

Class 21: Outline

Hour 1:

Expt. 9: Faraday's Law

Hour 2:

Faraday's Law

Transformers

Magnetic Materials

Last Time: Faraday's Law

Faraday's Law of Induction

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

Changing magnetic flux *induces* an EMF

Lenz: Induction ***opposes*** change

What can change?

$$\mathcal{E} = -N \frac{d}{dt} (BA \cos \theta)$$

Quantities which can vary with time:

- Magnitude of B
- Area A enclosed by the loop
- Angle θ between B and loop normal

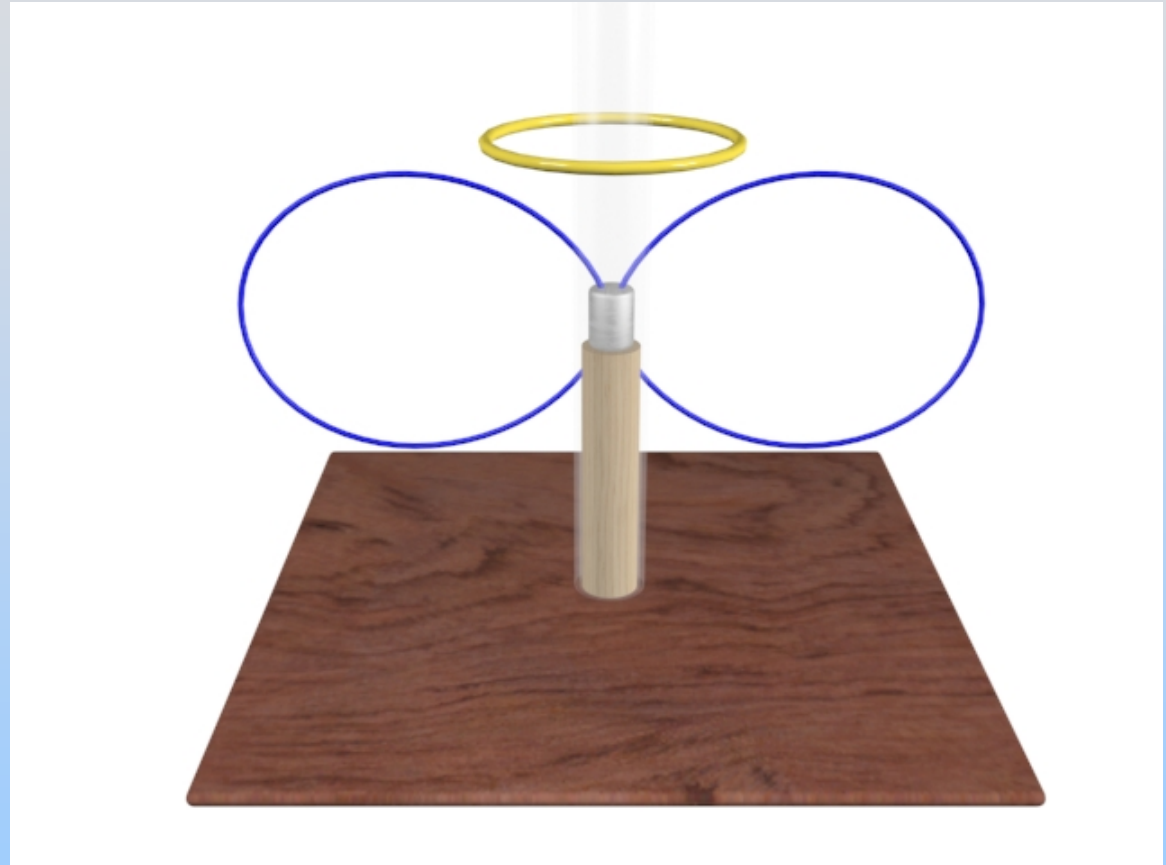
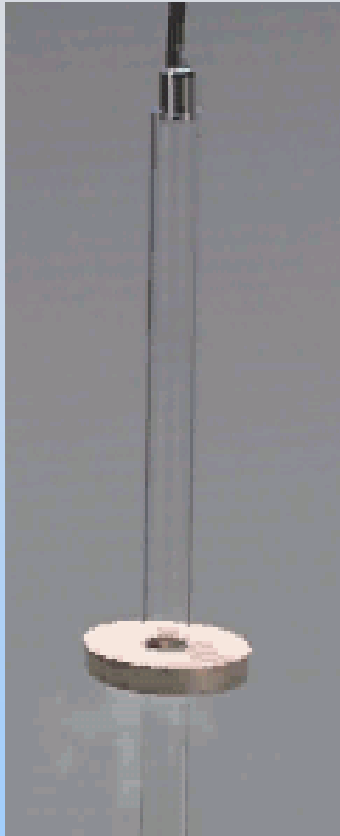
Magnet Falling Through a Ring



http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/faraday/07-FallingMagnetResistive/07-FallMAgRes_f54_320.html

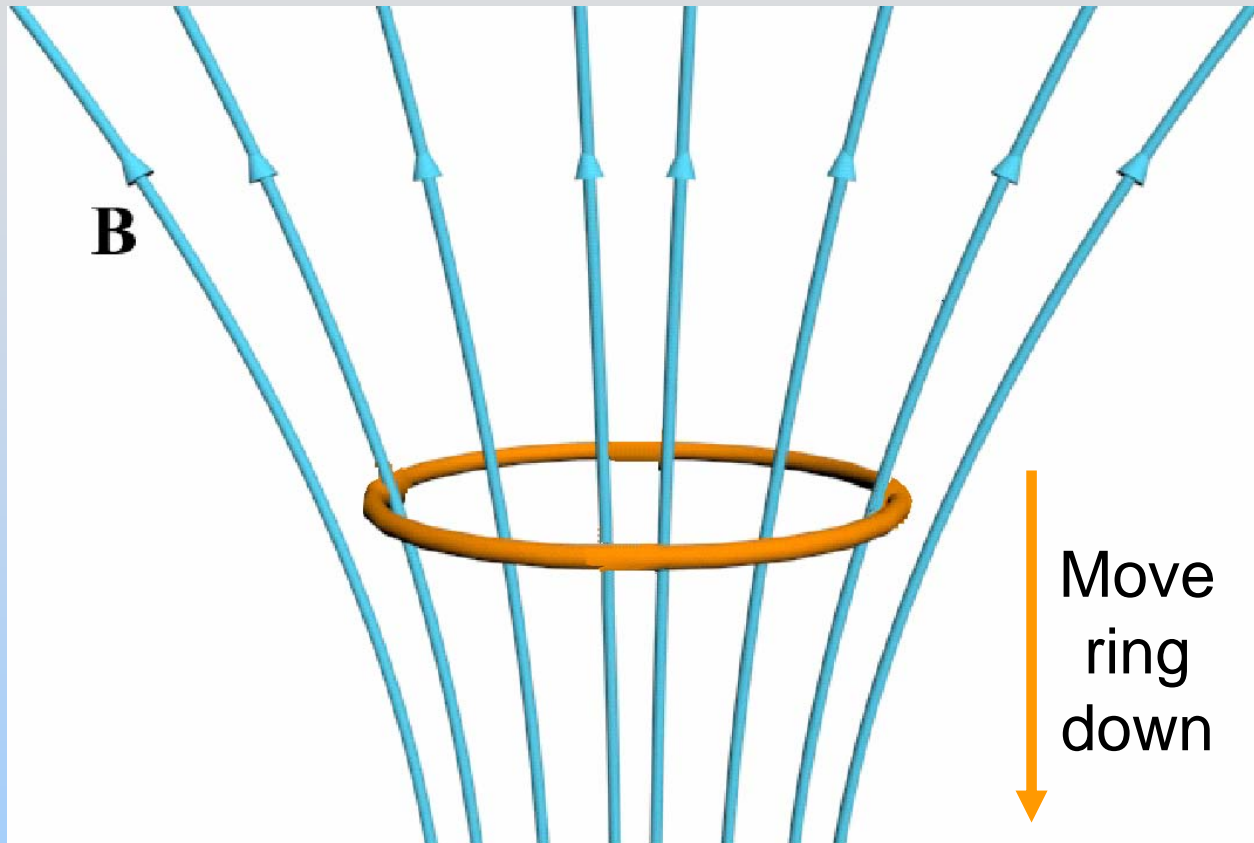
Falling magnet slows as it approaches a copper ring which has been immersed in liquid nitrogen.

Example: Magnitude of B Magnet Falling Through a Ring



Falling magnet approaches a copper ring
or Copper Ring approaches Magnet

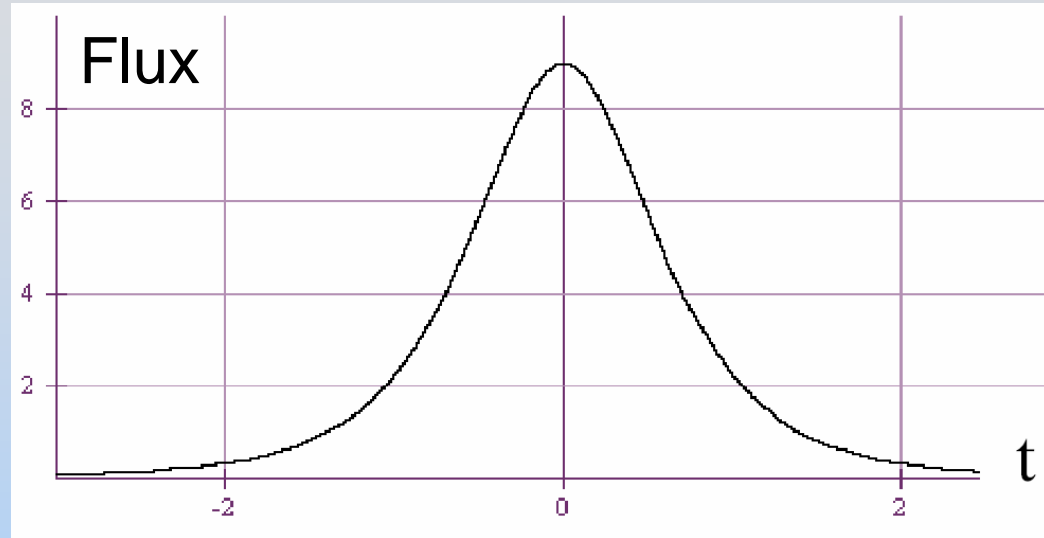
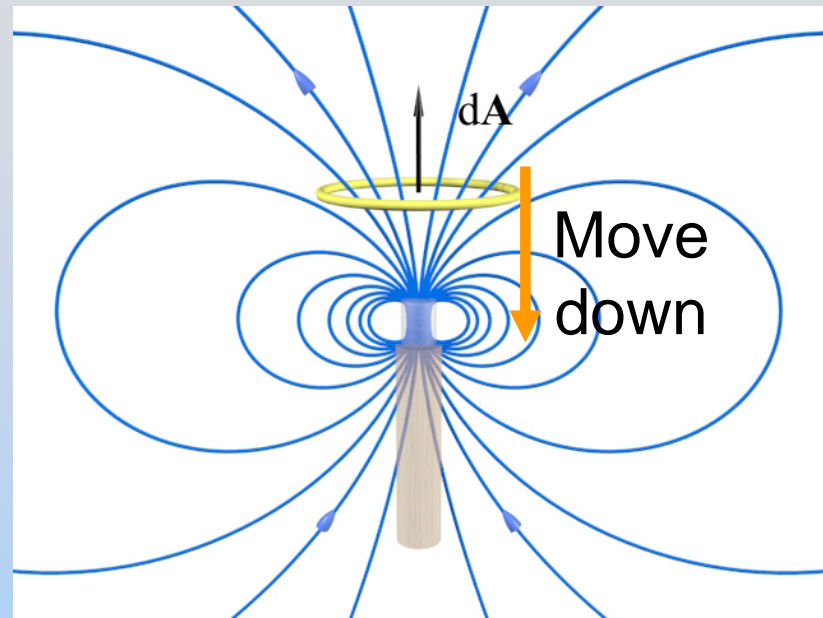
Moving Towards Dipole



As ring approaches, what happens to flux?

It increases

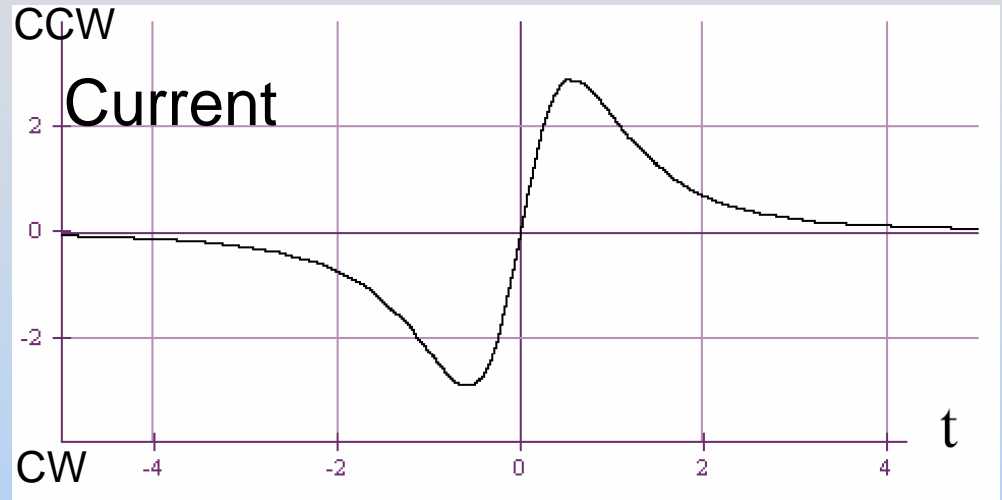
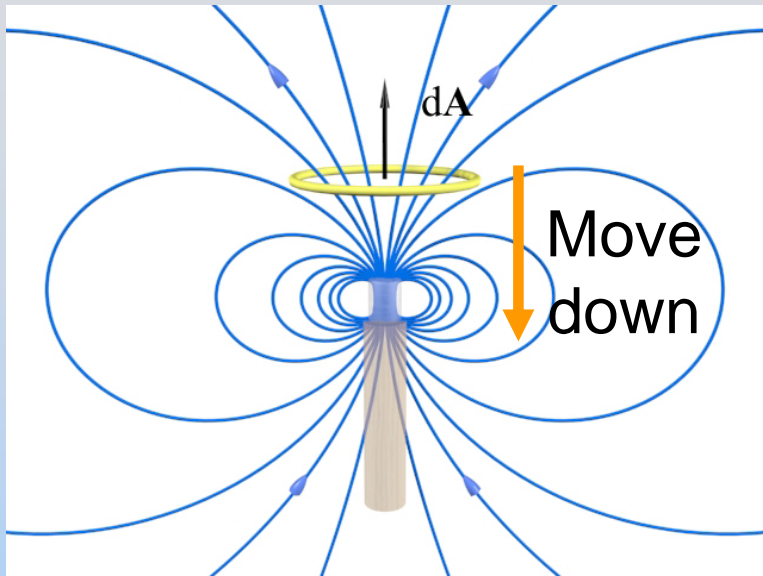
Moving Over Dipole



Flux increases then decreases

Note we have arbitrarily assigned dA
up

Moving Over Dipole



Current first goes in one direction, then other
It **ALWAYS** opposes the changing flux

**Five PRS Questions:
Predictions for Experiment 9
Faraday's Law**

Experiment 9: Faraday's Law of Induction

- Data
 - Current, ChA (A)
 - Run #1
 - y = - integral(x)
 - Run #1

Experiment Setup

Sensors Timers... Connect Change

Science Workshop 750

Sensors

- Acceleration Sensor
- Barometer
- Charge Sensor
- Colorimeter
- Signal Output
- Output

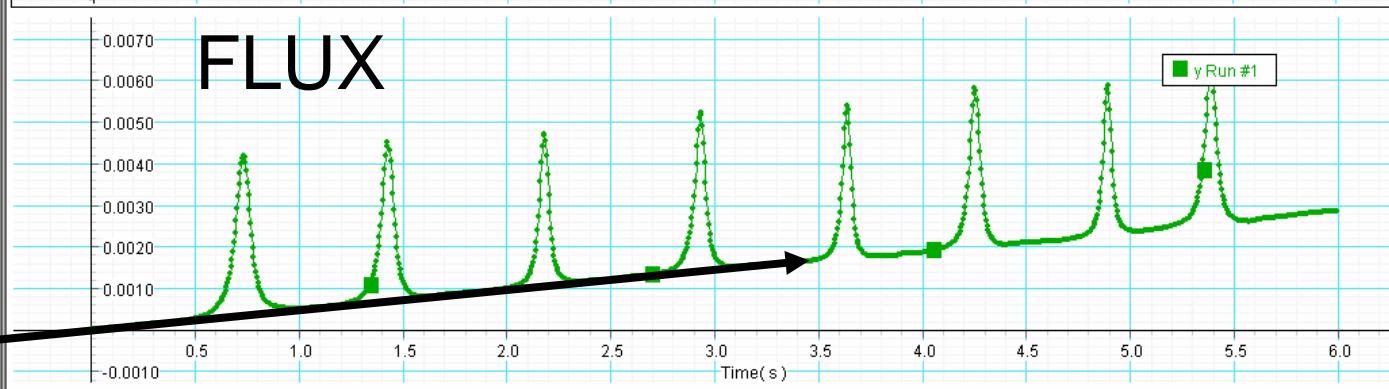
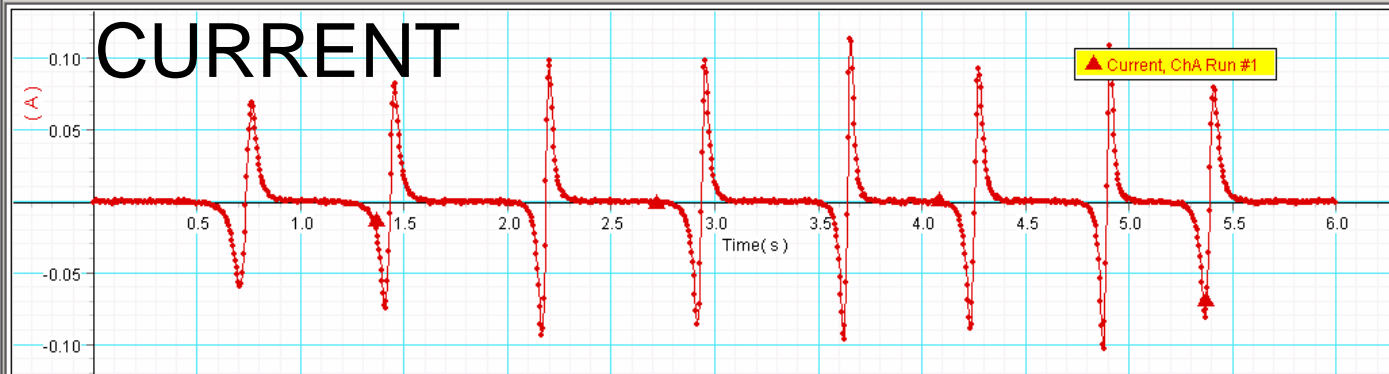


Current Sensor

- Displays
 - Digits
 - Graph
 - Current (top curve) and flux (bot
 - Table

Current (top curve) and flux (bottom curve)

Fit Data



Imperfect
current 0

Four PRS Questions:
Force on A Loop Below Magnet
Moving Upward;
Moving Rail;
Moving Rectangle near Wire;
Generator.

Brakes

Magnet Falling Through a Ring



What happened to kinetic energy of magnet?

Eddy Current Braking

<http://demoroom.physics.ncsu.edu/html/demos/163.html>

What happened to kinetic energy of pendulum?

Eddy Current Braking

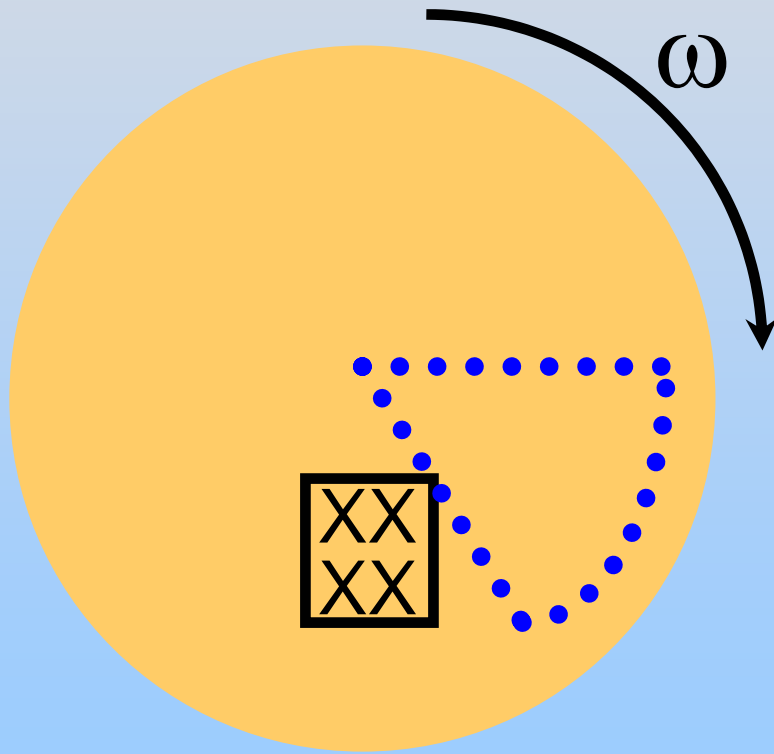
<http://demoroom.physics.ncsu.edu/multimedia/video/5K20.22.1.MOV>

What happened to kinetic energy of disk?

Demonstration: Eddy Current Braking

Eddy Current Braking

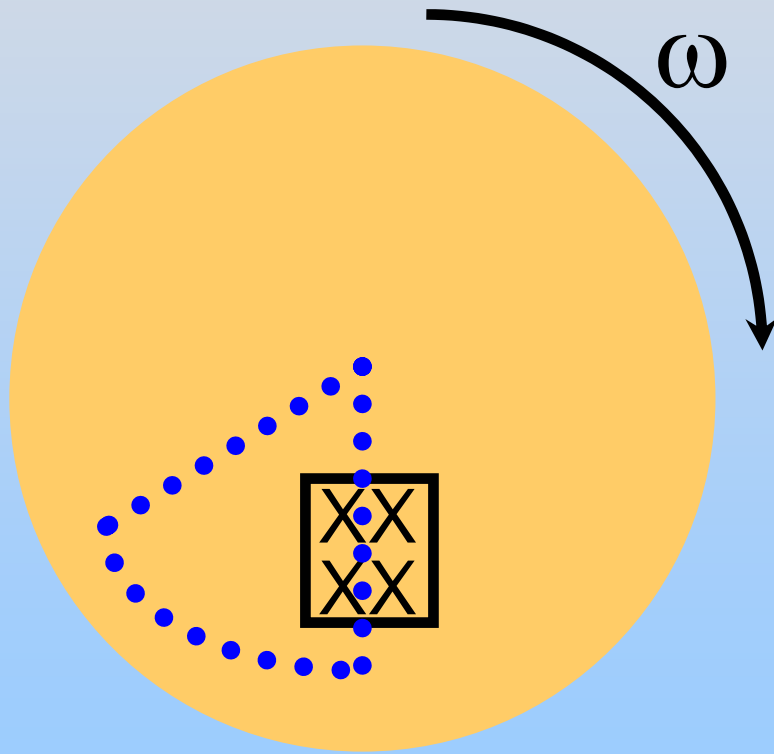
The magnet induces currents in the metal that dissipate the energy through Joule heating:



1. Current is induced counter-clockwise (out from center)
2. Force is opposing motion (creates slowing torque)

Eddy Current Braking

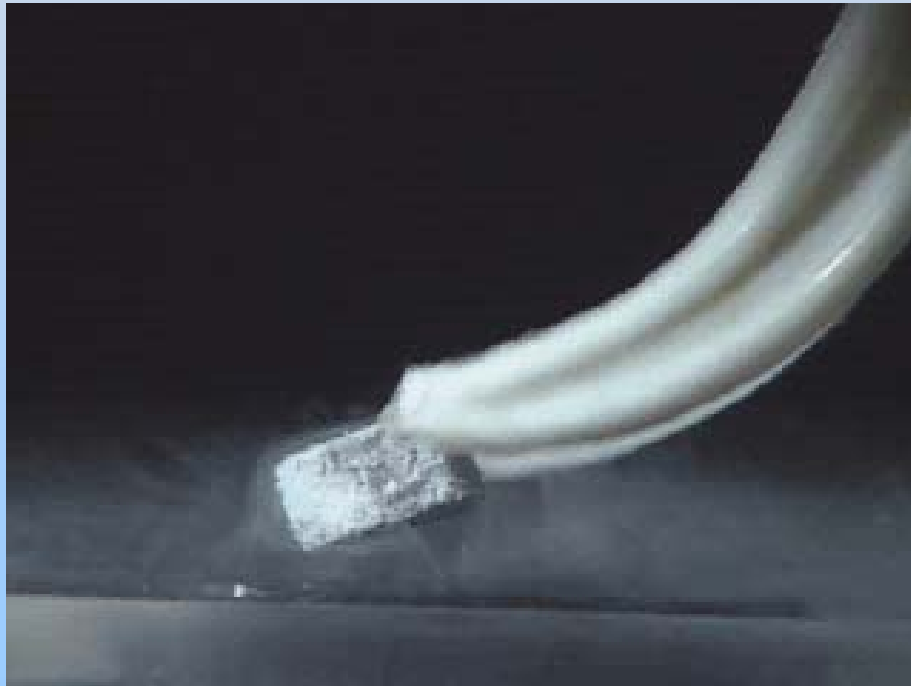
The magnet induces currents in the metal that dissipate the energy through Joule heating:



1. Current is induced clockwise (out from center)
2. Force is opposing motion (creates slowing torque)
3. EMF proportional to ω

$$4. F \propto \frac{\mathcal{E}^2}{R}$$

Demonstration: Levitating Magnet Superconductor & Magnet

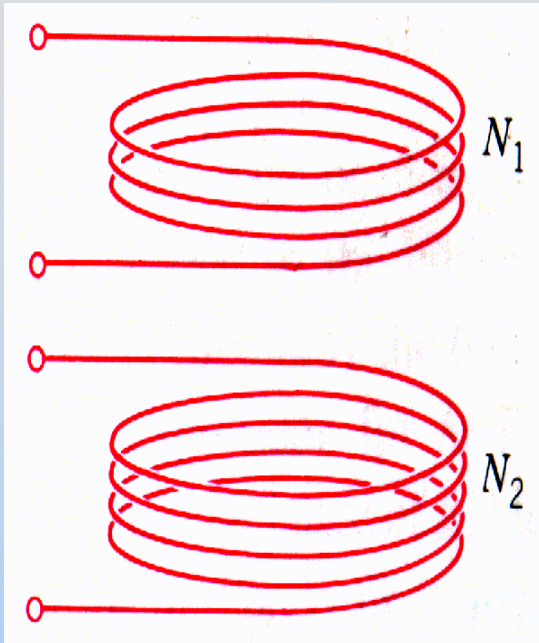


http://ocw.mit.edu/ans7870/8/8.02T/f04/visualizations/faraday/16-superconductor/16-12_wmv320.html

PRS Questions: Loop in Uniform Field

Mutual Inductance

Mutual Inductance



A current I_2 in coil 2, induces some magnetic flux Φ_{12} in coil 1. We define the flux in terms of a “mutual inductance” M_{12} :

$$N_1 \Phi_{12} \equiv M_{12} I_2$$

$$\rightarrow M_{12} = \frac{N_1 \Phi_{12}}{I_2}$$

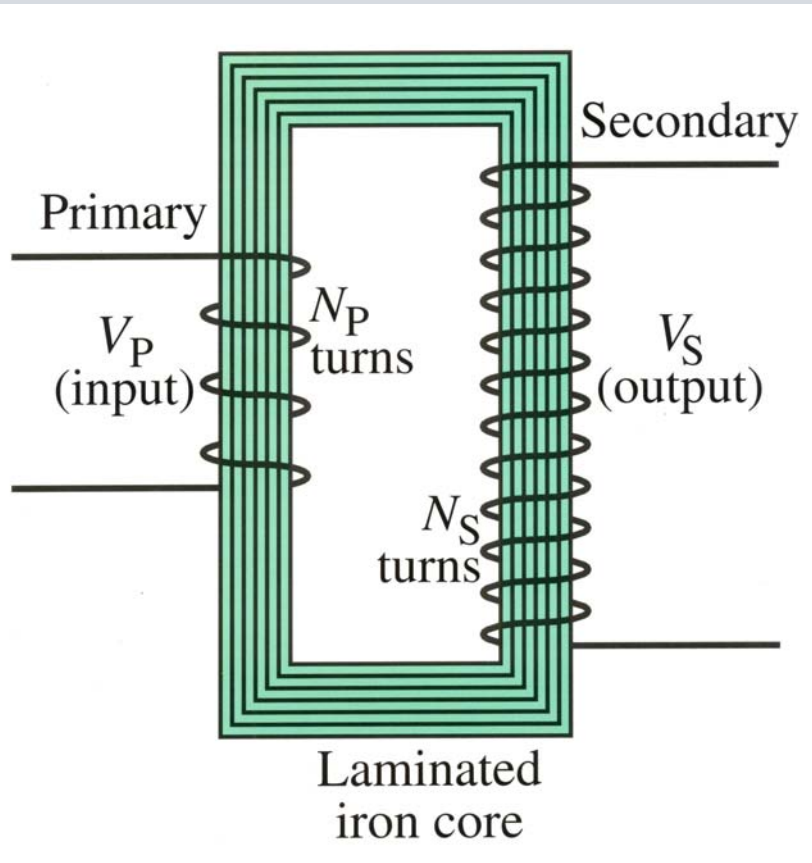
$$M_{12} = M_{21} = M$$

$$\mathcal{E}_{12} \equiv -M_{12} \frac{dI_2}{dt}$$

Demonstration: Remote Speaker

Transformer

Step-up transformer



$$\mathcal{E}_p = N_p \frac{d\Phi_B}{dt}$$

$$\mathcal{E}_s = N_s \frac{d\Phi_B}{dt}$$

$$\frac{\mathcal{E}_s}{\mathcal{E}_p} = \frac{N_s}{N_p}$$

$N_s > N_p$: step-up transformer

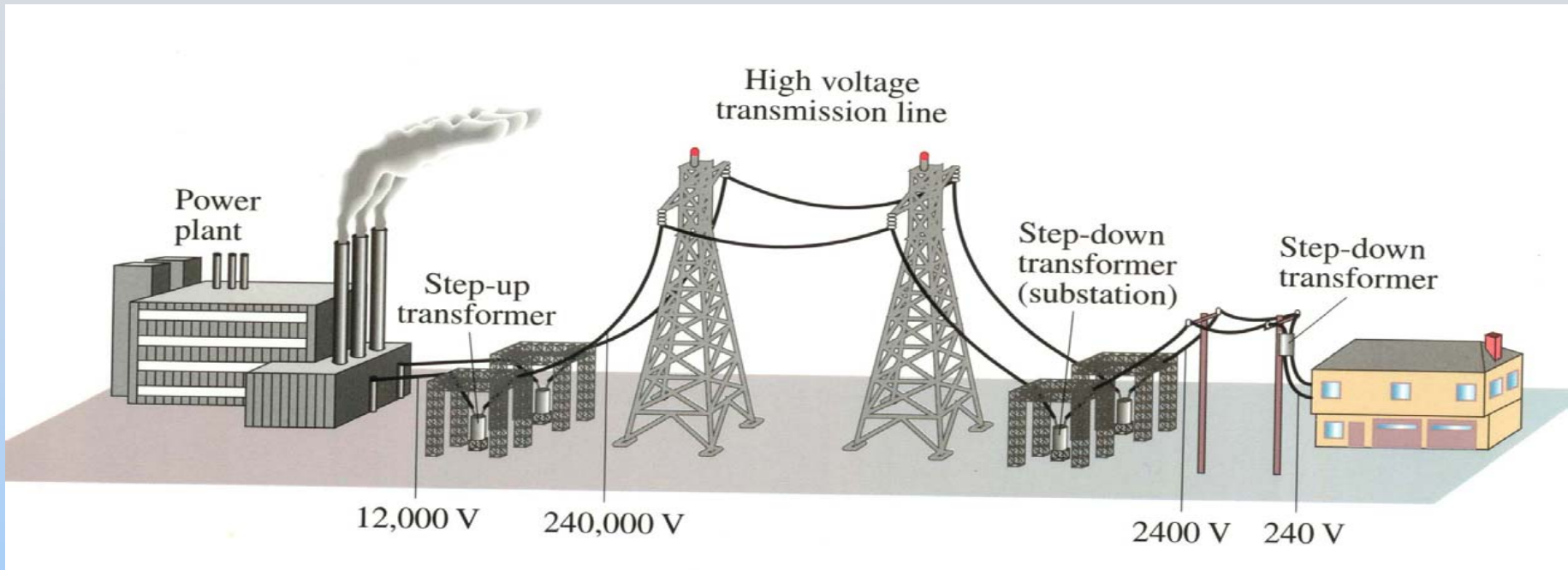
$N_s < N_p$: step-down transformer

Demonstrations:

**One Turn Secondary:
Nail**

**Many Turn Secondary:
Jacob's Ladder**

Transmission of Electric Power



Power loss can be greatly reduced if transmitted at high voltage

Example: Transmission lines

An average of 120 kW of electric power is sent from a power plant. The transmission lines have a total resistance of 0.40 Ω . Calculate the power loss if the power is sent at (a) 240 V, and (b) 24,000 V.

$$(a) \quad I = \frac{P}{V} = \frac{1.2 \times 10^5 \text{ W}}{2.4 \times 10^2 \text{ V}} = 500 \text{ A}$$

83% loss!!

$$P_L = I^2 R = (500 \text{ A})^2 (0.40 \Omega) = 100 \text{ kW}$$

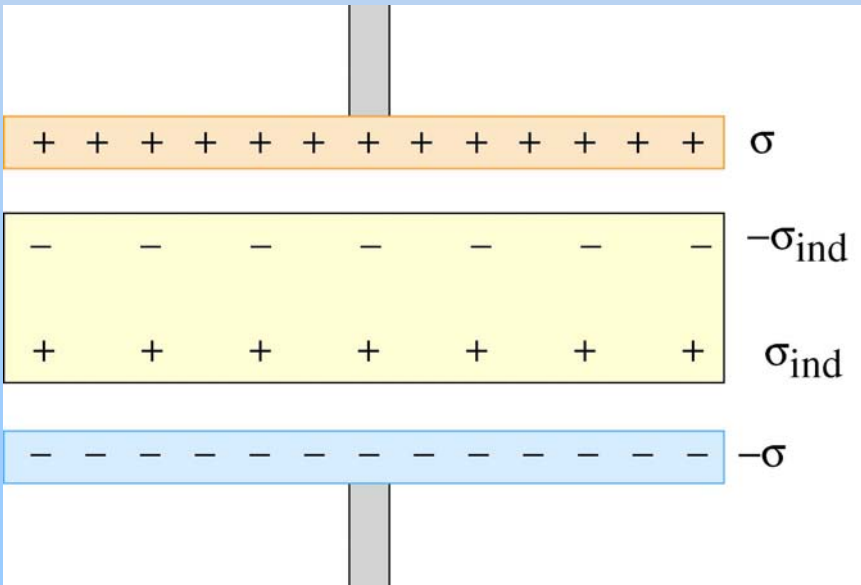
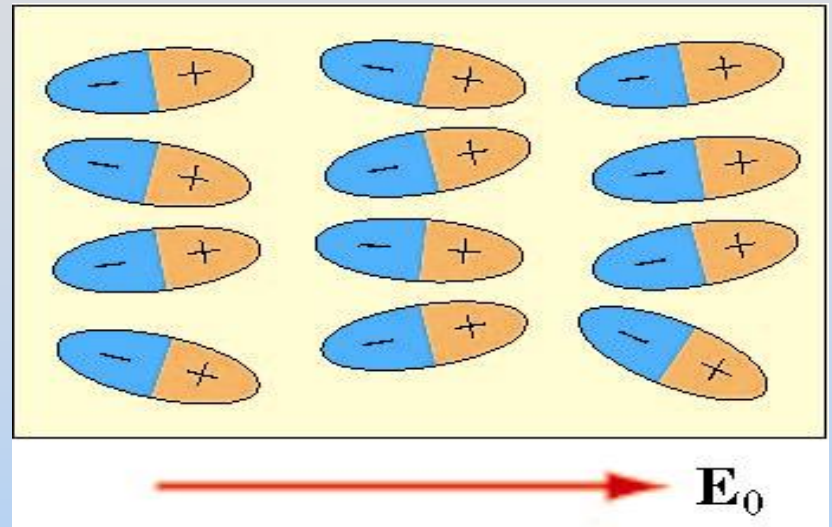
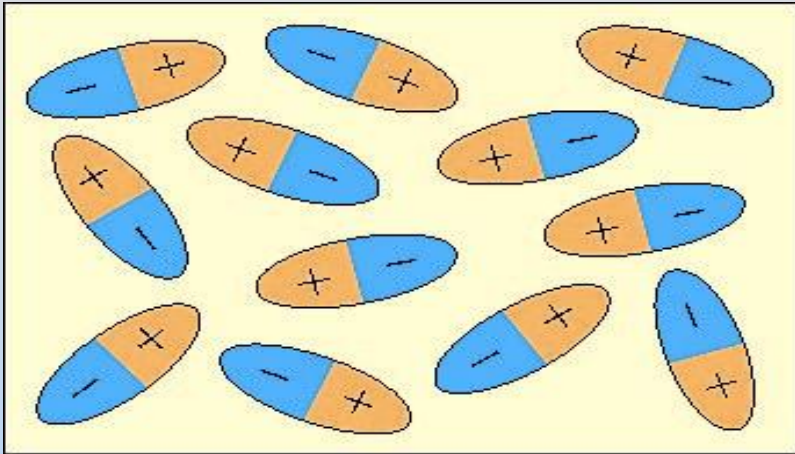
$$(b) \quad I = \frac{P}{V} = \frac{1.2 \times 10^5 \text{ W}}{2.4 \times 10^4 \text{ V}} = 5.0 \text{ A}$$

0.0083% loss

$$P_L = I^2 R = (5.0 \text{ A})^2 (0.40 \Omega) = 10 \text{ W}$$

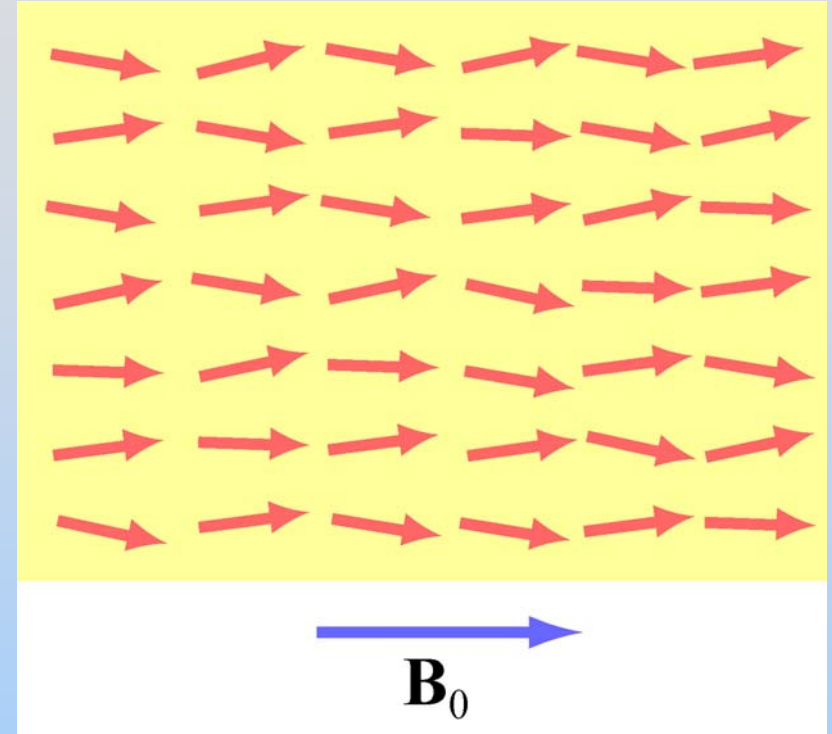
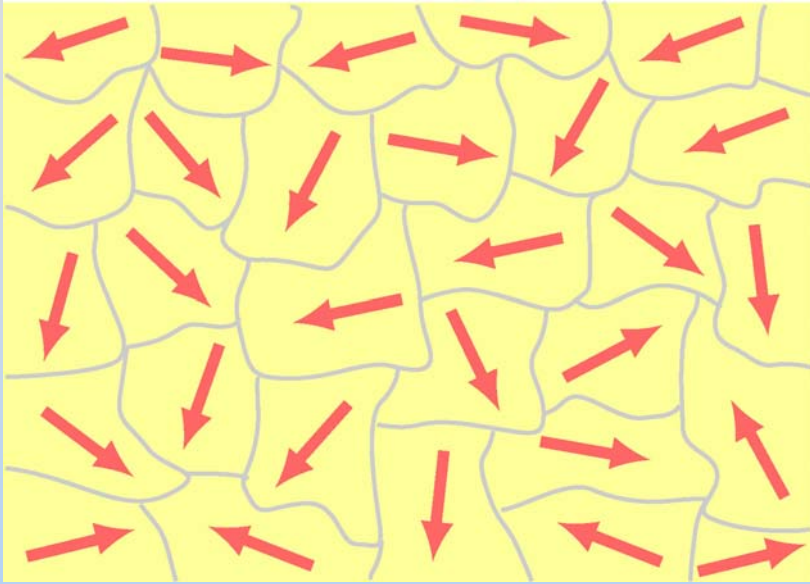
Magnetic Materials

Recall Polar Dielectrics



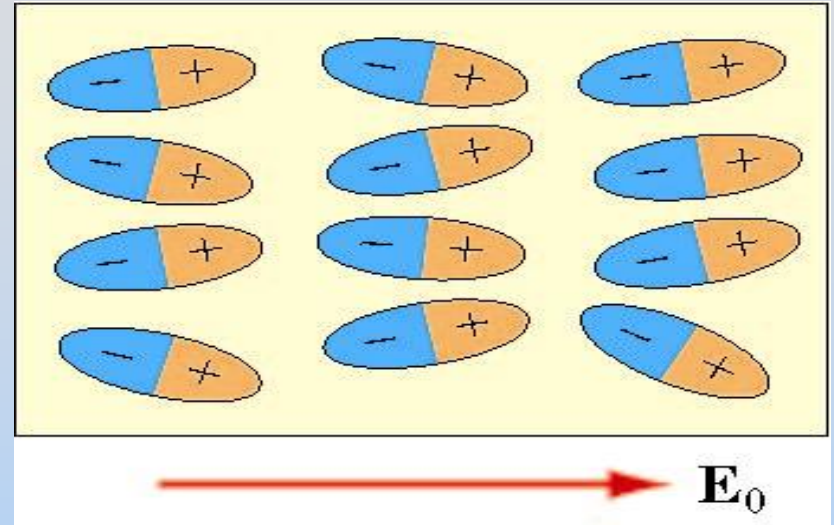
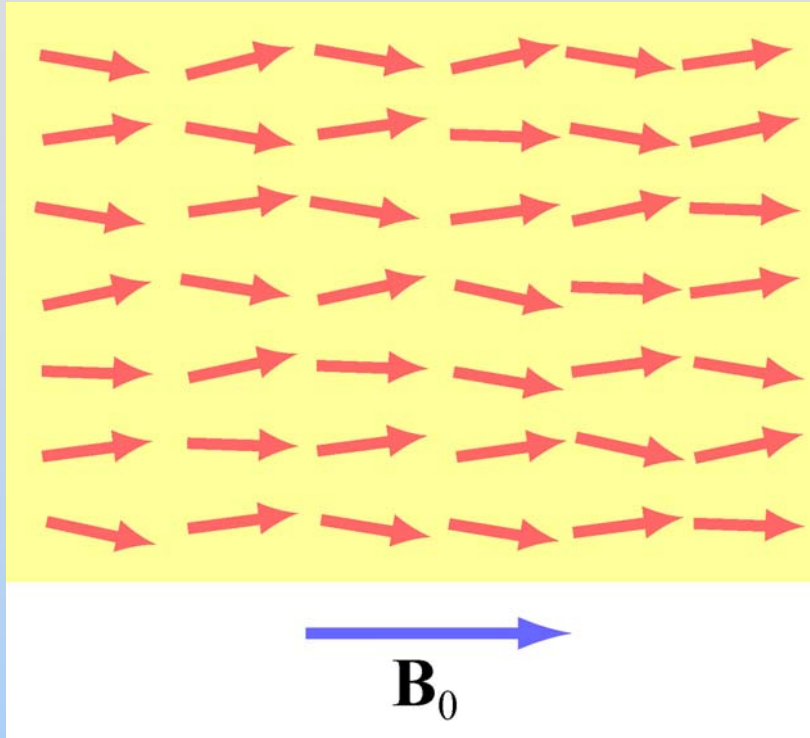
Dielectric polarization ***decreases*** Electric Field!

Para/Ferromagnetism



Applied external field B_0 tends to align the atomic magnetic moments

Para/Ferromagnetism

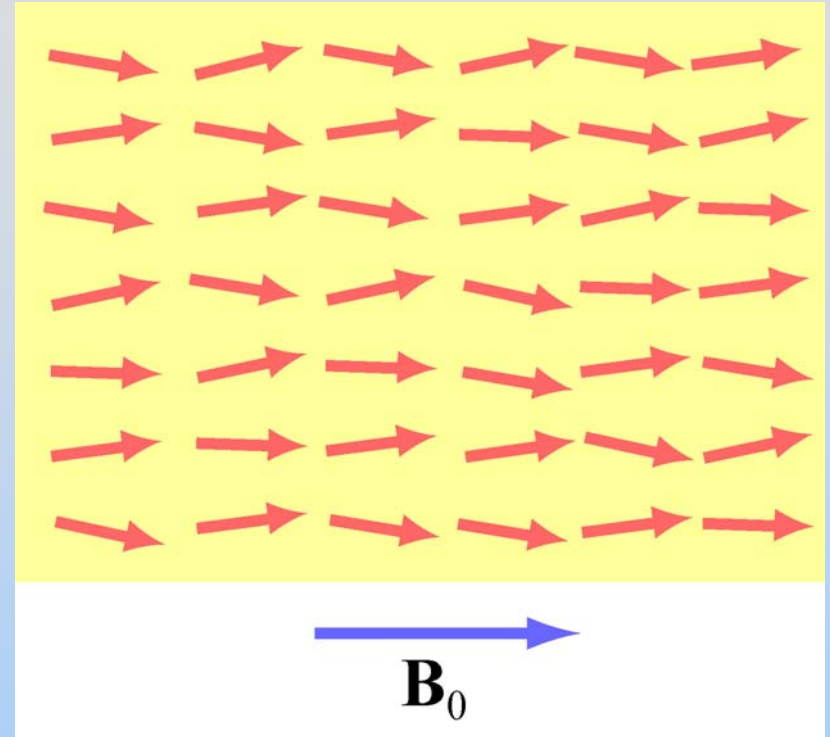
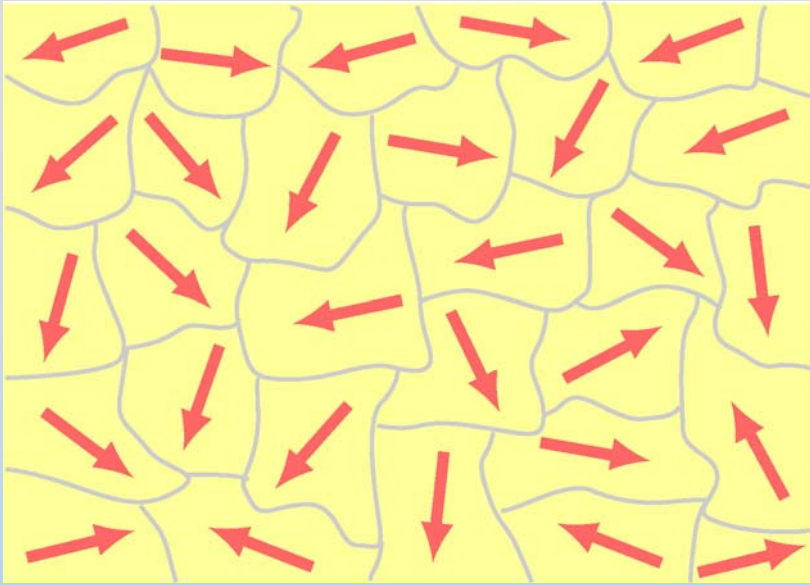


The aligned moments tend to **increase** the B field

$$\vec{\mathbf{B}} = \kappa_m \vec{\mathbf{B}}_0$$

Compare to: $\vec{\mathbf{E}} = \frac{\vec{\mathbf{E}}_0}{\kappa_E}$

Para/Ferromagnetism

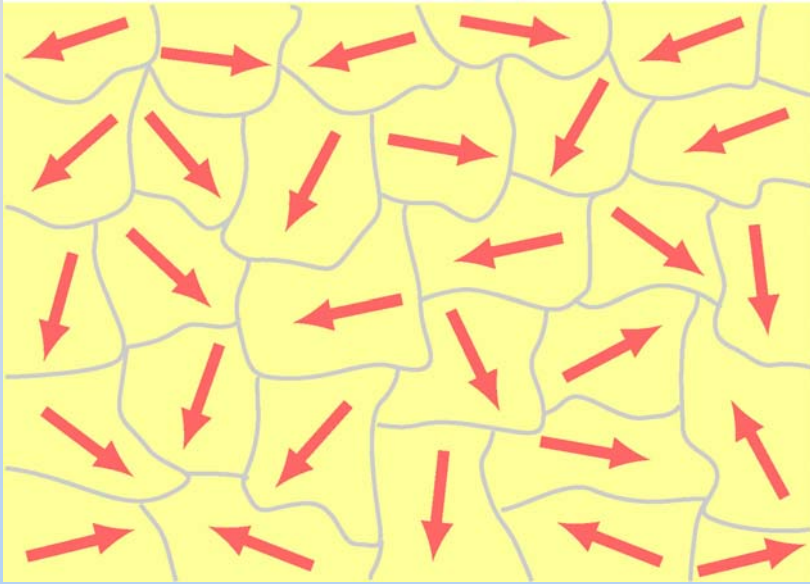


Paramagnet: Turn off B_0 , everything disorders

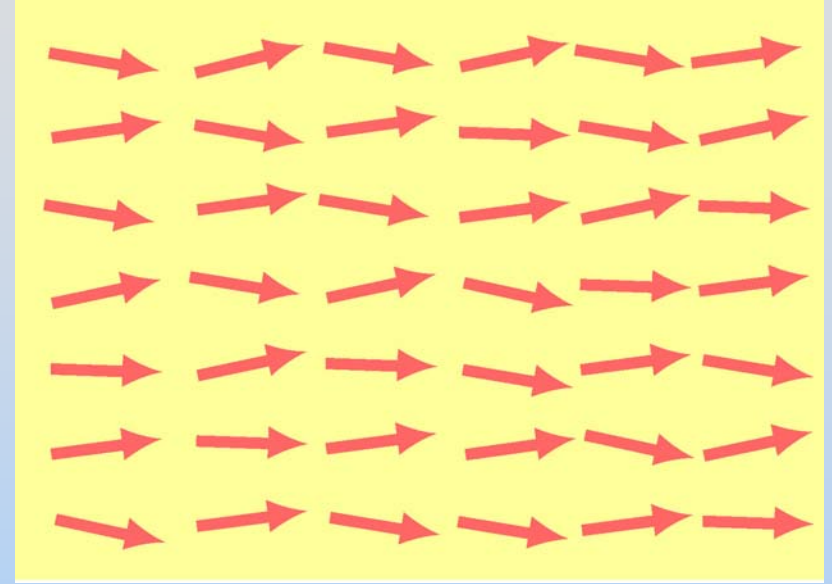
Ferromagnet: Turn off B_0 , remains (partially) ordered

This is why some items you can pick up with a magnet even though they don't pick up other items P21- 34

Magnetization Vector



$M=0$



$M>0$

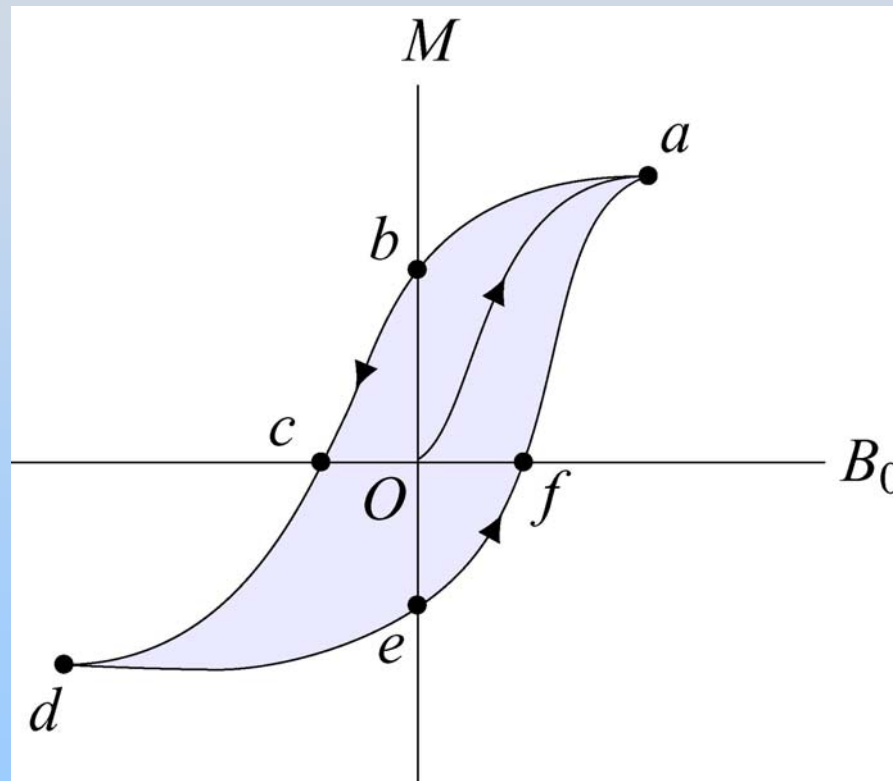
Useful to define “Magnetization” of material:

$$\vec{\mathbf{M}} = \frac{1}{V} \sum_{i=1}^N \vec{\mu}_i = \frac{\vec{\mu}}{V}$$

$$\vec{\mathbf{B}} = \vec{\mathbf{B}}_0 + \mu_0 \vec{\mathbf{M}}$$

Hysteresis in Ferromagnets

The magnetization M of a ferromagnetic material depends on the *history* of the substance



Magnetization remains even with B_0 off !!!