PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

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Two Week Schedule

- Today: Current, resistance
- Circuits: Ch 18
- Friday 11/6: QUIZ 3 (Ch 17 and 18)
-

Quiz results – posted soon

17.1 Electric Current

Electric current

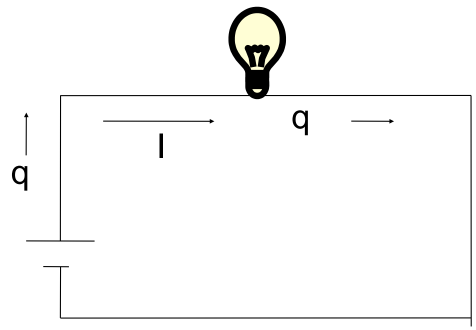
Drift speed

Current sources: Batteries

Charge flow slowly in a wire

Carry kinetic energy like water in a pipe

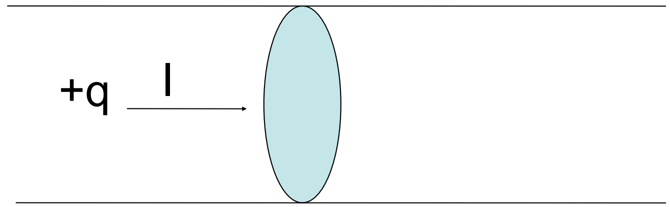
The energy can be released eg. Lightbulb



There is an electric field in the conductor.
Non-Equilibrium System. – Charges move

Electric Current, I

rate of +charge flow through a surface



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

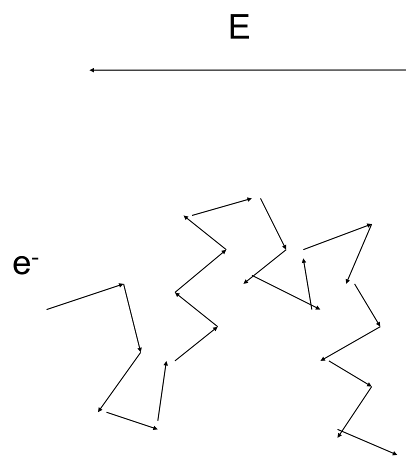
Units Coulombs/sec – Ampere (A)

A flashlight bulb carries a current of 0.1 A. (a) Find the charge passed in 10 s. (b) How many electrons does this correspond to?

(a)
$$I = \frac{\Delta q}{\Delta t}$$
$$\Delta q = I\Delta t = 0.1(10) = 1C$$

(b)
$$q = Ne$$
$$N = \frac{q}{e} = \frac{1}{1.6x10^{-19}} = 6.2x10^{18}\, electrons$$

Drift Velocity

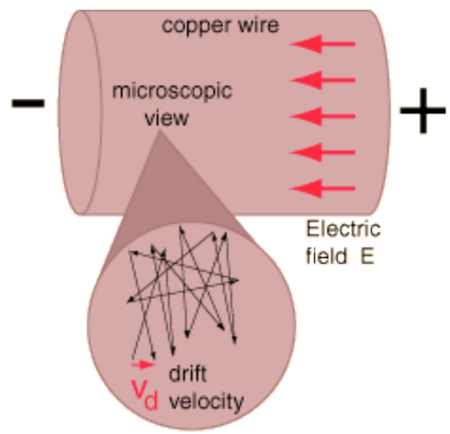


$$\tau \approx 10^{-14} s$$

Collisions of electron with the lattice (a.k.a resistance) slows down the velocity.

Drift velocity- Average velocity in the direction of the flow.

The electron moves at the Fermi speed, and has only a tiny drift velocity superimposed by the applied electric field.



Avogadro's number   Density

$$n = \frac{(N_A\, atoms / mole)(\rho \;\; kg / m^3)}{A(kg / mole)}$$

Atomic mass

$$V_d = \frac{\Delta x}{\Delta t}$$

Current – like a fluid through a pipe.

Rate of flow is

$$\frac{charge}{time} = \left(\frac{charge}{volume}\right)\left(\frac{volume}{time}\right) = (qn)\left(\frac{A\Delta x}{\Delta t}\right) = qnAv_d$$

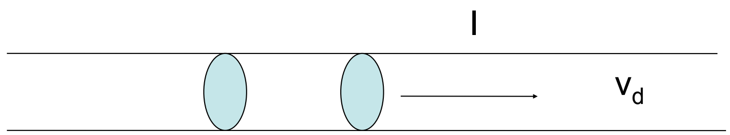
$$I = \frac{\Delta q}{\Delta t} = qnAv_d$$

V_d –Drift velocity

n – no. of charge carriers/volume

q- charge per charge carrier

17.2 Find the drift velocity of electrons in Cu. For I=10 A, A=3x10^{-6} m^2. Use density of Cu, ρ=8.95 g/cm^3(each atom of Cu contributes 1 carrier electron) M_A=63.5g/mole



$$I = qnAv_d \qquad q = e$$

$$n = \frac{atoms}{m^3} = \frac{grams}{cm^3}\frac{10^6\,cm^3}{m^3}\frac{atoms}{gram}$$

The drift velocity is very low.

The current is large because of the large number of charge carriers.

The electrical signal travels fast, because electrons interact and “push” other electrons in the conductor

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Amp hour (unit of charge)

How much charge is equal to 2100 mAh (milliamp hours)

charge=(current)(time)

Ni-MH Nickel metal hydride battery

A battery with a 2 amp hr rating is used to power a flashlight that draws 5 A of current. How long will the battery last

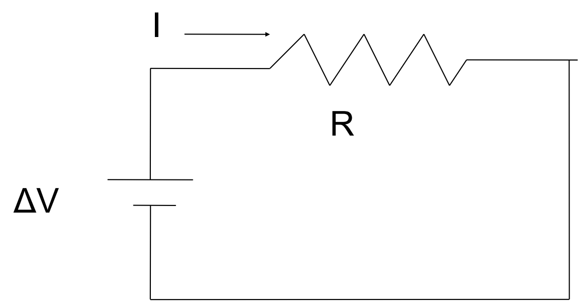
$$Q = I\Delta t$$

$$\Delta t = \frac{Q}{I} = \frac{2amp.hr}{5amp} = 0.4hr$$

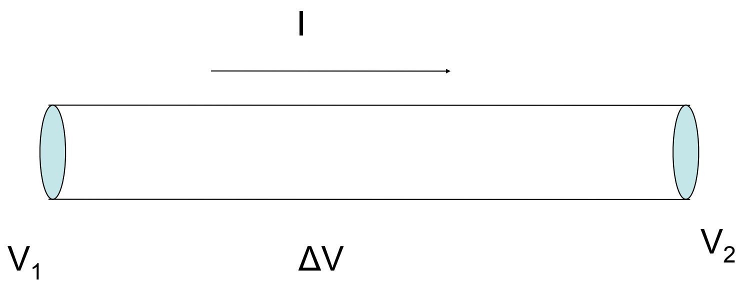
Resistance Chapter 17.4

Resistance

R units Volts/Ampere , Ohms (Ω)



Resistance

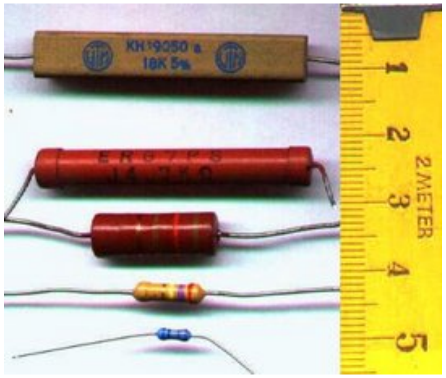


$$R = \frac{\Delta V}{I}$$

Resistance, units Volts/Ampere = Ohm (Ω)

Resistance causes conversion of potential energy to heat.

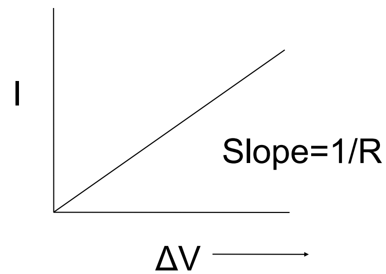
Resistors



carbon resistors
wire wound resistors
thin metal film resistors

Ohm's Law

For many conductors I is linear with ΔV,



$$I \propto \Delta V$$

$$I = \frac{1}{R}\Delta V$$

$$\Delta V = IR$$

R is a constant

Gravitational analogy to $\Delta V=IR$

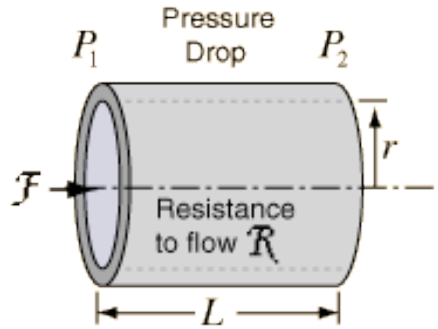
Water flow in a river

Water flow is fast where the slope is steep (large potential drop).

H_2O resistor

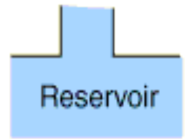
$$\text{Volume Flowrate} = \mathcal{F} = \frac{P_1 - P_2}{\mathcal{R}} = \frac{\pi(\text{Pressure difference})(\text{radius})^4}{8(\text{viscosity})(\text{length})}$$

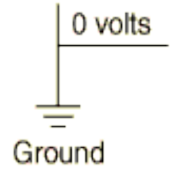
$$\text{Resistance to Flow} \quad \mathcal{R} = \frac{8\eta L}{\pi r^4}$$



E&M & H_2O

The reservoir can supply water to the circuit, and holds the pressure of the adjacent pipes at the pressure of the reservoir.





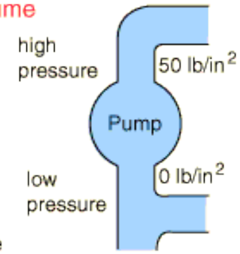
The ground can supply charge to the circuit, but its main function is to hold the voltage of nearby wires at the voltage of the earth.

$$\text{pressure} = \frac{\text{energy}}{\text{volume}}$$

$$\text{pressure} = \frac{F}{A}$$

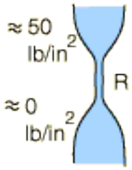
$$\frac{F}{A} = \frac{F\,d}{A\,d} = \frac{W}{V}$$

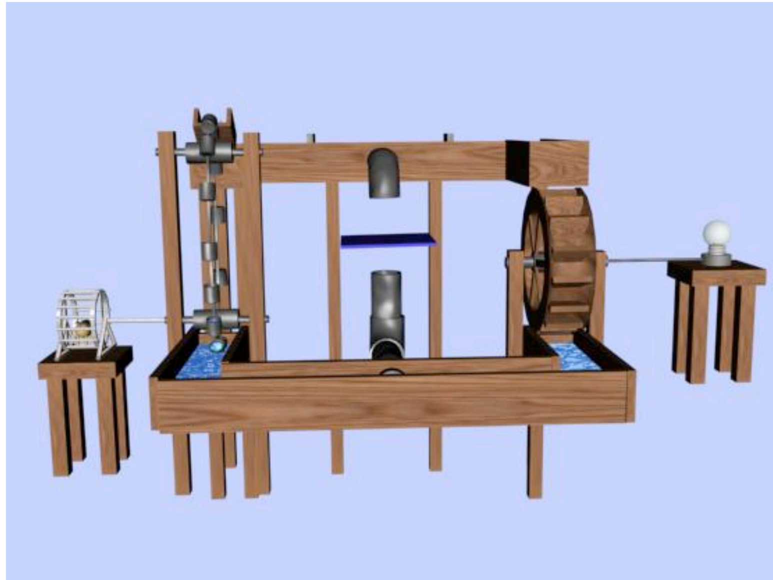
$$= \frac{\text{energy}}{\text{volume}} \quad \frac{\text{joule}}{m^3}$$

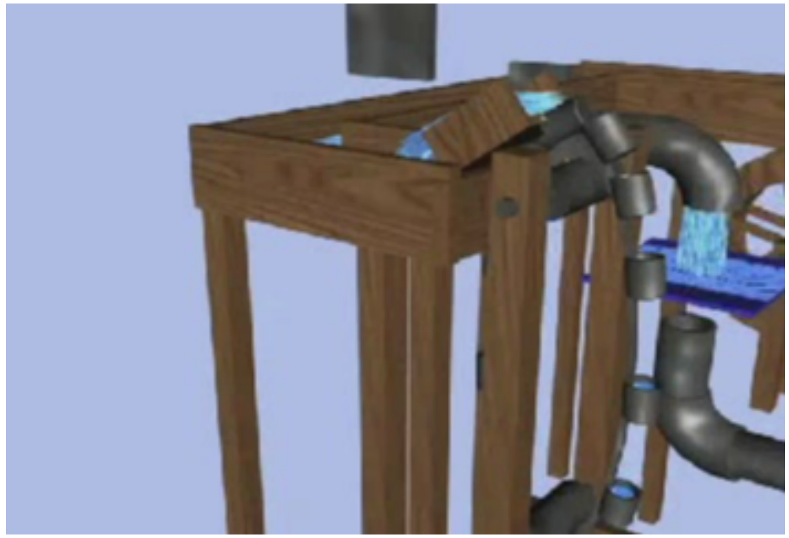


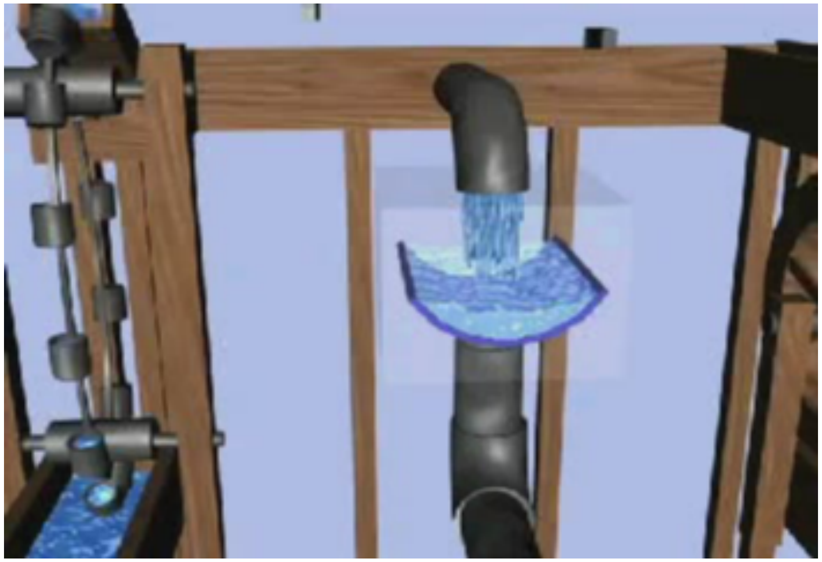
E&M & H_2O

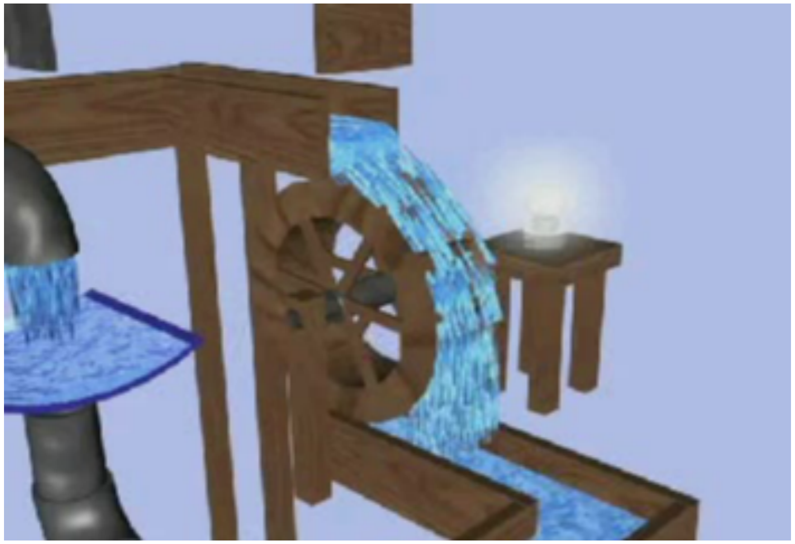
The resistance of a constriction in a large pipe is so great that essentially all the pressure drop will appear across the resistance.





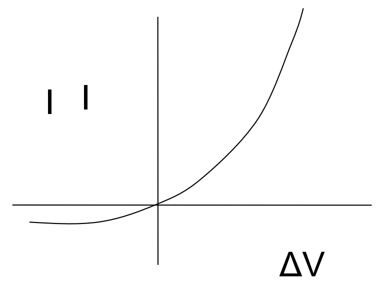






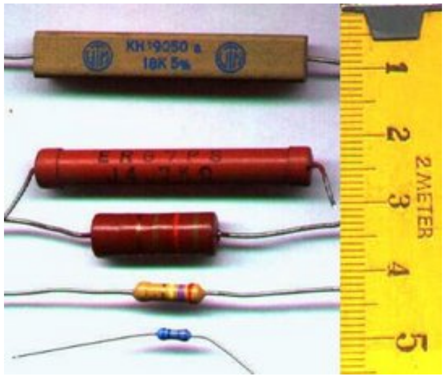
Some materials show non-ohmic resistance

Semiconductor diode



Does the resistance of the diode increase or decrease as ΔV increases?

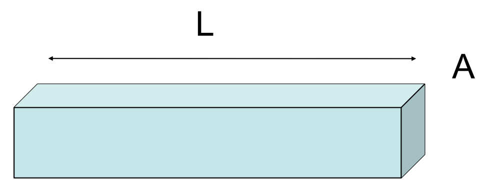
Resistors



carbon resistors
wire wound resistors
thin metal film resistors

Resistance of a resistor is determined by the geometry of the resistor and the resistivity.

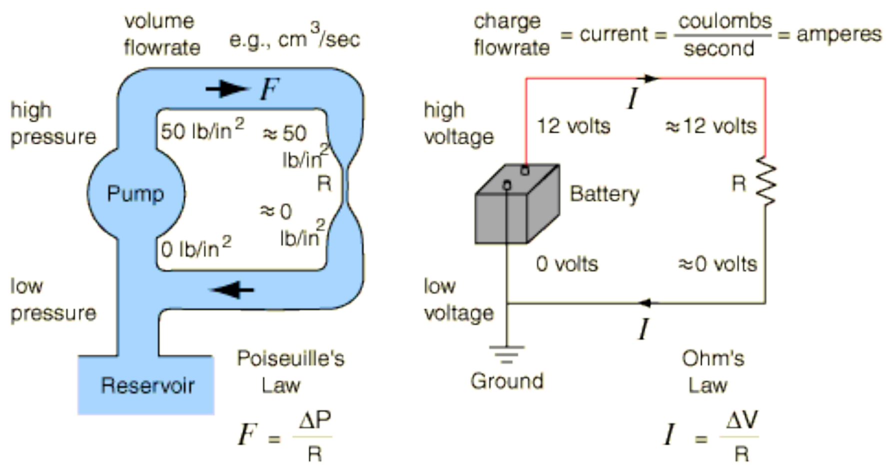
Resistivity, ρ
Property of conducting material



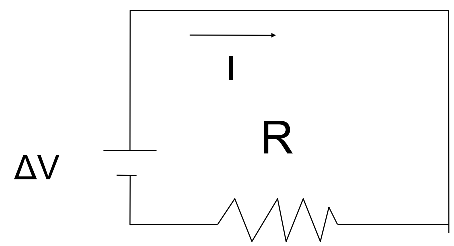
$$R = \rho \frac{L}{A}$$

ρ Resistivity, ohms meter (Ω·m)

Voltage – Pressure Analogy



A light bulb connected to a 3.0 V battery draws a current of 0.2 A. Find the resistance of the light bulb.

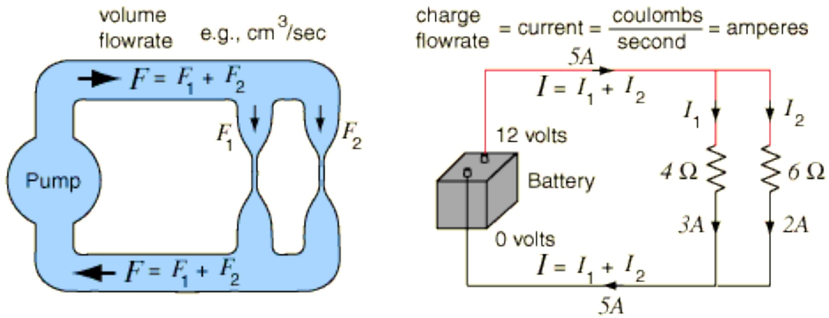


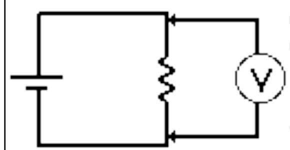
$$V = IR$$

$$R = \frac{V}{I} = \frac{3.0}{0.2} = 13\Omega$$

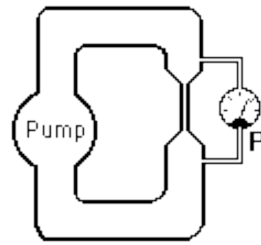
We assume that the resistance of the wires is negligible compared to the resistance of the light bulb.

Voltages in Parallel



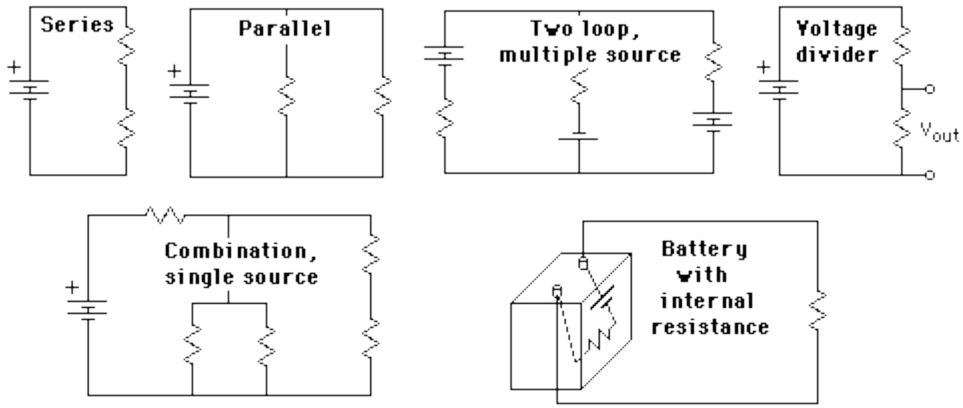


A voltmeter is connected in parallel to measure the voltage change across a circuit element



A pressure gauge is connected in parallel to measure the pressure drop across the resistance.

Circuits with Resistors



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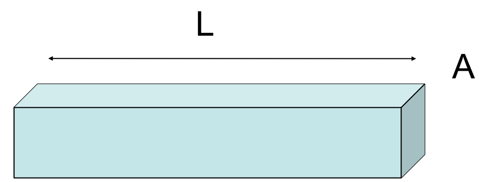
Resistivity, ρ
Property of conducting material



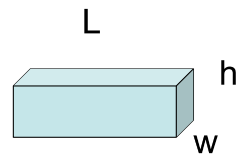
$$R = \rho \frac{L}{A}$$

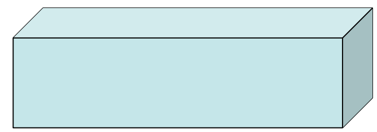
ρ Resistivity, ohms meter (Ω·m)

Resistivities of different materials

Material	Resistivity, ρ ($\Omega \cdot m$)
Copper	1.7×10^{-8}
Iron	10×10^{-8}
Carbon	4×10^{-5}
Silicon	6×10^{2}
Glass	10^{10}-10^{14}
NaCl solution(sat.)	4×10^{-2}
Blood	1.5

A block of metal has a resistance R. If each of the dimensions of the block are doubled, what will the resistance be?





$$R_o = \rho \frac{L_o}{w_o h_o}$$

L= $2L_o$

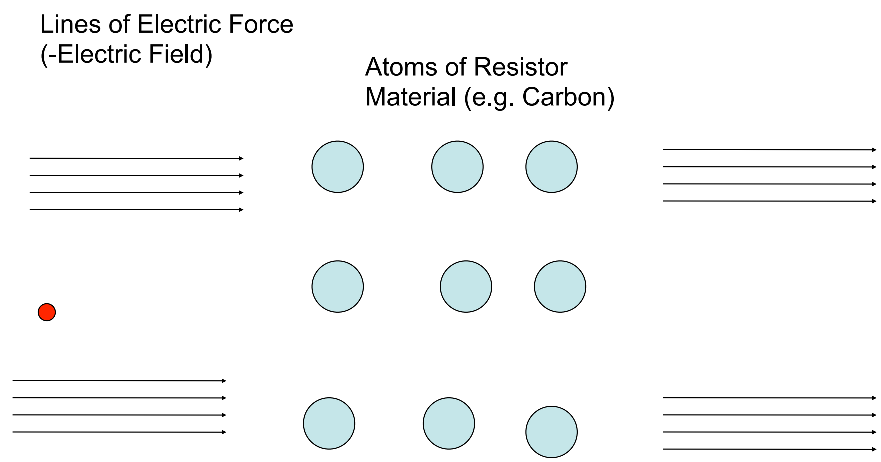
w= $2w_o$

h= $2h_o$

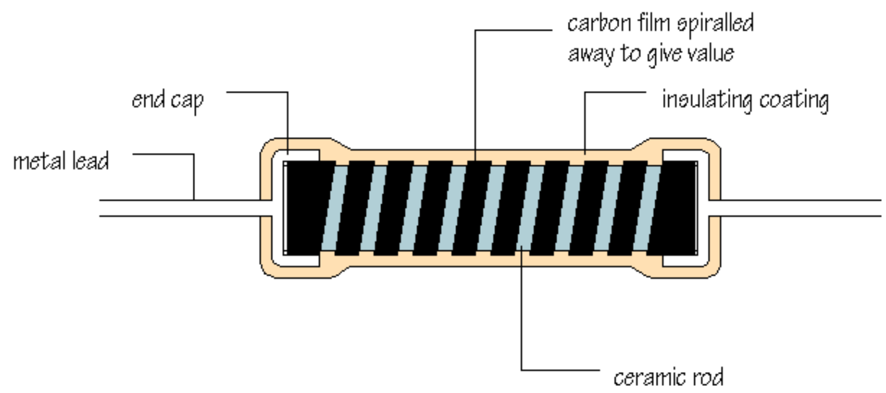
$$R = \rho \frac{2L_o}{2w_o 2h_o} = \frac{R_o}{2}$$

Electrons in a Resistor

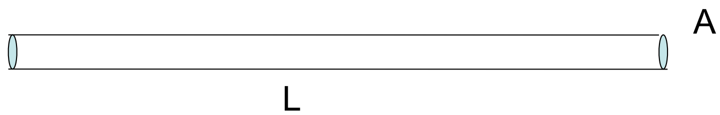
F= ma = qE



Resistor Fabrication

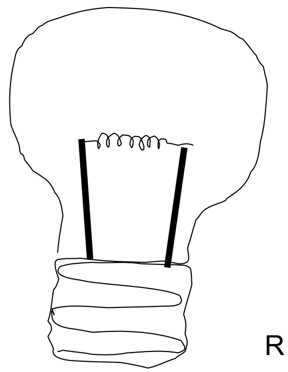


A power cable made out of copper has a length of 10m has an diameter of 2 mm. Find the resistance of the wire. $\rho_{Cu} = 1.7x10^{-8} \Omega \cdot m$.



$$R = \frac{\rho L}{A} = \frac{\rho L}{\pi (\frac{d}{2})^2} = \frac{1.7x10^{-8}(10)}{\pi (\frac{0.002}{2})^2} = 5.4x10^{-2} \Omega$$

Resistance of a light bulb filament.



Thin tungsten coil.

R=150 Ω
ρ =73 x10^{-8} Ω–m (at 2000 C)
L=0.5 m

Find the diameter of the wire.

$$R = \frac{\rho L}{A} = \frac{4\rho L}{\pi d^2}$$

$$d = \sqrt{\frac{4\rho L}{\pi R}} = \sqrt{\frac{4(73x10^{-8})(0.5)}{\pi(150)}} = 5.5x10^{-5}m$$

55 μm

Temperature dependence of resistance metal conductors

At higher T the collisions with the lattice are more frequent.

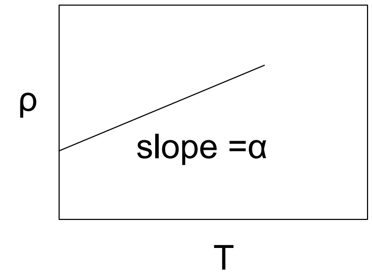
v_D becomes lower

R becomes larger

Temperature coefficient of resistivity

For small changes in T

$$\rho = \rho_o[1+\alpha(T-T_o)]$$



Material	α (C°)$^{-1}$ near 20° C
Copper	3.9×10^{-3}
Tungsten	4.5×10^{-3}
Silicon	-7.5×10^{-3}

Thermometry

A platinum resistance thermometer uses the change in resistance to measure temperature. If a student with the flu has a temperature rise of 4.5^o C measured with a platinum resistance thermometer and the initial R= 50.00 ohms. What is the final resistance? $\alpha=3.92x10^{-3}\ ^oC^{-1}$

$$R \propto \rho$$

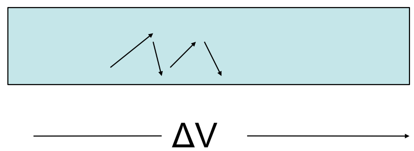
$$R = R_o[1+\alpha(T - T_o)]$$

$$R = 50.00[1+3.92x10^{-3}(4.5)]$$

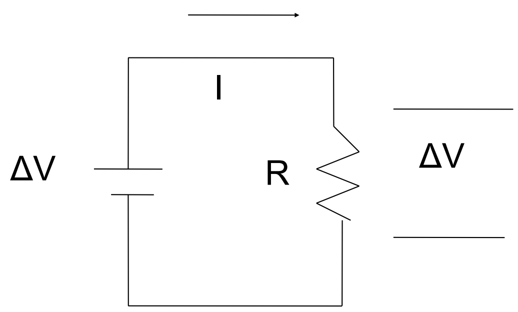
$$R = 50.00[1.018] = 50.88\Omega$$

Electrical energy, power

The power dissipated in a resistor is due to collisions of charge carriers with the lattice. Electrical potential energy is converted to Kinetic energy is converted into heat.



Energy dissipated in a resistor



Voltage drop

Change in PE =qΔV

Dissipated as heat

Power dissipated in a resistor

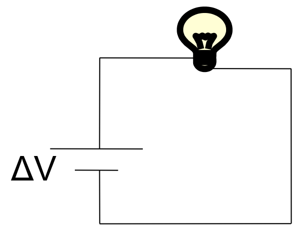
$$P = \frac{work}{time} = \frac{q\Delta V}{\Delta t}$$

$$P = I\Delta V$$

$$P = I(IR) = I^2R$$

$$P = (\frac{\Delta V}{R})\Delta V = \frac{\Delta V^2}{R}$$

Three equivalent relations for the power



A lightbulb has an output of 100 W when connected to a 120V household outlet. What is the resistance of the filament?

$$P = \frac{\Delta V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{120^2}{100} = 144\Omega$$

A heating element in an electric range is rated at 2000 W. Find the current required if the voltage is 240 V. Find the resistance of the heating element.

$$P = IV$$

$$I = \frac{P}{V} = \frac{2000}{240} = 8.3A$$

$$P = I^2R$$

$$R = \frac{P}{I^2} = \frac{2000}{8.3^2} = 29\Omega$$

Cost of electrical power

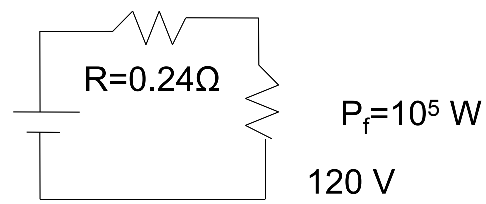
Kilowatt hour = 1kW x1hr=1000J/s(3600s)=3.6×10^6J

1kW hr costs ~ $0.15

How much does it cost to keep a 100W light on for 24 hrs?

$$Cost = \frac{\$}{kwhr} kwhr = 0.15(0.10)(24) = \$0.36$$

A 10 km copper power cable with a resistance of 0.24 Ω leads from a power plant to a factory. If the factory uses 100 kW of power at a voltage of 120 V how much power would be dissipated in the cable.



$$P_f = I\Delta V_f$$

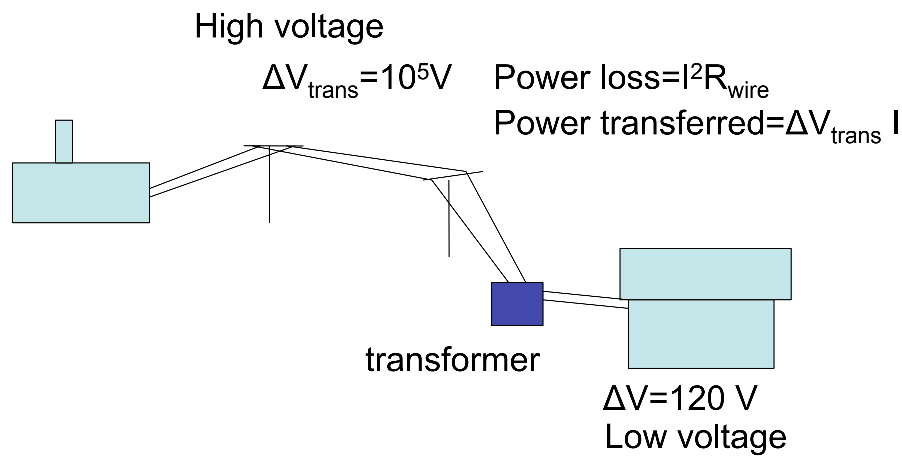
$$I = \frac{P_f}{\Delta V_f} = \frac{10^5}{120} = 8.3x10^2 A$$

A large current is required to provide this power at low voltage

$$P_c = I^2 R_c = (8.3x10^2)^2(0.24) = 1.6x10^5 W$$

Very lossy cable

Power Transmission



High voltage transmission- power transmitted with lower current. Therefore lower I^2R loss in the line.