Lecture 10

May 3, 2011

Current, Voltage, Resistance
Joule Heating.

Appliances and
their evaluation

Next set of topics:
Electric Energy Concepts
Electrical Laws (Ohm's law, Joule Heating)
Faraday's law and the Generation of electricity
Transmission of electricity (transformers)

Next week Solar cells and their efficiency, basics of quantum theory

Supplementary notes on web
RK is rather inadequate for these topics.

Common Denominator

Coal, Petroleum, Natural Gas, Nuclear, Hydro all end up creating electricity
Electricity is a crucial part of the energy enterprise giving it portability.

Electricity Basics:

Electrostatics:

Rubbing generates electrical potential, Lightening, ...

Q Coulomb

Unit of charge is a Coulomb

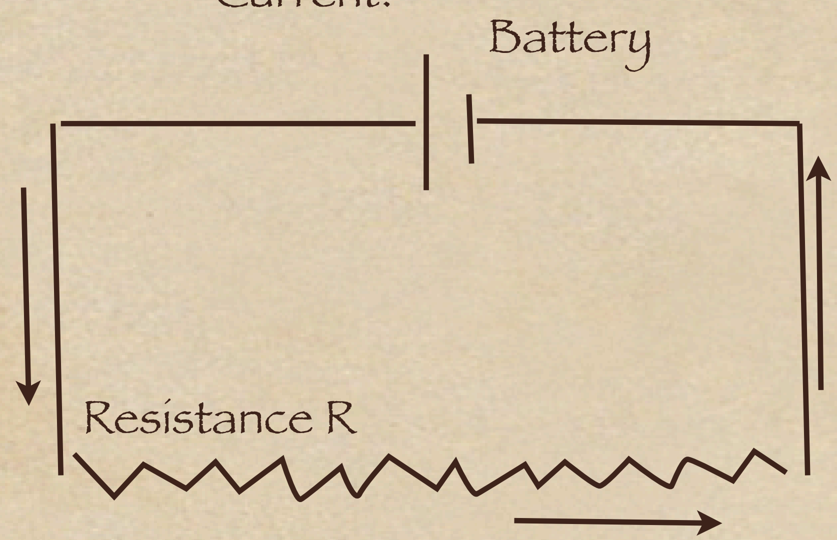
Like charges repel
Opposite charges attract
F is the force between two charges

$$F(R) = k\frac{Q_1 Q_2}{R^2}$$

$$[k] = 8.99 \times 10^9 \text{ Newton Meter/Coulomb}^2$$

Moving charges give currents: electrodynamics

Current:



I Ampere = Coulomb/sec

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

Useful Analogy: Charge "Q" is the total quantity of water in a tank.

Current "I" is the amount of water flowing through a pipe per second

Unlike charge, the current has a direction. We may speak of Q as a scalar and I as a vector.

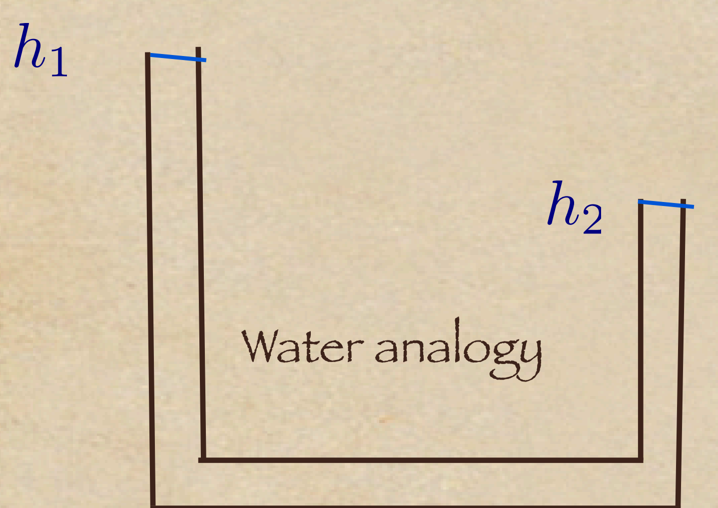
Example1: 100 Coulombs in 10 seconds gives a current of 10 amperes

Example2 : A bulb has a flow of 1 amp and is used for 10 minutes. Total charge = 600 seconds x 1 ampere = 600 Coulombs

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
Rate of doing work is power {watts}	Rate of doing work is power P {watts}

Voltage: = potential difference

Analogy is to a height difference in water

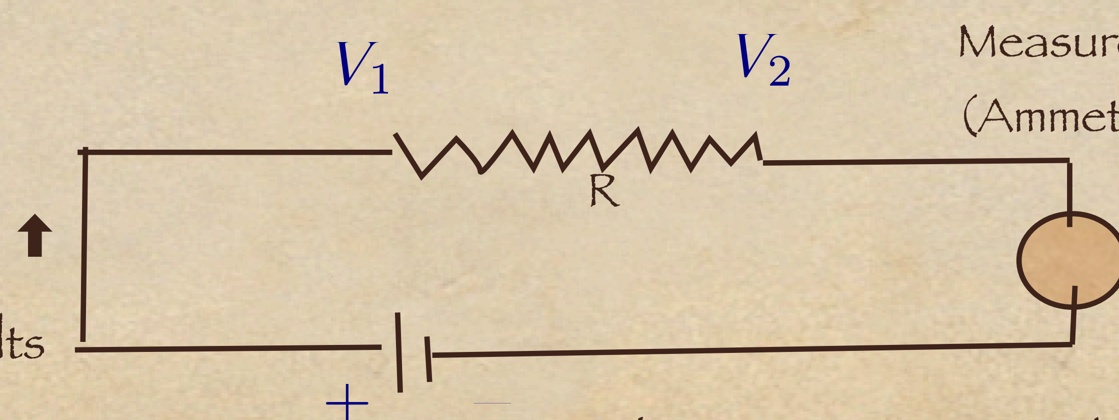


$$V \sim h_1 - h_2$$

Voltage= potential difference
W= work done in moving a charge against a potential

$$V = V_1 - V_2$$

$$W = V \times Q$$



Measures current (Ammeter)

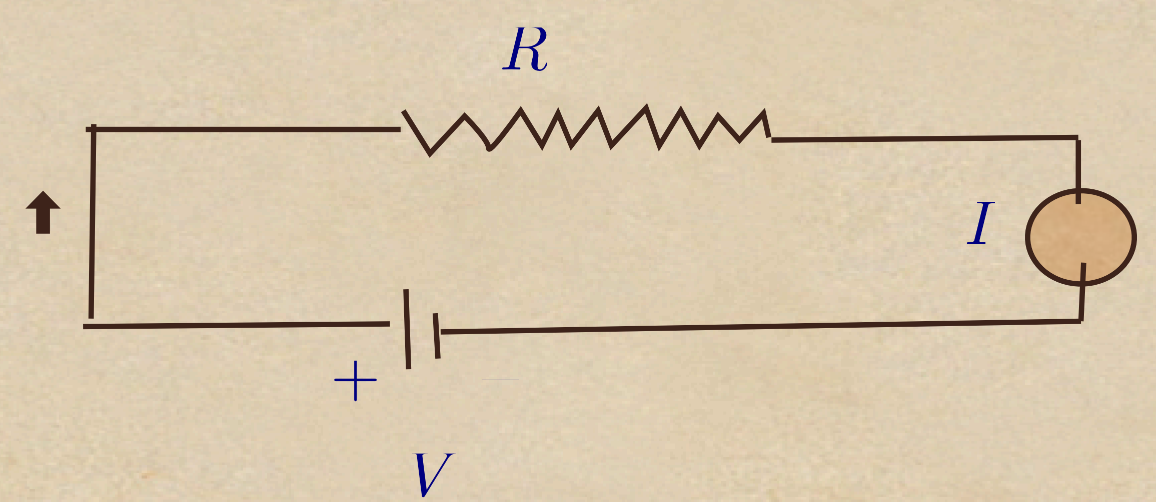
$$[V] = Joules/Coulomb$$

$$[V] = Volt$$

Car battery : 12 Volts
Cells: 1.5 Volts

Car battery passes 2 Coulombs charge doing 24 J work.

Resistance and Ohm's law



True for most metallic wires

R= resistance of the wire

$$V = I \times R$$

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

$$[R] = Ohms \;\rightarrow\; \Omega$$
$$[R] = \text{Volts/Ampere}$$

Example : Battery 12 V, connect to resistance 1 Ohm gives current of 12 ampere.

by changing the resistance, we change the current in this situation

Work done and power relationship

Summarizing:

A) we saw that a charge Q can be moved against a voltage V and the work done is

$W = Q \times V$. Here Q is in Coulombs, V in volts, and W is in Joules (recall work done is dimensionally the same as energy.

B) We also saw that the current I is related to charge Q through

$I = Q/\Delta t$ where the variable Δt is the time interval during which Q flows.

C) Now recall that power P is the rate of doing work, i.e.

$P = W/\Delta t$. Hence

$P = Q \times V/\Delta t$

We now use the definition of current above and conclude that

$P = V \times I$

Here if we write V in volts and I in Coulomb per second (i.e. amperes) then P is automatically in Watts.

Current, Voltage, and Power redux

$I = f(V)$

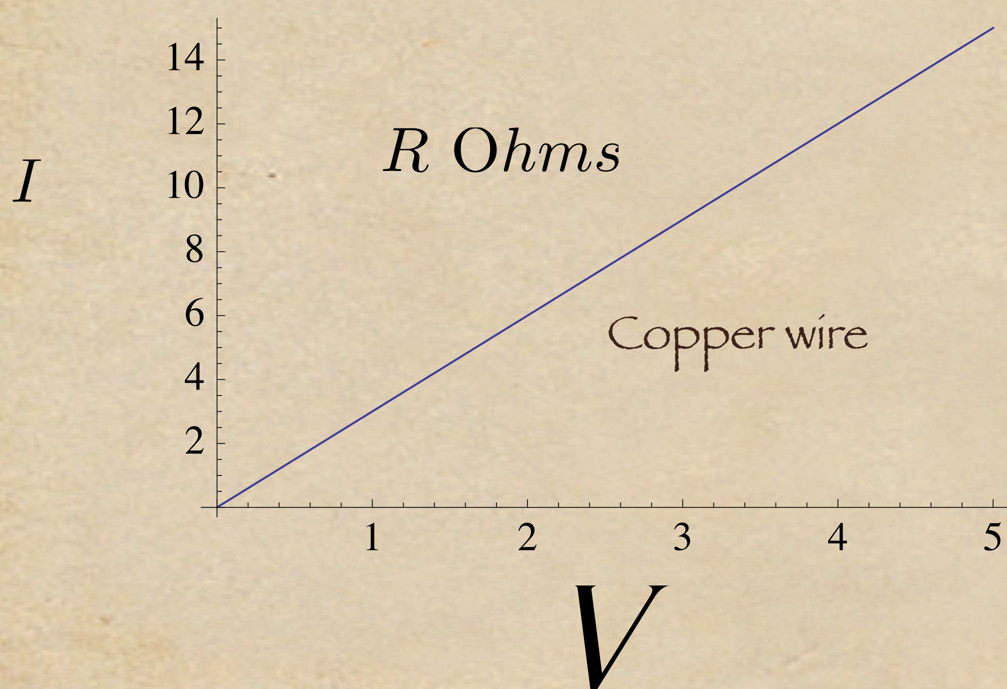
I Amperes

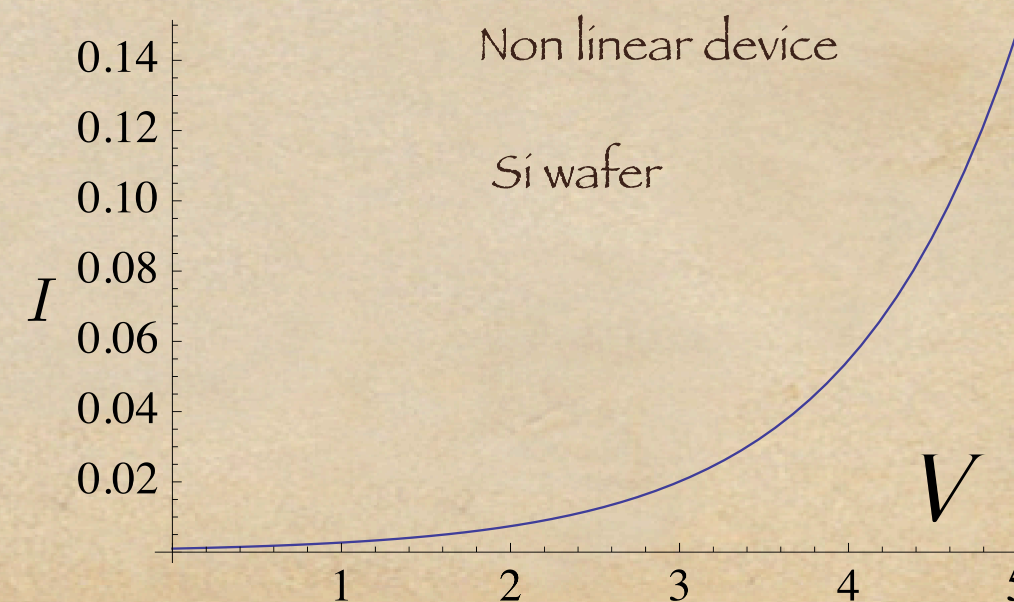
$V = I \times R$ Ohm's Law for resistances (Linear curves)

V Volts

$P = I\ V$ Power in Watts

$P = I^2 R$ for resistances





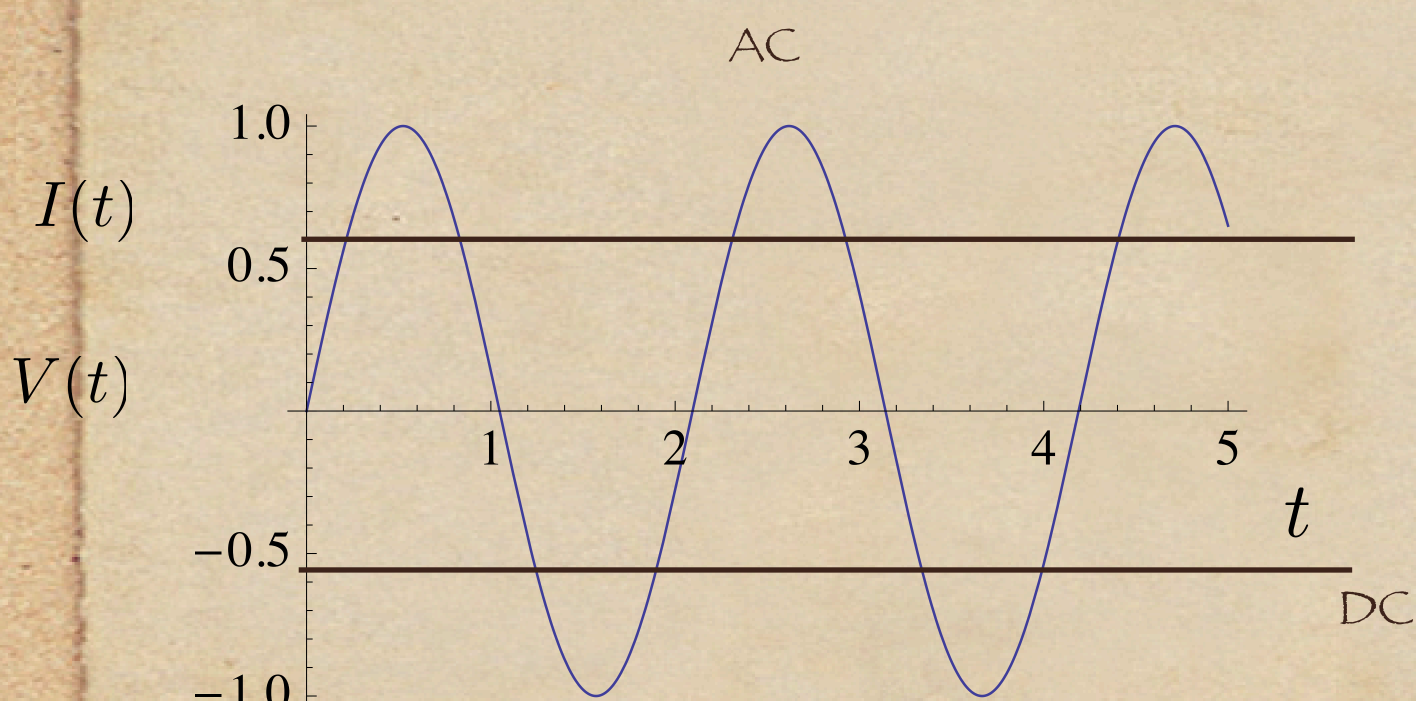
Household voltage 115 V (USA) 220 V (India) 240 V (UK)

DC = direct current

AC= alternating current

AC is much easier to generate using the idea of electromagnetic induction of Michael Faraday

Practical usage case: AC current and AC voltage, where these are time dependent



$$\sin(\omega t)$$

$$\omega = \frac{2\pi}{T}$$

Cycles per second

Household current

60 Hertz= 60 cycles per second

POWER and Energy used

Joule Heating is covered in this equation

$$P = I \times V \;\; Watts \qquad\qquad I \sim \; Amps, \& \; V \sim \; Volts$$

Example: 12 V battery drawing 10 amps current (high beam) consumes 120 Watts power

Combining Ohms law and Power equation, we can solve many problems.

$$V = I \times R \;\; (1)$$
$$P = I \times V \;\; (2)$$

P V R I

Four variables two equations

Hence given any two, the other two follow

I) Given Voltage Source

V

Connected to various resistances

R

$$I = V/R$$

$$P = V^2/R$$

II) Given Current Source

I

Connected to various resistances

R

$$V = IR$$

$$P = I^2R$$

III) Given Voltage Source

V

Connected to various appliances with given

P

$$I = P/V$$
$$R = V^2/P$$

Question:Given 1000 Watts toaster running for 5 minutes, what is the current drawn and energy used, and charges to PG&E!!!

$$V = 115\ Volts$$

$$I = 1000/115 = 8.7\ Amps$$

$$R = V^2/P = 13.2\ Ohms$$

$$E = 1kW \times 5minutes \times 1\ hour/60minutes = .083kWH$$
$$\times .12\$\ per\ kwH$$
$$= .010\$$$

Cooking range	12 kW
Heat pump	12 kW
Clothes dryer	5 kW
Oven	3.2 kW
Microwave Oven	1.5 kW
Hand Iron	1 kW
Room Airconditioner	1.6 kW
TV	.33 kW

Determining Joule heating losses

We would like to be able to calculate the losses to Joule heat in various situations.

Suppose a 1000 MW power plant sends its power out on a 800,000 V high voltage line. If the total resistance of the line is 2.2 Ω, what percentage of the electrical power will be lost due to Joule heating?

We may find the current in the transmission line, because we know that $P = IV$, so $I = P/V$:

$$I = \frac{P}{V} = \frac{1000 \text{ MW}}{800\,000 \text{ V}} = \frac{1\,000\,000\,000 \text{ W}}{800\,000 \text{ V}} = 1250 \text{ A}.$$

The power in Joule heating is found by $P_{\text{Joule heating}} = I^2R$,

$$P_{\text{Joule heating}} = I^2R = (1250 \text{ A})^2 \times 2.2\ \Omega = 3{,}437{,}500 \text{ W} = 3.44 \text{ MW}.$$

Hence $\frac{P_{\text{Joule heating}}}{P_{\text{transmitted}}} = \frac{3.44 \text{ MW}}{1000 \text{ MW}} = 0.344\%$ and so about one-third of a percent of the transmitted electric power is lost to Joule heating in this case.

How about a lower voltage?

Same problem but now we transmit the power on a 400 Volt line

$$I = \frac{P}{V} = \frac{10^9\ W}{400V} = 2.5 \times 10^6\ Amps$$

Joule Heating:

$$P_{Joule} = I^2 \times R = 2.2 \times 6.25 \times 10^{12} = 1.37 \times 10^{13} W$$

But !! $$P_{Generated} = 10^9 W$$

This is a big problem!

$$P_{Joule} = I^2 \times R$$
$$P_{Generated} = I \times V$$

$$P_{Joule} = P^2_{Generated} \times \frac{R}{V^2}$$

Big V is the solution.

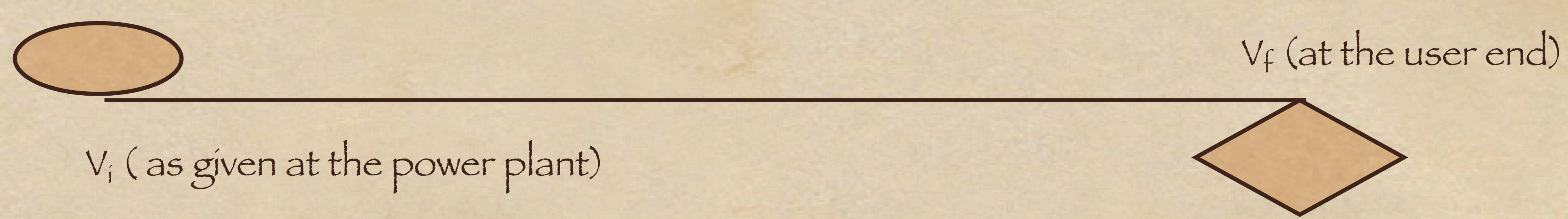
Comment: In using the above relations, we should note that the Ohm's law needs to be handled carefully:

In particular we cannot use

$$V = I \times R$$ Wrong formula

to calculate I from the given line voltage V and resistance R.

Key point is that the voltage line has a potential drop across its length:



$$V_i - V_f = I \times R$$ Correct formula