Your questions/comments

IMPORTANT ANNOUNCEMENT: Exam 2 coming up Th Oct. 23, 2015!
Will cover Lect. 6 (circuit elements) – Lect. 12 (currents & magnetism)
Review session T Oct. 21, 2015 from 6-8pm (180 Bevier)

“What is the material covered on Exam II?”

“I know you explained it in class last time, and the hula hoop example really helped, but I'm having issues applying our knowledge on flux on actual problems, such as the Rotating Loop checkpoint.”

“the graphs are a little confusing. can we go over a couple different examples of them and different situations of flux changes?”

“Can we take a second during lecture to walk through how transformers work on a more in-depth level than was offered in the pre-lecture?”

“how do you know which coil of a transformer is primary and secondary?”

Phys 102 – Lecture 14

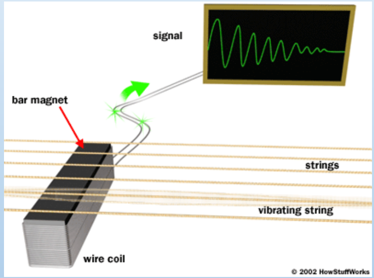
Faraday's law of induction

Today we will...

- Continue our discussion of electromagnetic induction unifying electricity & magnetism
  - Last time: Lenz' law for EMF ***direction***
  - Today: Faraday's law for EMF ***magnitude***
- Apply these concepts
  - Lenz' & Faraday's law are basis for electrical generators & transformers, and much more

Power plant

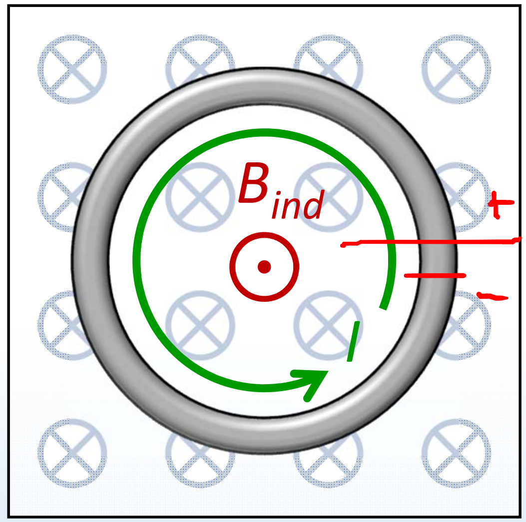
Credit card reader



Guitar pickup

ACT: Lenz' law refresher

A conducting loop is placed in a uniform *increasing B* field



EMF opposes change in flux:

1. Φ increasing
2. B_{ind} opposes B_{ext}
3. Current CCW (RHR)

In which direction does the current flow around the loop?

A. Clockwise
B. Counterclockwise
C. The current is zero

What about the magnitude of the EMF?

Faraday's law of induction

Change in flux Φ through a loop induces an EMF ε

Induced EMF ε

$$\boxed{\varepsilon = -\frac{\Delta\Phi}{\Delta t}}$$

Rate of change of flux Φ

Magnitude

Induced EMF ε = rate of change of flux Φ

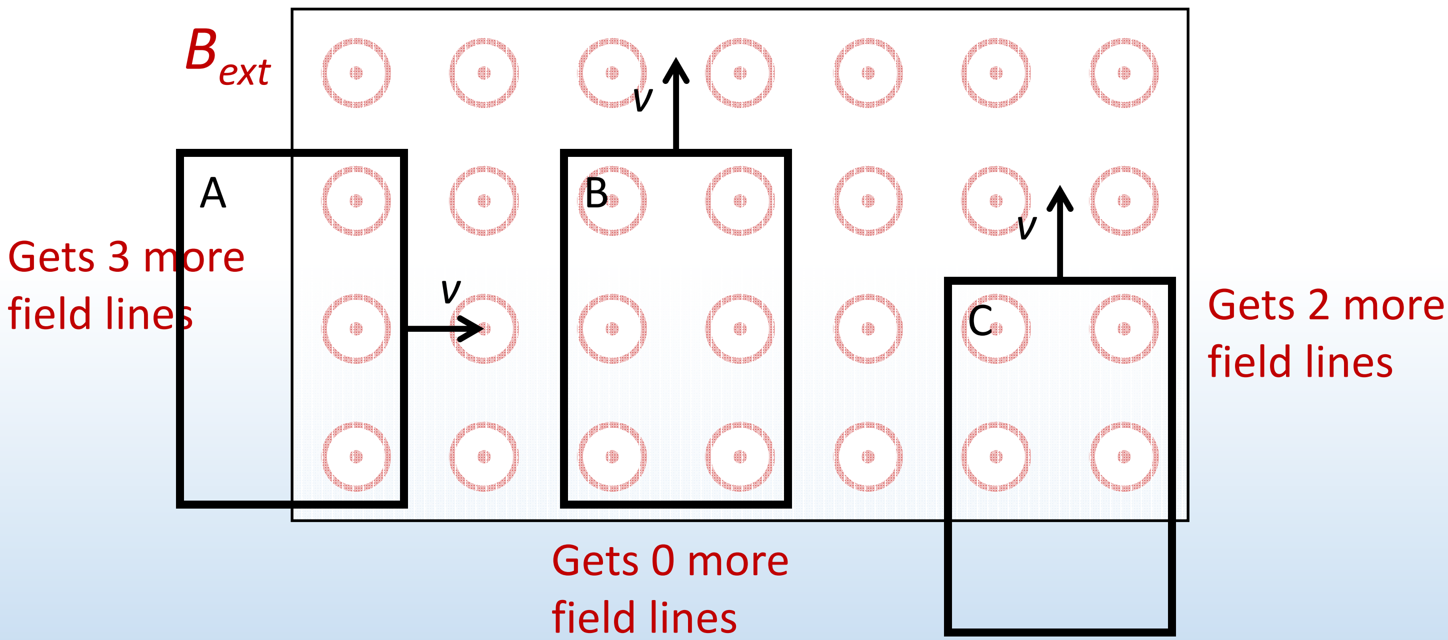
$$|\varepsilon| = \left|\frac{\Delta\Phi}{\Delta t}\right| = \left|\frac{\Phi_f - \Phi_i}{t_f - t_i}\right|$$

Direction

Lenz' law: EMF ε ***opposes*** change in flux Φ

ACT: moving loops

Three loops are moving at the same speed *v* in a region containing a uniform *B* field. The field is zero everywhere outside.



In which loop is $|\varepsilon|$ greatest at the instant shown?

A. Loop A

~~B. Loop B~~

$|\varepsilon| = 0$

C. Loop C

Faraday's Law of Induction

"Induced EMF" = rate of change of magnetic flux

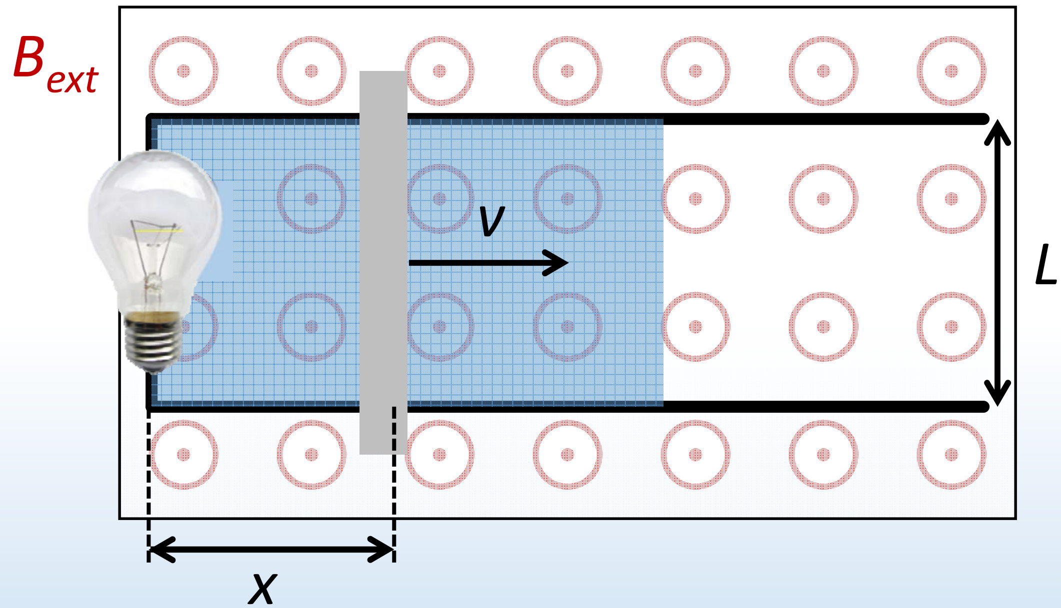
$$\boxed{\varepsilon = -\frac{\Delta\Phi}{\Delta t}}$$

Since $\Phi = BA\cos\varphi$, 3 things can change Φ

1. Area of loop covered by flux
2. Magnetic field *B*
3. Angle *φ* between normal and *B*

Calculation: changing area

A bar slides with speed *v* on a conducting track in a uniform *B* field



What is the magnitude of the EMF induced in the circuit?

$$|\varepsilon| = \left|\frac{\Delta\Phi}{\Delta t}\right| \qquad \Phi = B_{ext}Lx \quad \text{and only } x \text{ is changing}$$

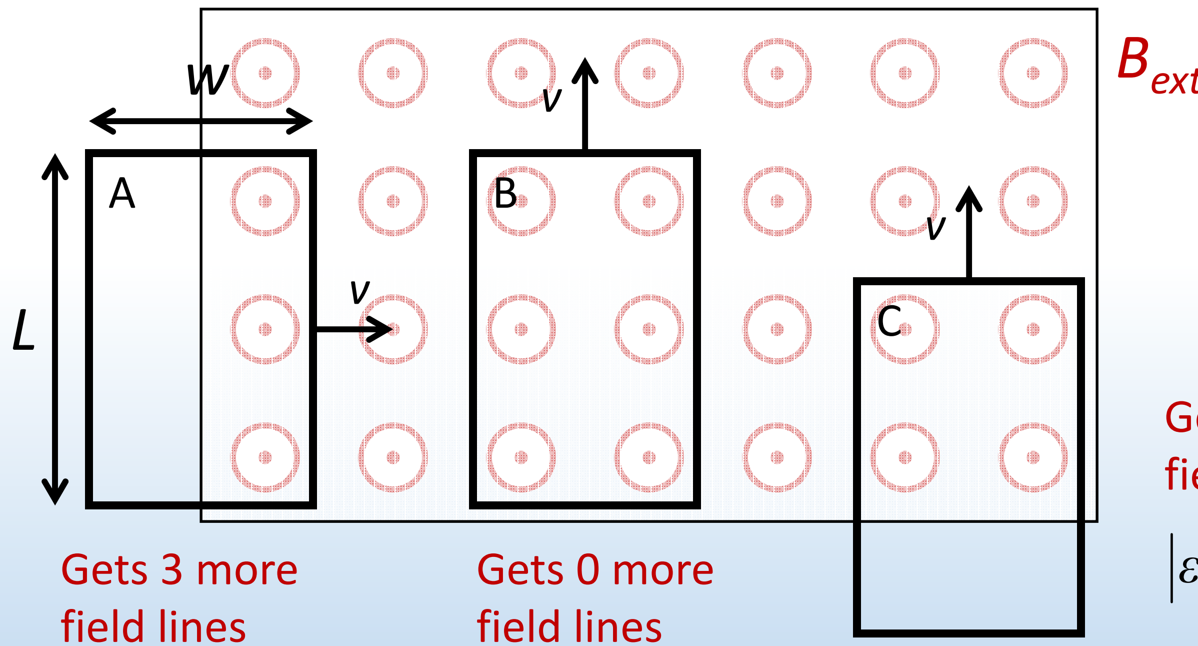
Phys. 101

$$= \frac{\Delta(B_{ext}Lx)}{\Delta t} = B_{ext}L\frac{\Delta x}{\Delta t} = B_{ext}Lv$$

Same answer as in Lect. 13!

Moving loops revisited

Three loops are moving at the same speed *v* in a region containing a uniform *B* field. The field is zero everywhere outside.



Gets 3 more field lines

$$|\varepsilon_A| = B_{ext}Lv$$

Gets 0 more field lines

$$|\varepsilon_B| = 0$$

Gets 2 more field lines

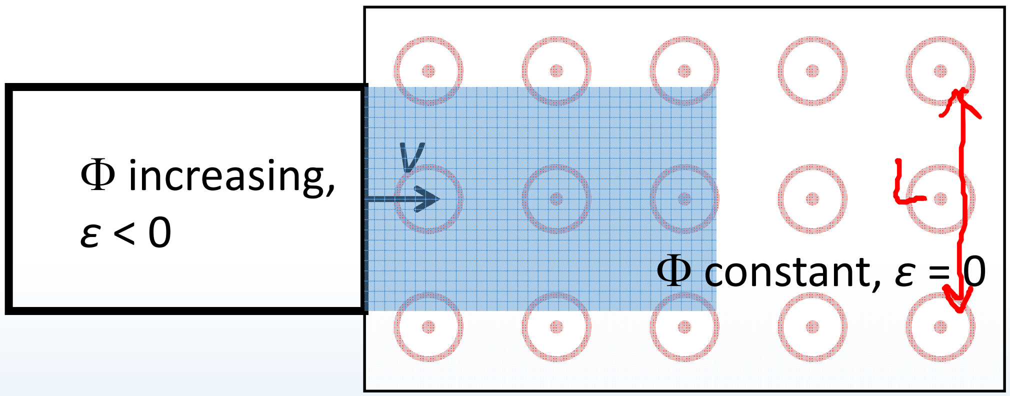
$$|\varepsilon_C| = B_{ext}wv$$

Since $L > w$, $|\varepsilon_A| > |\varepsilon_C|$

ACT: Moving loop

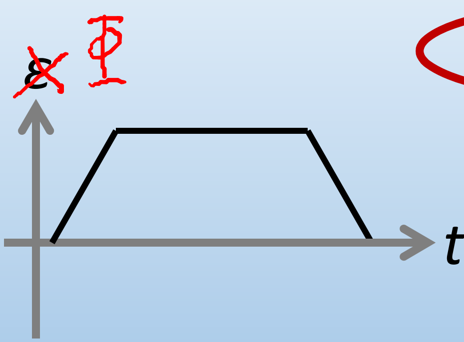
A loop moves through a region with a uniform *B* field at a constant speed *v.* The field is zero outside.

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t}$$

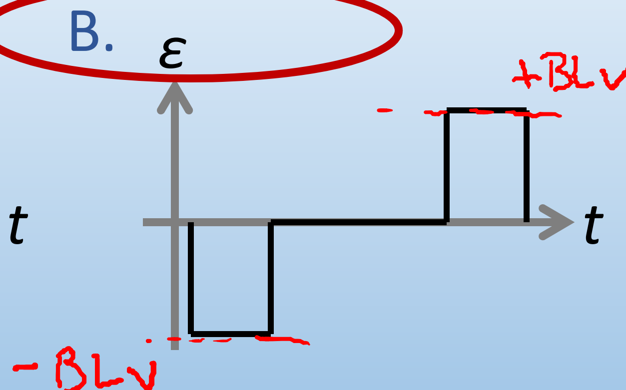


Which diagram best represents the EMF ε in the loop vs. time?

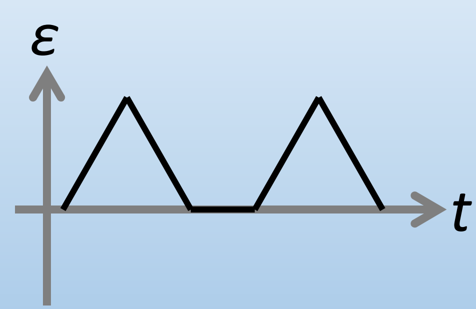
A.



B.



C.



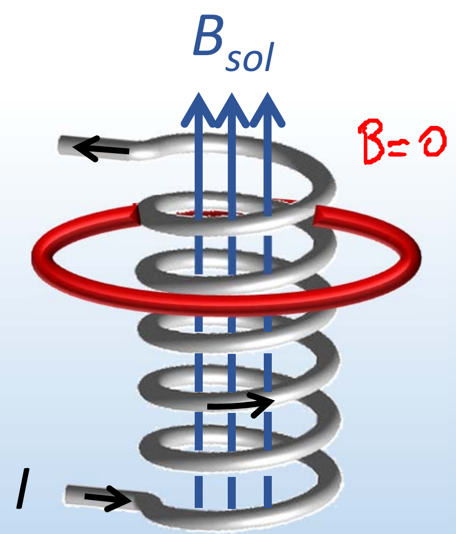
Calculation: solenoid cannon

A loop of radius ~~r_{loop} = 11 cm~~ is placed around a long solenoid. The solenoid has a radius r_{sol} = 4.8 cm and n = 10,000 turns/m of wire. The current I through the solenoid increases at a rate of 1.5 A/s.

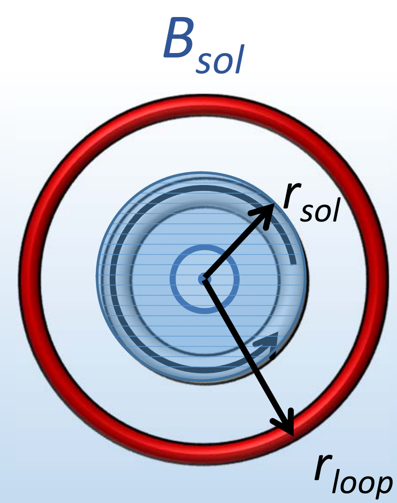
EXAM 2, FA13

What is the EMF $|\varepsilon|$ in the loop?

$$|\varepsilon| = \left|\frac{\Delta\Phi}{\Delta t}\right| \qquad \Phi = B_{sol} A_{sol} \cos\varphi$$



Side view



Top view

B field is changing, area is constant

$$B_{sol}(t) = \mu_0 n I(t)$$

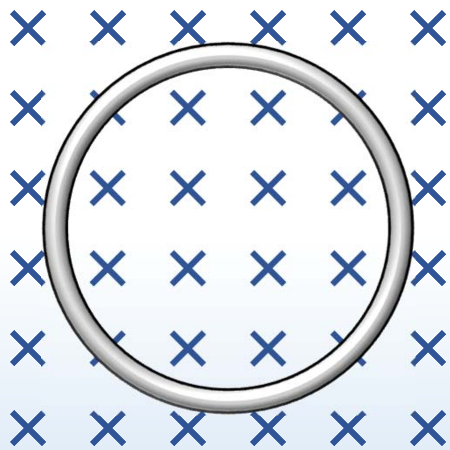
$$|\varepsilon| = \frac{\Delta B_{sol}}{\Delta t} A_{sol} = \mu_0 n \frac{\Delta I}{\Delta t} A_{sol}$$

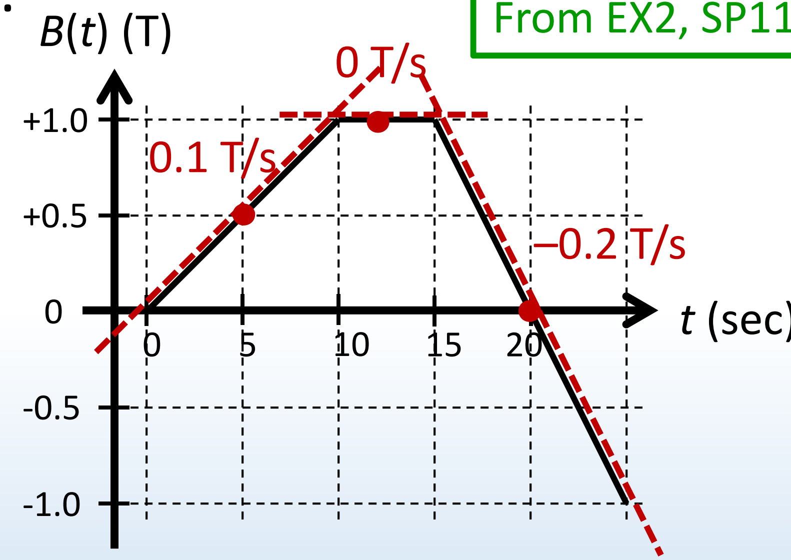
$$= 4\pi \times 10^{-7} 10000 \cdot 1.5 \cdot (\pi 0.048^2) = 0.136\,\text{mV}$$

ACT: time-varying B field

A circular loop is placed in a uniform *B* field that varies in time according to the plot on the right.

From EX2, SP11





At which time is the EMF magnitude $|\varepsilon|$ in the loop largest?

A. $t = 5$ s

~~B. $t = 12$ s~~

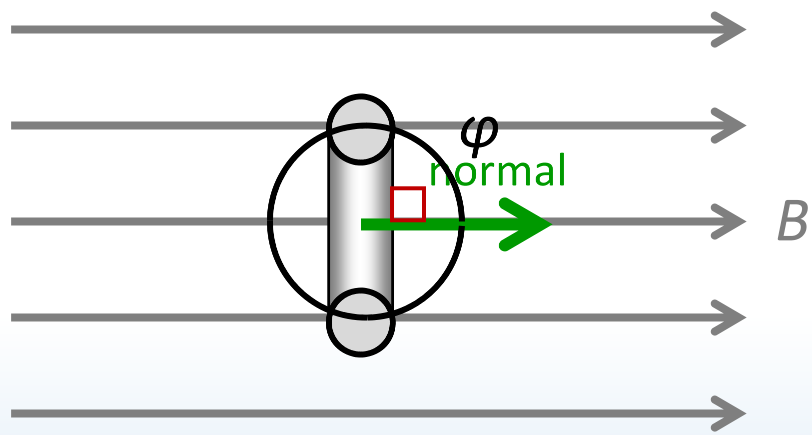
C. $t = 20$ s

$\Delta\Phi/\Delta t$ represents rate of change or *slope* of Φ vs. *t* at that particular time

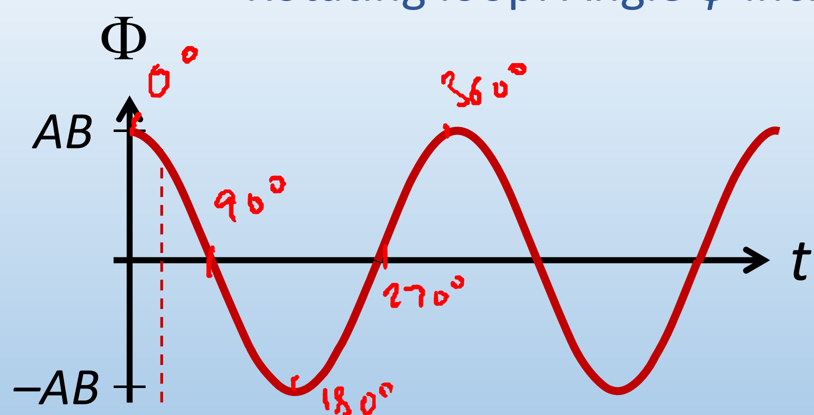
Note: $\Phi = 0$ at $t = 20$ s, but NOT $|\Delta\Phi/\Delta t|$

Changing φ

EMF can be induced by changing angle φ between loop normal and B field



Rotating loop: Angle φ increases at a rate ω (in rad/s)

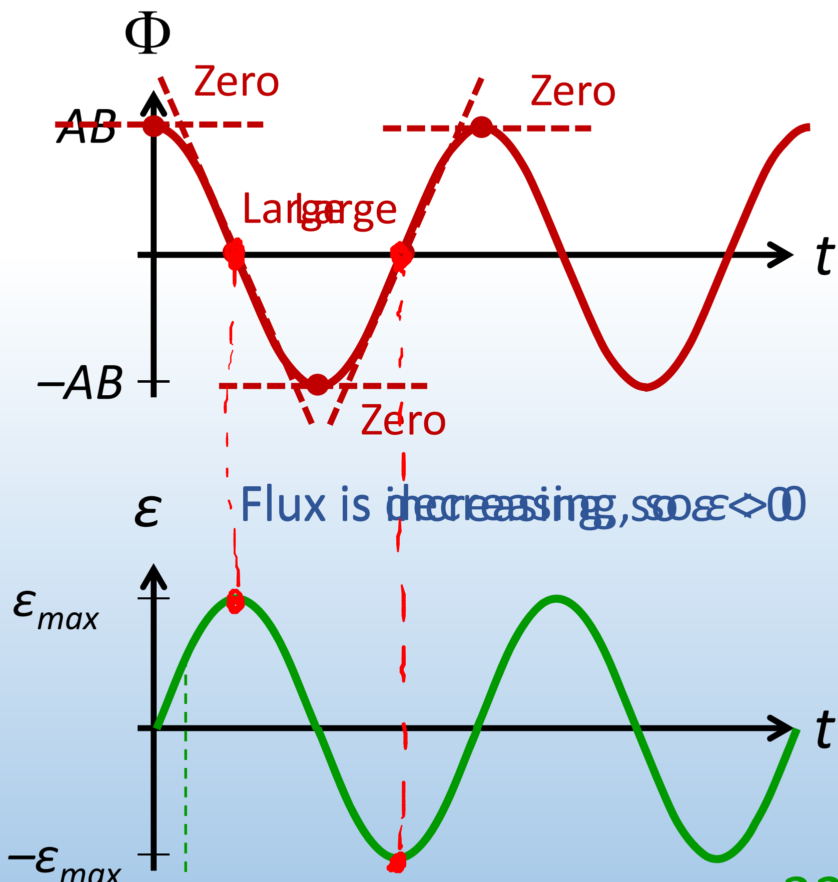


φ = 30° (***CheckPoint 1.1***) 55%

$$\Phi(t) = AB\cos\varphi = AB\cos\omega t$$

Calculation: EMF from changing φ

What is the EMF induced by changing angle φ between loop normal and B field?



$$\Phi(t) = BA\cos\omega t$$

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t}$$

ΔΦ/Δt represents rate of change or *slope* of Φ vs. *t* at that particular time

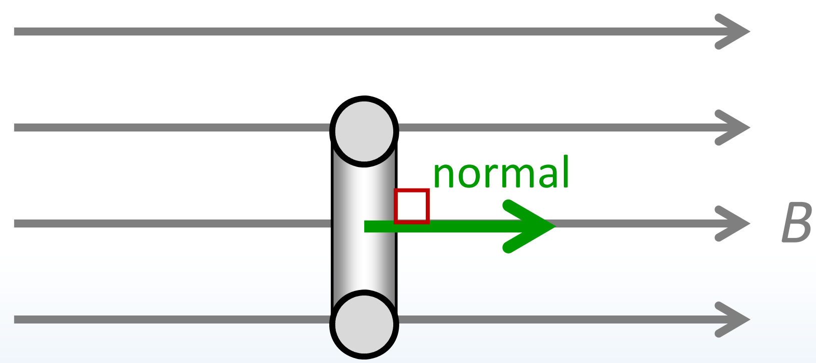
$$\varepsilon(t) = \varepsilon_{\max}\sin\omega t$$

EMF is a sine wave!

φ = 30° (***CheckPoint 1.2-1.3***) 32% 51%

ACT: Rotating loop

The loop below rotates in a uniform *B* field. Which of the following factors can increase the EMF in the loop?



$$\varepsilon(t) = \varepsilon_{\max} \sin \omega t$$

$$\varepsilon_{\max} = \omega NBA$$

DEMO

A. Increasing the rotation rate ω Yes. Increases rate of change

B. Wrapping more turns of wire around the loop Yes. Multiplies Φ

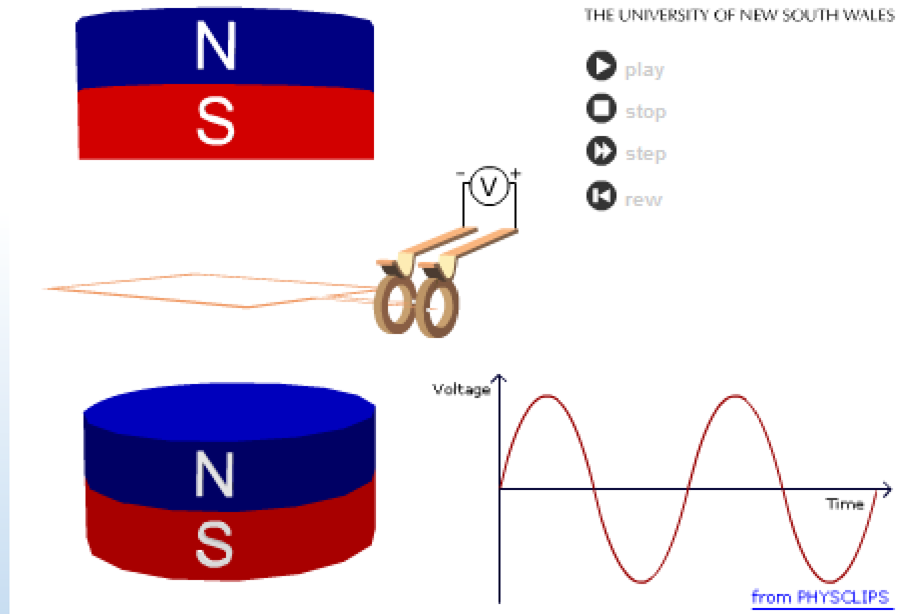
C. Increasing the *B* field Yes. Increases Φ

D. All of the above

Application: generators AC

Electrical generators use external energy source (gas, steam, water, wind, nuclear, etc) to spin loop in *B* field


U of I coal power plant



Why electrical current from outlets is alternating current (AC)

In US, current oscillates at a frequency of 60 Hz (cycles/s)

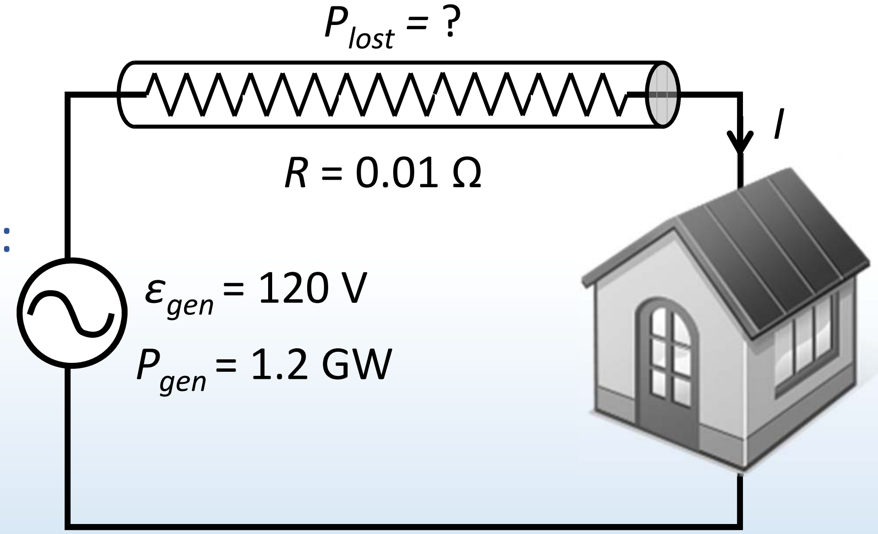
→ 120V

What about the voltage generated?

Calculation: CheckPoint 2

A generator produces 1.2 Giga Watts of power, which it transmits to a town through power lines with total resistance 0.01 Ω.

How much power is lost in the lines if it is transmitted at 120 V?



Power delivered by generator through lines:

$$P_{gen} = I\varepsilon_{gen}$$

$$I = 1.2\times10^{9}/120 = 10,000,000\text{ A}$$

Power lost in lines:

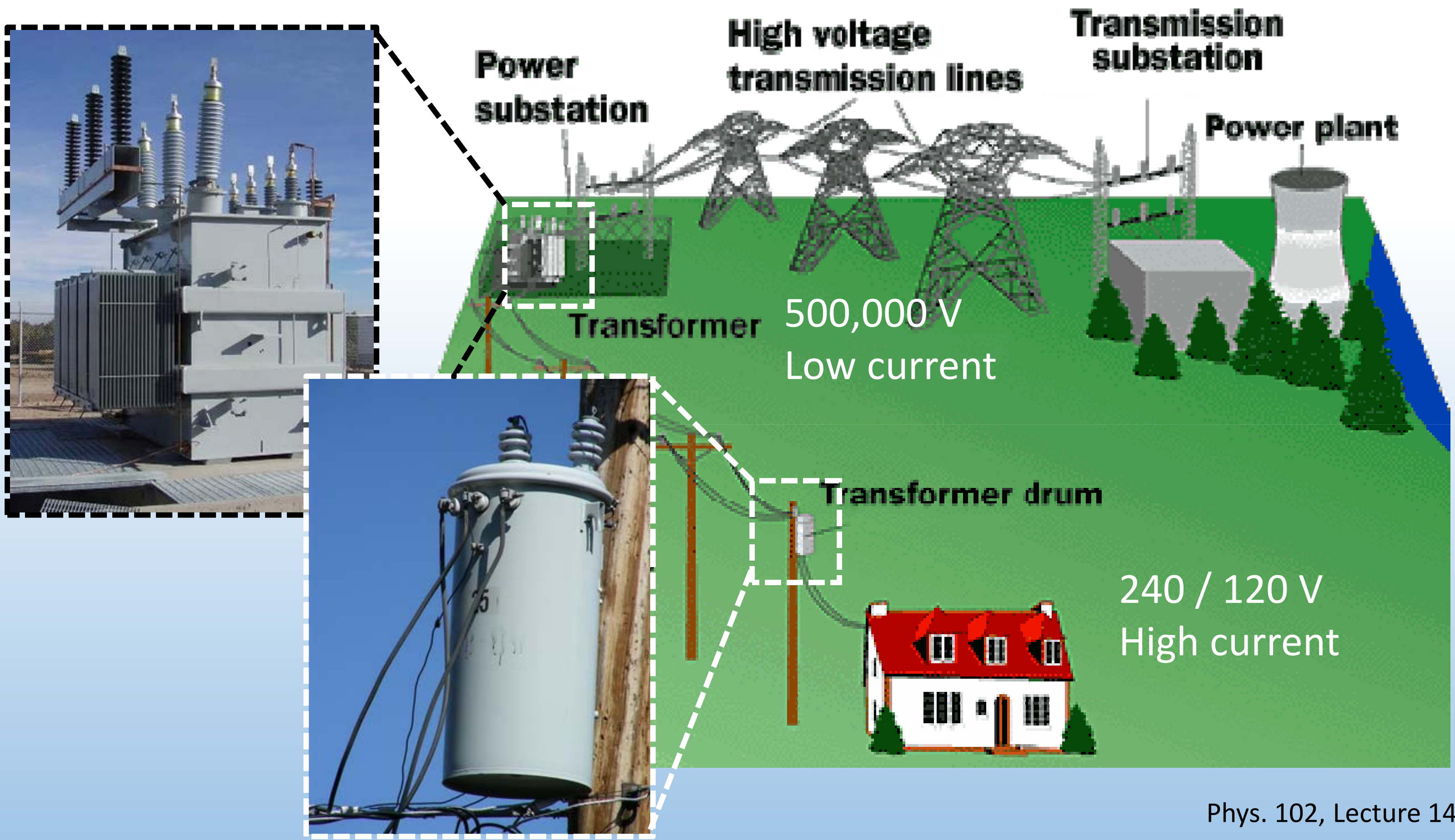
$$P_{lost} = I^2R = (10,000,000)^2 0.01 = 1.0\,\text{GW!}$$

Large current is the problem. Since *P = IV,* modern power transmission uses *high voltage* and *low current* to deliver electrical power.

If ε_{gen} = 12,000 V, lose only 0.0001 GW!

Electrical power distribution

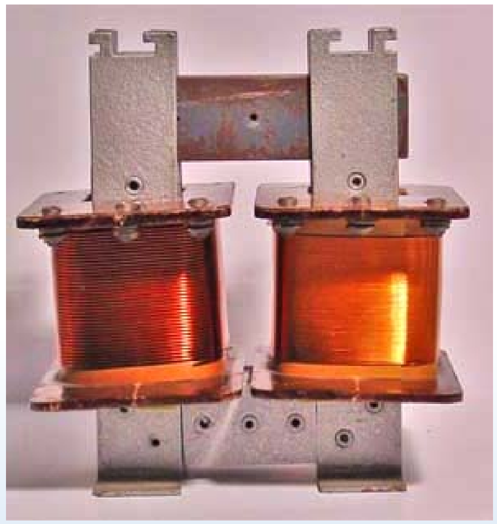
Transformers make it possible to distribute electrical power at high voltage and "step-down" to low voltage at your house.

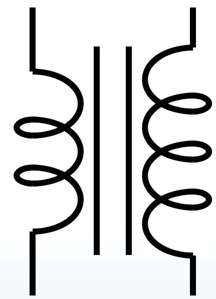


Transformers

primary secondary

Transformers are made of two coils wound around a common iron core





- Key to modern electrical system
- Transform between high and low voltages
- Very efficient

Principles of transformers

Transformers work by Faraday's law. Changing current in "primary" creates changing flux in primary and "secondary"

Flux in each turn

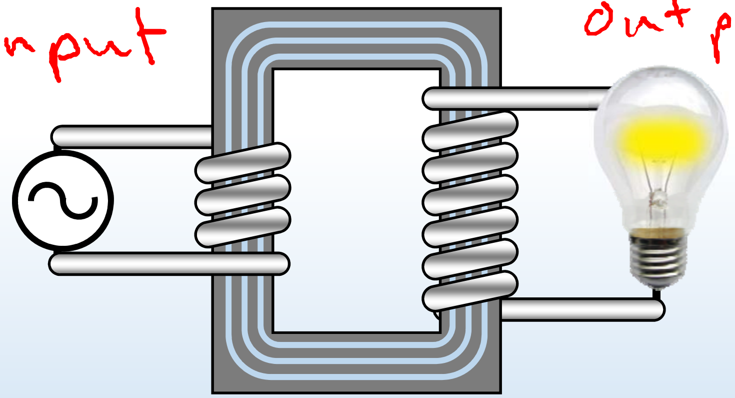
$$V_p = -N_p \frac{\Delta\Phi}{\Delta t} \qquad V_s = -N_s \frac{\Delta\Phi}{\Delta t}$$

$$\boxed{\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}}$$

"Step-up" transformer: $N_s > N_p$

Input

Output



"Primary" coil with N_p turns

"Secondary" coil with N_s turns

Core ensures *B* field of primary passes through secondary

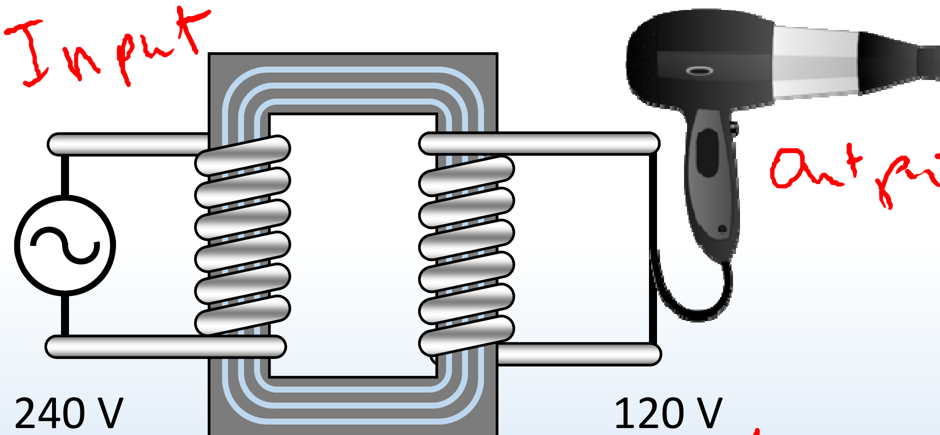
Energy is conserved

$$P_p = I_p V_p = I_s V_s = P_s$$

ACT: CheckPoint 3.1

You are going on a trip to France where the outlets are 240 V. You remember from PHYS 102 that you need a transformer, so you wrap 100 turns of a *primary*.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad \frac{120}{240} = \frac{N_s}{100}$$



How many turns should you wrap around the *secondary* to get 120 V out to run your hair dryer?

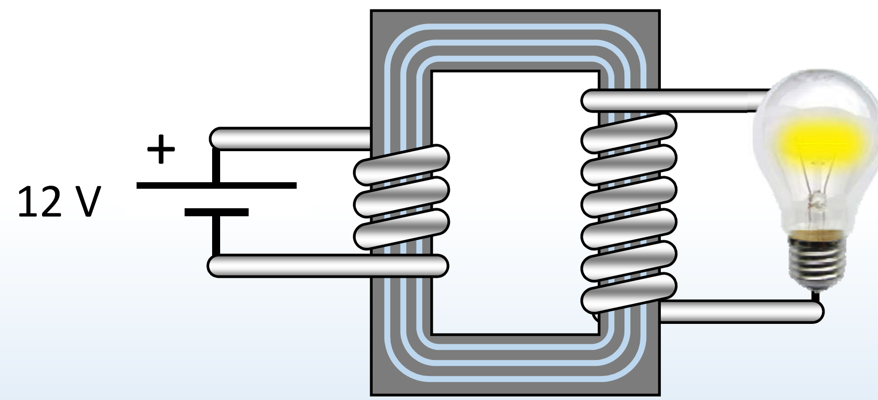
A. 50 — 41%
B. 100 — 31%
C. 200 — 28%

By halving the number of turns around the secondary you decrease the voltage in the secondary by half.

ACT: Transformers

A 12 V battery is connected to a transformer that has a 100 turn primary coil and 200 turn secondary coil.

Transformers depend on a *<u>change in flux</u>* so they only work for alternating currents!



What is the voltage across the secondary after the battery has been connected for a long time?

A. $V_s = 0$ V   B. $V_s = 6$ V   C. $V_s = 12$ V   D. $V_s = 24$ V

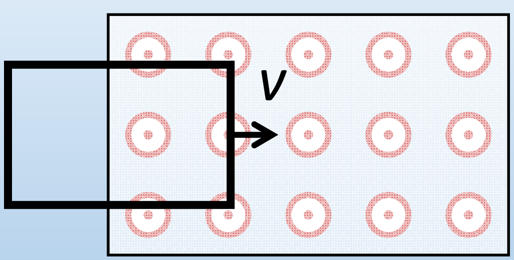
Summary of today's lecture

Faraday's law: "Induced EMF" = rate of change of magnetic flux

$$\boxed{\varepsilon = -\frac{\Delta\Phi}{\Delta t}}$$

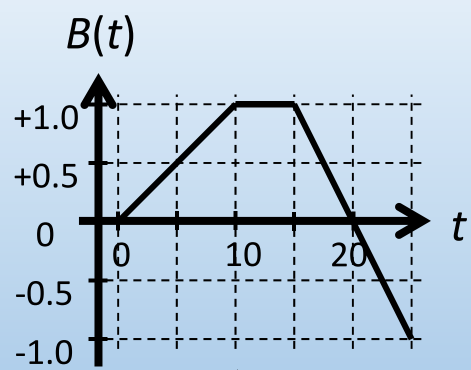
Since $\Phi = BA\cos\varphi$, 3 things can change Φ

1. Area of loop



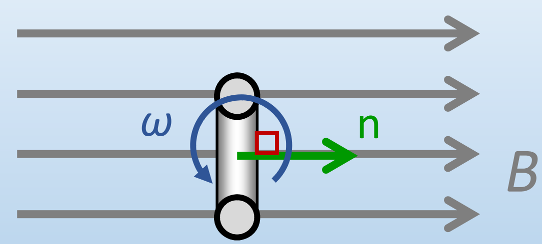
$$\varepsilon = BLv$$

2. Magnetic field *B*



$$\varepsilon = -\frac{\Delta B}{\Delta t}A$$

3. Angle *φ*



$$\varepsilon(t) = \omega NBA\sin\omega t$$