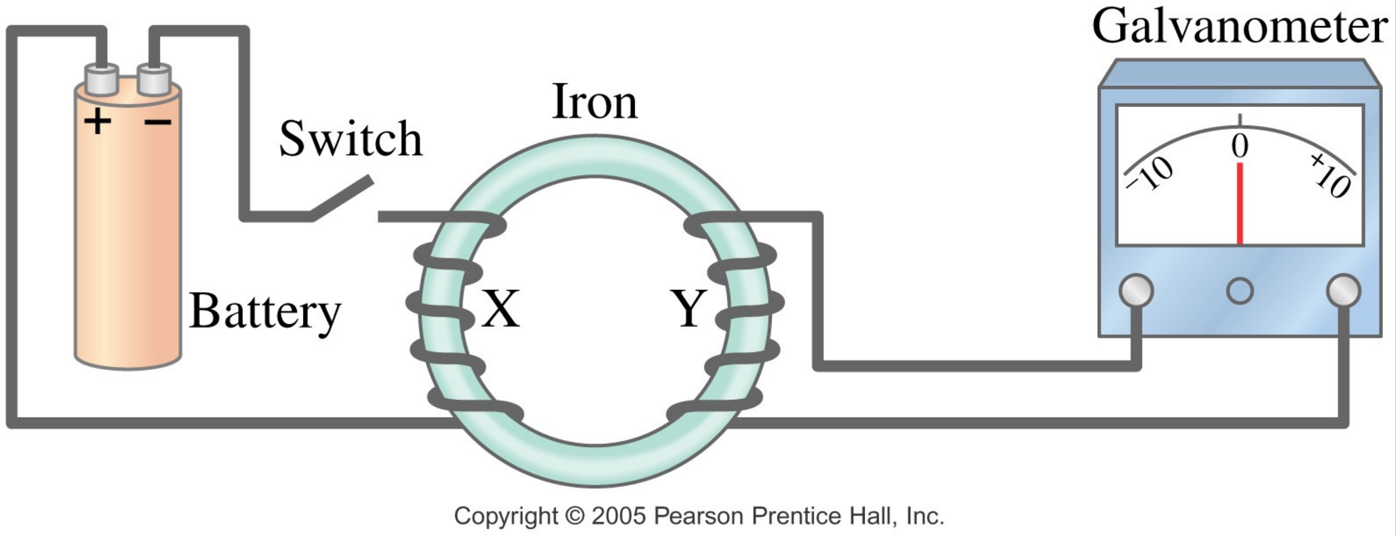
Chapter 30: Induction

Faraday looked for evidence that a magnetic field would induce an electric current with this apparatus:



Remember that:

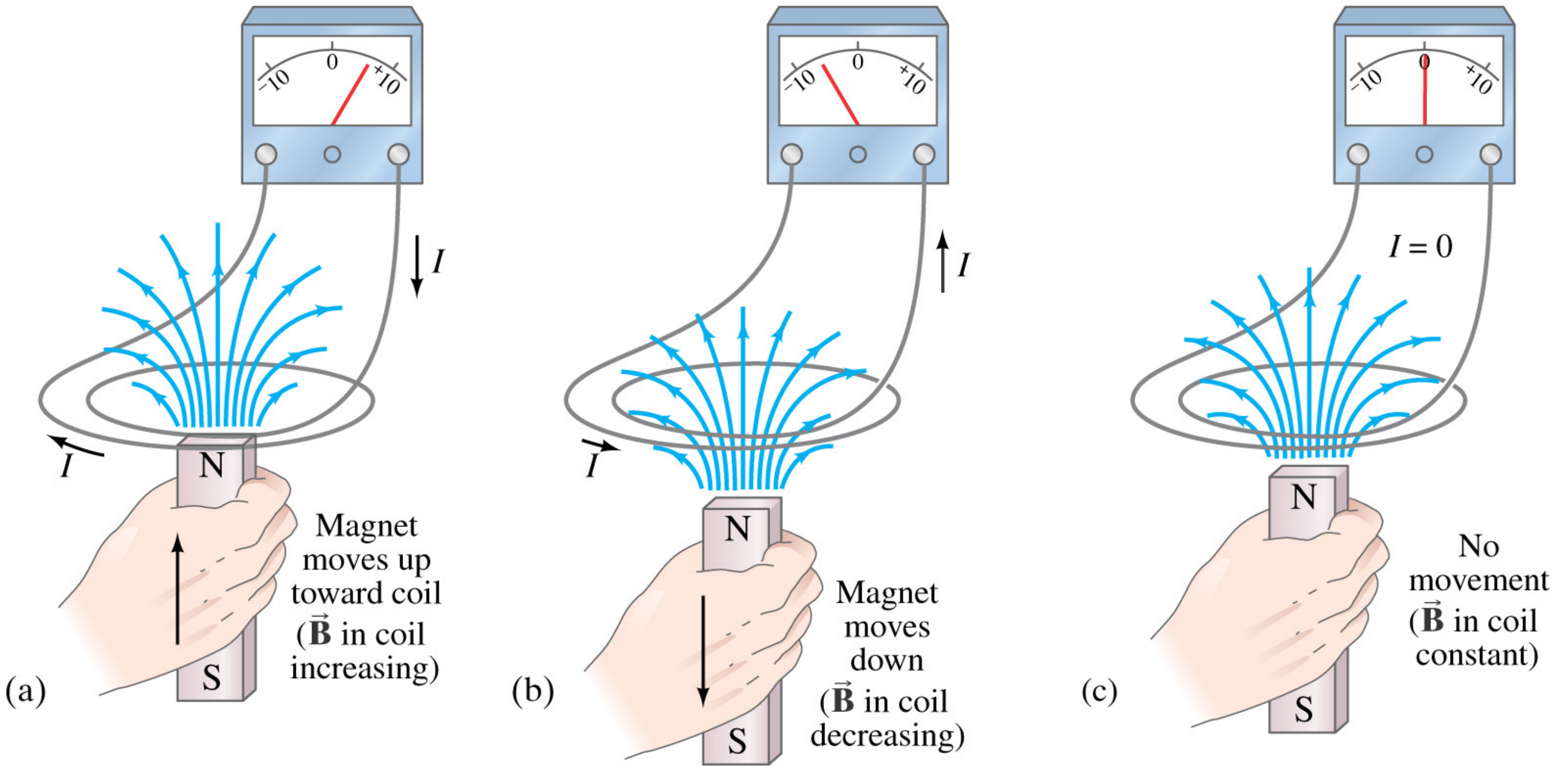
$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

He noticed that a constant current in X produced a constant magnetic field which produced NO current in Y. BUT, when the current was starting or stopping, it did produce a current in Y.

Therefore: a **constant** magnetic field produces **NO** current, but ***a changing magnetic field can produce an electric current – INDUCED CURRENT***

Induced EMF

Therefore, a changing magnetic field induces an emf.



Magnetic flux

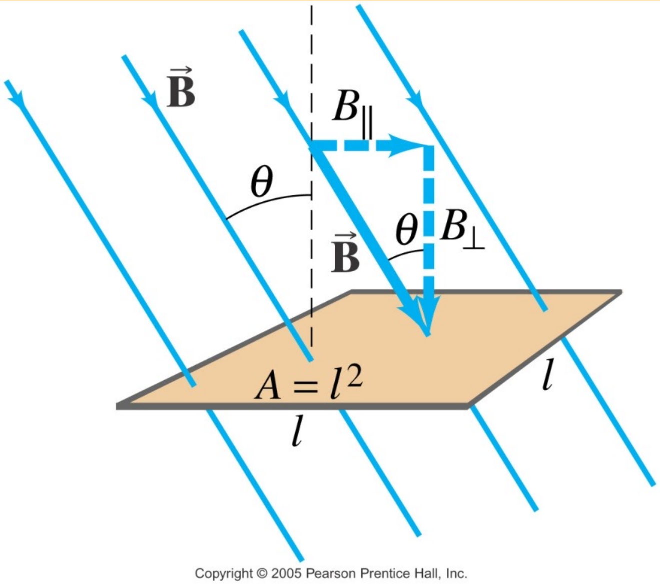
The induced emf in a wire loop is proportional to the rate of change of magnetic flux through the loop.

Magnetic flux:

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

$d\vec{A}$ is a vector of magnitude dA that is perpendicular to a differential area dA

$$\Phi_B = B_\perp A = BA\cos\theta$$



Unit of magnetic flux: weber, Wb.

1 Wb = 1 T·m^2

Ex. A square loop of wire 10.0 cm on a side is in a 1.25-T magnetic field B. What are the maximum and minimum values of flux that can pass through the loop? 0.0125 Wb and 0

Faraday's Law and Lenz's Law

Faraday's law of induction:

[1 loop]

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

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

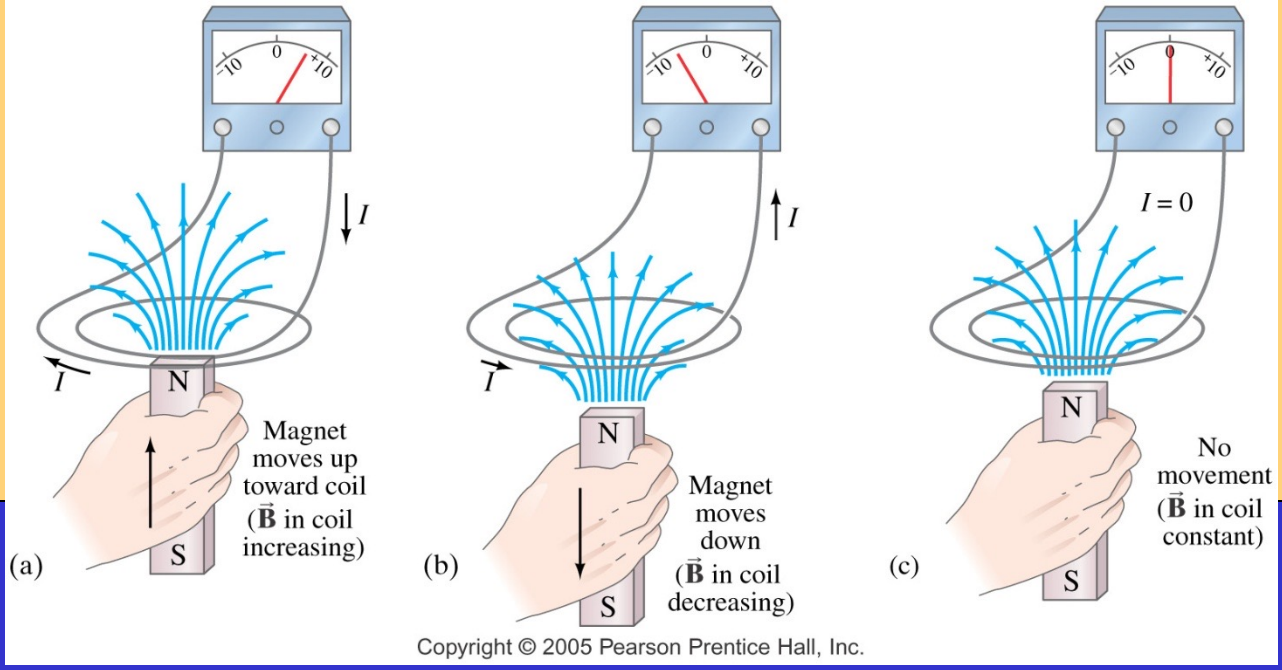
[N loops]

$$\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}$$

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

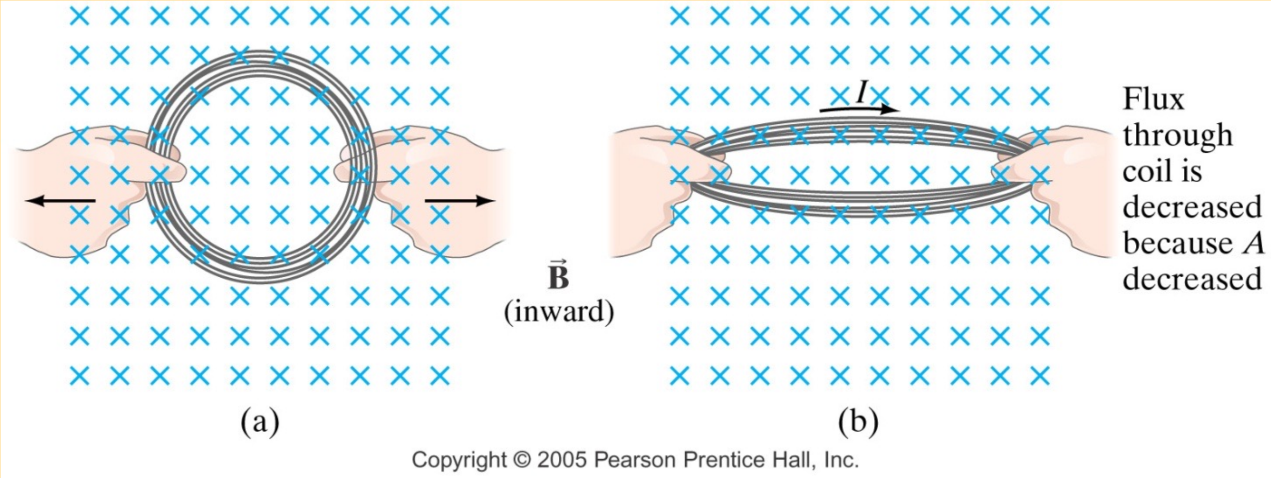
The minus sign gives the direction of the induced emf:

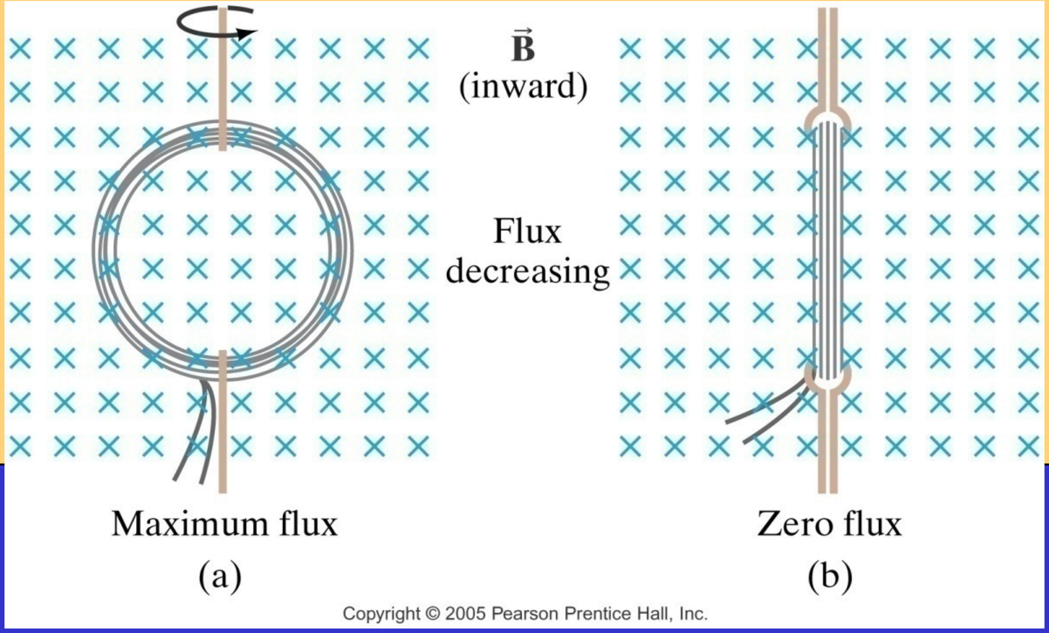
Lenz's Law: **A current produced by an induced emf moves in a direction so that the magnetic field it produces opposes the original change in flux**



Magnetic Flux

Magnetic flux will change if the area of the loop changes:

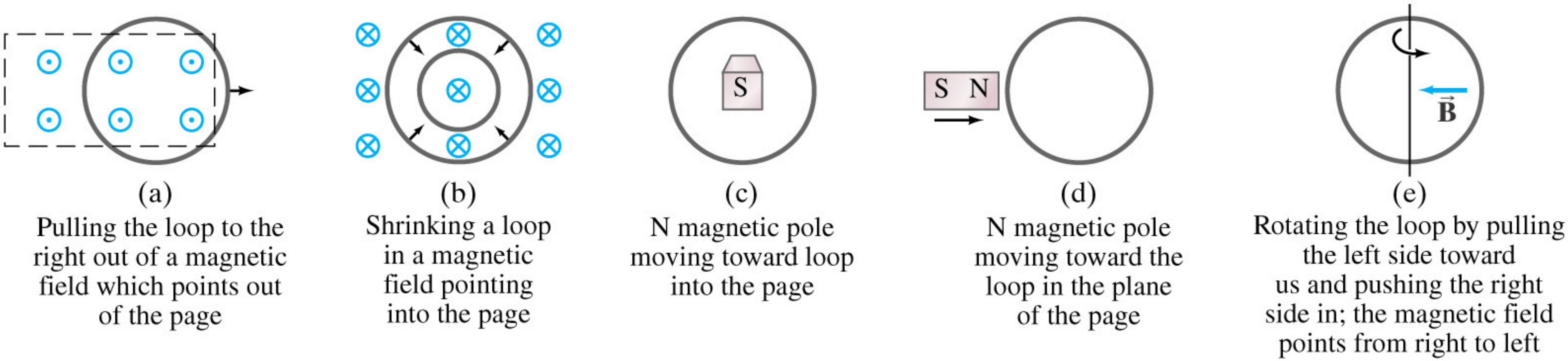




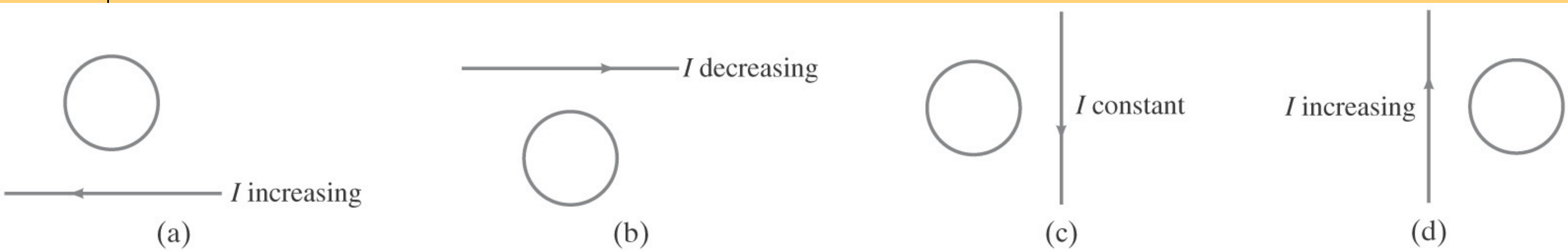
Magnetic flux will change if the angle between the loop and the field changes:

Lenz's Law

Ex. In which direction is the current induced in the loop for each situation?



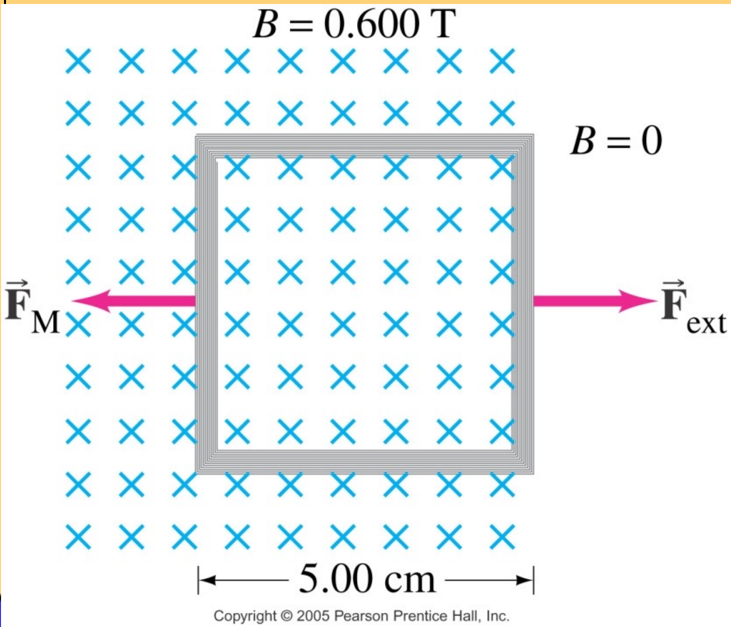
a) counterclockwise b) clockwise c) counterclockwise d) no current e)counterclockwise



a)counterclockwise b) clockwise c) no current d) counterclockwise

Emf and induce current

Ex. A square coil of wire with side L=5.00 cm contains 100 loops and is positioned perpendicular to a uniform 0.600-T magnetic field (see figure). It is quickly pulled from the field at constant speed (moving perpendicular to B) to a region where B drops abruptly to zero. At t=0, the right edge of the coil is at the edge of the field. It takes 0.100 s for the whole coil to reach the field-free region. The coil's total resistance is 100Ω . Find (a) the rate of change in flux through the coil and (b) the emf and current induced. (c) How much energy is dissipated in the coil? (d) What was the average force require?



$$a) -1.50\times10^{-2} Wb/s$$

$$b) emf = 1.50V, I = 15.0mA$$

$$c) E = Pt = (I^2R)t = 2.25\times10^{-3} J$$

$$d) F = W/d = 0.0450N$$

$$F = N(iLB)$$

EMF induced in a moving conductor

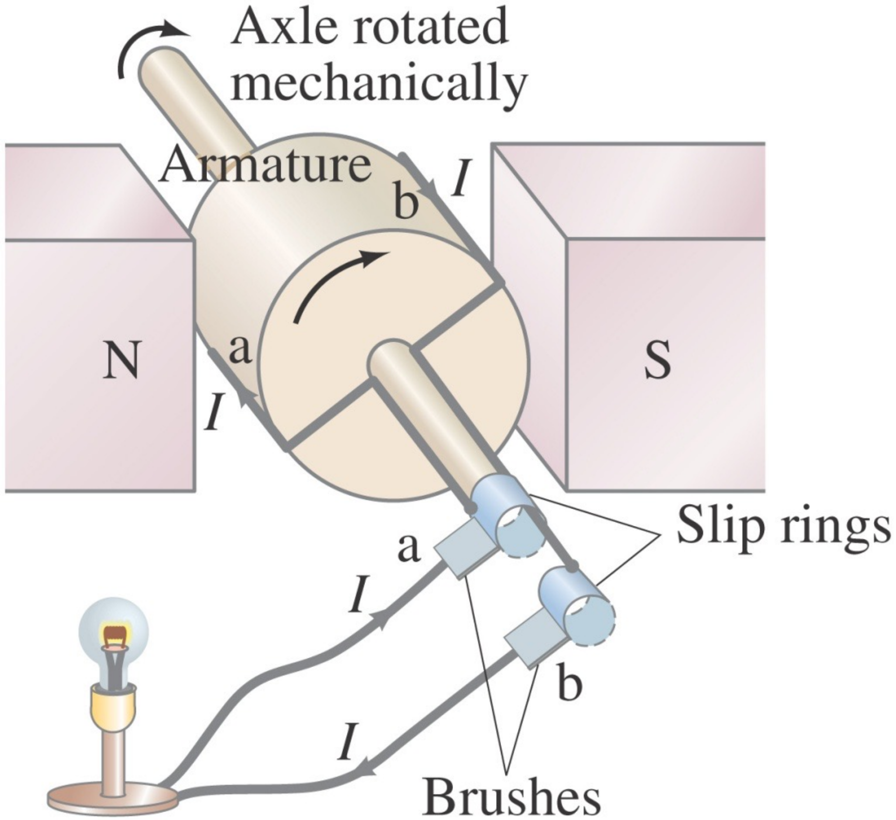
This is an **ac generator**:

A generator is the opposite of a motor – it transforms mechanical energy into electrical energy.

The axle is rotated by an external force such as falling water or steam.

An emf is induced in the rotating coil. A changing magnetic flux induces an electric current.

This is is the most important application of Faraday's law.



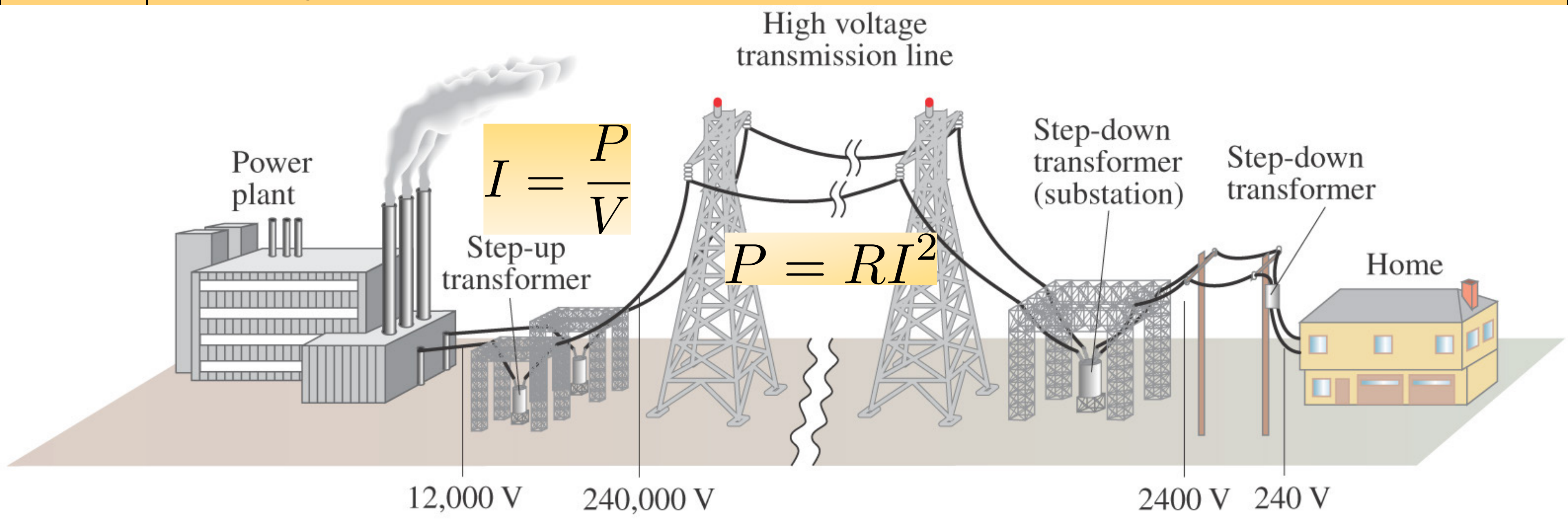
https://www.youtube.com/watch?v=gQyamjPrw-U

http://www.youtube.com/watch?v=k7Sz8oT8ou0

Transformers & Transmission of Power

Transformers are important in the transmission of electricity. Power plants are far from metropolitan areas, electricity is transmitted over long distances. Power loss in the transmission lines can be **minimized** if the power is transmitted at **high voltage**.

Transformers work only if the current is changing; this is one reason why electricity is transmitted as ac.



$$I = \frac{P}{V}$$

$$P = RI^2$$

http://www.youtube.com/watch?v=WTIQ_xcp0sU&feature=related
http://www.youtube.com/watch?v=YcBgxVfD70Q&feature=related

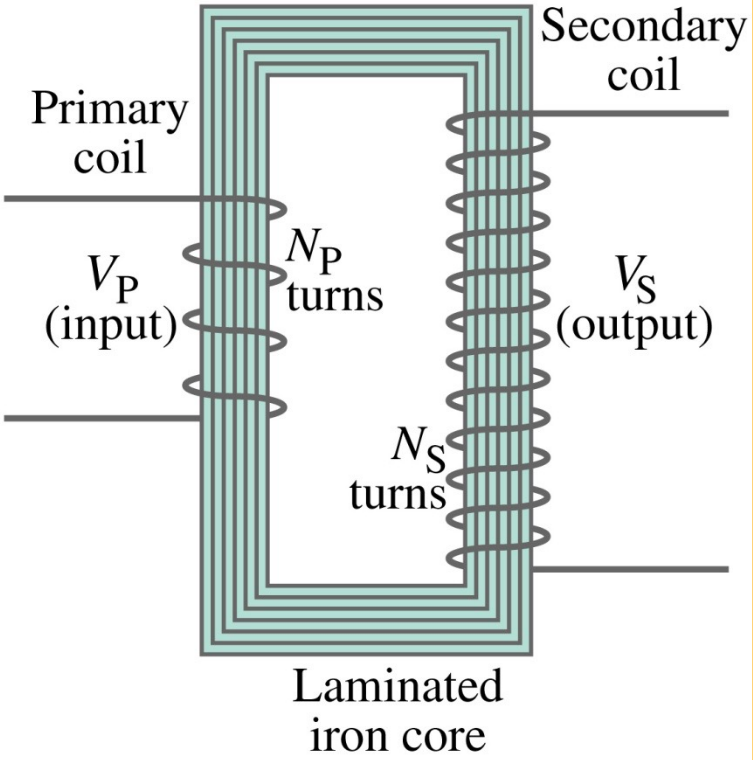
Transformers and Transmission

A transformer consists of two coils, either interwoven or linked by an iron core. A changing emf in one induces an emf in the other.

Ac voltage in primary coil – changing magnetic field induces ac voltage in the secondary coil

$$V_S = N_S \frac{\Delta\Phi_B}{\Delta t}, \; V_P = N_P \frac{\Delta\Phi_B}{\Delta t}$$

$$\frac{V_S}{N_S} = \frac{V_P}{N_P} \Rightarrow \frac{V_S}{V_P} = \frac{N_S}{N_P}$$



Energy must be conserved; therefore power output is equal to the power input (if there is no loss)

$$V_P I_P = V_S I_S \Rightarrow \frac{I_S}{I_P} = \frac{N_P}{N_S}$$

Transformers and Transmission

Ex. A transformer for home use of a portable radio reduces 120-V ac to 9.0-V ac. The secondary coil contains 30 turns and the radio draws 400 mA. Calculate (a) the number of turns in the primary coil, (b) the current in the primary and (c) the power transformed.

$$a)\frac{V_S}{N_S}=\frac{V_P}{N_P}\Rightarrow N_P=400turns$$

$$b)\frac{I_S}{I_P}=\frac{N_P}{N_s}\Rightarrow I_P=0.030A$$

$$c)P=I_SV_S=3.6W$$

Transformers and Transmission

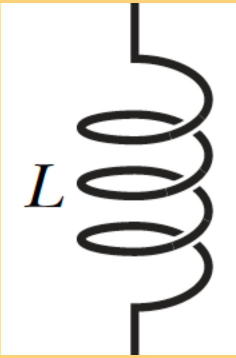
Ex. An average of 120kW of electric power is sent to a small town from a power plant 10 km away. The transmission lines have a total resistance of 0.40 Ohms. Calculate the power loss if the power is transmitted at (a) 240 V and (b) 24,000 V

$$a) I = \frac{P}{V} = 500A \Rightarrow P_{loss} = I^2 R = 100kW$$

$$b) I = \frac{P}{V} = 5.0A \Rightarrow P_{loss} = I^2 R = 10W$$

Inductance

When a changing current passes through a coil (or solenoid), a changing magnetic field flux is produced inside the coil and this in turn induces an emf.



$$\mathcal{E} = -L\frac{\Delta I}{\Delta t}$$

L is called self-inductance or simply inductance. Its magnitude depends on the size and shape of the coil.

Unit: henry(H) where 1H=V.s/A=Ωs

Energy Stored in an Electric Field

A charged capacitor stores electric energy; the energy stored is equal to the work done to charge the capacitor.

$$\Delta W = V\Delta q \Rightarrow W = \frac{V_f}{2}Q$$

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}$$

For parallel plates

$$C = \epsilon_0 \frac{A}{d}$$

$$\Rightarrow PE = \frac{1}{2}CV^2 = \frac{1}{2}\varepsilon_0 E^2 Ad$$

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2$$

To bring two equal charges close together (as when charging the capacitor), we need to do work, we inject energy. Thus, energy is associated with the presence of an electric field.

Energy Stored in a Magnetic Field

The energy stored is an inductance carrying a current I is

$$PE = \frac{1}{2}LI^2$$

$$\frac{1}{2}LI^2 = \frac{1}{2}\left(\frac{\mu_0 N^2 A}{l}\right)\left(\frac{Bl}{\mu N}\right)^2 \Rightarrow \frac{1}{2}LI^2 = \frac{1}{2}\frac{B^2}{\mu_0}Al$$

energy density = $\frac{1}{2}\frac{B^2}{\mu_0}$

*) To bring two wires with opposing current close together, we need to do work, we inject energy. Thus, energy is associated with the magnetic field.

*) When the current decreases/increases in an inductor, the creation of a magnetic field requires energy from the electrons that are flowing.