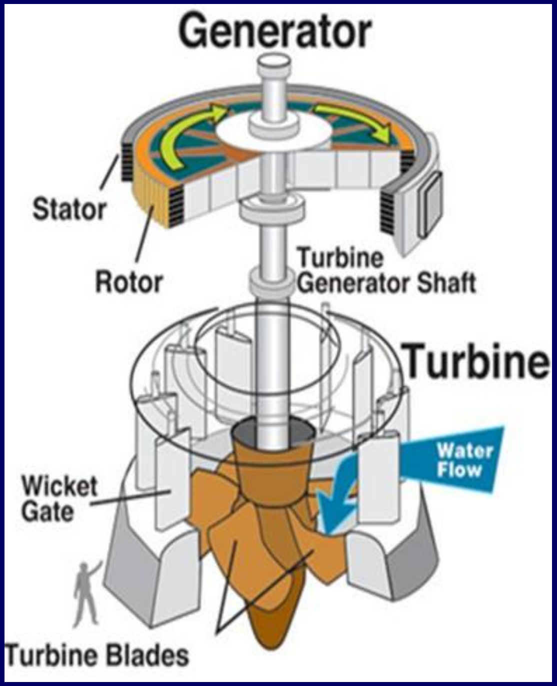
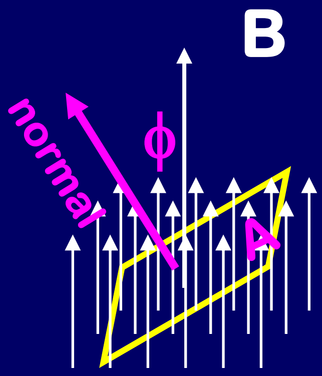
Physics 102: Lecture 11

Generators and Transformers



Review: Magnetic Flux & Induction



Flux: $\Phi = B\,A\cos(\phi)$

ϕ is angle between normal and B

Induced voltage: $\varepsilon = -\dfrac{\Delta\Phi}{\Delta t} = -\dfrac{\Phi_f - \Phi_i}{t_f - t_i}$

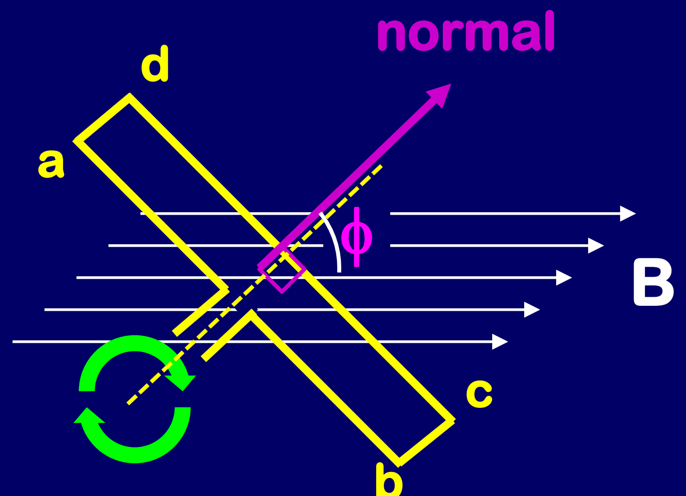
3 things can change Φ:

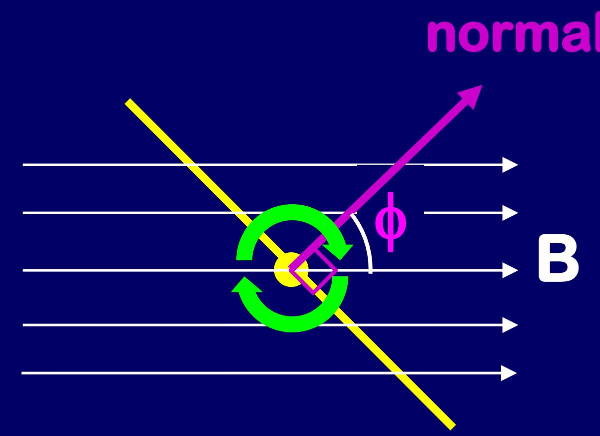
Last lecture
1. Area of loop
2. Magnetic field B

Today
3. Angle ϕ between normal and B

Generators and EMF

A loop of wire is rotated (ex: by a steam engine turbine) in a uniform B field





$$\Phi = B\,A\cos(\phi)$$

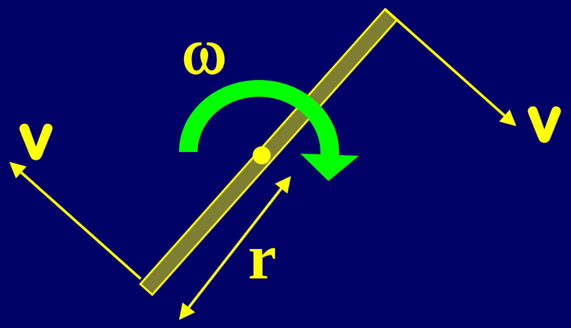
Loop normal rotates relative to B field

=> ϕ changes => Φ changes => emf in loop

=> voltage generated!

Review (Phys 101): Rotation Variables v, ω, *f*, T

- Velocity (v):
  - How fast a point moves.
  - Units: usually m/s



- Angular Frequency (ω):
  - How fast something rotates.
  - Units: radians / sec

$$\omega = v / r$$

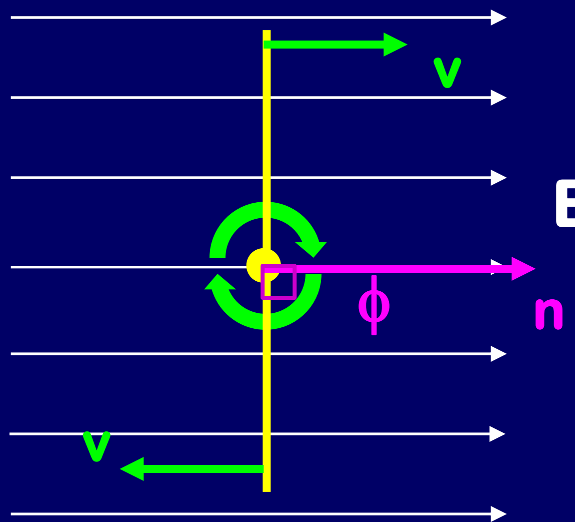
- Frequency (*f*):
  - How fast something rotates.
  - Units: rotations / sec = Hz

$$f = \omega / 2\pi$$

- Period (T):
  - How much time one full rotation takes.
  - Units: usually seconds

$$T = 1 / f = 2\pi / \omega$$

Generator: flux



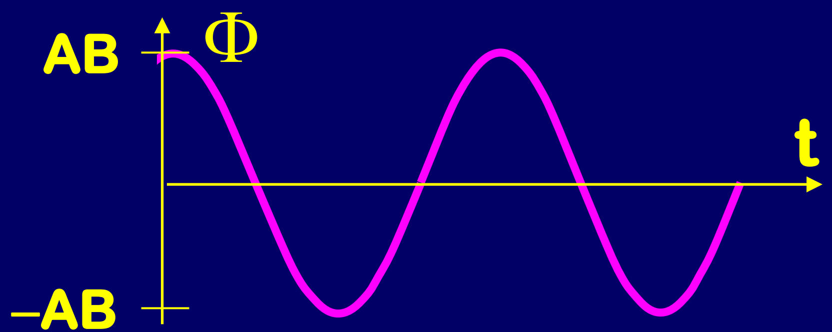
t = 0, Φ = AB (max)

t > 0, Φ < AB

t = T/4, Φ = 0

t > T/4, Φ < 0

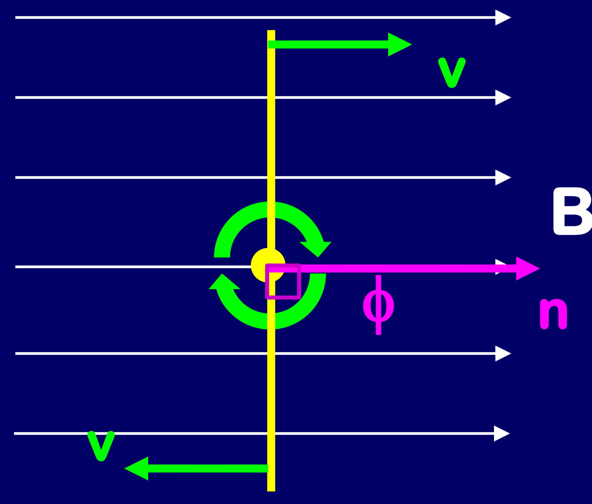
t = T/2, Φ = –AB (min)



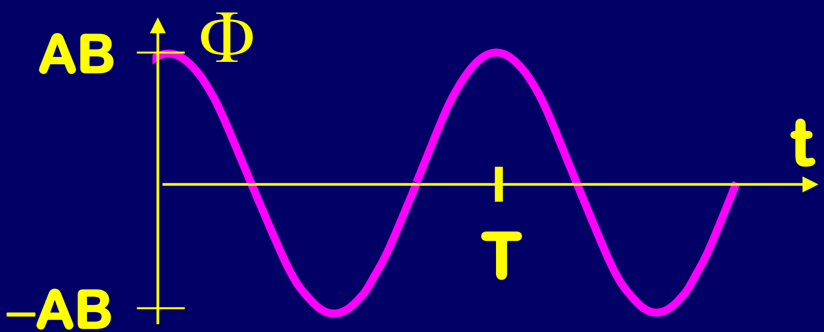
$$\Phi = B\,A\cos(\phi) = B\,A\cos(\omega t)$$

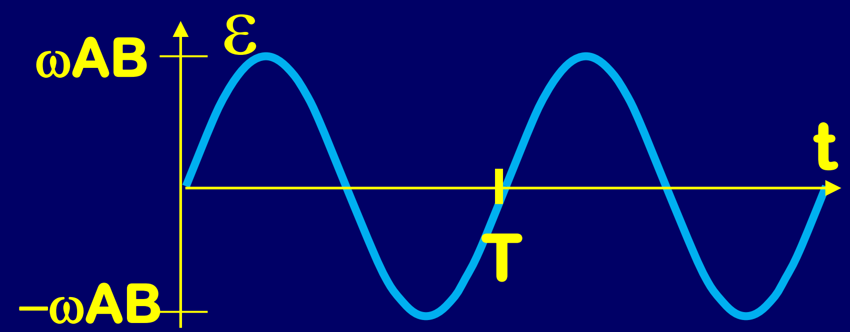
Generator: EMF

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



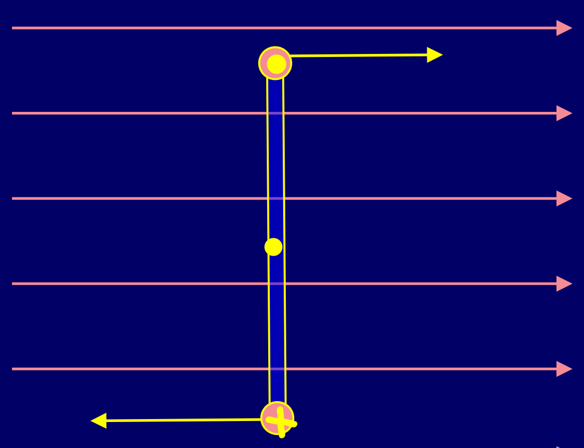
- t = 0, Φ ~const, ε = 0
- t > 0, Φ ↓, ε > 0
- t = T/4, Φ ↓, ε (max)
- t > T/4, Φ ↓, ε > 0
- t = T/2, Φ ~const, ε = 0





$\Phi = B\,A\cos(\omega t)$ $\qquad$ $\varepsilon = \omega\,B\,A\sin(\omega t)$

Comparison:
Flux vs. *EMF*

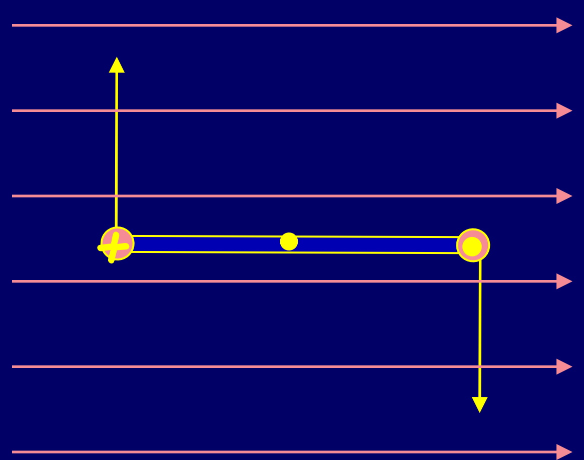


Flux is <u>maximum</u>

- Most lines thru loop

EMF is <u>minimum</u>

- Just before: lines enter from left
- Just after: lines enter from left
- No change!



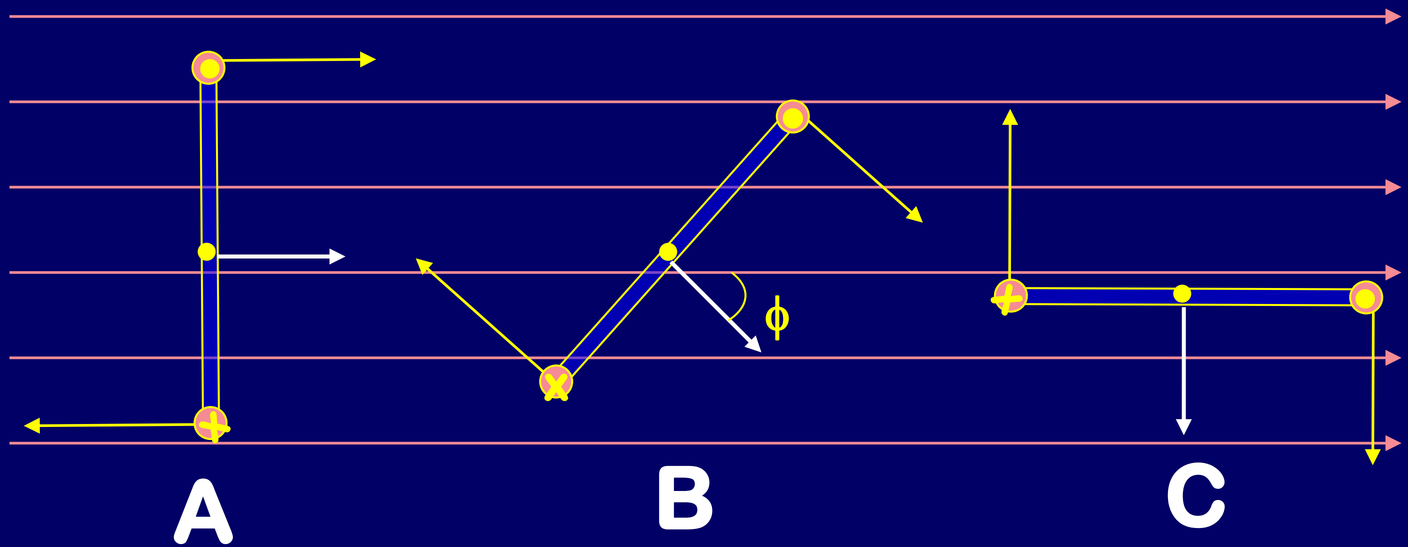
Flux is <u>minimum</u>

- Zero lines thru loop

EMF is <u>maximum</u>

- Just before: lines enter from top.
- Just after: lines enter from bottom.
- Big change!

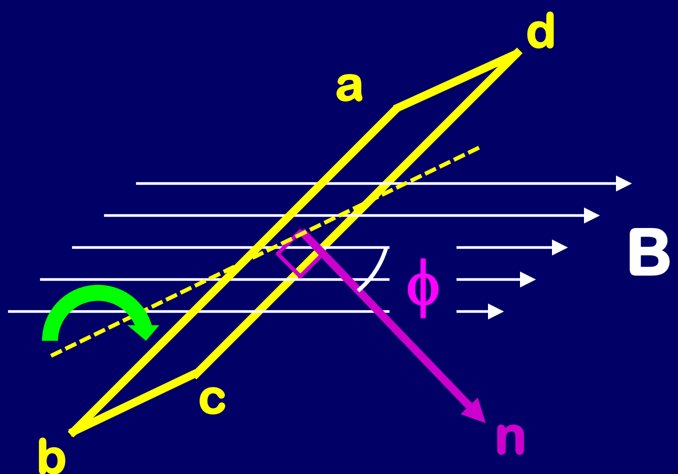
ACT: Generators and EMF



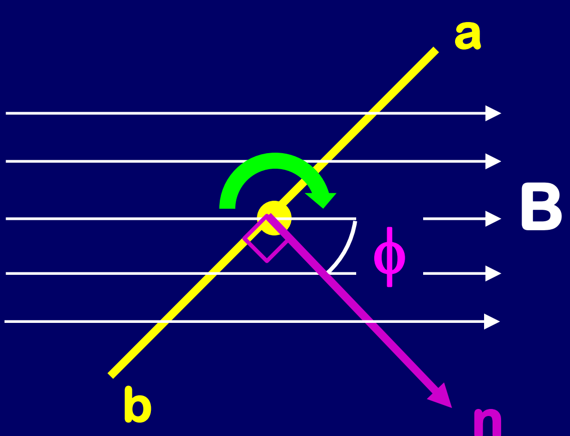
At which time does the loop have the greatest emf (greatest $\Delta\Phi / \Delta t$)?

ACT: EMF direction

In which direction does the current flow in wire a-b at the moment shown?



Side view



A) ↗ B) EMF = 0 C) ↙

Generators and Torque

$\varepsilon = \omega A B \sin(\phi)$

Voltage!

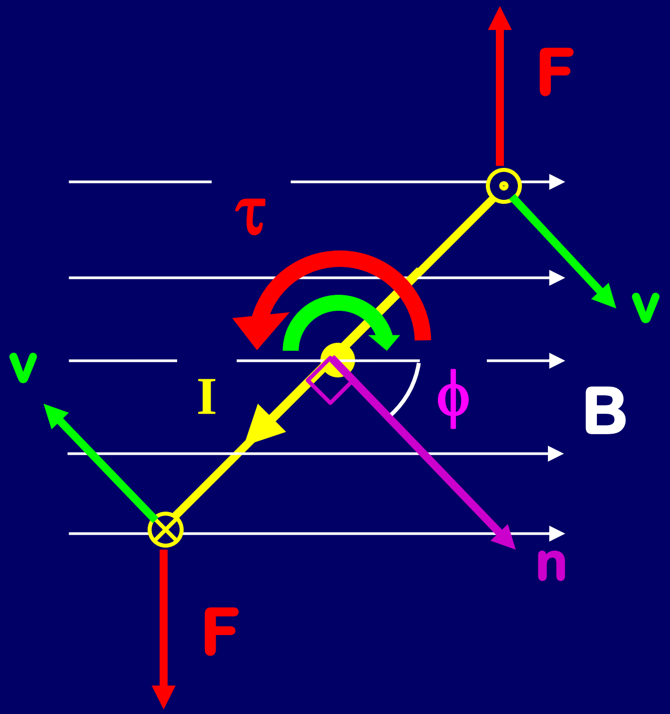
Connect loop to resistance R use I=V/R:

$I = \omega A B \sin(\phi) / R$

Recall:

$\tau = A B I \sin(\phi)$

$= \omega A^2 B^2 \sin^2(\phi)/R$



Direction: use RHR1

Torque, due to current and B field, tries to slow spinning loop down.
Must supply external torque to keep it spinning at constant ω

Generator

Example

A generator consists of a square coil of wire with 40 turns, each side is 0.2 meters long, and it is spinning with angular velocity ω = 2.5 radians/second in a uniform magnetic field B=0.15 T. Calculate the maximum EMF and torque if the resistive load is 4Ω.

ε = **NA B ω sin(ϕ)**

=

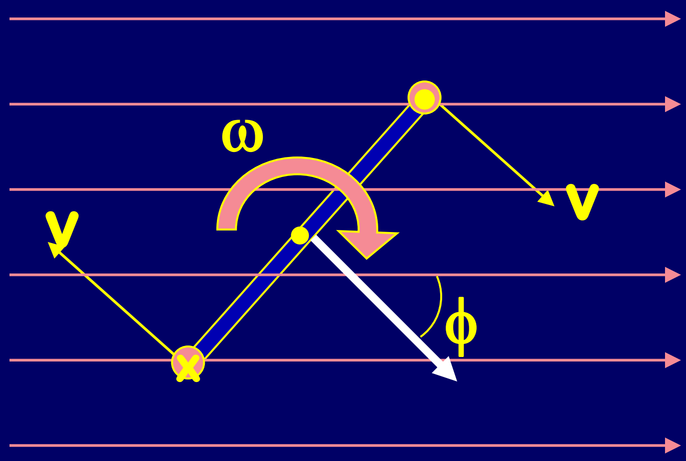
=

τ = **NI A B sin(ϕ)**

=

=

=



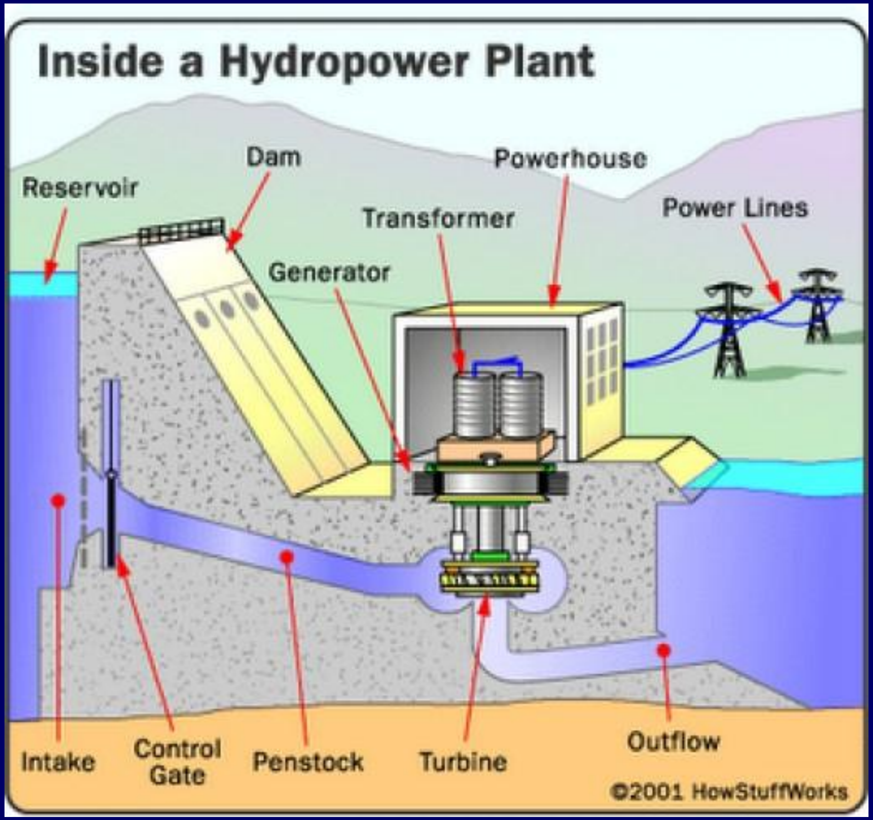
Note: Emf is maximum at ϕ=90

Note: Torque is maximum at ϕ=90

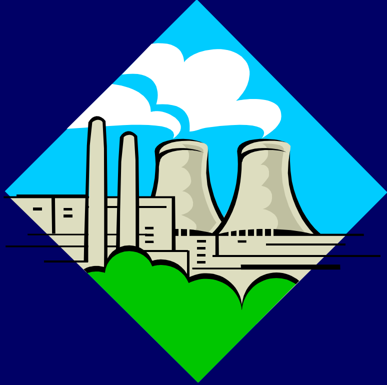
In a hydropower plant, that torque is supplied by falling water.

The power plant delivers AC (alternating current) power to your house: the voltage and current switch directions at f=60 Hz (more next lecture). At your house: 120 V.

There is a big challenge getting electric current to your house: $P = I^2 R$!



Power Transmission



Example

A generator produces 1.2 Giga watts of power, which it transmits to a town 7 miles away through power lines with a total resistance 0.01 ohms. How much power is lost in the lines if the energy is transmitted at 120 Volts?

$\boxed{P = IV}$ Power delivered by generator through lines

$I = P/V = 1.2\times10^9$ W/120 V = 10,000,000 Amps in lines!

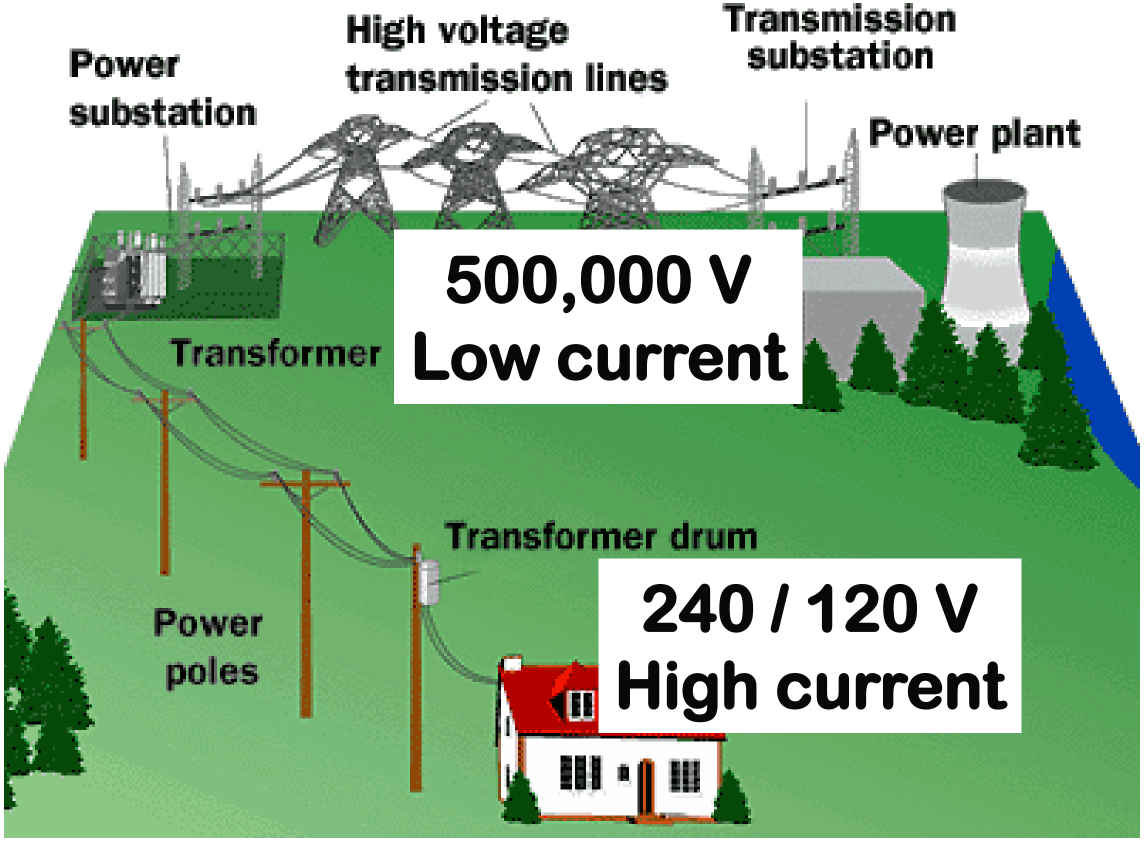
$\boxed{P = I^2R}$ Power lost in lines

$= 10{,}000{,}000^2\,(.01)$ = 1.0 Giga Watt Lost in Lines!

Large current is the problem. Since P=IV, use high voltage and low current to deliver power.

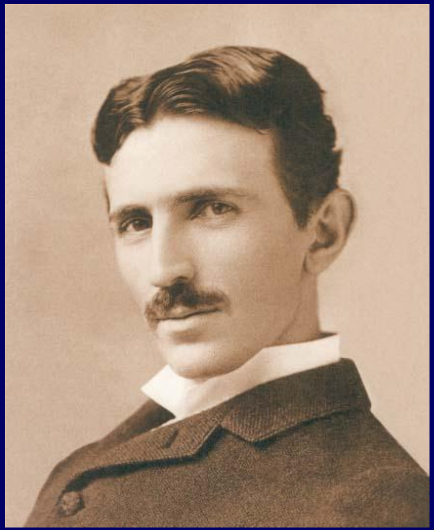
If V = 12,000 Volts, lose 0.0001 Giga Watts!

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



Transformers

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



Nikola Tesla

Transformers

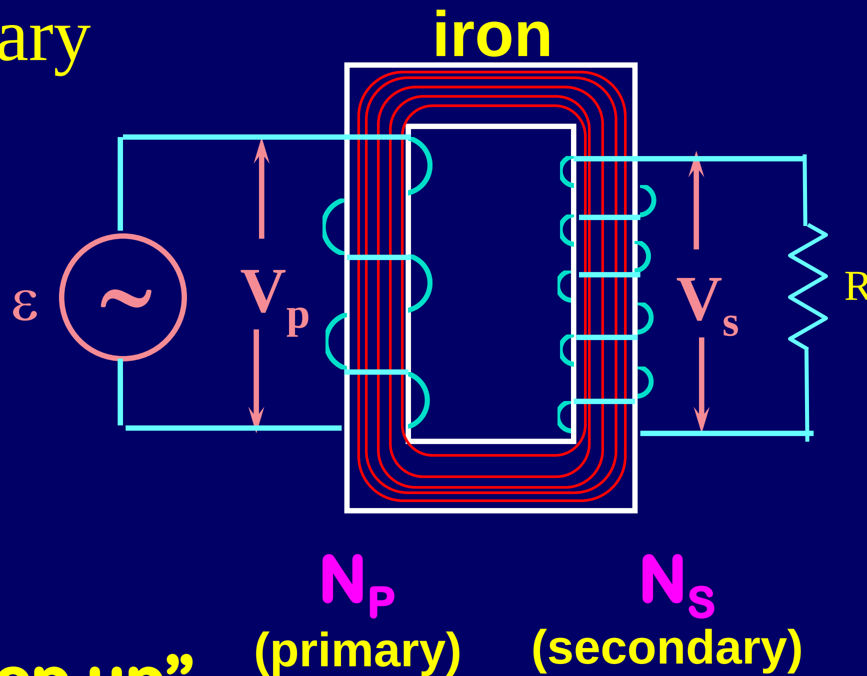
Key to efficient power distribution

Changing current in "primary" creates changing flux in primary and "secondary".

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

Same $\Delta\Phi/\Delta t$

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



$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$N_s > N_p: V_s > V_p$ **"step up"**

$N_s < N_p: V_s < V_p$ **"step down"**

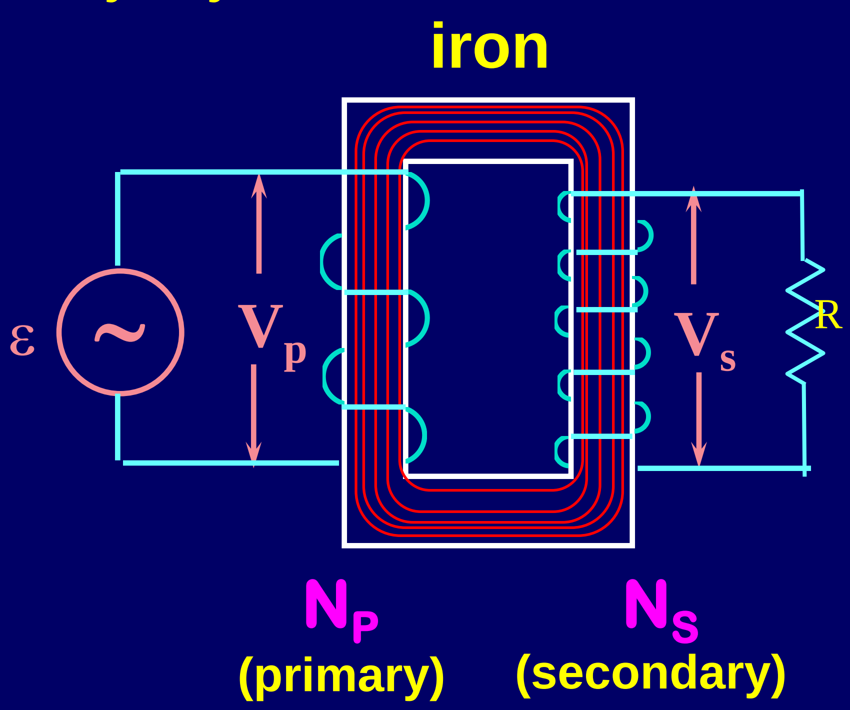
Energy conservation! $I_p V_p = I_s V_s$

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

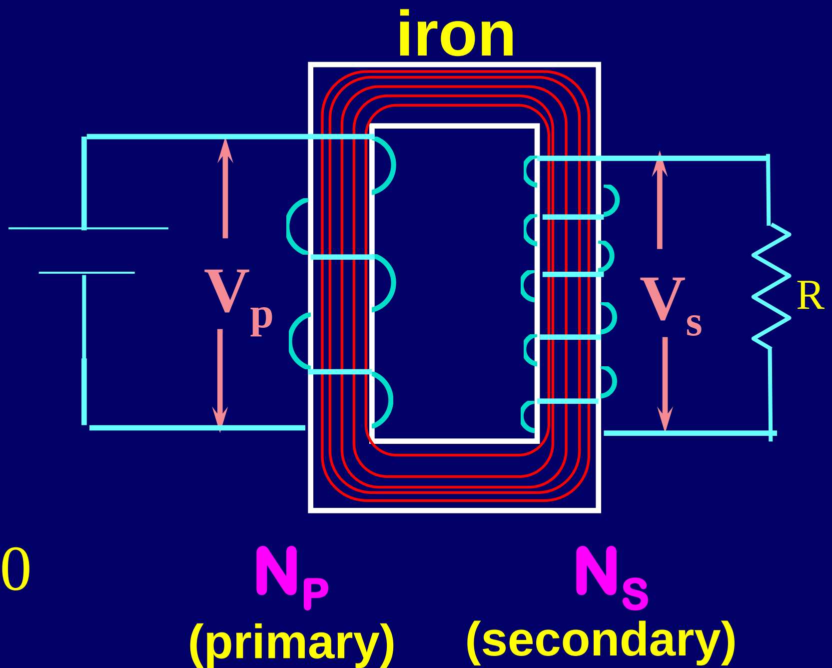
CheckPoint 3.1

The good news is you are going on a trip to France. The bad news is that in France the outlets have 240 volts. You remember from P102 that you need a transformer, so you wrap 100 turns around the primary. How many turns should you wrap around the secondary if you need 120 volts out to run your hair dryer?

1) 50 **2) 100** **3) 200**



ACT: Transformers



A 12 Volt battery is connected to a transformer transformer that has a 100 turn primary coil, and 200 turn secondary coil. What is the voltage across the secondary after the battery has been connected for a long time?

A) $V_s = 0$ B) $V_s = 6$ C) $V_s = 12$ D) $V_s = 24$

Questions to Think About

- In a transformer the side with the most turns always has the larger peak voltage. (T/F)
- In a transformer the side with the most turns always has the larger peak current. (T/F)
- In a transformer the side with the most turns always dissipates the most power. (T/F)
- Which of the following changes will increase the peak voltage delivered by a generator
  - Increase the speed it is spinning.
  - Increase the area of the loop.
  - Increase the strength of the magnetic field.