Lecture 11

May 5, 2011

Summary of last lecture:

Parallel and Series resistors

electromagnetic induction Faraday and generation of electricity

AC currents and transformers

Water	Electricity
Total water in tank	Charge Q in battery [Coulomb]
Rate of flow of water in a pipe	Current I [Amperes]
Height of tank	Potential V [Volts]
Height difference	Potential difference
Constriction of pipe carrying water	Resistance R [Ohms]
Work done in forcing water through a pipe	Work done in pushing charge through a circuit
Rate of doing work is power {watts}	Rate of doing work is power P {watts}

$$I = \frac{Q}{\Delta t}$$

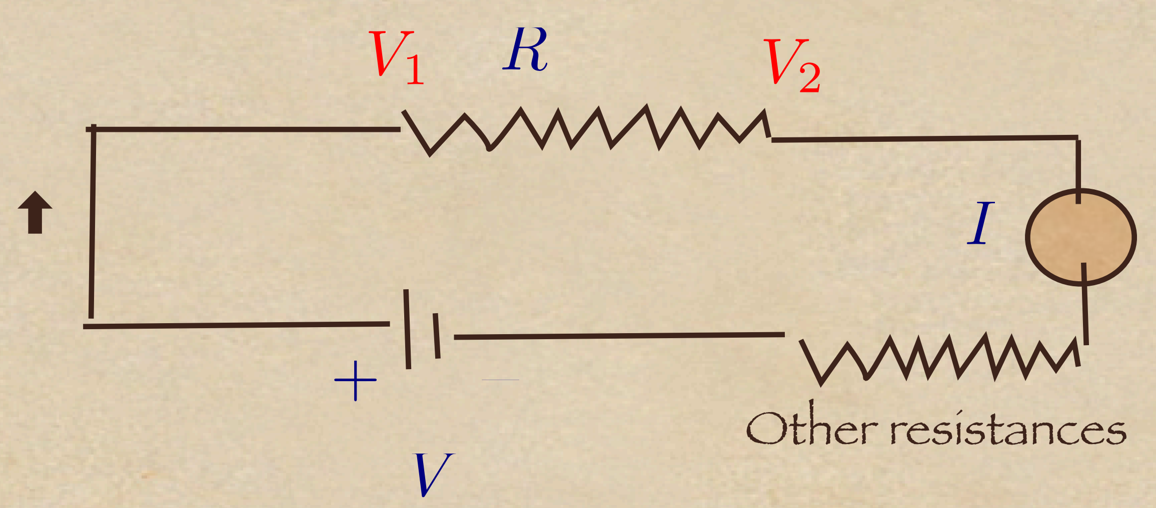
$$V = V_1 - V_2$$

$$V = I \times R$$

$$W = V \times Q$$

$$P = I \times V$$

Resistance and Ohm's law

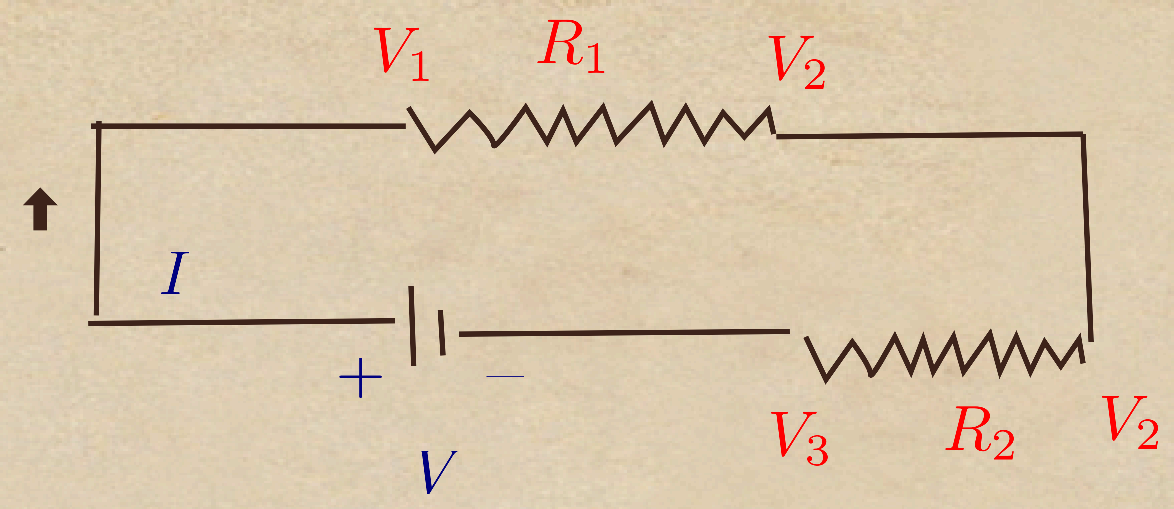


$$[R] = Ohms \rightarrow \Omega$$

$V_1 - V_2 = I \times R$ Potential drop across R and current I are connected by Ohm's law

$P = (V_1 - V_2) \times I = I^2 \times R$ Power dissipated in (Joule) heating across R

Resistors in “series”



Note that the current I
is common to both resistances.

$$V = V_1 - V_3, \quad (1)$$

$$V_1 - V_2 = I\ R_1, \quad (2)$$

$$V_2 - V_3 = I\ R_2, \quad (3)$$

Adding (2) and (3) we get on using (1)

$$V_1 - V_3 = V = I\ (R_1 + R_2), \quad (4)$$

Hence effective resistance is the sum of the two when placed in “series”.

$$R_T = R_1 + R_2$$

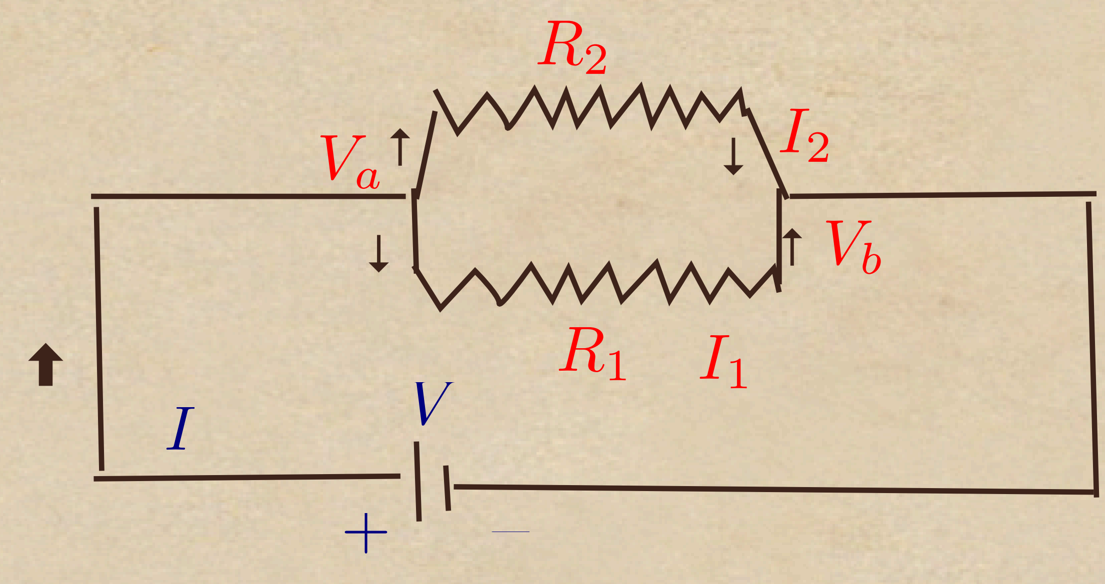
$$V = I \times R_T$$

$$P_1 = (V_1 - V_2) \times I = I^2 R_1 = V^2 \frac{R_1}{R_T^2}, \quad (5)$$

Power dissipated in the resistor

$$P_2 = (V_2 - V_3) \times I = I^2 R_2 = V^2 \frac{R_2}{R_T^2}, \quad (6)$$

Resistors in "parallel"



$$I = I_1 + I_2, \quad (1)$$

$$V = V_a - V_b, \quad (2)$$

$$V = I_1 \times R_1, \quad (3)$$

$$V = I_2 \times R_2, \quad (4)$$

Using (1) we write the total current as

$$I = V \times (\frac{1}{R_1} + \frac{1}{R_2}), \quad (5)$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2}, \quad (6)$$

$$P_1 = V \times I_1 = \frac{V^2}{R_1}, \quad (7)$$

$$P_2 = V \times I_2 = \frac{V^2}{R_2}, \quad (8)$$

Comparing the two

Series

If we take

R_1/R_2=very small

Parallel

$$R_T = R_1 + R_2$$

$$R_T = \frac{R_1 R_2}{R_1 + R_2}, \quad (6)$$

$$P_1 = V^2 \frac{R_1}{R_T^2},$$ ← small

most of power used → $$P_1 = V \times I_1 = \frac{V^2}{R_1}, \quad (7)$$

$$P_2 = V^2 \frac{R_2}{R_T^2},$$ ← most of power used

small → $$P_2 = V \times I_2 = \frac{V^2}{R_2}, \quad (8)$$

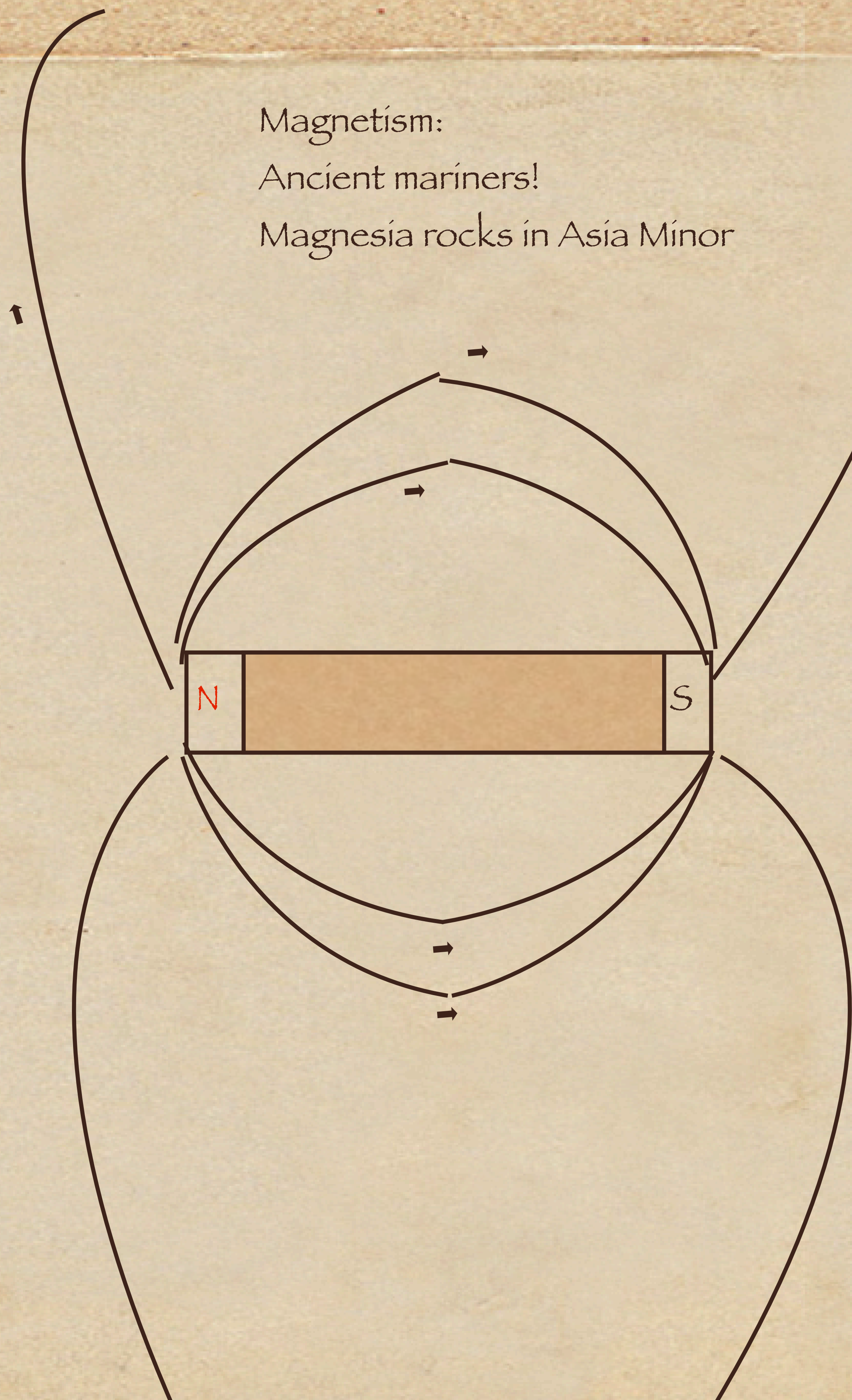
Next Set of Topics
Magnetism

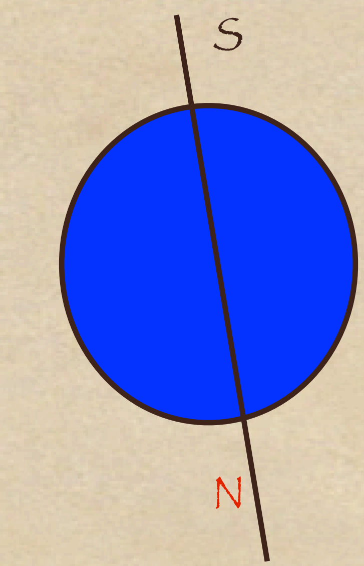
Elementary Magnetism
Faraday's discovery of induction and electrical motors/generators
Transformers
Transmission power lines and use of transformers

Magnetism:

Ancient mariners!

Magnesia rocks in Asia Minor





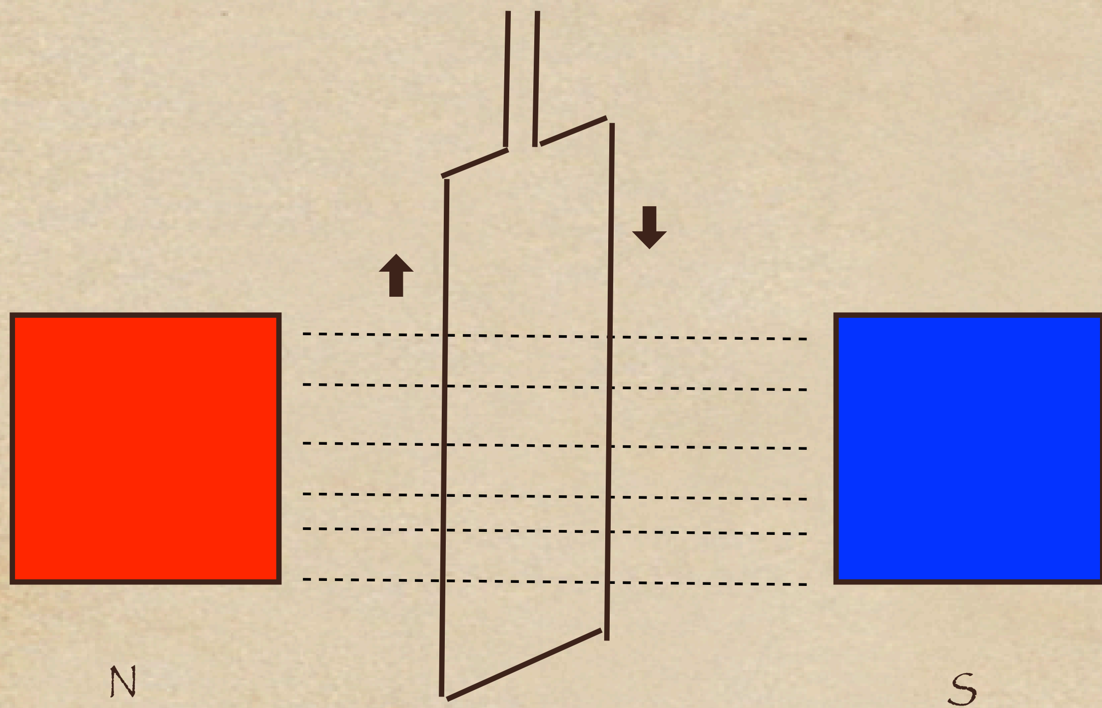
Force is repulsive between N-N and S-S poles

Attractive between N-S poles

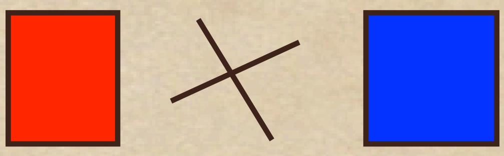
Lines of force:

Faraday 1850

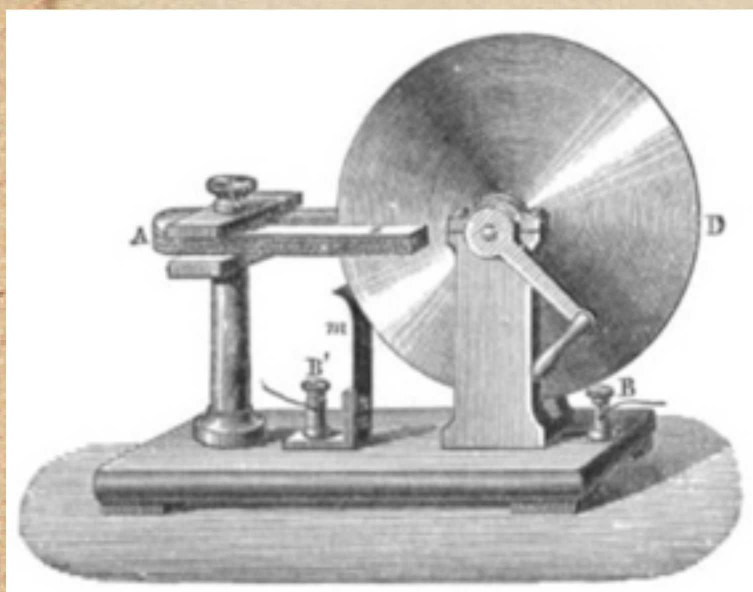
Moving coil in a static magnetic field produces current!



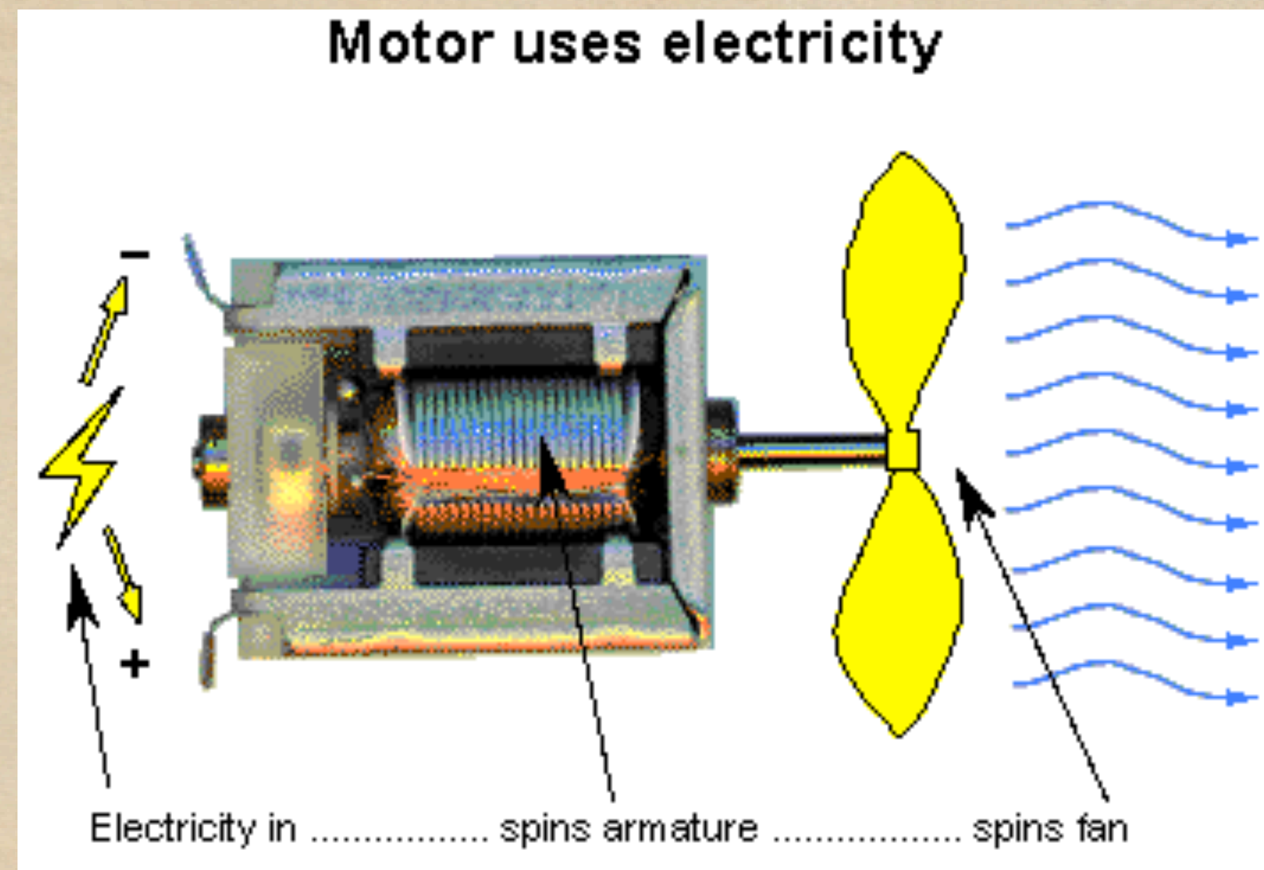
Magnetic forces similar in general form, but much weaker than electrical forces. North and south polarity of magnets. No single (mono) poles in magnetism unlike electricity. However these two combine beautifully.

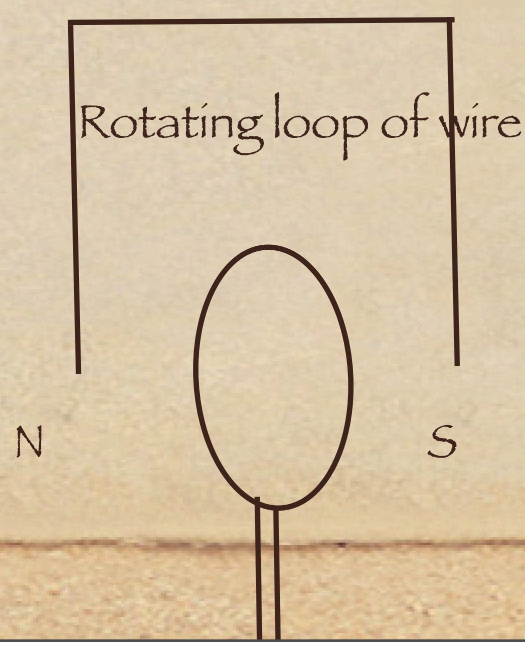


$$V \propto Rate\ of\ Change\ of\ Normal\ Area \times Pole\ strength$$



Faraday 1850

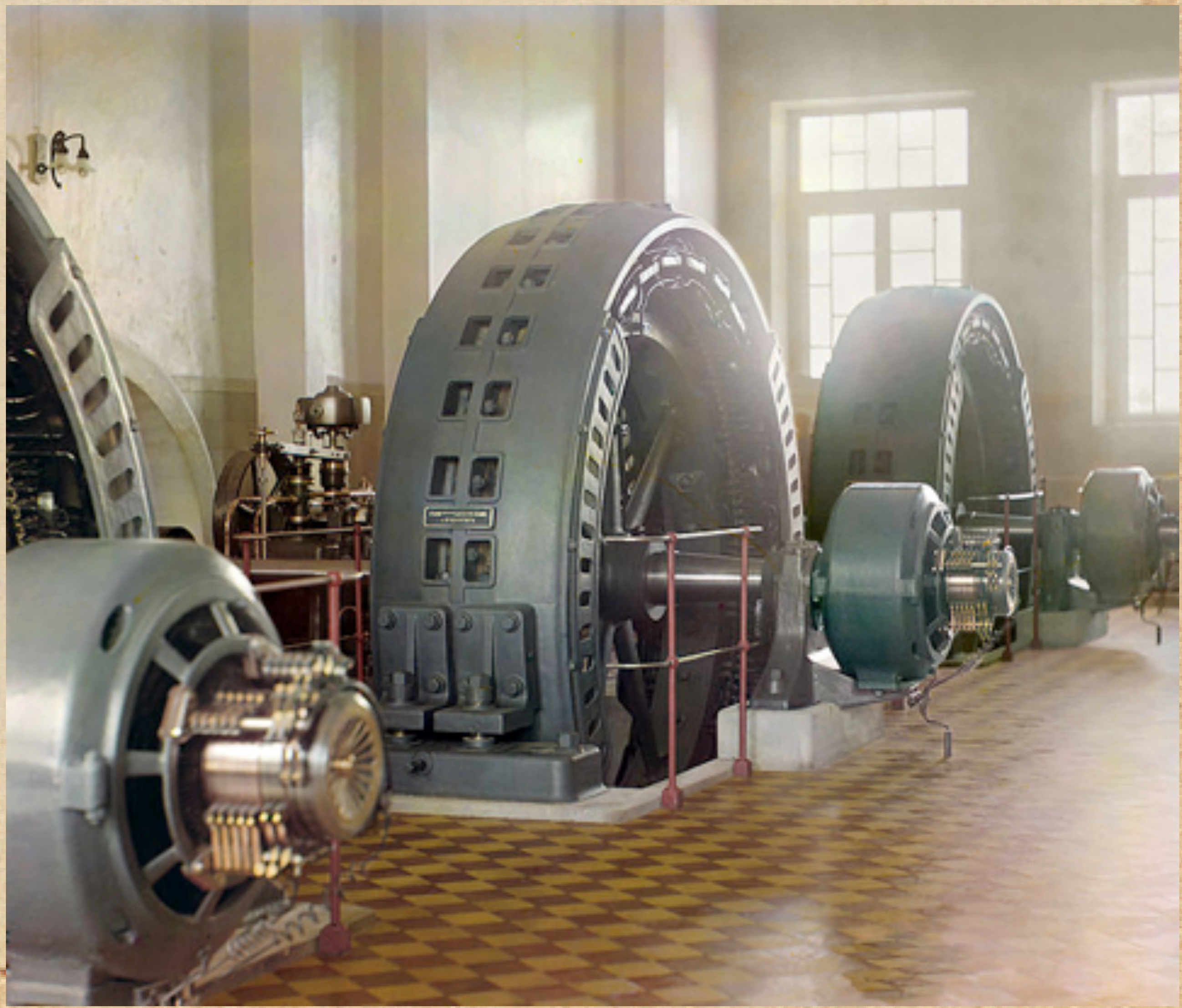




AC current proportional to rate of rotation of loop

Animation can be found here

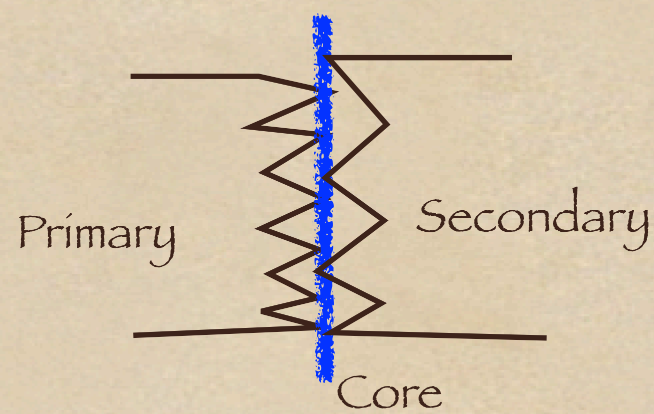
http://www.generatorguide.net/howgeneratorworks.html



Transformers

In all power generation schemes, the mechanical energy obtained by one of several means, is used to rotate the coils in a fixed magnetic field, and hence produce current.

Transformers:



Two loops of AC (not DC) current in close proximity transform voltages according to number of loops

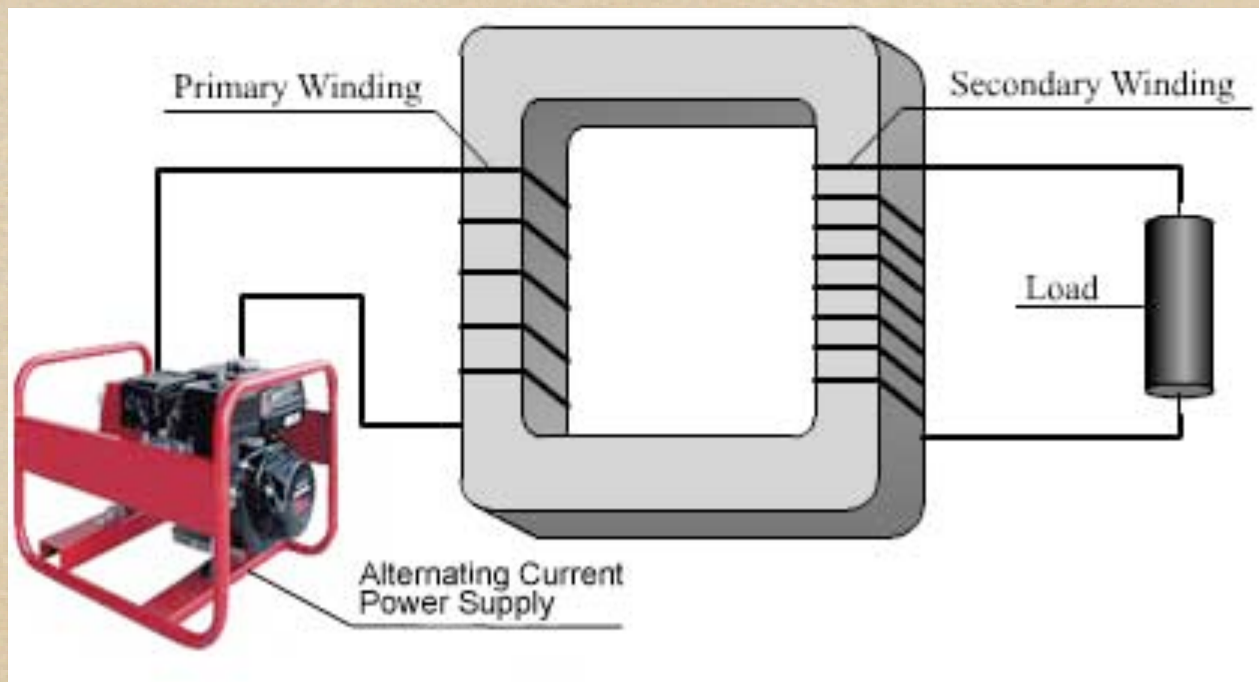
$$V_p/N_p = V_s/N_s$$

Primary coil V_p is voltage and N_p is # of loops

Secondary coil V_s is voltage and N_s is # of loops

$$V_s = V_p \times N_s/N_p$$

We can choose N_p and N_s and thereby manipulate voltages!



98% efficiency of conversion and hence extremely powerful idea

Example 1:

Step down transformer

Door chimes at 6 V, input at 115 V

$$V_s = V_p \times N_s/N_p$$

One solution:

$$V_p = 115\ V$$
$$N_s = 6$$
$$N_p = 115$$

Example 2

Step up:

Appliance made in UK used in USA

$$V_s = V_p \times N_s/N_p$$

$$V_s = 230\ V$$
$$N_s = 230$$
$$N_p = 115$$

Example 3: Transformers in Transmission systems;

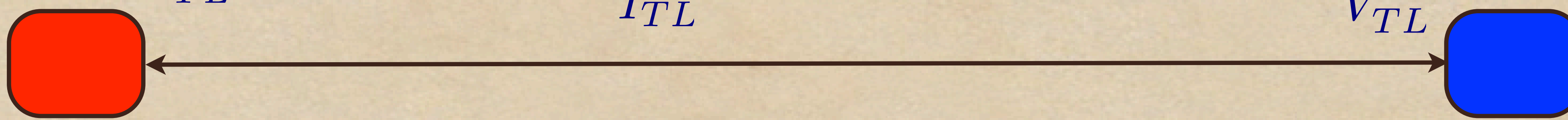
$$V_p = 125,00\ V$$
$$V_s = 500,000\ V$$
$$N_s = 400$$
$$N_p = 100$$

$$\Delta V = V_{TL}^{I} - V_{TL}^{F}$$

R_{TL}

V_{TL}^{I} I_{TL} V_{TL}^{F}

P_{P-P}



T-L

Transmission Line

P-P

(Power Plant)

User

$$P_{P-P} = V_{P-P} \times I_{P-P}$$

$$\mathrm{V}_{P-P} = 12,500V$$
$$I_{P-} = 1000A$$
$$P_{P-P} = 12.5MW$$

$$\mathrm{R}_{TL} = 2\ \Omega\ (Ohm)$$

$$\mathrm{P}_{Joule-Heating} = \Delta V \times I_{TL}$$
$$P_{Joule-Heating} = I_{TL}^2 \times R_{T-L}$$

Using Ohm's law

$$\Delta V = I_{TL} \times R_{TL}$$

To minimize Joule heating we need to make I_{TL} small.

Key point is that I_{TL} is determined by the P_{P-P} via

$$\mathrm{P}_{P-P} = V_{T-L}^I \times I_{T-L}$$

Hence:

$$\mathrm{I}_{T-L} = \frac{P_{P-P}}{V_{T-L}^I}$$

$$\mathrm{P}_{Joule-Heating} = \frac{P_{P-P}^2}{(V_{T-L}^I)^2} \times R_{TL}$$

Need to boost up V^I

Example: Power plant without transformer

$$V'_{TL} = 12,500V$$
$$I_{TL} = 1000Amps$$
$$R_{TL} = 2\Omega$$
$$\therefore \Delta V = 2000V$$

$$P_{JouleHeating} = \Delta V \times I_{TL} \rightarrow 2 \times 10^6 W$$
$$i.e.\ 2MW$$
$$P_{PP} = 12.5MW$$

Power Plant with Transformer

Step up voltage by factor or 10

$$V^{\prime}_{TL} = 125,000\ V$$

$$\because I_{TL} = P_{P-P}/V^{\prime}_{TL}$$

$$I_{TL} = 100\ Amps$$

$$\Delta V = 200V$$

$$P_{Joule-Heating} = \Delta V \times I_{TL} = 2 \times 10^4 W$$

This is a hundred times smaller!!

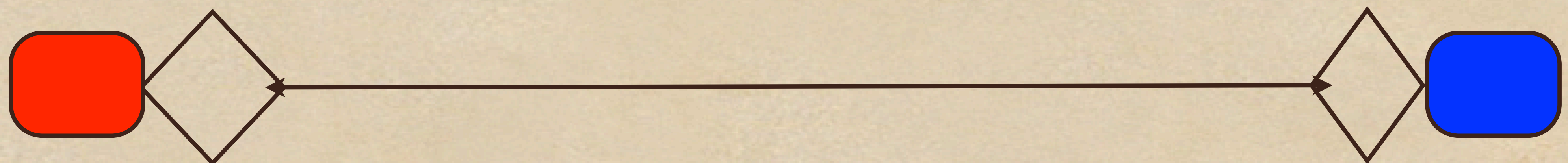
Typical values

$$V_{PP} = 138,000V$$
$$V_{Cables} = 765,000V$$

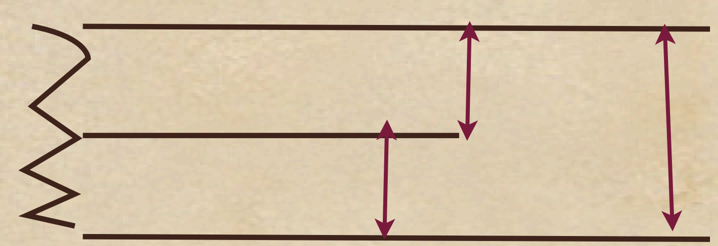
Step up Transformer

Step down Transformer

P_{P-P}



At home the step down transformer gives out with a center tap 230 V



A few odd ends:

Electrical shock to humans:

Dry skin 100,000 Ohms
Wet skin 1000 Ohms

$$V=115 \text{ V}$$
$$R= 1000\ \Omega$$
$$I = .115 Amp$$

In a few minutes this current can kill!
Ventricular fibrilliation
de fibrilliation is often done with 10 amps for 1/1000 sec!

Do not touch a live wire..

If you must (e.g. to save someone)

A few odd ends:

Electrical shock to humans:

Dry skin 100,000 Ohms
Wet skin 1000 Ohms

V=115 V
R= 1000 Ω
$I = .115 Amp$

In a few minutes this current can kill!
Ventricular fibrilliation
de fibrilliation is often done with 10 amps for 1/1000 sec!

Do not touch a live wire..

If you must (e.g. to save someone)
Use the back of the palm:
Not the front,
since muscles contract making it hard to release the wire!!