12/2: Announcements

1: Reminder: the Final Exam is Thursday morning, Dec 9, 08:00-11:00 a.m., in 2722 York Hall. You must bring:
Photo ID (e.g., UCSD I.D., driver's license, credit card w/ photo),
Scantron (same as before, the half-sheet red, X-101864-PAR-L) + pencils, Scientific Calculator, and three 3'x5' cards on which to write equations (I recommend taping/stapling them together).
If you neglect to bring your photo ID, you will have until 11:00 to go home, get your ID, and return to the final exam with it so we can verify your identify (otherwise you get a 0). The final exam will cover everything discussed in the lectures up through the end of lecture on Dec 2: from section 19.1 up through section 23.4. There will be at least 2 problems repeated from the quizzes and at least 2 problems taken directly from the extra practice problems (see below).

2: We're still aiming to hold two Review Sessions: One to review chapter 23 material, and one to review material for the entire course (plus practice problems: see below). Locations/Times are still TBD: Likely 12/6 or 12/7. I'll post an announcement on the main web page as soon as the time/location are confirmed.
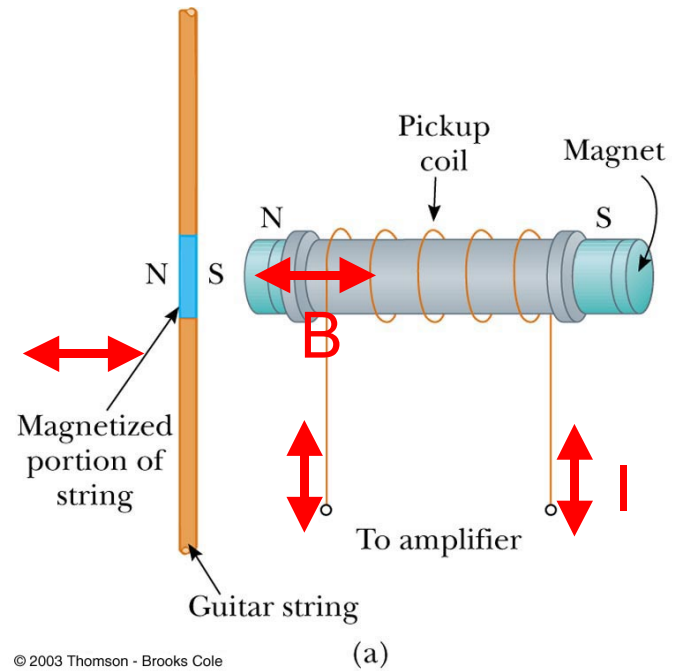
3: Some additional Practice Problems -- I'll post them on the web page approximately 12/3.

4. Reminder: Next week, both Grigor and I will have regular Monday office hours as usual. Both of us will move office hours from Thursday 12/9 to Wednesday 12/8 (AM: 11:30-12:30; GA: 2:00-3:00)
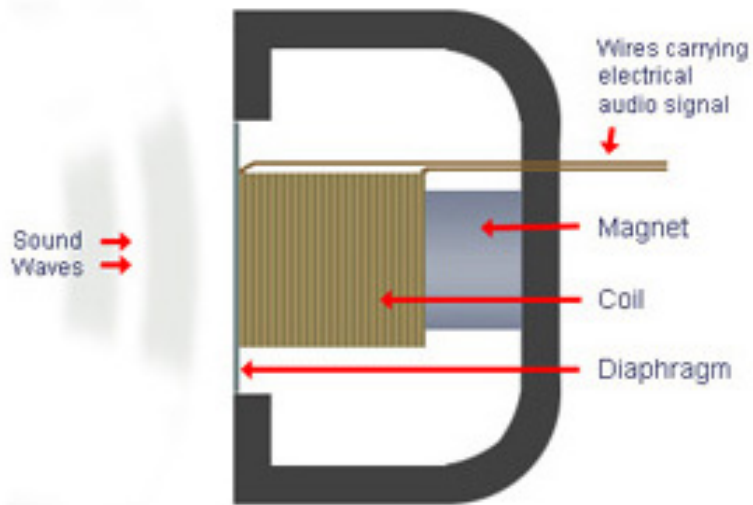
Application: Electric Guitars

changing magnetic flux induces
voltage in pickup coil

Microphones / acoustic pick-ups

(me in 1998, BTW)

Cross Section of a Microphone's Diaphragm

Wires carrying electrical audio signal

Sound Waves

Magnet

Coil

Diaphragm

microphones.audiolinks.com

Ground Fault Interrupters

Hair dryer

Ground fault interrupter

Wall outlet

120 V

(a)

Ground Fault Interrupters

Hair dryer

I

Ground fault interrupter

Wall outlet

120 V

(a)
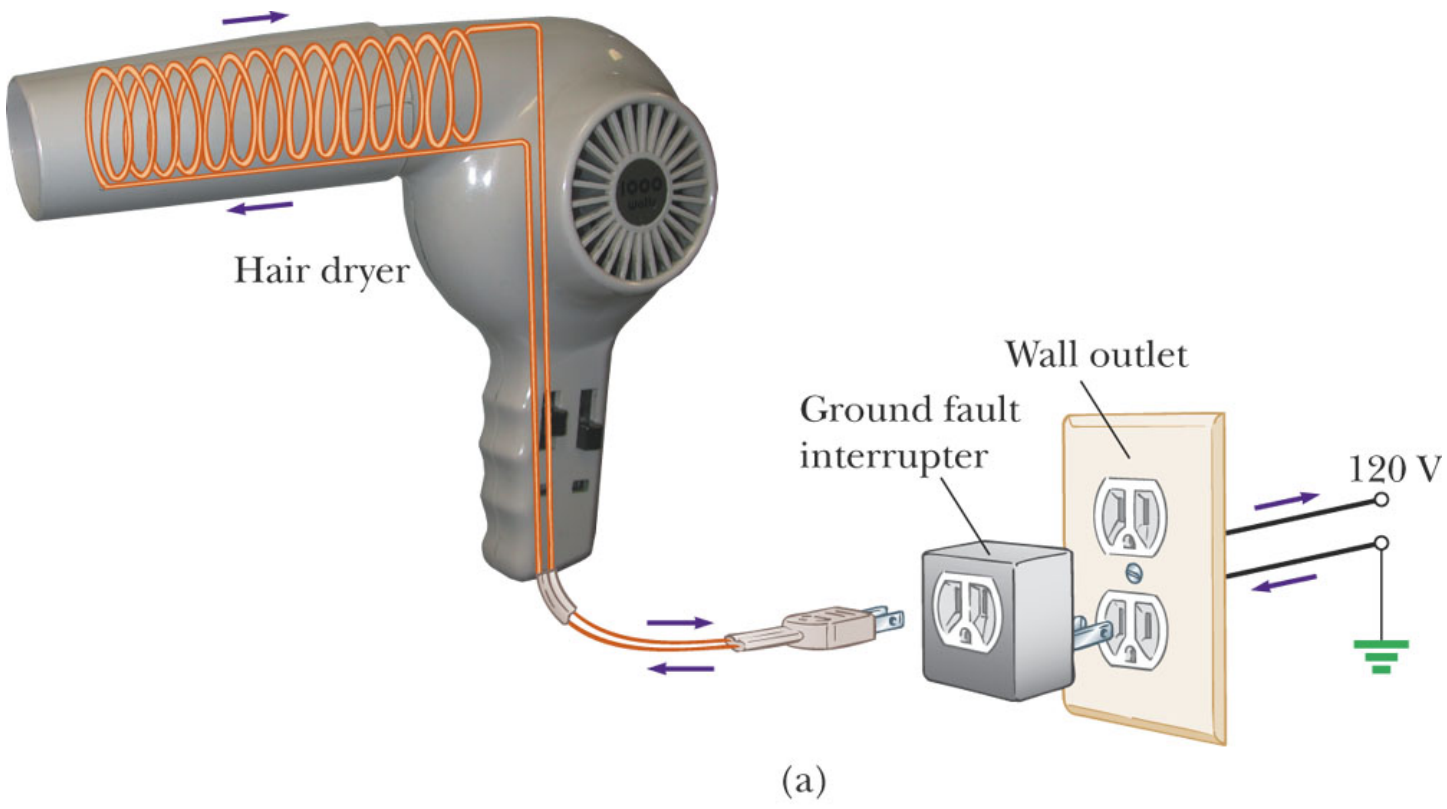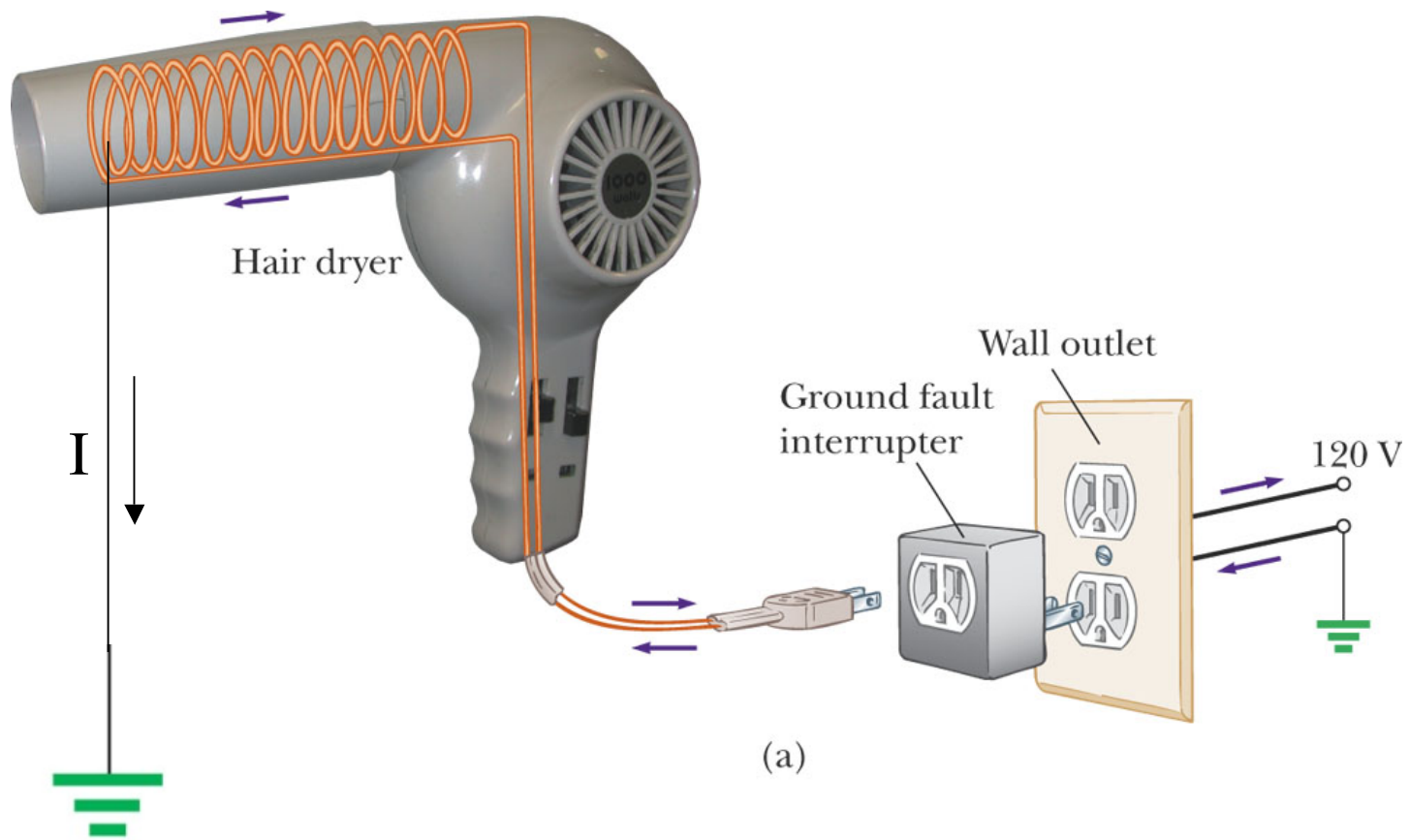
If a connection to ground is accidentally made…

Ground Fault Interrupters

Hair dryer

I

Ground fault interrupter

Wall outlet

120 V

(a)
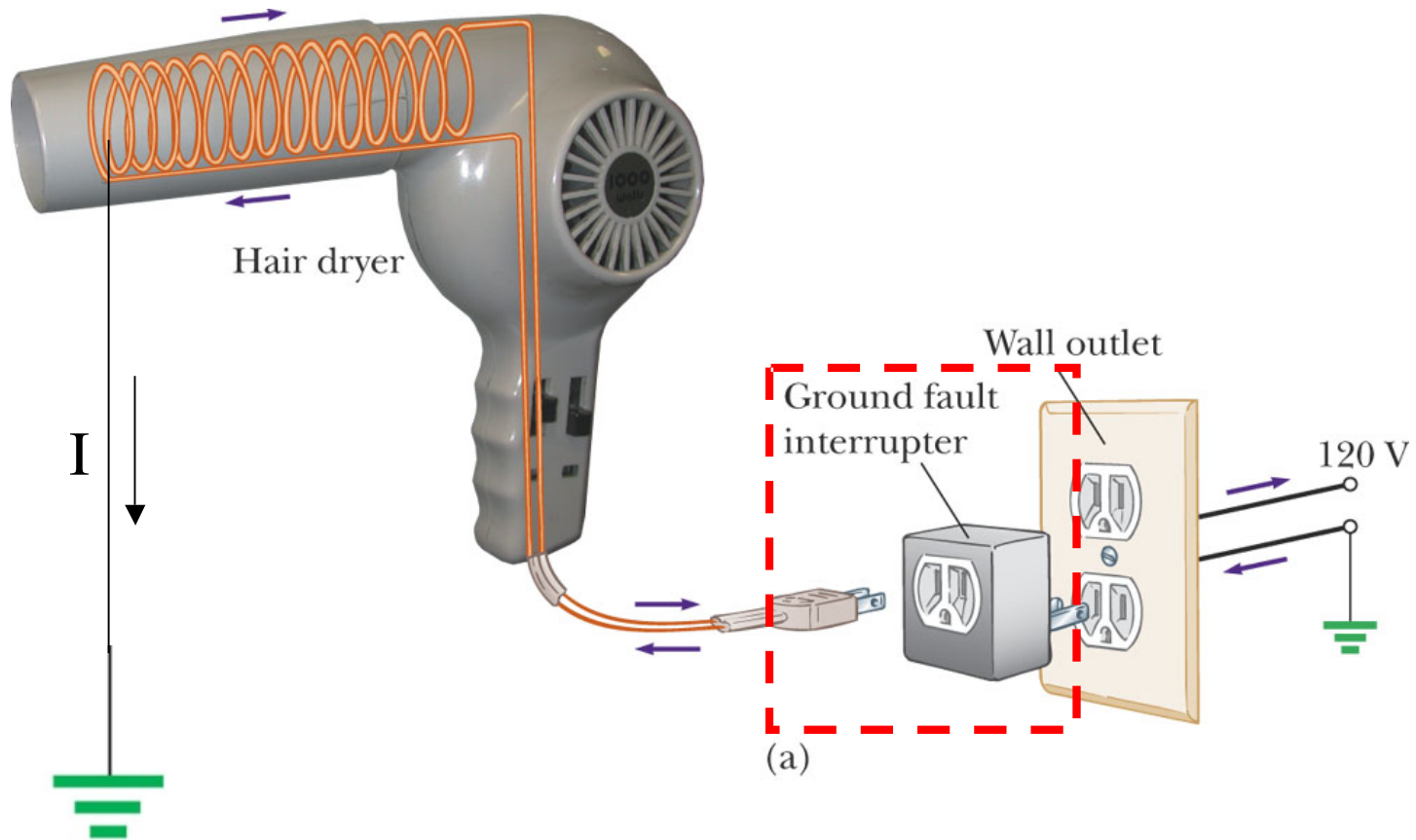
… the ground fault interrupter shuts off the device

Ground Fault Interrupters
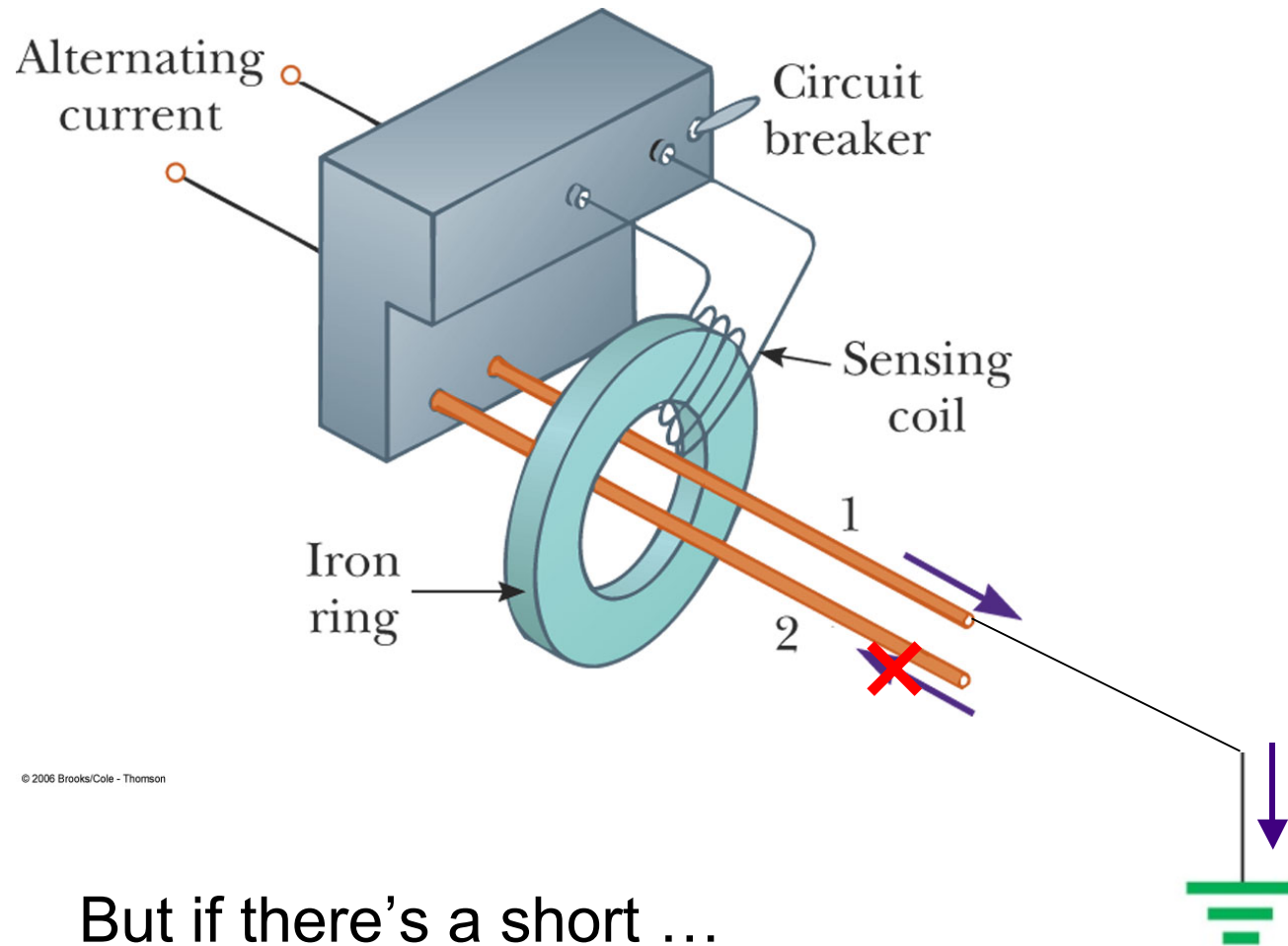

Alternating current

Circuit breaker

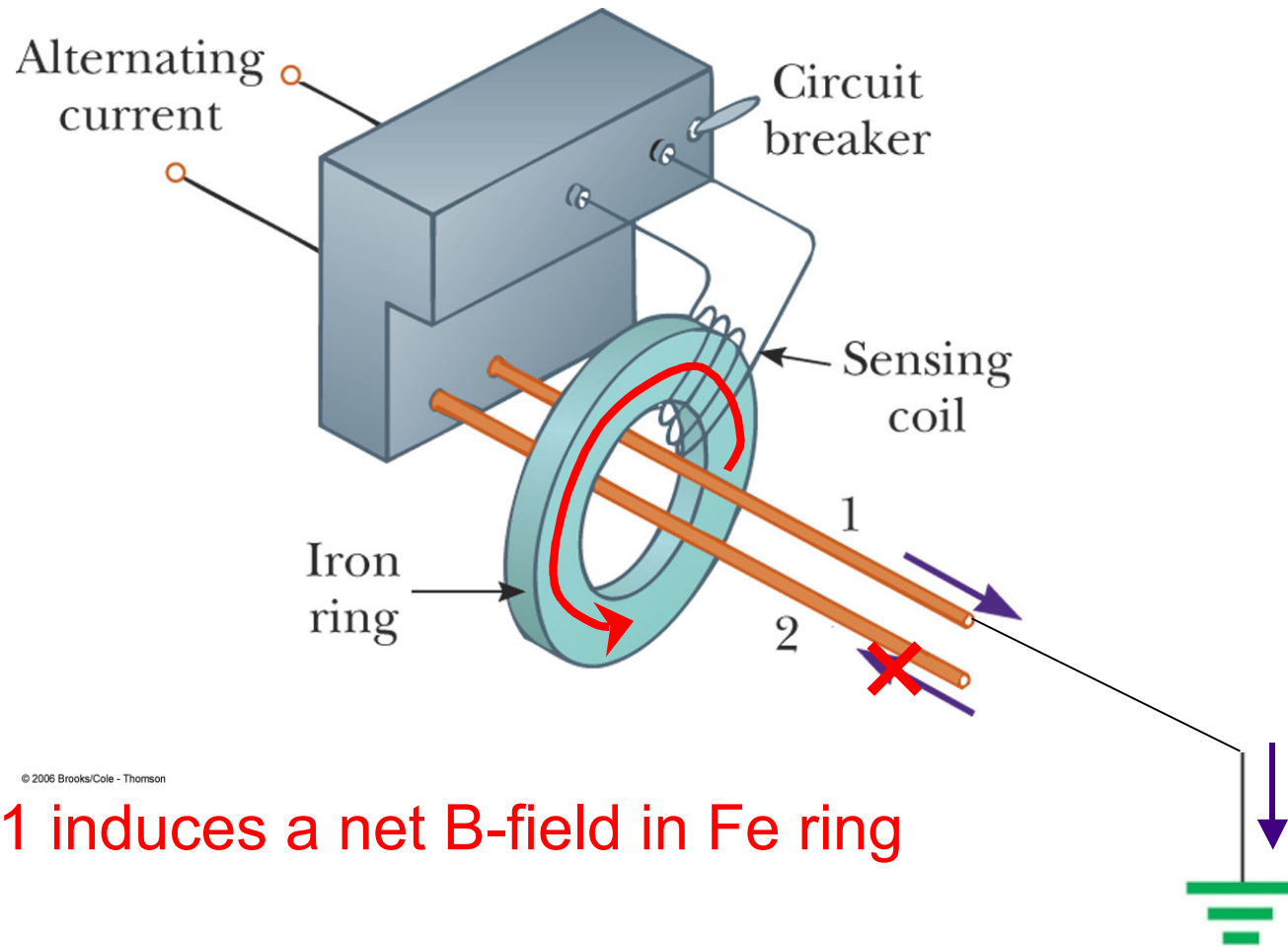Sensing coil

1

2

Iron ring
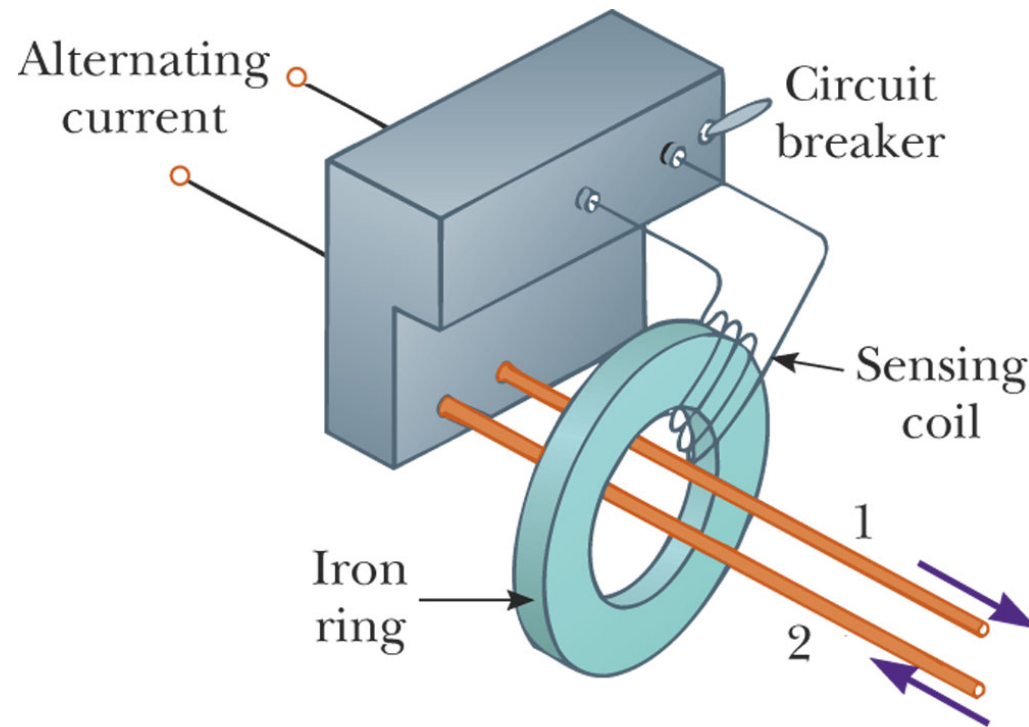
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Under normal operation, I_1 & I_2 are equal and opposite. Net B-field through Fe ring is zero.

Ground Fault Interrupters

Alternating current

Circuit breaker

Sensing coil

Iron ring

1

2

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But if there's a short …

Ground Fault Interrupters

Alternating current

Circuit breaker

Sensing coil

Iron ring

1

2

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… wire 1 induces a net B-field in Fe ring

Ground Fault Interrupters

Alternating current

Circuit breaker

Sensing coil

Iron ring

1

2
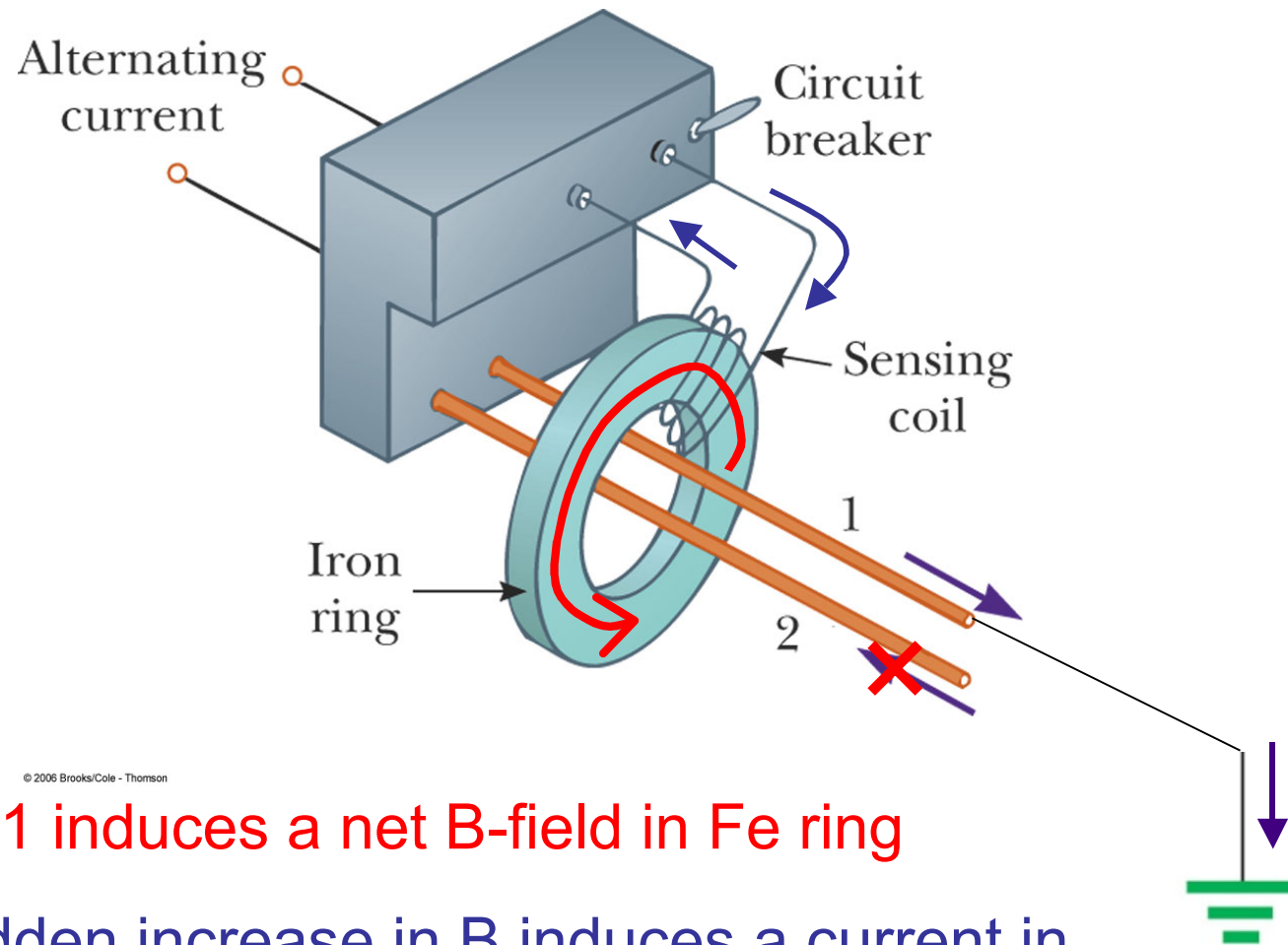
© 2006 Brooks/Cole - Thomson

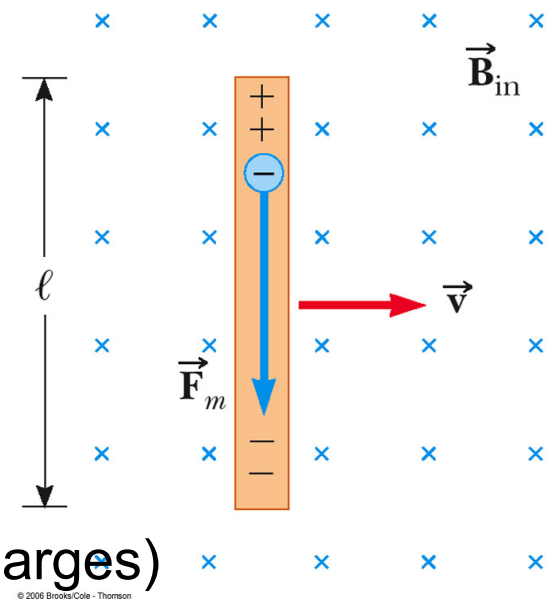… wire 1 induces a net B-field in Fe ring

The sudden increase in B induces a current in sensing coil, which triggers the circuit breaker

23.2 Motional EMF

ε_{ind} from a conductor which is
moving through a B-field

Conducting rod moving at a constant velocity $\vec{v}$

Charges experience $\vec{F}_M = qvB$ upward (for + charges)

Negative charges accumulate at bottom. Net + charge
accumulates at top.

This continues until $\vec{F}_E$ and $\vec{F}_B$ are balanced: $qE = qvB$

Potential difference $\Delta V = E\ell = B\ell v$
Upper end is at higher potential than lower end.

AC Current Generators

Uses mechanical work to generate electrical current. Rotary motion from falling water (hydroelectric) or steam (coal-fired plant) directed against turbine blades.
A coil rotates, Φ_B through the coil changes, and EMF is produced. (similar to a motor in reverse)

EMF in wire BC = $B\ell v_\perp = B\ell v\sin\theta$

EMF in wire AD = $B\ell v_\perp = B\ell v\sin\theta$

Total EMF $\varepsilon = 2B\ell v\sin\theta$

Assume loop rotates with constant angular speed $\omega = \theta/t$. ($\omega = 2\pi f$)

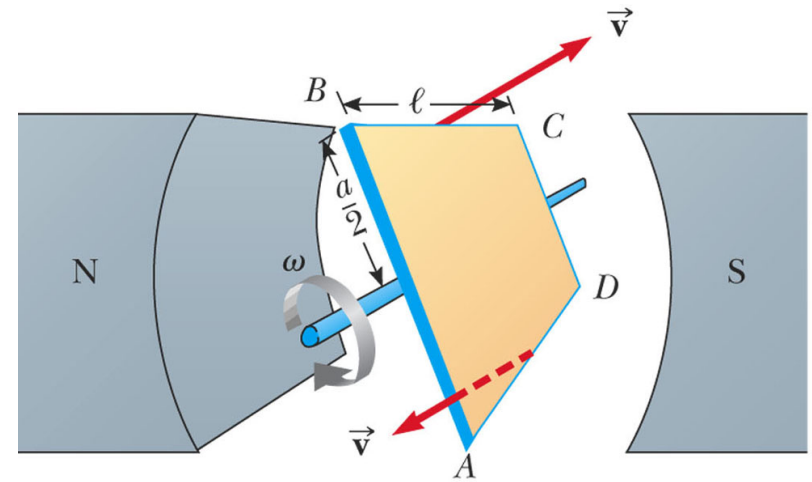$v = r\omega = (a/2)\omega$
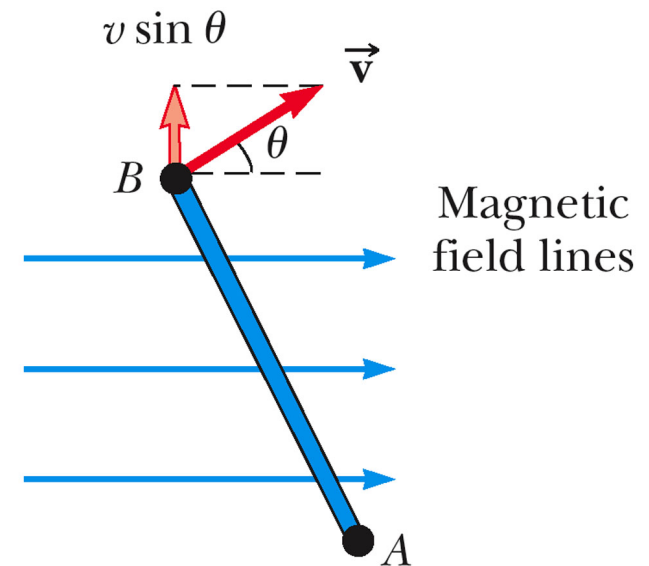
$\varepsilon = 2B\ell\,(a/2)\omega\,\sin\omega t$

$a\ell$ = Area A

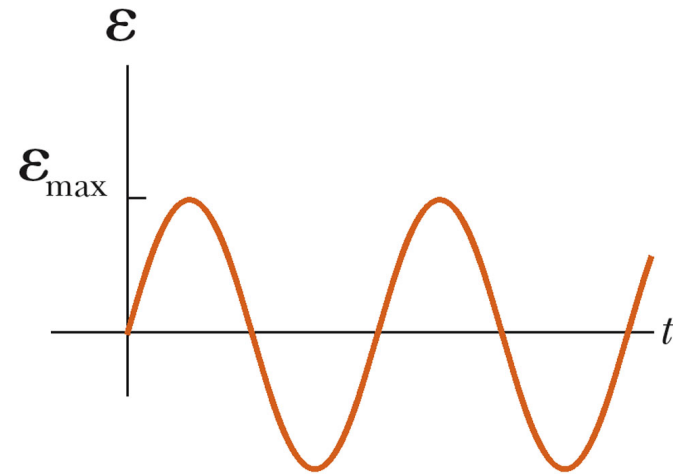Assume coil has N loops:

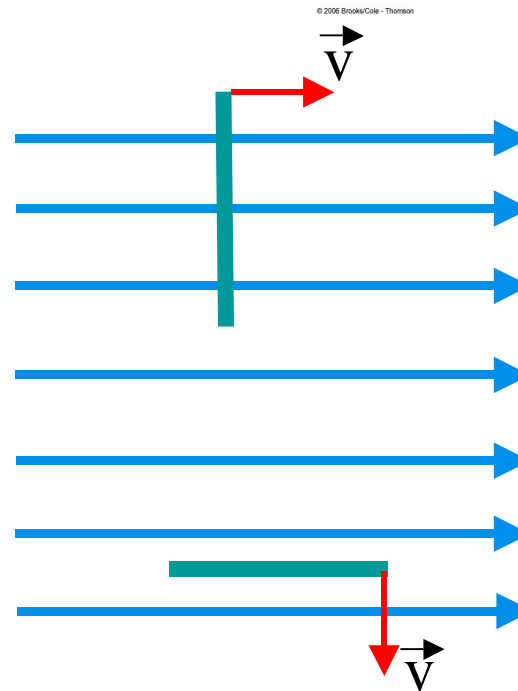**$\varepsilon = NBA\omega\,\sin\omega t$**

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$\varepsilon_{max} = NBA\omega$

ε

ε_{max}

t

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$\varepsilon = 0$ when $\theta = 0°$ or 180°: when plane of loop is ⊥ to B-field

$\vec{V}$

$v \sin \theta$

$\vec{v}$

θ

B

Magnetic field lines

A

$\varepsilon = \varepsilon_{max}$ when $\theta = 90°$ or 270°: when plane of loop is parallel to B-field lines ($v_\perp$ is maximized)

$\vec{V}$

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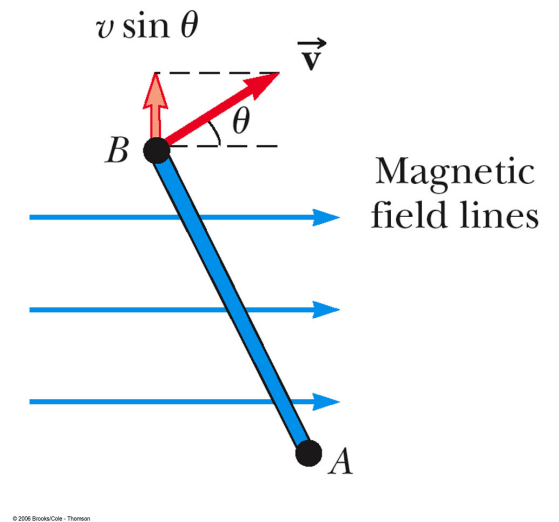
One similarity between electric motors and AC generators:

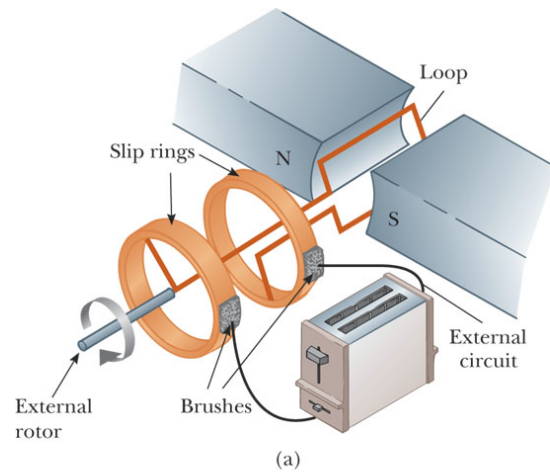In AC generators, the maximum induced EMF occurs when $d\Phi_B/dt$ is the greatest during the loop's rotation -- this occurs when the plane of the loop is PARALLEL to the B-field.

In electric motors, the maximum torque on a current-carrying loop occurs when the plane of the loop is PARALLEL to the B-field.

AC generators

f = 60 Hz (U.S. & Canada), 50 Hz for Europe
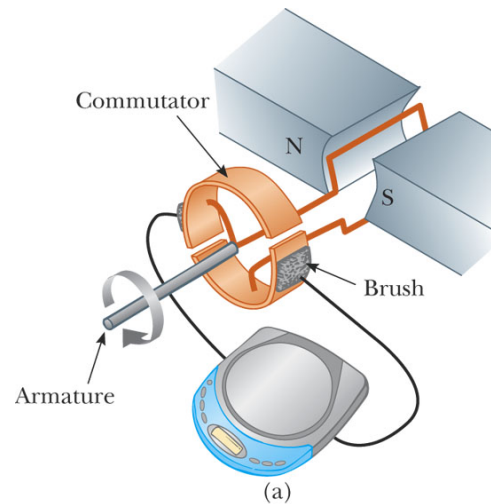
$\omega = 2\pi f = 377$ rad/s
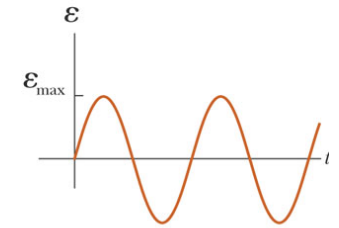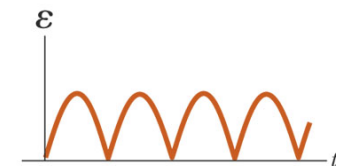

DC generators: use commutators

To get a DC output with minimal fluctuations: Use many loops & commutators distributed around the axis of rotation so that sinusoidal pulses overlap in phase

Example for an AC generator

In a model AC generator, a 50-turn coil measuring 0.1m x 0.2 m rotates at a frequency of 20 revs/second in a field of 0.5 T. What's the maximum instantaneous EMF that can be produced?

Soln: Use $\varepsilon_{max} = NBA\omega$

$\varepsilon_{max} = (50)(0.5T)(0.1m 0.2m)(2\pi{*}20 \text{ Hz}) = 62.8 \text{ V}$

The total resistance of the wire is 10 Ω. What's the maximum instantaneous induced current I_{max}?

$I_{max} = \varepsilon_{max} / R = 62.8 \text{ V} / 10 \ \Omega = 6.28 \text{ A}$

Remember: ε and I vary sinusoidally as a function of time; ε_{max} and I_{max} are their amplitudes.

Transformers

Device for
transforming an AC
voltage to a higher
or lower voltage

Soft iron

ΔV_1

N_1 N_2

S

R

Z_1

Primary
(input)

Z_2

Secondary
(output)
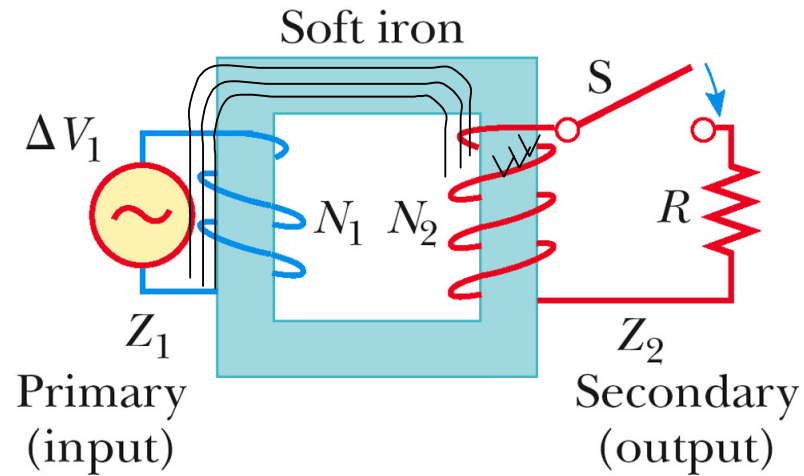
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"Soft magnetic" iron core: increases the magnetic flux,
and provides a medium such that nearly all Φ_B passing
through coil 1 ends up in coil 2, too.

Transformers

voltage across primary:
$\Delta V_1 = -N_1 \, d\Phi_B/dt$

Induced voltage across
secondary: $\Delta V_2 = -N_2 \, d\Phi_B/dt$

$$\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1}$$

Soft iron

Primary (input)

Secondary (output)

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When $N_2 > N_1$ $\Delta V_2 > \Delta V_1$ -- it's a step-up transformer
When $N_2 < N_1$ $\Delta V_2 < \Delta V_1$ -- it's a step-down transformer
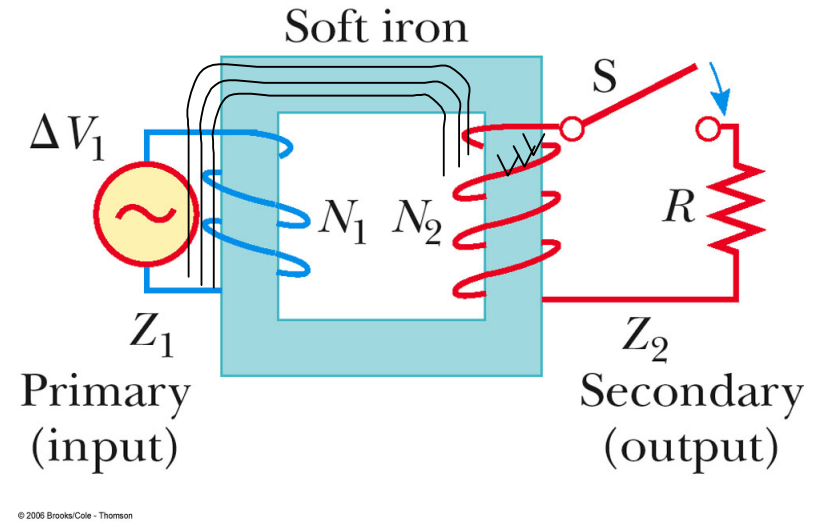
Power input = power output

An ideal transformer is defined as one where there is no power loss between the input & output:

$$I_1 \Delta V_1 = I_2 \Delta V_2$$

So in a step-up transformer, ΔV_2 may be very high but I_2 will be low.

This stems from conservation of energy!

Electric Power Distribution

Recall why it's useful to transmit power at high voltage and low I (minimizes resistive power losses during transmission).

But lower voltage is safer to handle.

So we use transformers to step-up/step-down voltage as needed

Electric Power Distribution

Transformer substation

Power substation

~20 kV

200-365 kV

4-7 kV

240V

Transmission Line (10s–100s of miles)

Distribution line in city

Power plant

(San Onofre nuclear power plant)

Transformer drum
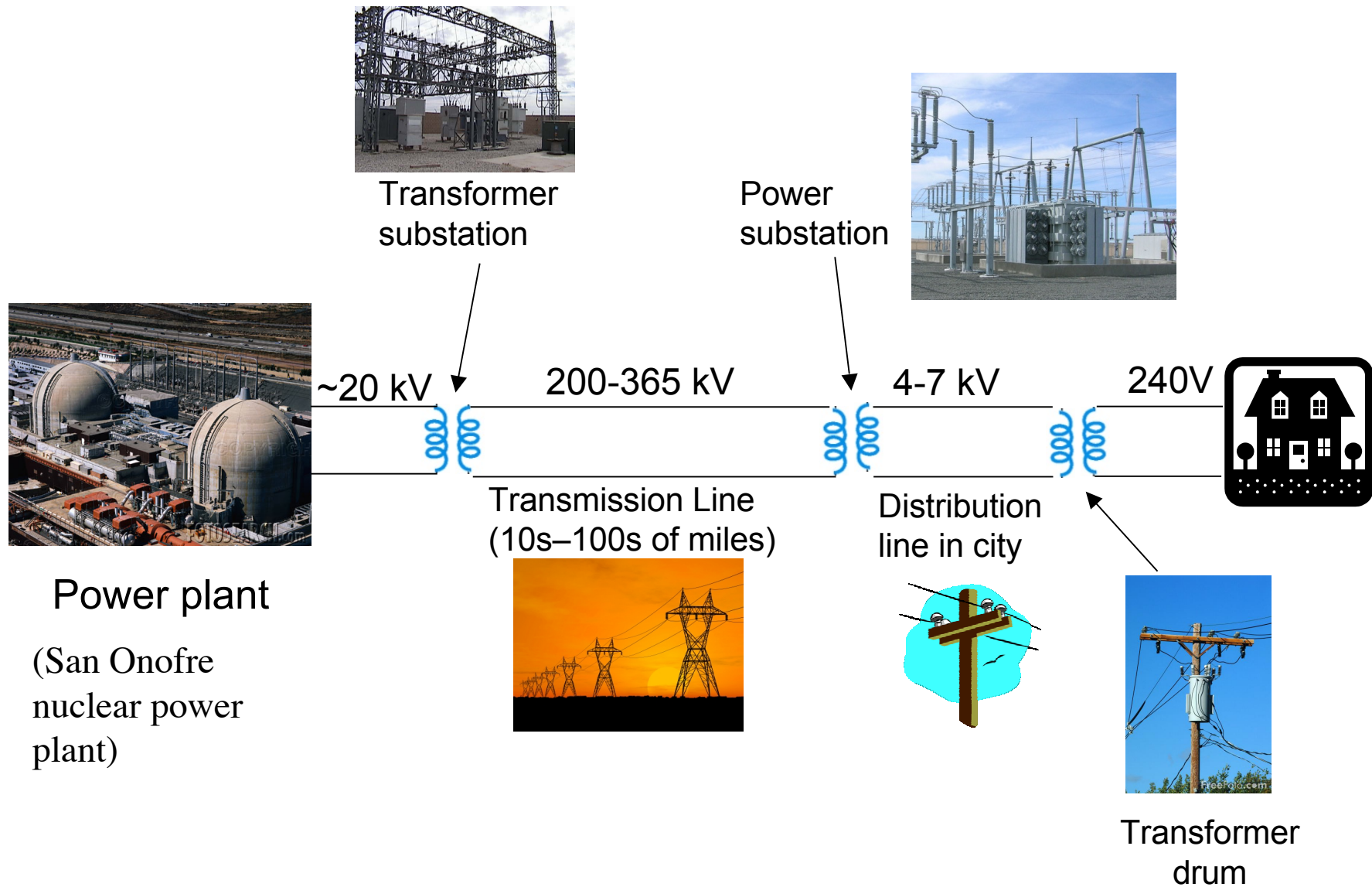
23.3 Lenz's Law:

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

Determines the direction the induced current flows.

The current caused by the induced EMF travels in the direction that creates a magnetic field whose flux OPPOSES the CHANGE in the original magnetic flux.

i.e., the induced current will flow to try to maintain the original magnetic flux thru the loop.

Lenz's Law:

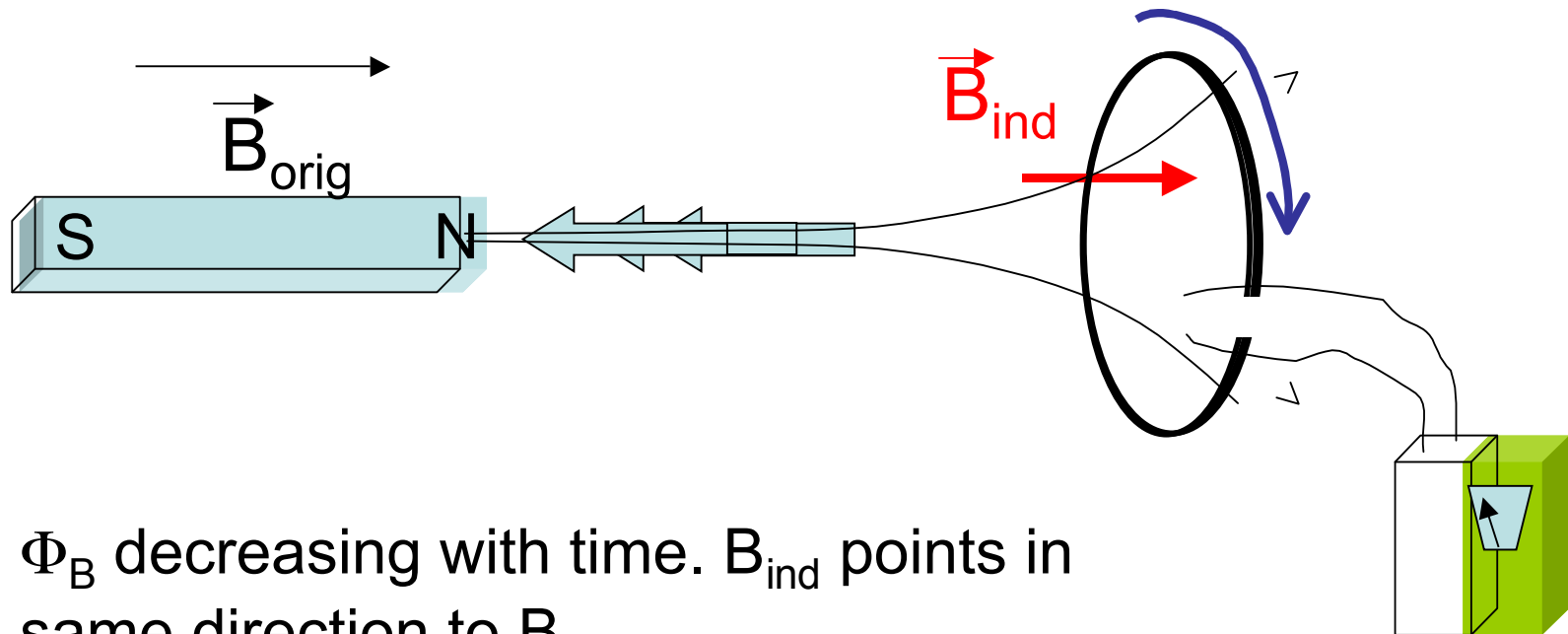Induced B-field B_{ind} "shores up" original Φ_B if original Φ_B is shrinking with time, or opposes the original Φ_B if original Φ_B is growing with time.
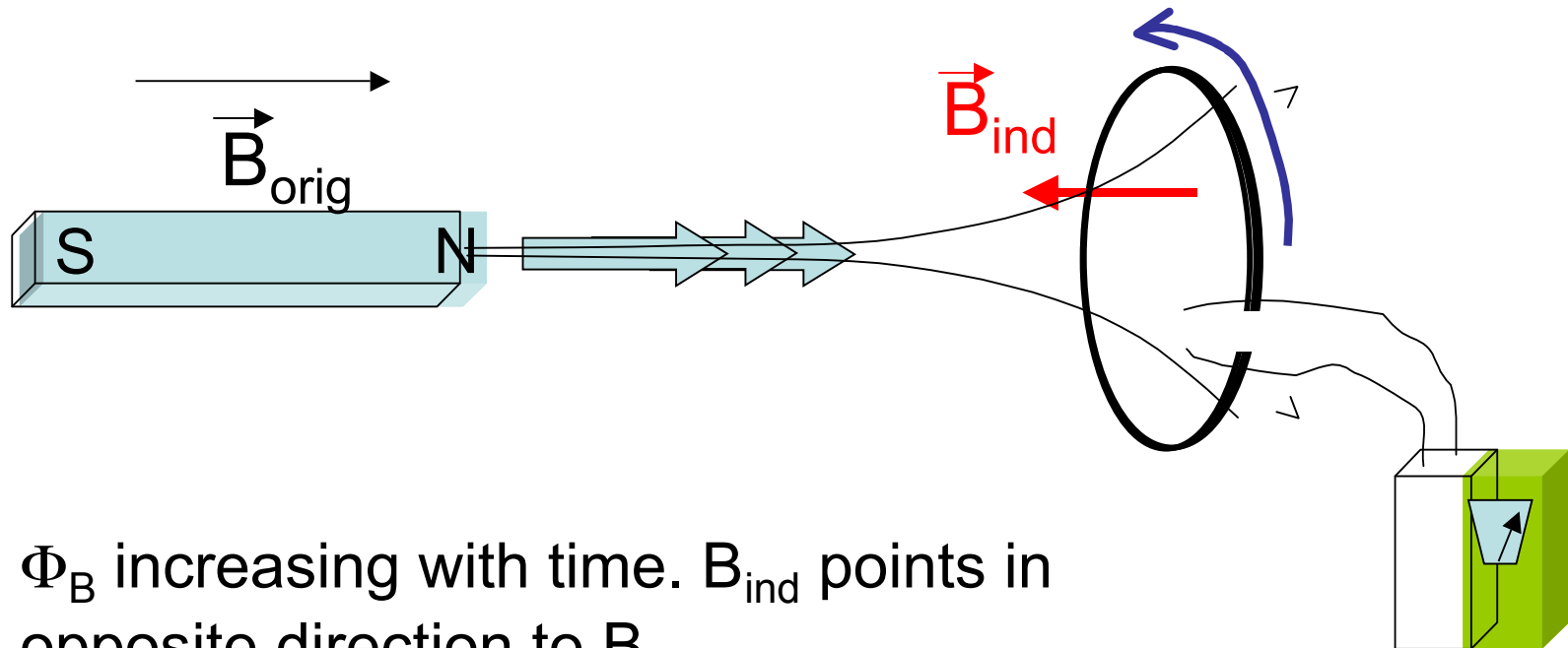
Φ_B increasing with time. B_{ind} points in opposite direction to B_{orig}.

Lenz's Law:

Induced B-field B_{ind} "shores up" original Φ_B if original Φ_B is shrinking with time, or opposes the original Φ_B if original Φ_B is growing with time.

$$\vec{B}_{orig}$$

$$\vec{B}_{ind}$$

S   N

Φ_B decreasing with time. B_{ind} points in same direction to B_{orig}.

Lenz's Law:

Induced B-field B_{ind} "shores up" original Φ_B if original Φ_B is shrinking with time, or opposes the original Φ_B if original Φ_B is growing with time.

Φ_B (now defined as flux towards the left) is decreasing with time. B_{ind} points in same direction to B_{orig}.

Lenz's Law:

Induced B-field B_{ind} "shores up" original Φ_B if original Φ_B is shrinking with time, or opposes the original Φ_B if original Φ_B is growing with time.
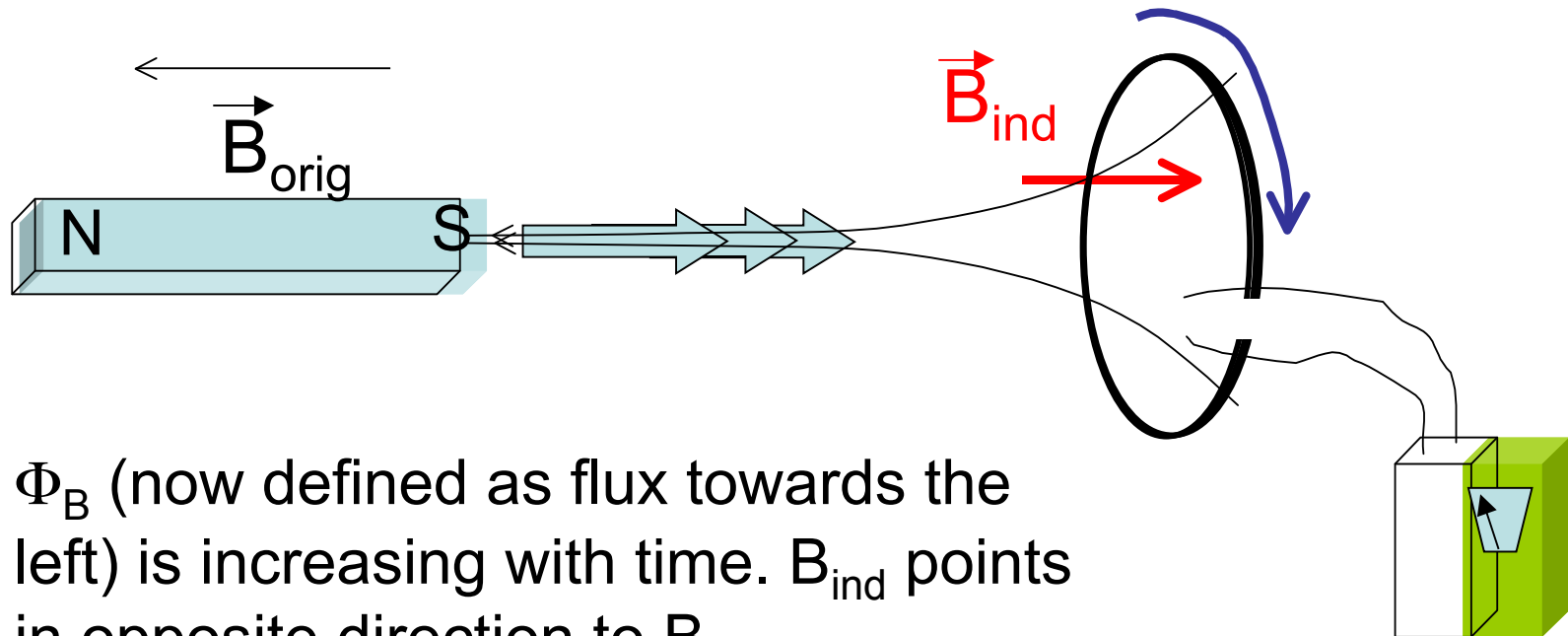
Φ_B (now defined as flux towards the left) is increasing with time. B_{ind} points in opposite direction to B_{orig}.
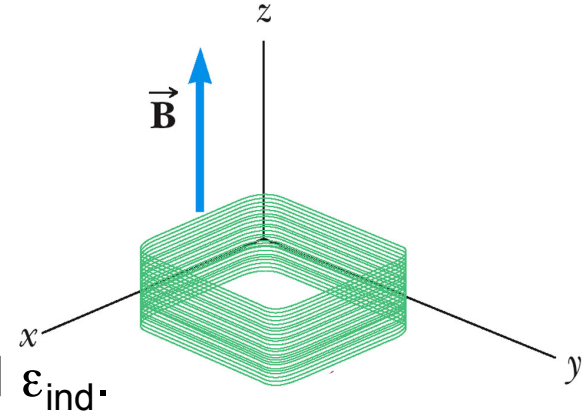
Example

Given: a square coil with 25 turns. Each side is 1.8cm. The total resistance of the coil 0.35Ω. A uniform B-field is applied in the +z direction.

a) If B changes from 0 T to 0.5 T in 0.8 s, find ε_{ind}.

First, find $\Phi_{Binitial}$ & Φ_{Bfinal}:

$\Phi_{Binitial} = B_{init}A \cos 0° = 0$

$\Phi_{Bfinal} = B_{final}A \cos 0° = 0.5T(0.018m)^2 = 1.62 \times 10^{-4}$ Wb

$\Delta\Phi_B = \Phi_{bfinal} - \Phi_{Binitial} = 1.62 \times 10^{-4}$ Wb

Then use Faraday's Law:

$\varepsilon_{ind} = -N \Delta\Phi_B/\Delta t = -25(1.62 \times 10^{-4}$ Wb$) / 0.8s = -5.06 \times 10^{-3}$ V

Example

Given: a square coil with 25 turns. Each side is 1.8cm. The total resistance of the coil 0.35Ω. A uniform B-field is applied in the +z direction.

b) Find the magnitude & direction of the current induced while the field is changing.

Use Ohm's Law to find the magnitude of I

$I = \Delta V/R = 5.06 \times 10^{-3}$ V $/ 0.35Ω = 1.45 \times 10^{-2}$ A

The direction is found from Lenz's Law: $\vec{B}$ is increasing up through the loop. Φ_B is also positive and increasing. The induced B-field will thus point downward. The induced current will circulate clockwise (right-hand rule with thumb pointing downward).
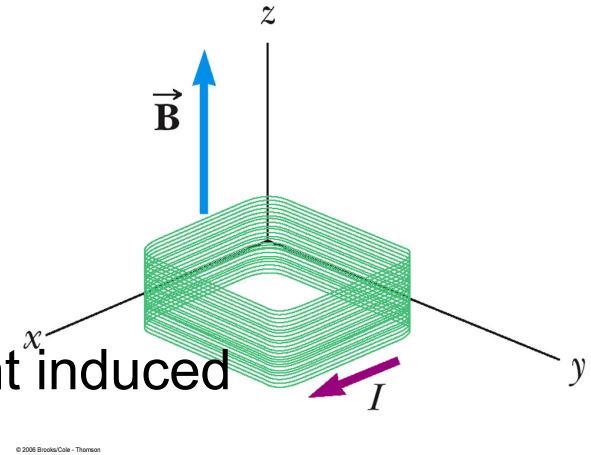
Eddy Currents

Drop a magnet down a cylindrical conductor, N-pole first.

S

N
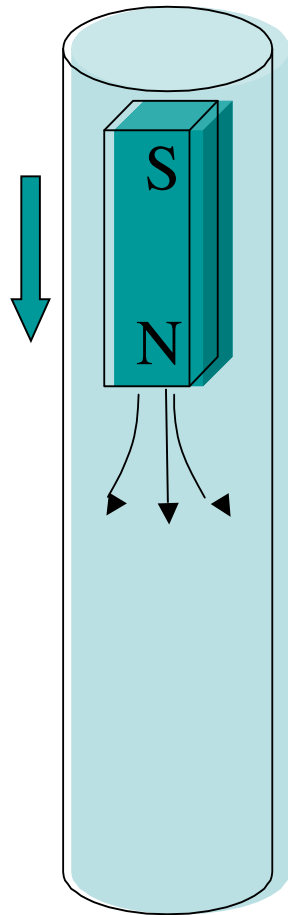
Ahead of (below) the magnet:

B increasing

Eddy Currents

Drop a magnet down a cylindrical conductor, N-pole first.
Currents are induced in the conductor to oppose the
movement of the magnet:

Ahead of (below) the magnet:

B increasing

I_{ind}

induced magnetic dipole

two N poles: repel
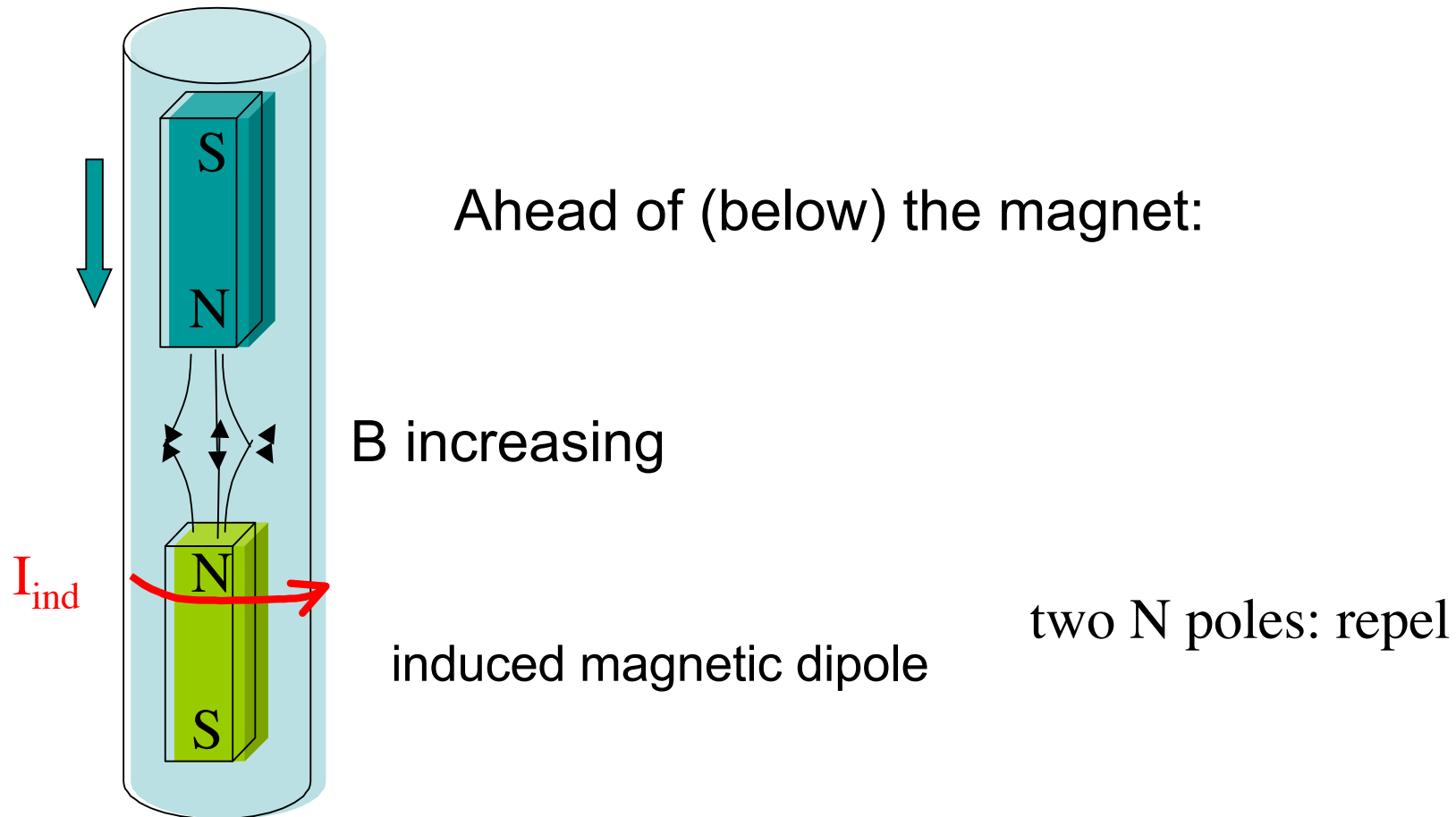
Eddy Currents

In the region behind (above) the magnet:

I_{ind}
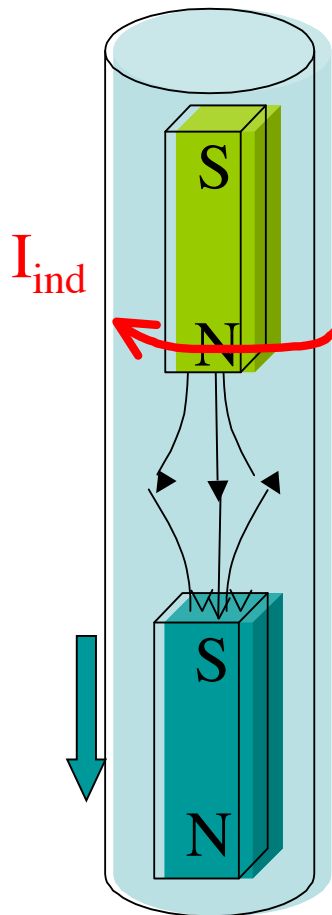
induced magnetic dipole

B decreasing

N & S pole: attract

S

N

S

N

Eddy Currents

Selected yt videos of eddy currents:

http://www.youtube.com/watch?v=nrw-i5Ku0mI

http://www.youtube.com/watch?v=pcVG6c_OvYU

http://www.youtube.com/watch?v=37e_OROP9dA

http://www.wonderhowto.com/how-to-experiment-with-magnets-and-eddy-currents-353892/

23.4 Induced emf and Electric Fields

- Eddy currents: An electric field is created in the conductor as a result of the changing magnetic flux

- If there is an induced current, there must also exist an induced electric field (associated with the induced EMF) which will drive that current

- Even in the absence of a conducting loop, a changing magnetic field will generate an electric field even in empty space

- This induced electric field has different properties than the E-field produced by stationary charges (electrostatic field)

dB/dt > 0

- The emf for any closed path can be expressed as the line integral of $\vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$ over the path

- Faraday's Law can be written in a general form

$$\varepsilon = \oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d\Phi_B}{dt}$$
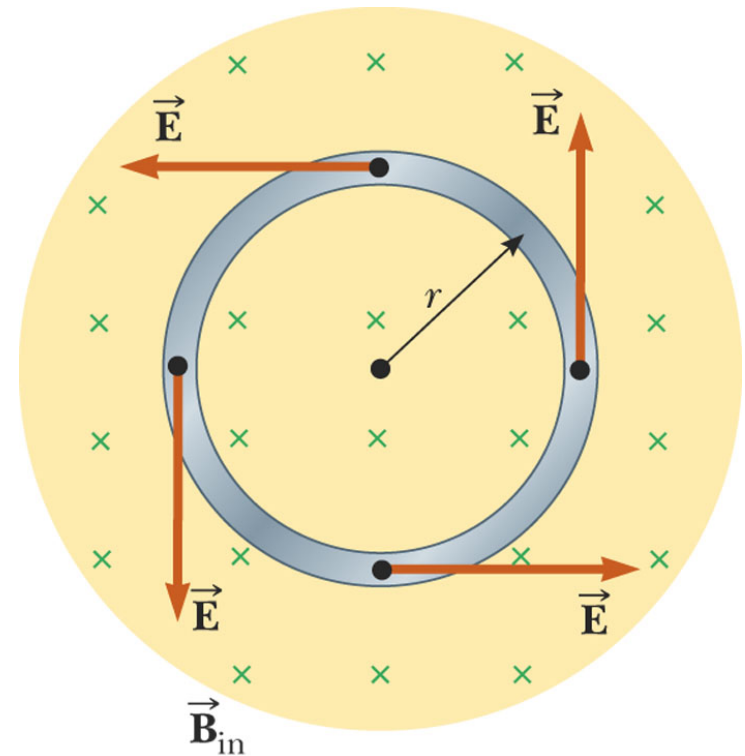
The induced electric field is a nonconservative field that is generated by a changing magnetic field

Work done to move a charge around a closed loop is not zero

In Ch 19, we said that all E-field lines begin and end on charges. That's only true for ELECTROSTATIC fields (all charges stationary)

E-field lines due to changing B-fields form closed loops, and are independent of the presence/lack of charges

Some final notes (I):

Though we did not get to these topics in the lectures, I want to encourage you to read ahead in your textbook on your own in the second half of chapter 23 and at least the first half of chapter 24:

1) Inductors/inductive circuits have many applications in many electronic devices, particularly when you combine inductors with resistors and capacitors in circuits driven by an AC voltage source. Speaker stereo systems, for example, rely on circuits with high inductance values to dampen out rapidly-variable electronics signals associated with high-frequency (high-pitch) sounds; these are the "woofer" speakers which permit only low-frequency electronic signals associated with low-frequency (low-pitch) sounds. Circuits with high capacitance values, meanwhile, can dampen out slowly-variable electronic signals associated with low-frequency (low-pitch sounds), allowing only high-frequency signals (from high-pitch sounds) through -- these are the "tweeter" speakers for higher-pitch sounds.

Circuits combining inductors with capacitors that have adjustable capacitance values are also used in radios to pick up the broadcast signals of a radio station broadcasting at a certain frequency (the "resonant frequency" as discussed in chapter 24)

2) Maxwell's Equations, discussed in chapter 24, are a set of 4 equations, most of which were already discussed in previous chapters -- these equations describe fully the behavior of electric and magnetic fields and how/why they change in time. The group of four equations together provides a cornerstone of modern physics in that they predict the existence and properties of electromagnetic radiation (light) and thus unify electricity, magnetism, and light.

Some final notes (II):

Just to add on to what I discussed on Tuesday 11/30 regarding debunking the magnetic "therapy" bracelets -- While these bracelets offer no medical benefits to those who purchase them, their existence does not mean that magnetism has no proper utility in the medical field.

MRI (magnetic resonance imaging) is a powerful radiological tool to diagnose internal conditions in a patient without resorting to surgery. MRI studies the magnetic dipoles of the atoms in a patient's body and how they respond to a strong external magnetic field (atoms corresponding to various types of tissues in the body will respond differently, allowing a 3-D map of the interior of the patient to be made).

Also common during MRI procedures is to use a "contrast", which is a tracing substance injected intraveneously into the patient's bloodstream to better track the flow of blood (and determine if there is internal bleeding). One common contrast includes an iron-gadolinium substance; both elements are ferromagnetic and thus their signature is captured very easily by the MRI imaging process.

Finally, if someone says that they "have a magnetic bracelet", don't jump down their throat just yet, as they might not be referring to therapy bracelets. Some bracelets and necklaces sold nowadays come with magnetic clasps for easy fastening/unfastening. Also, back in June, I saw an ad for a Father's Day gift consisting of a wristband with a magnet on it to which you can attach loose nuts/bolts so you don't lose them while working. That is, in addition to the MRI, these are two examples of magnetism used properly to better our lives, etc.

Some additional notes on AC voltages and currents:

We ran out of time at the last lecture to go into this in detail. I'll post my notes here, though this will not be covered on the final exam.
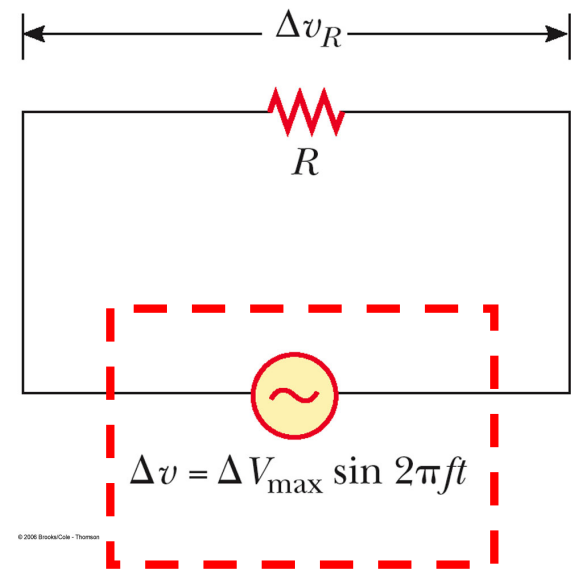
AC circuits: time-dependent voltage

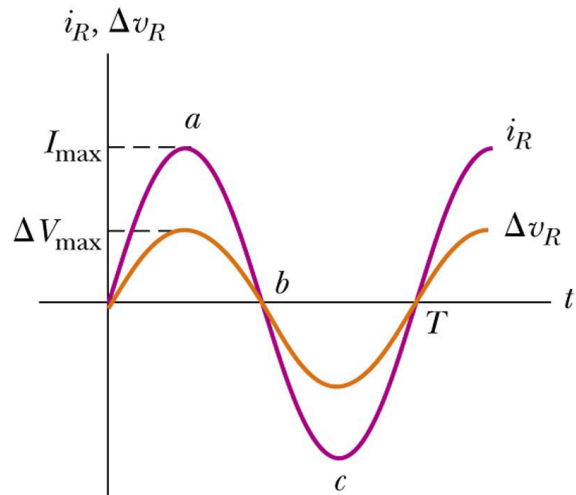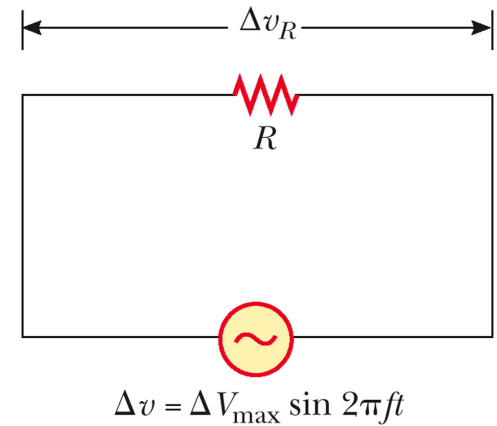AC generator drives voltage:

$$\Delta v = \Delta V_{max} \sin 2\pi f t$$

$$= \Delta V_{max} \sin \omega t$$

f = freq in Hz (cyc s^{-1}, or s^{-1})

ΔV & current alternate between positive and negative values, but as we'll see, current & voltage do not always vary in phase, because Resistors, capacitors and inductors react differently to time-dependent voltages.

AC circuit with a Resistor:

$$\Delta v_R$$

$$\Delta v = \Delta V_{max} \sin 2\pi ft$$

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Plot of I(t) and ΔV_R(t)

They reach their max/min points simultaneously.

"Vary in phase"

What's the AVERAGE current over one cycle?

What's the AVERAGE voltage over one cycle?

Zero for both.

But the direction of current has no effect on the behavior of the resistor: the same amount of power gets dissipated either way. You get the same frequency of collisions between the electrons and the molecular lattice

Recall $P = I^2R$: I =instantaneous current. P is the same whether I is + or −.

RMS current:

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707\, I_{max}$$

Average power dissipated through the resistor (over 1 or more cycles)

$$\wp_{av} = I_{rms}^2 R$$

RMS Voltage:

$$\Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}} = 0.707\, \Delta V_{max}$$

AC voltage of 120 V RMS means that $\Delta V_{max} = 170$ V

If we use RMS values, then many of the equations for AC currents will have forms quite similar to those for DC circuits.

Ohm's Law for an AC circuit with a resistor:

$$\Delta V_{R,rms} = I_{rms}R$$ and $$\Delta V_{R,max} = I_{max}R$$

Example:

Given: a 60-W lightbulb connected to a 120-volt (RMS) AC circuit. Calculate I_{rms}, R, I_{max} and ΔV_{max}

60 W is the average power dissipated. $P = I_{rms}^2 R = \Delta V_{R,rms} I_{rms}$

I_{rms} = 0.5 A

$R = P / I_{rms}^2 = 240 \, \Omega$

$I_{max} = \sqrt{2} \, I_{rms} = 0.707$ A

$\Delta V_{max} = \sqrt{2} \, \Delta V_{R,rms} = 170$ V

Note: $\Delta V_{max} = I_{max} R$
      170V = 0.707A×240Ω