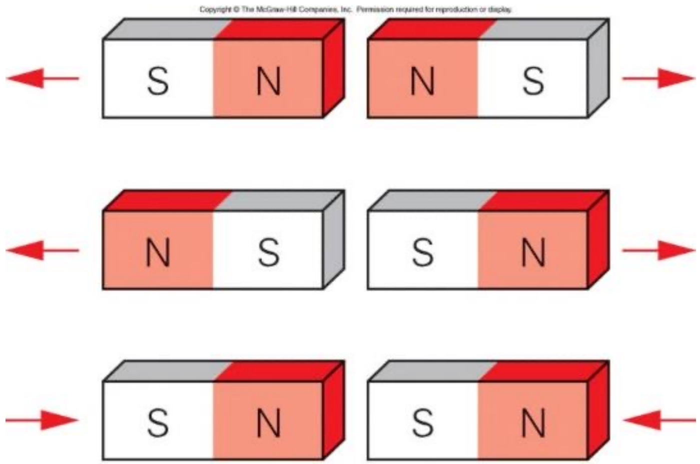
Anonymous





Things We Already Knew

Magnets Have Poles

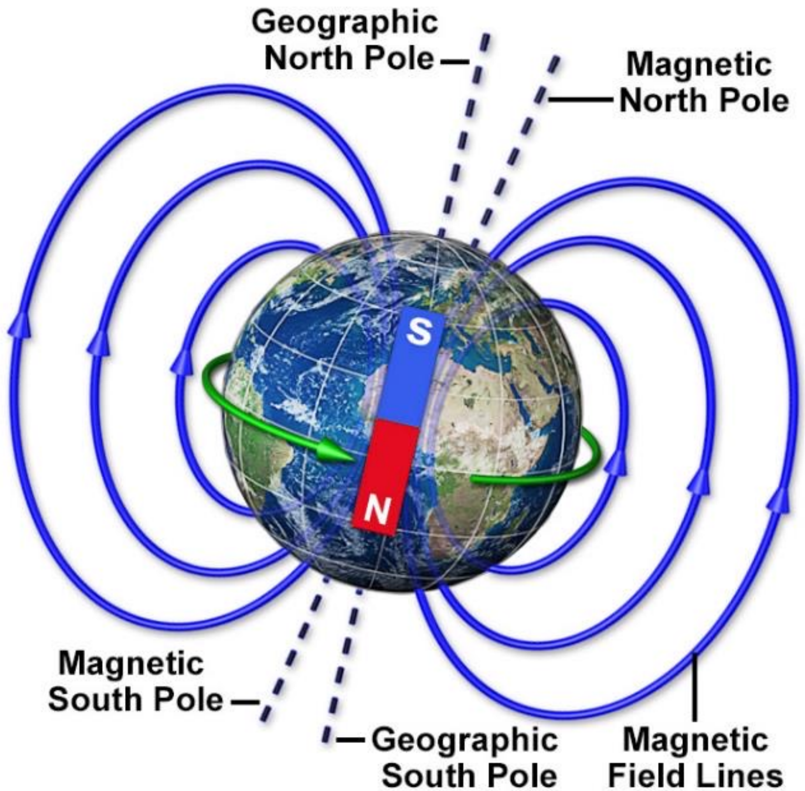


Source: Griffith

- We call them North pole and South pole
- Like poles repel; opposite poles attract
- A magnet has both a North and a South pole, regardless of size! No single poles.

The Earth is a Magnet

- Our tiny magnetic field
  - 100,000 times smaller than an MRI magnet
- Magnetic poles and geographic poles
  - Nearly the same location
  - The magnetic poles move
- A compass points North
  - A North seeking pole
- Notice the polarity of the Earth!



Source: www.nationalmaglab.org

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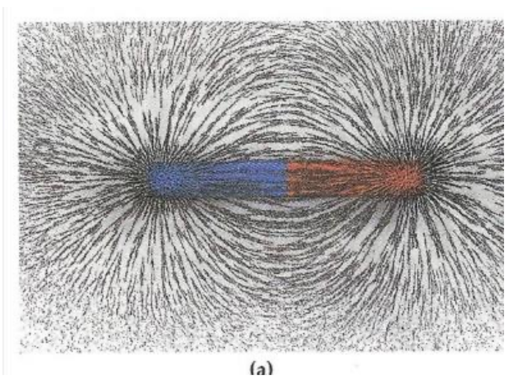
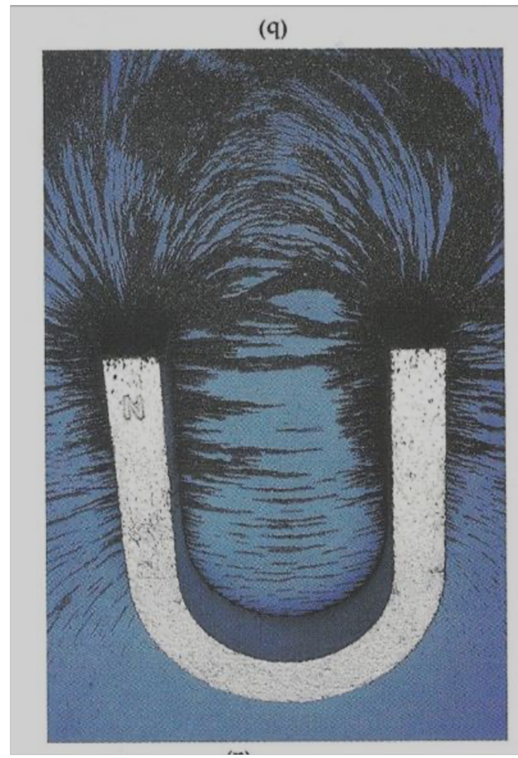
We Can See Magnetic Fields

- Iron powder follows the magnetic field lines



Source: Walker

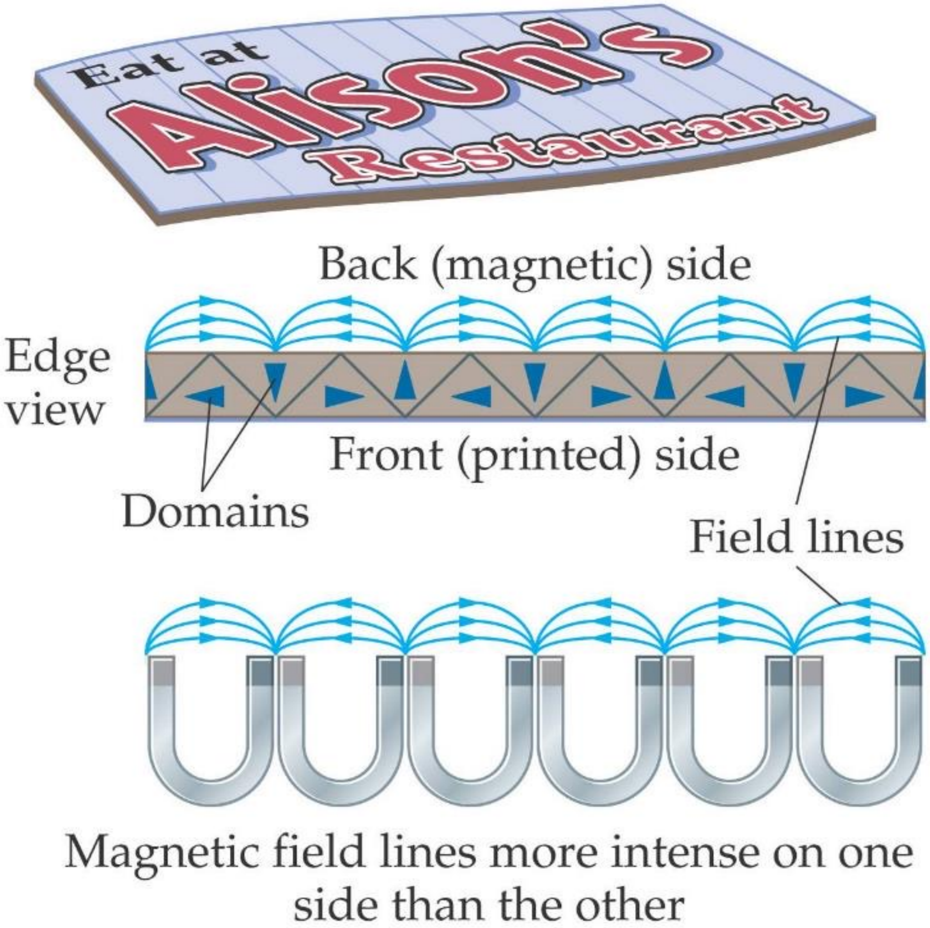


Source: Colts web site

We Can See Magnetic Fields

- Green paper

Magnet Viewer
Magne-Rite, Inc.



Source: Walker

Spontaneous Materials

Two Simple Tests

The First Test

- How does a material respond to a magnetic field?
  - Magnet sticks: “magnetic”
    - Ferromagnetic
    - Ferrimagnetic
  - Magnet doesn’t stick: “nonmagnetic”
    - Paramagnetic
    - Diamagnetic

The Second Test

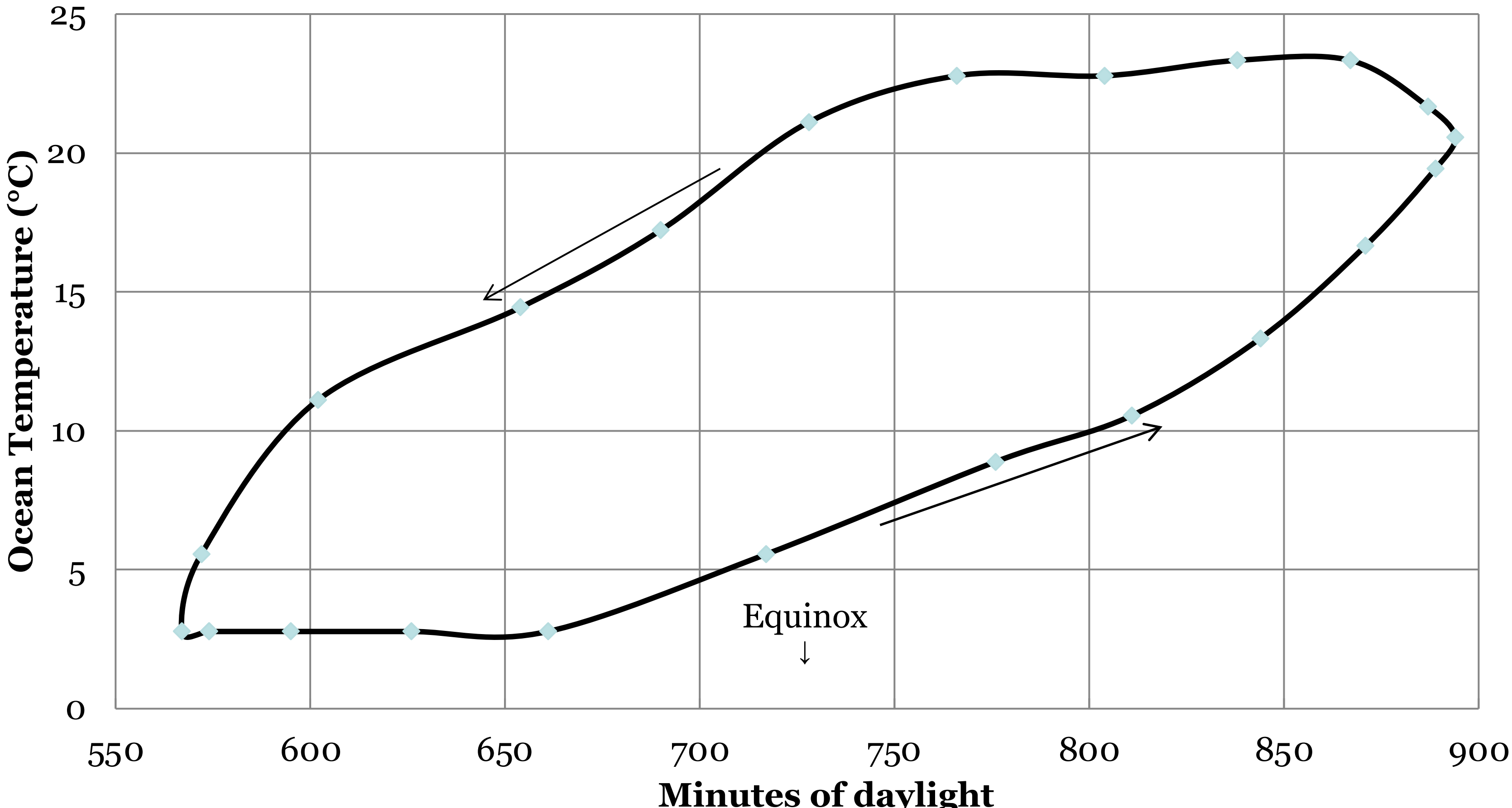
- What happens when the magnetic field is removed?
  - Doesn't remain magnetic
    - soft magnetic material
  - Remains magnetic
    - Easy to change, recording material
    - Difficult to change, permanent magnet

Magnetic Theory

Hysteresis

- A *delayed and nonlinear* response to a stimulus

Ocean Temperature
Cape May, NJ



Sources: NOAA & U.S. Naval Observatory

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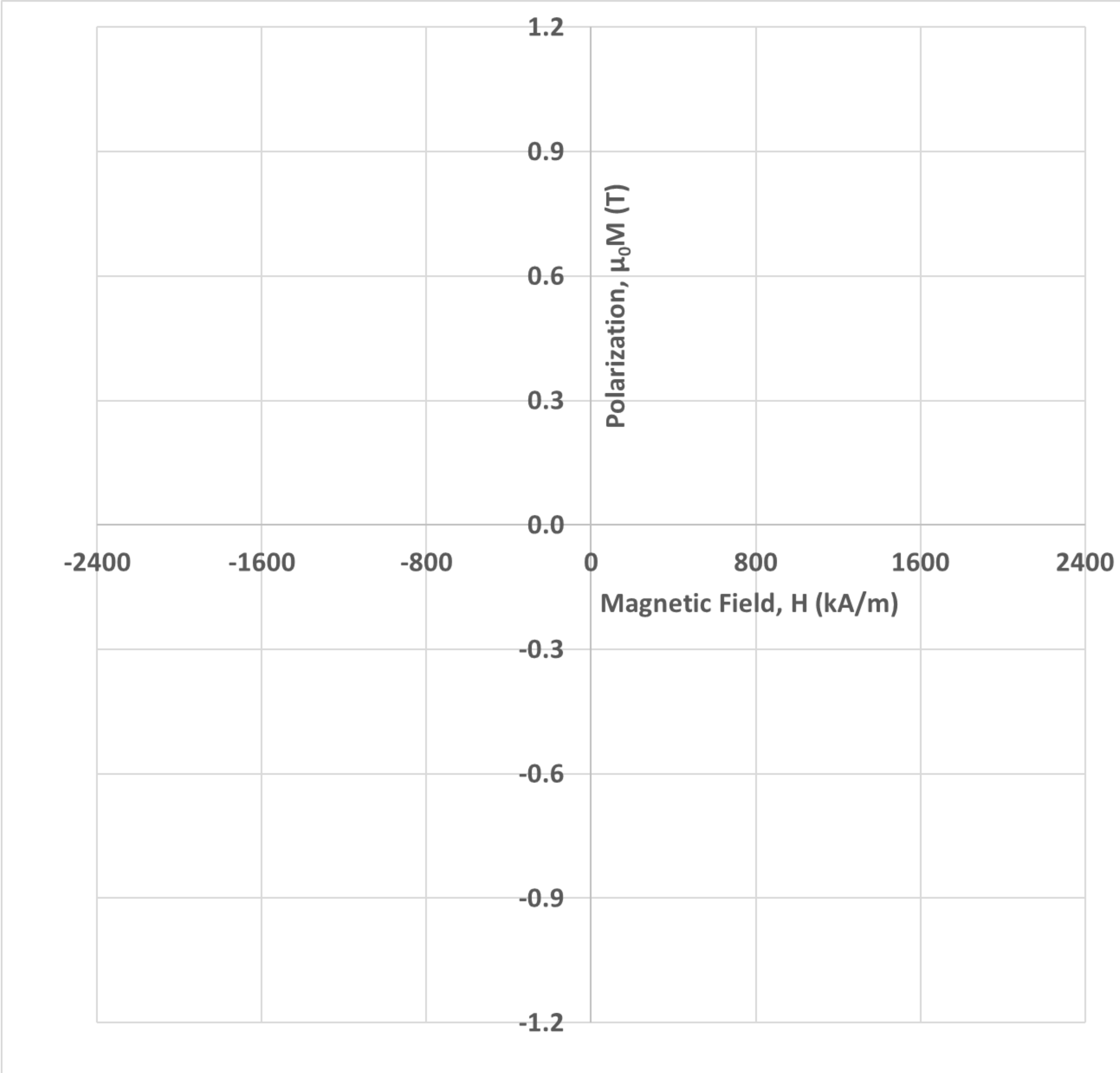
Hysteresis

- 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
- The *shape* of the hysteresis loop tells us what kind of material we have


1.2
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-0.3
-0.6
-0.9
-1.2
Polarization, μ0M (T)
-2400
-1600
-800
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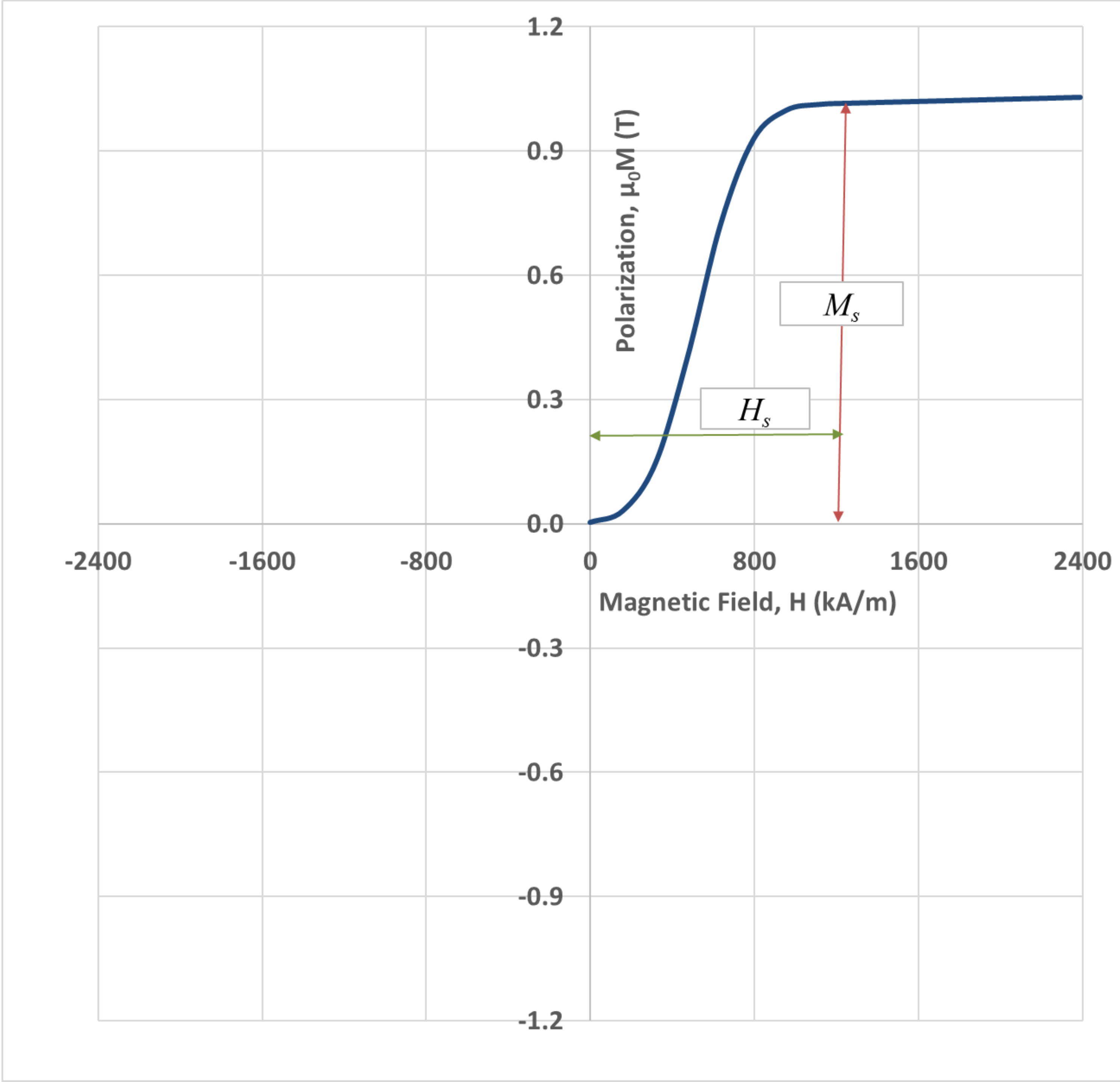
1600
2400
Magnetic Field, H (kA/m)



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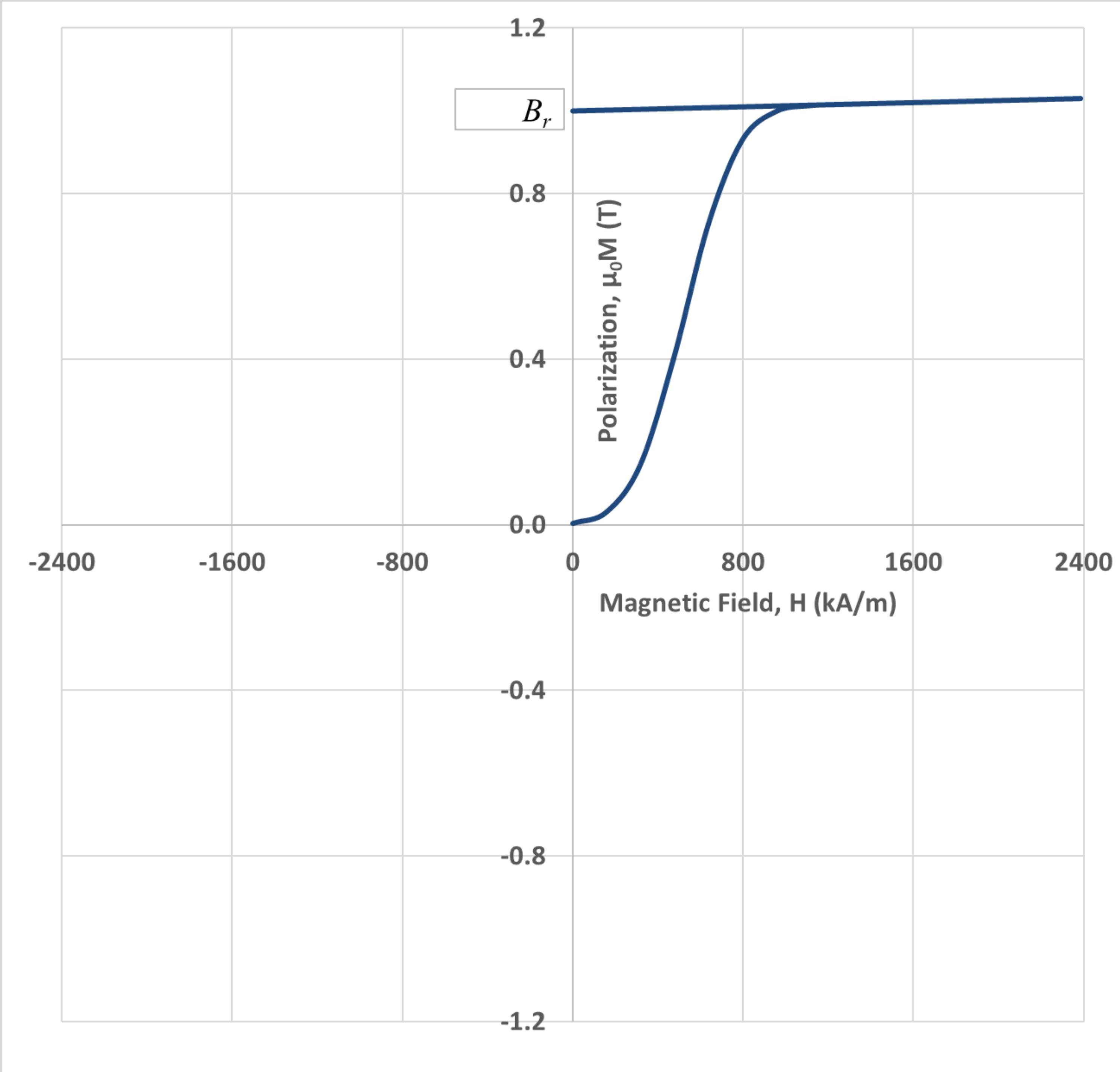
Polarization, $\mu_0 M$ (T)
Magnetic Field, H (kA/m)
M_s
H_s



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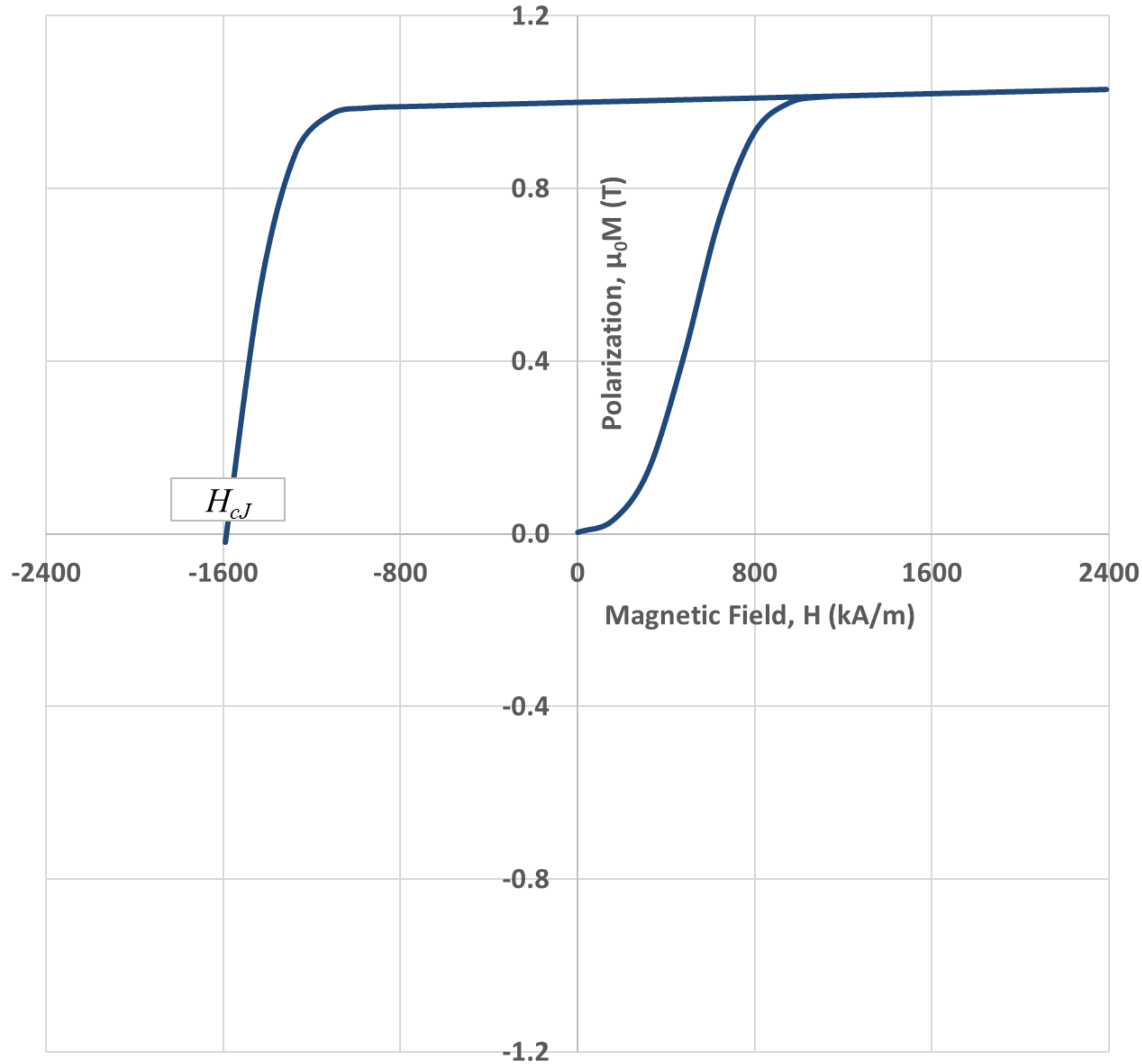
B_r
Polarization, μ_0M (T)
Magnetic Field, H (kA/m)



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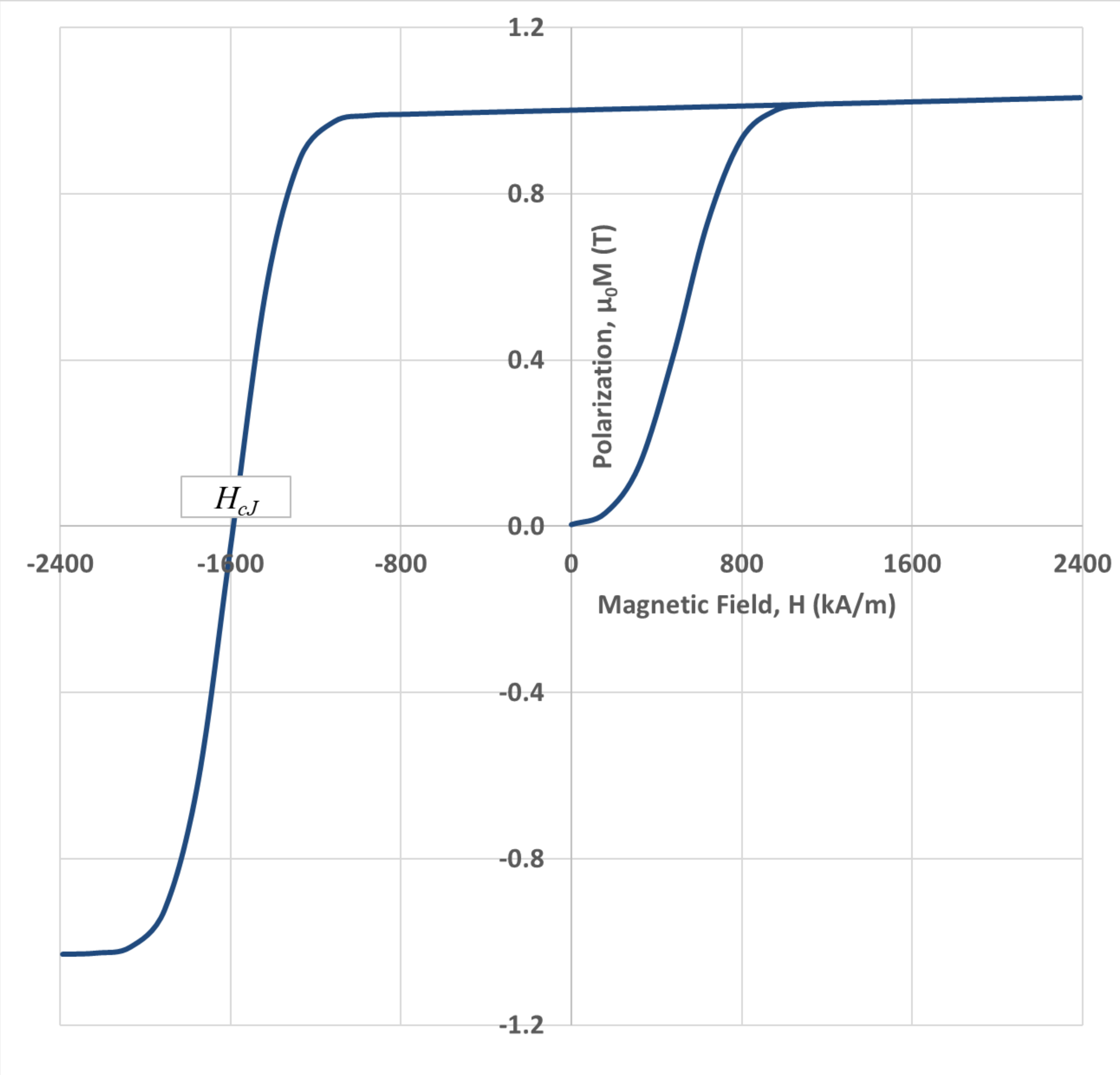
Polarization, $\mu_0 M$ (T)
Magnetic Field, H (kA/m)
H_{cJ}



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Magnetic Field, H (kA/m)
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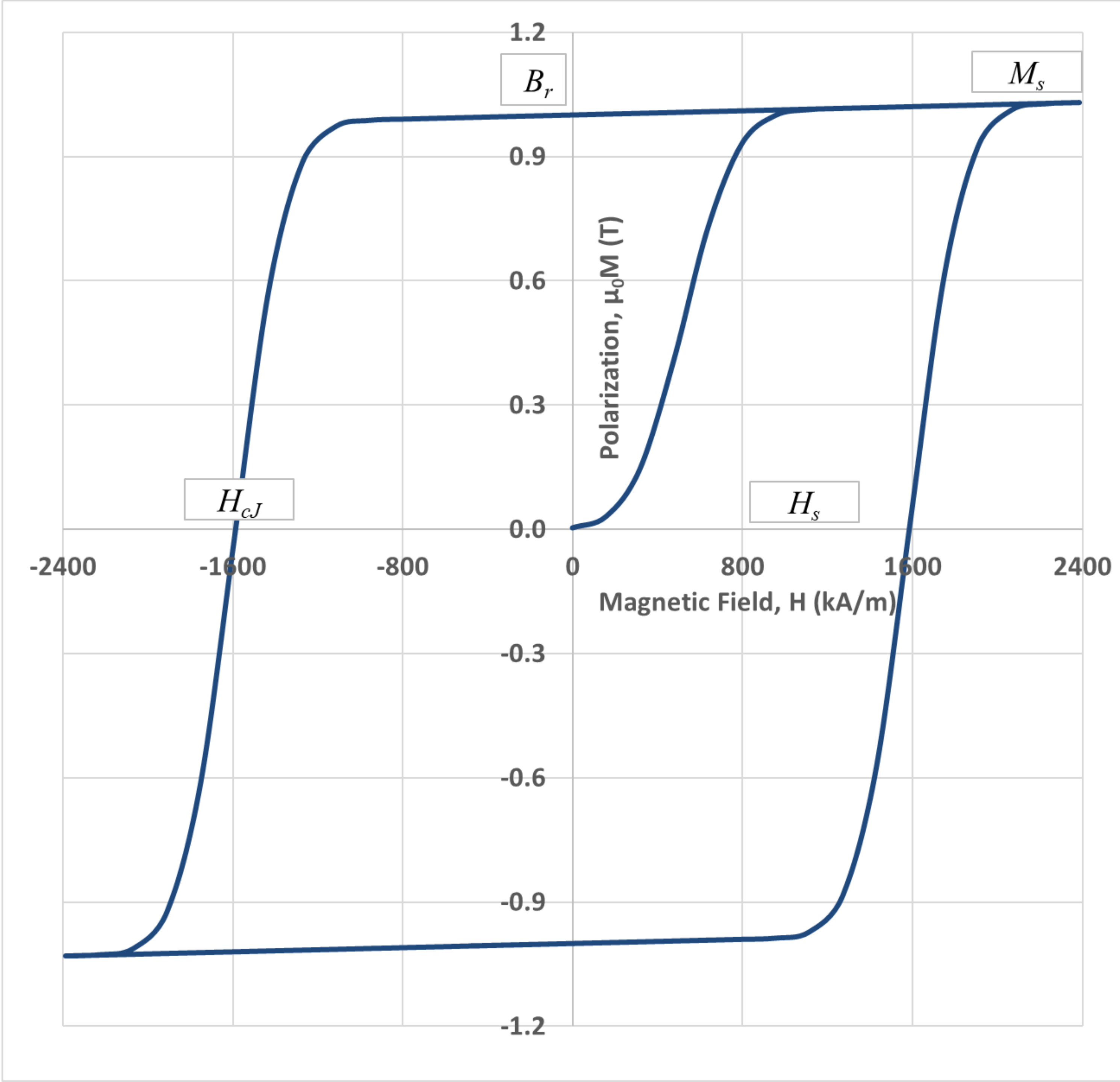

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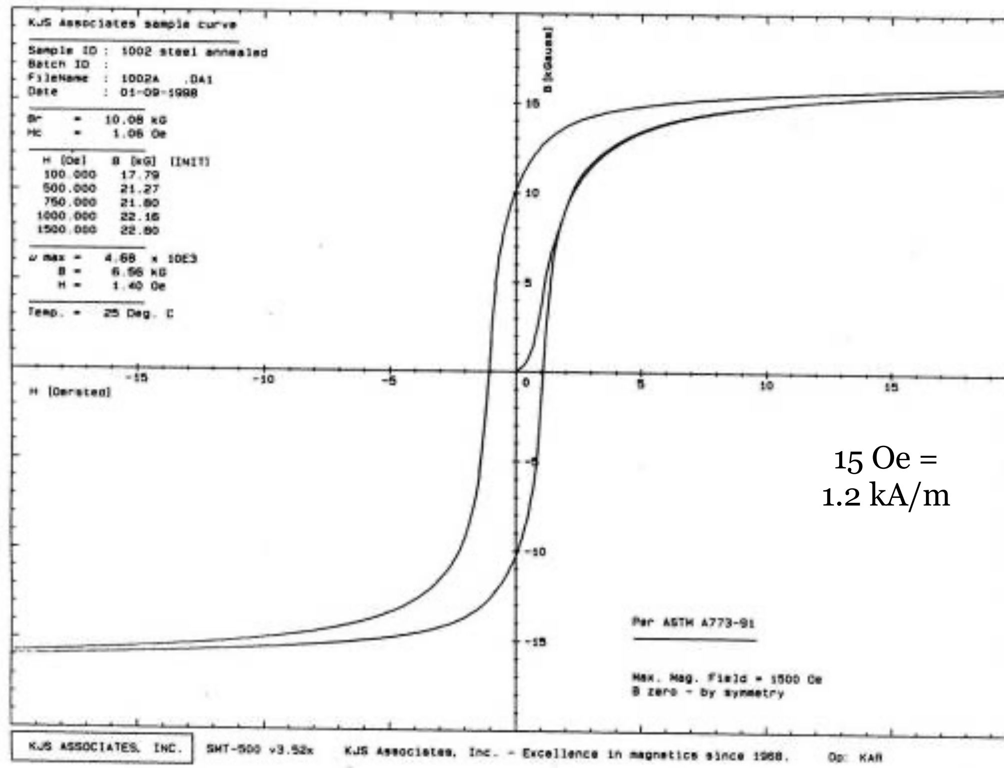
Magnetic Field, H (kA/m)
Polarization, μ_0M (T)
B_r
M_s
H_{cJ}
H_s

Two Types of Materials

- Soft Magnetic
- Hard Magnetic (Permanent Magnets)
- Notice
  - Height
  - Width
  - Watch the x-axis scale!

Soft Magnetic Materials

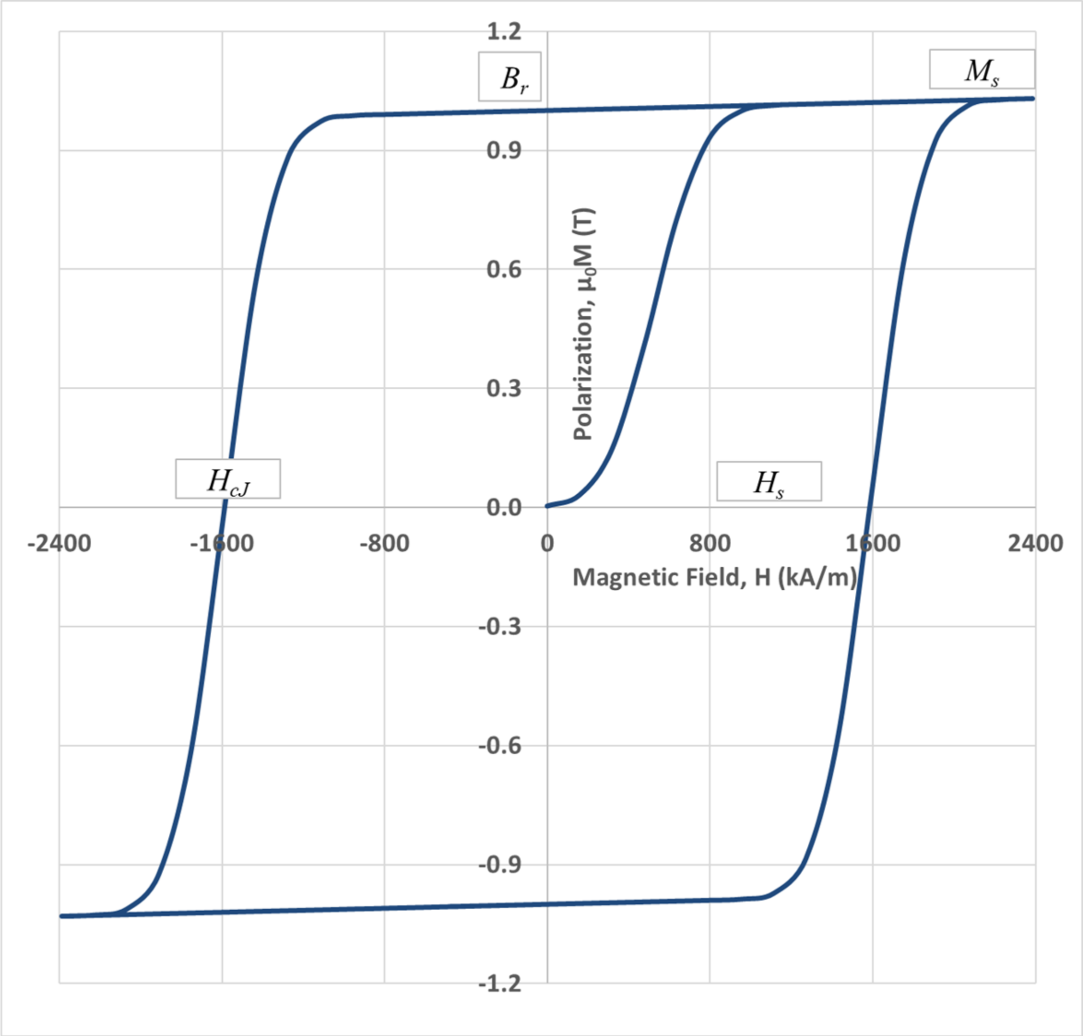
- Low H_{cJ}
- High flux, M_s
  - Iron
  - FeCo
- High permeability
  - Permalloy
  - Soft ferrite
- Low loss
  - Si-iron
  - Amorphous materials
  - Soft ferrites



Source: KJS Associates

Permanent Magnets

- High H_{cJ}
- High B_r
- Squareness H_k
- Applications
  - Motors, generators
  - Actuators
  - Speakers
- Materials
  - Alnico, Ferrite
  - SmCo, NdFeB



Spontaneous Materials

The Three Vectors

- B, Magnetic flux density or Induction.
- H, Magnetic field. (from current)
- M, Magnetization. (a material property)
- Vectors are not independent, but related.
- Induction is the combination of magnetization and magnetic field.

Flux Density or Induction, B

- Concentration of total magnetic flux in a region
- Lines of magnetic flux passing through a given area, lines per *area*

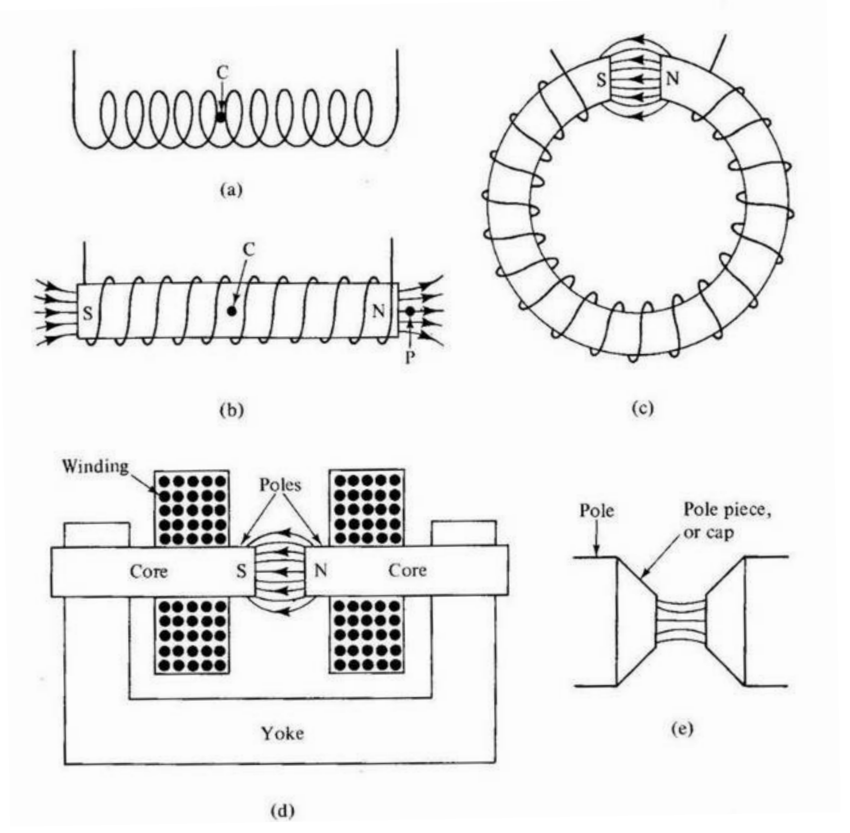
Units: Webers/m^2 or Tesla (T)

Magnetic Flux

$\Phi = B\ A\ cos\theta$

Magnetic Field, H

- A magnetic field created by current flowing in a wire.
- Units: Ampere-turn/meter (A/m), or Tesla (T) for $\mu_0 H$

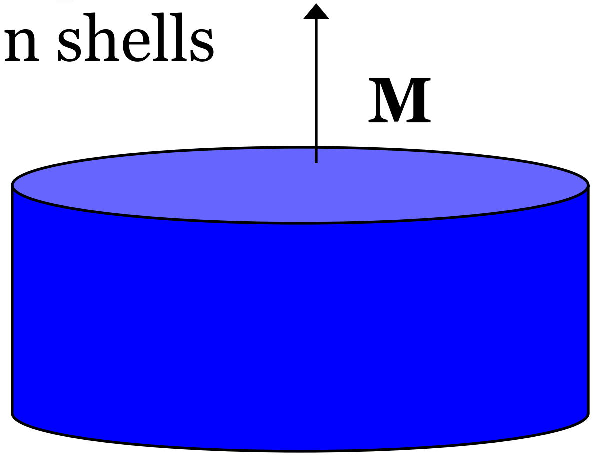


Source: Cullity-Graham

Magnetization, M

- The magnetic state of a material
- The sum of all the atomic magnetic moments per unit volume
- Magnetic moments originate from unpaired electron spins, usually in the 3d or 4f electron shells
- Units: A/m for M

  Tesla (T) for $J = \mu_0 M$



How are B, H and M related?

Induction, B is a combination of H and M.

In SI Units

$$B = \mu_0 (H+M)$$

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

$\mu_0 M = J$, Polarization

CGS Units

- SI units: meter, kilogram, second
- CGS units: centimeter, gram, second
  - $B = H + 4\pi M$
  - B in Gauss
  - H in Oersted
  - $4\pi M$ in Gauss
  - Older data tend to be in CGS units

Conversions

Quantity	Symbol	CGS Unit	SI Unit	Conversion
Magnetic Flux Density, Magnetic Induction	B	gauss (G)	tesla (T)	$1\text{T} = 10,000\text{G}$
Magnetic Field Strength	H	oersted (Oe)	ampere/meter (A/m)	$1\text{Oe} = 79.58\ \text{A}/\text{m}$
Magnetization	$4\pi M$ (CGS)	gauss (G)	Not used	
	M	emu/cm^3	ampere/meter (A/m)	$1\text{emu} = 1000\ \text{A}/\text{m}$
Polarization	J (SI)	Not used	tesla (T)	
Energy Product	$(BH)_{\text{max}}$	mega-gauss-oersted (MGOe)	joule/meter^3 (J/m^3)	$1\ \text{J}/\text{m}^3 = 125.7\text{G}\cdot\text{Oe}$

Source: IEEE Magnetics Society

Spontaneous Materials

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- Background

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- Things we already knew
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  - Viewing magnetic fields
- Two simple tests
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  - Does it remain magnetized?
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