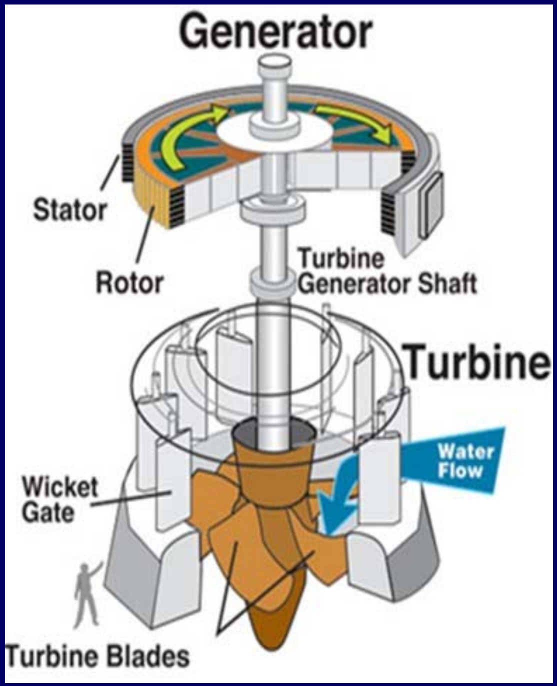
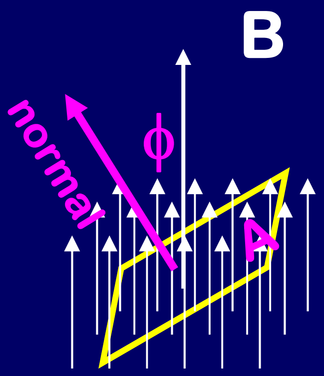
Physics 102: Lecture 11

Generators and Transformers



Review: Magnetic Flux & Induction



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

ϕ **is angle between normal and B**

Lenz' law

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

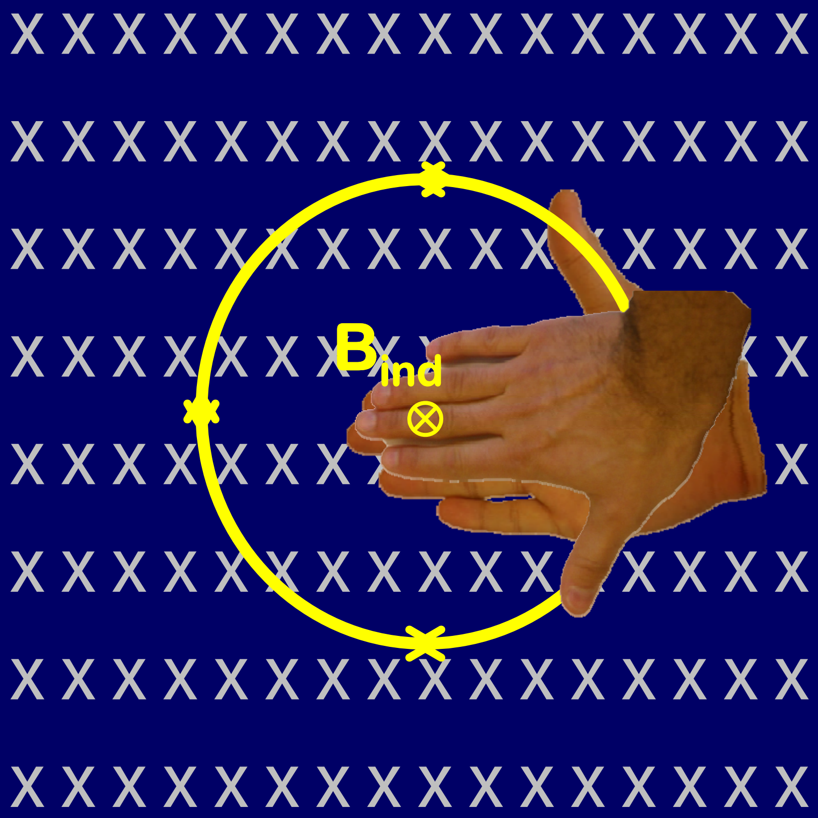
3 things can change Φ:

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

Today
3. Angle ϕ between normal and B

Lenz's Law

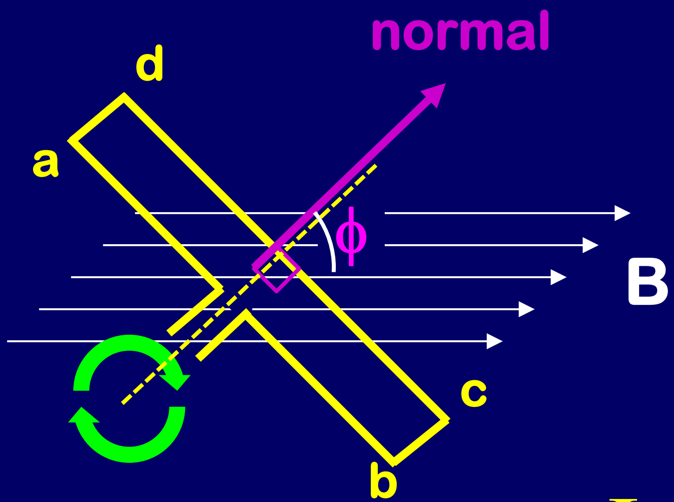
Induced emf opposes change in flux

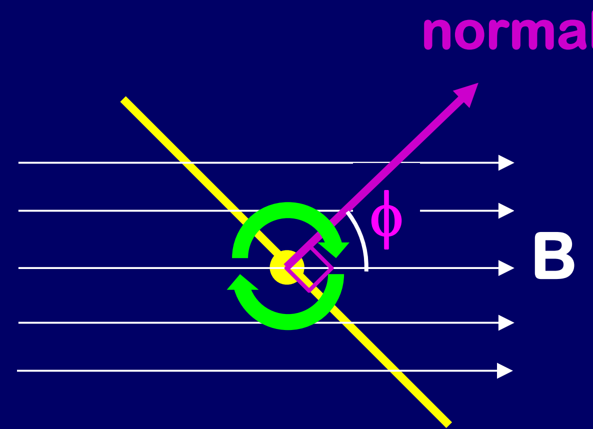


- If flux increases:
  New EMF makes new field **opposite to** original field
- If flux decreases:
  New EMF makes new field **in same direction as** original field

Generators and EMF

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





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

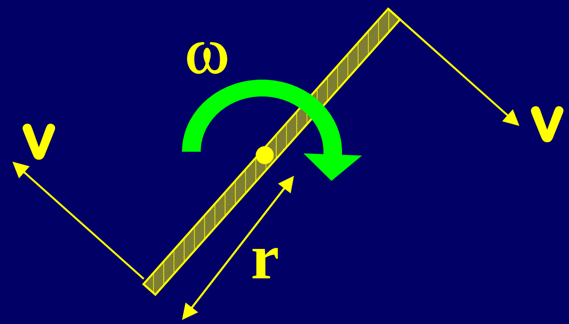
Loop normal rotates relative to B field

=> 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
- Frequency (*f*):
  - How fast something rotates.
  - Units: rotations / sec = Hz
- Period (T):
  - How much time one full rotation takes.
  - Units: usually seconds

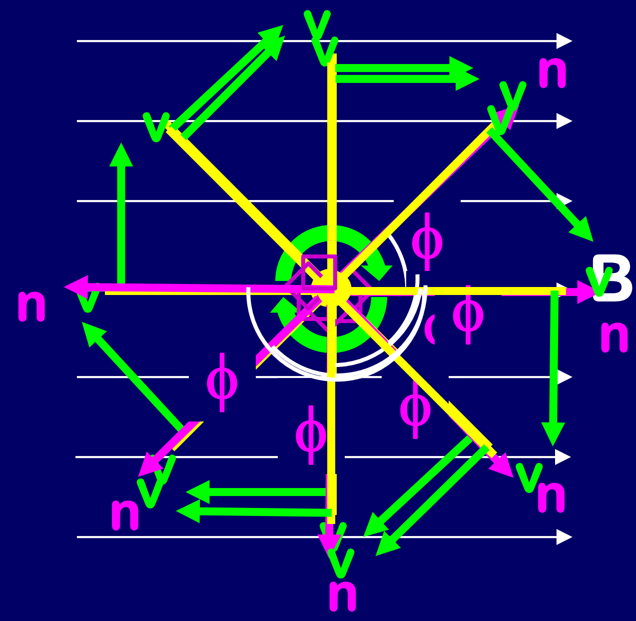


$$\omega = v / r$$

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

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

Generator: flux



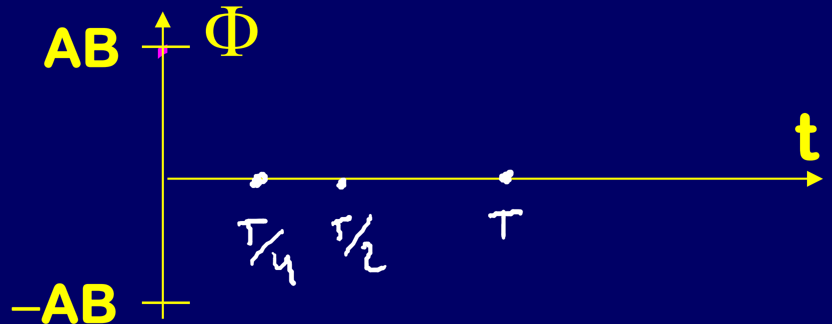
t = 0, Φ = AB (max)

t > 0, Φ < AB

t = T/4, Φ = 0

t > T/4, Φ < 0

t = T/2, Φ = –AB (min)

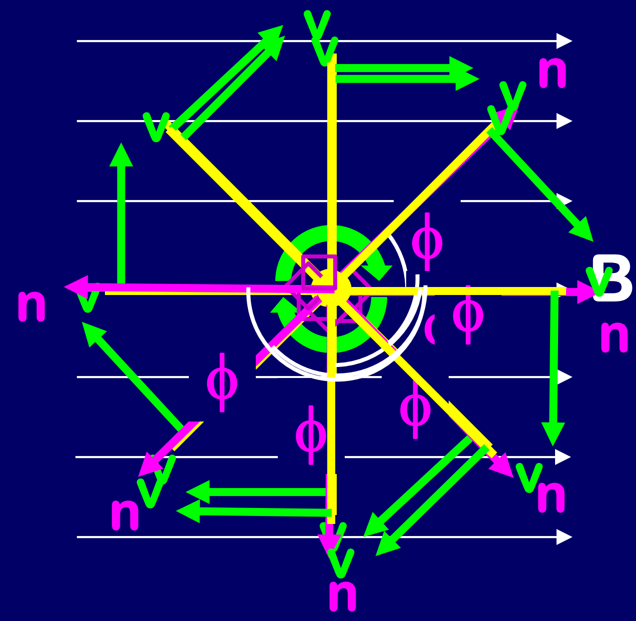


Answers to Checkpoints 1.1-1.3 follow…

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

Generator: EMF

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



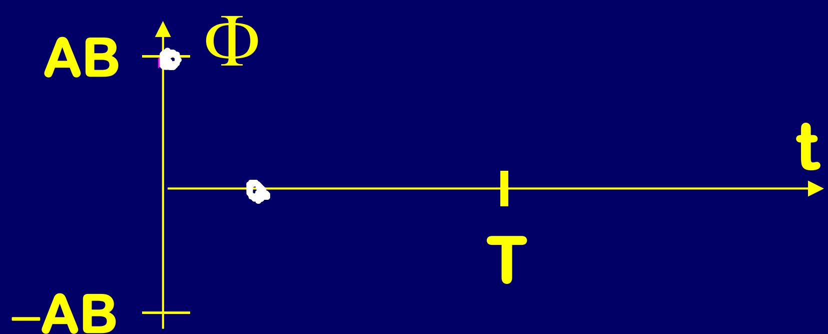
t = 0, Φ ~const, $\varepsilon = 0$

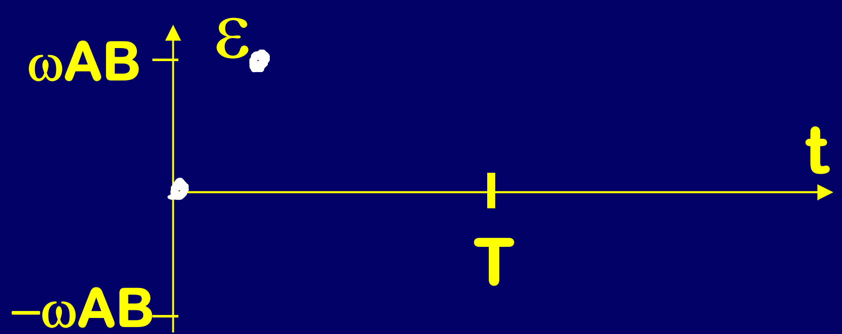
t > 0, $\Phi\downarrow$, $\varepsilon > 0$

t = T/4, $\Phi\downarrow$, ε (max)

t > T/4, $\Phi\downarrow$, $\varepsilon > 0$

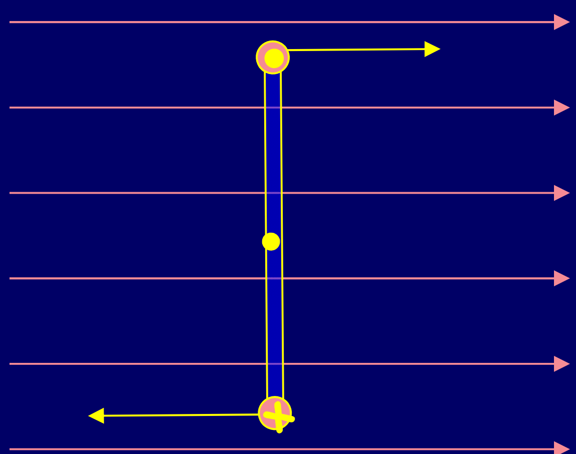
t = T/2, Φ ~const, $\varepsilon = 0$





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

Comparison:
Flux vs. *EMF*

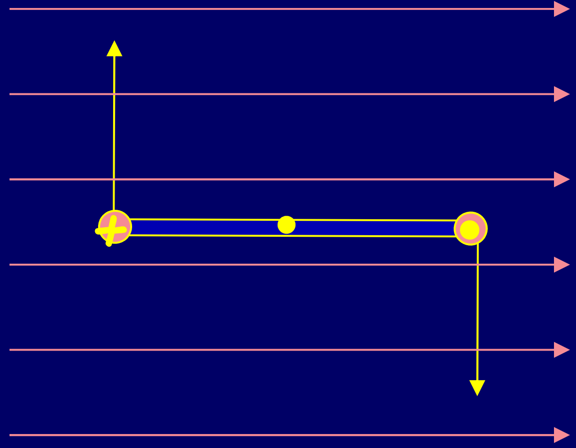


Flux is maximum

- Most lines thru loop

EMF is minimum

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

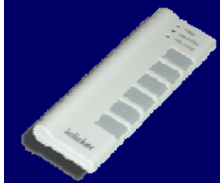


Flux is minimum

- Zero lines thru loop

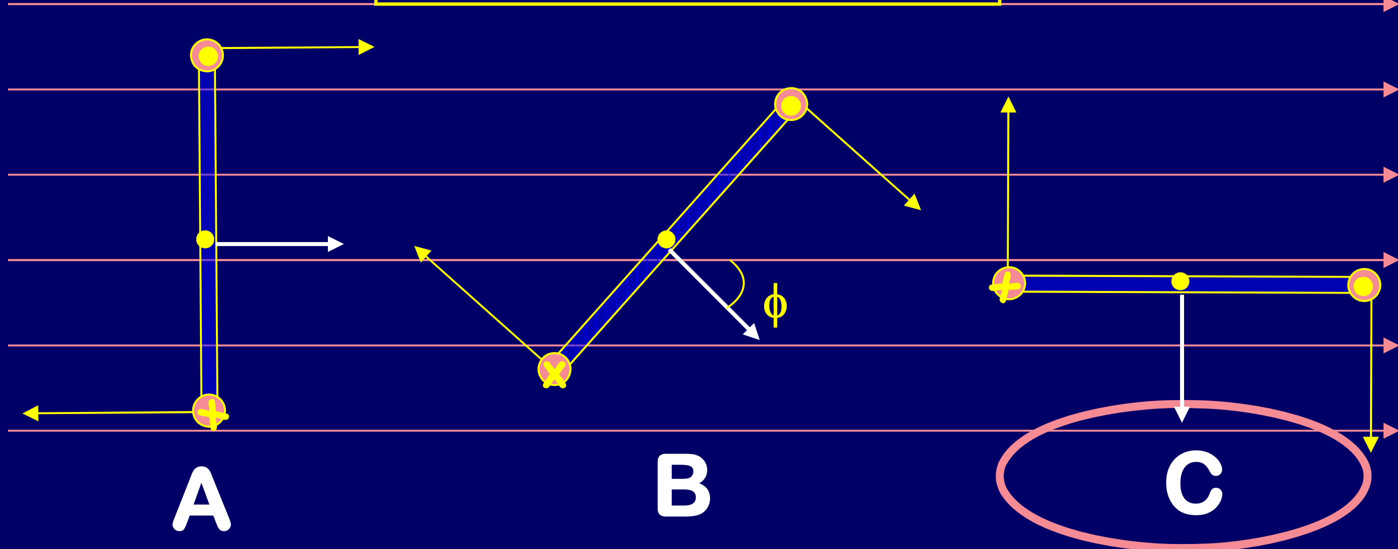
EMF is maximum

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



ACT: Generators and EMF

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



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

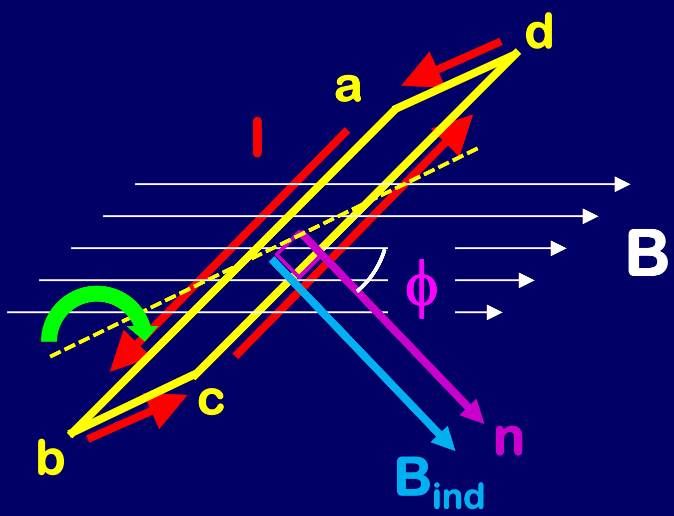
A) Has greatest flux, but $\phi = 0$ so $\varepsilon = 0$.

B) Intermediate flux, $\phi \approx 30$ so $\varepsilon \approx \omega AB/2$.

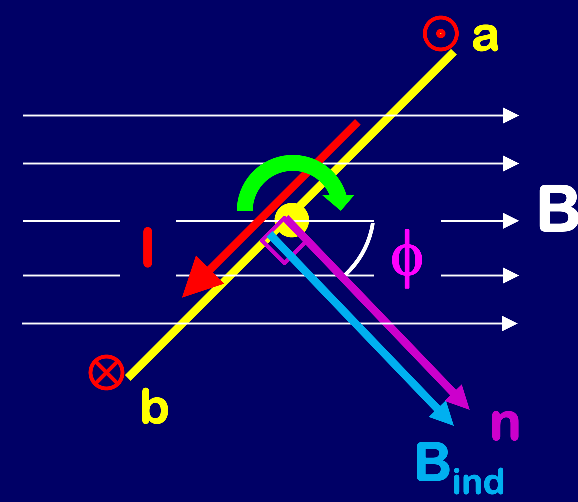
C) Flux is zero, but $\phi = 90$ so $\varepsilon = \omega AB$.

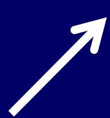
ACT: EMF direction

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

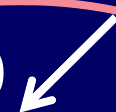


Side view



A) 

B) EMF = 0

C) 

Φ decreasing => B_{ind} along external B => current CCW (RHR2)

Generators and Torque

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

Voltage!

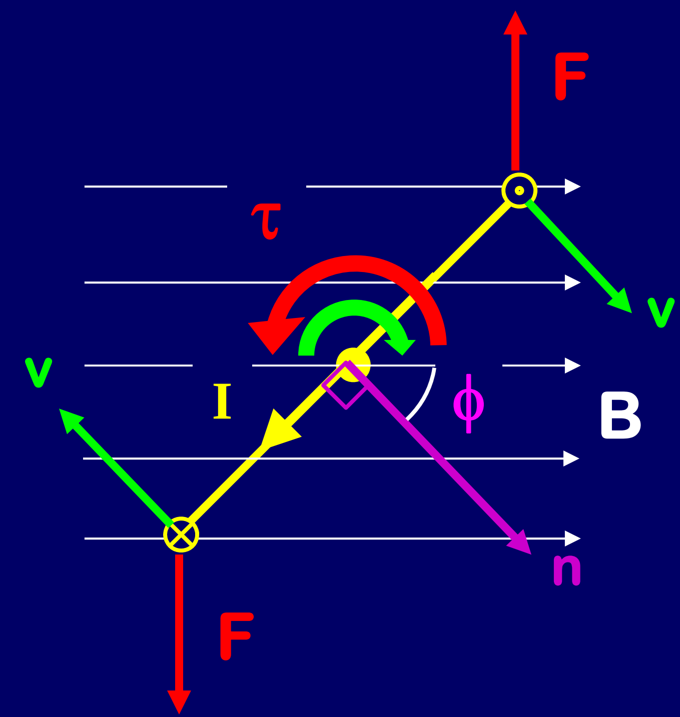
Connect loop to resistance R use I=V/R:

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

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

Example

Generator

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 $\omega = 2.5$ radians/second in a uniform magnetic field B=0.15 T. Calculate the maximum EMF and torque if the resistive load is 4Ω.

$\varepsilon = \mathbf{N} A B \omega \sin(\phi)$

$= (40)\,(0.2)^2\,(0.15)\,(2.5)$

= 0.6 Volts

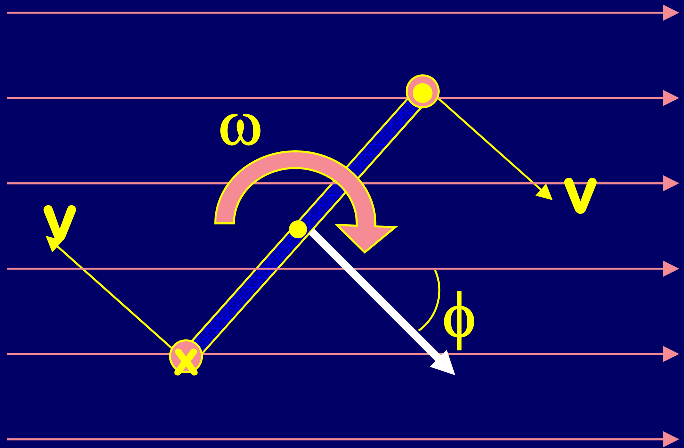
$I = \varepsilon / R$

$\tau = \mathbf{N} I A B \sin(\phi)$

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

$= (40)^2\,(2.5)\,(0.2)^4\,(0.15)^2/4$

= 0.036 Newton-meters



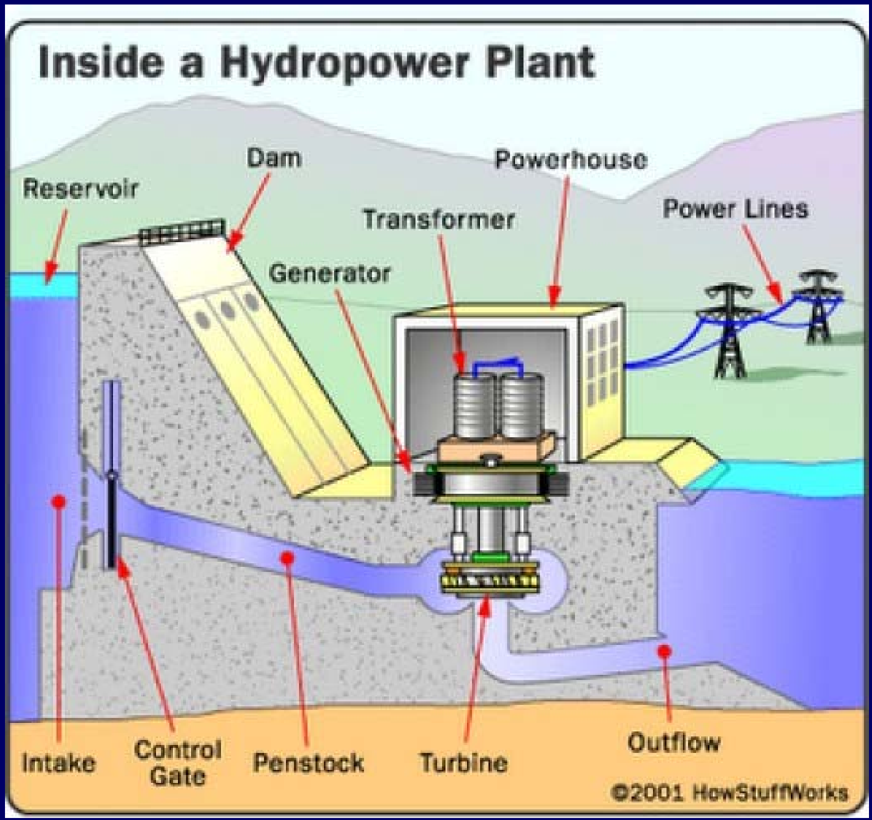
Note: Emf is maximum at ϕ=90

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: $P = I^2R$!



Power Transmission, CheckPoint 2.1

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?

$P = IV$ Power delivered by generator through lines

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

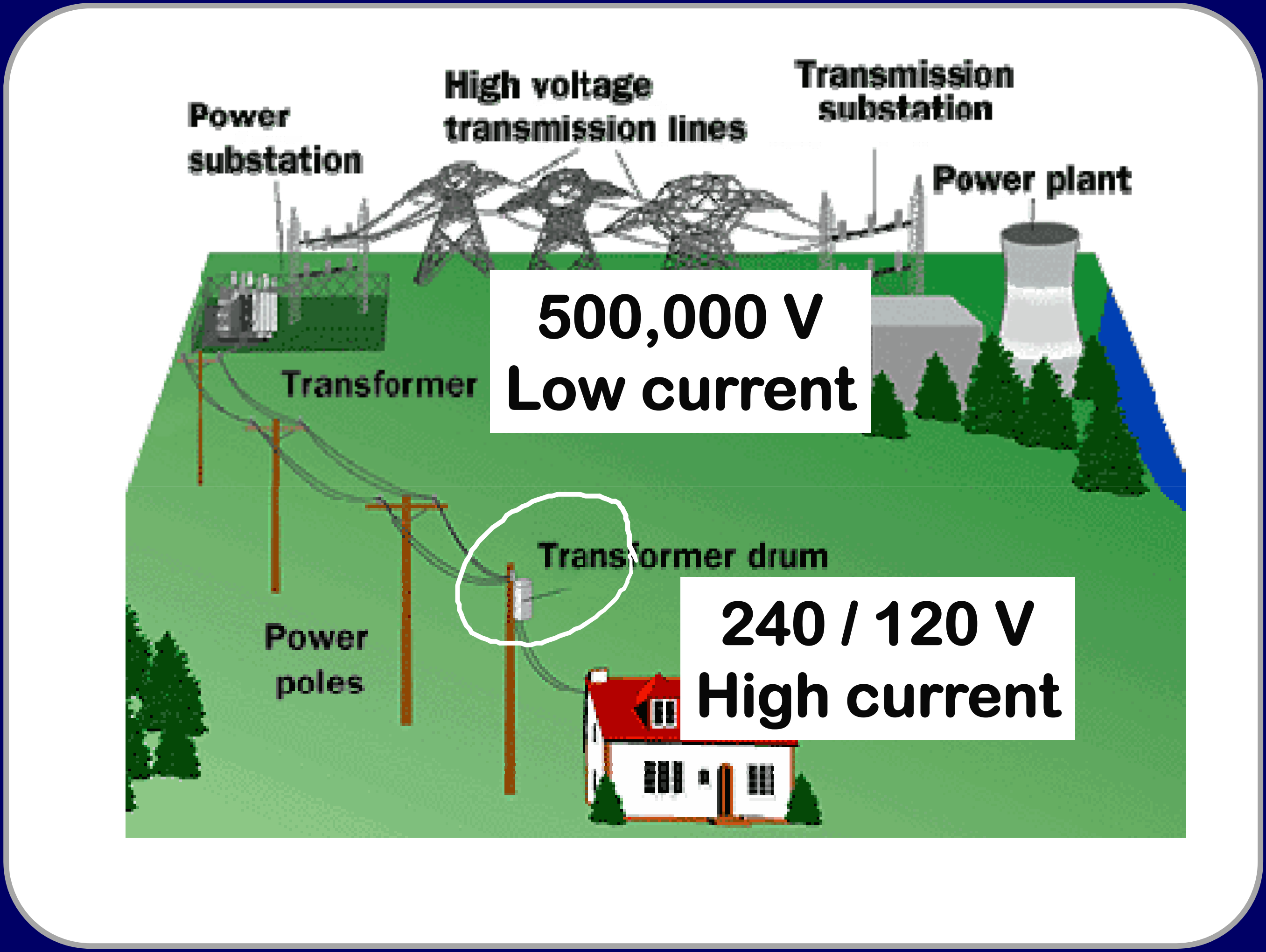
$P = I^2R$ Power lost in lines

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

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

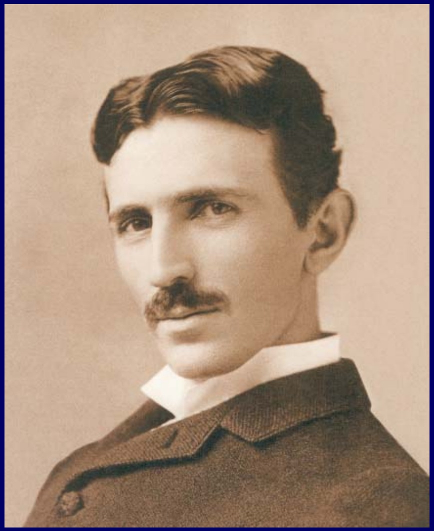
If V = 12,000 Volts, lose 0.0001 Giga Watts!

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

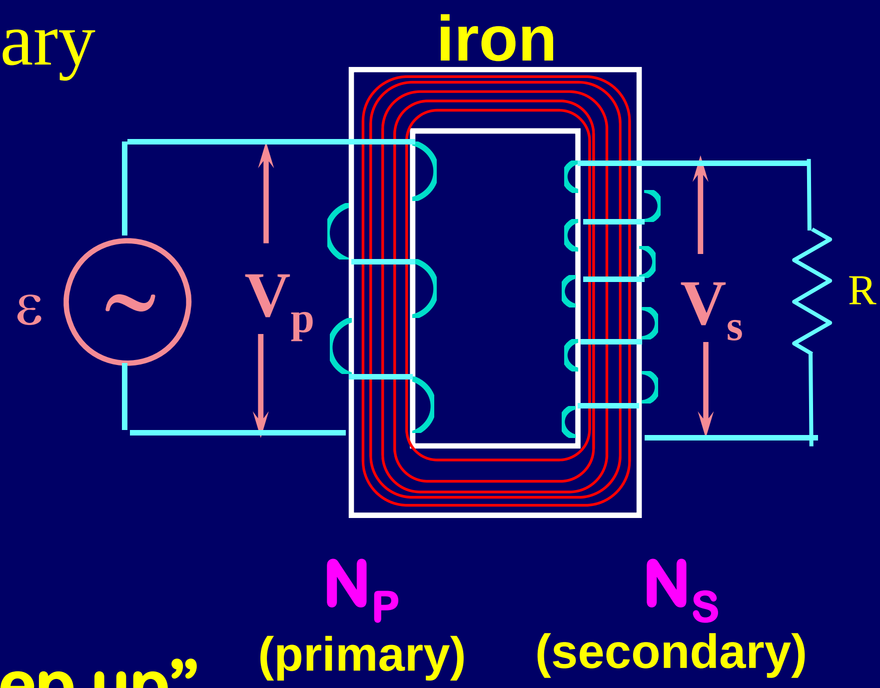
Key to efficient power distribution

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

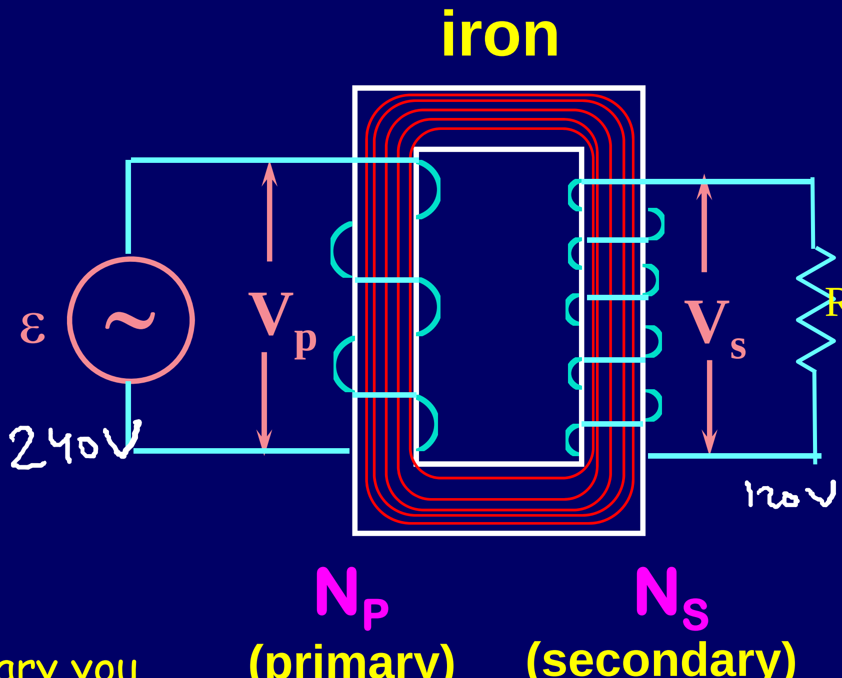
The good news is you are going on a trip to France. The bad news is that in France the outlets have 240 volts. You remember from P102 that you need a transformer, so you wrap 100 turns around the primary. How many turns should you wrap around the secondary if you need 120 volts out to run your hair dryer?

1) 50 — 57%
2) 100 — 19%
3) 200 — 25%

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

(120V / 240V = 50 / 100)

$$N_s = N_p\left(\frac{V_s}{V_p}\right) = 100\left(\frac{120}{240}\right) = 50$$

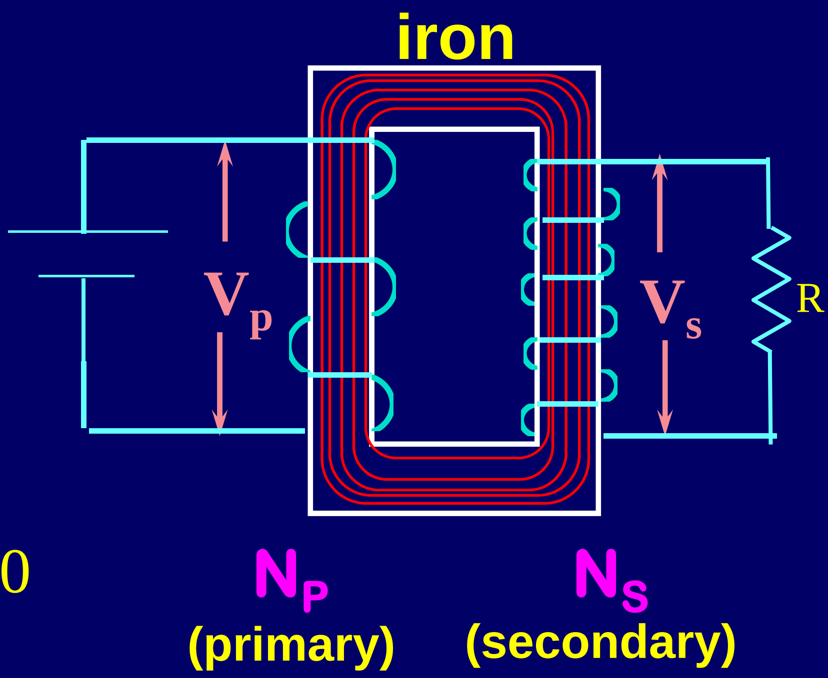


By halving the number of turns around the secondary you decrease the voltage in the secondary by half.

ACT: Transformers

Transformers depend on a change in flux so they only work for alternating currents!

$\mathcal{E} = -\frac{\Delta\Phi}{\Delta t}$



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)
  True
- In a transformer the side with the most turns always has the larger peak current. (T/F)
  False (has smaller current)
- In a transformer the side with the most turns always dissipates the most power. (T/F)
  False (equal)
- 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.

  All of them will!