Current & Resistance

PHY232 – Spring 2008
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(Ppt courtesy of Remco Zegers)

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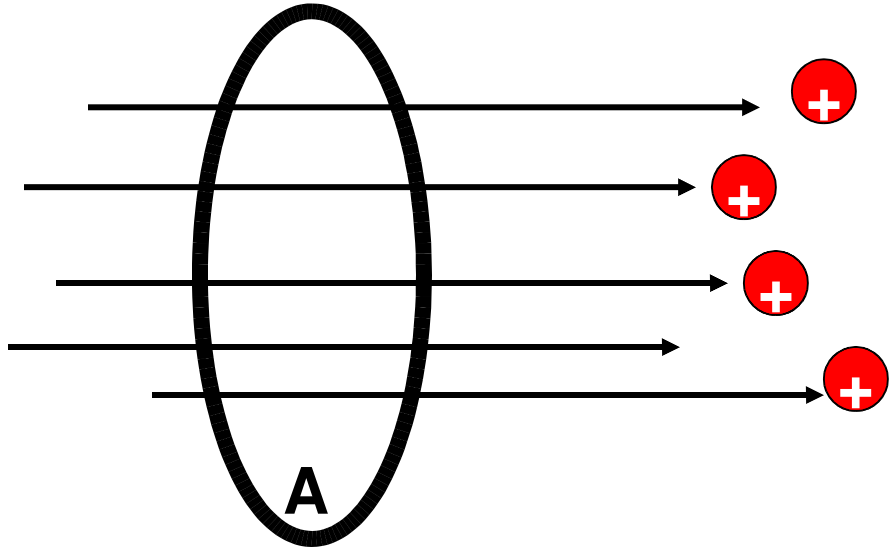
Electric current

So far we have studied Static Electricity. Now consider the situation where **charge can move** and hence produce an **electric current**.

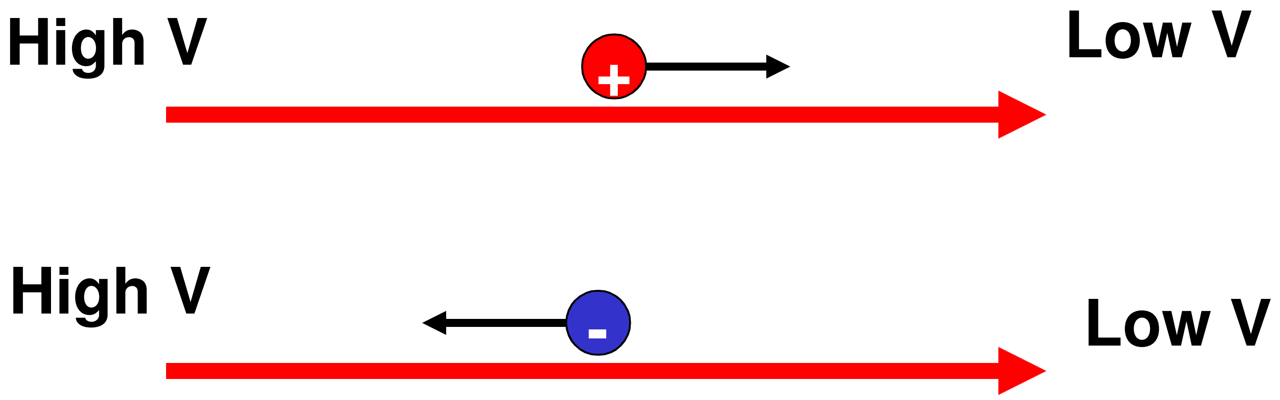


Current = amount of charge ΔQ that flows through an area A divided by the time interval Δt:

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

Electric current II

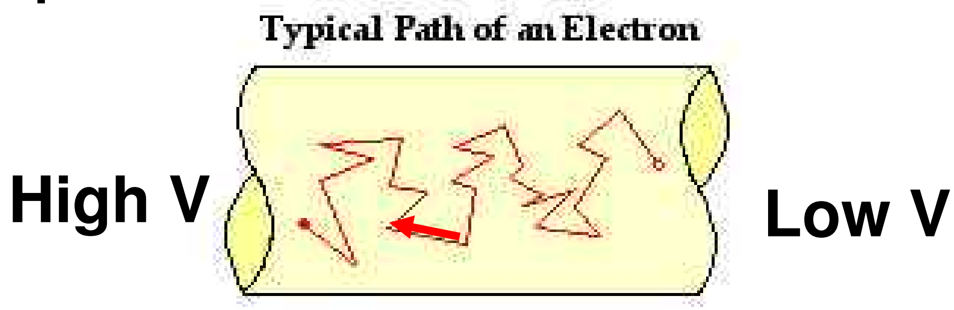
- A matter of convention: The direction of current is the direction in which positive charges flow, even though the flow is often of electrons (negative)



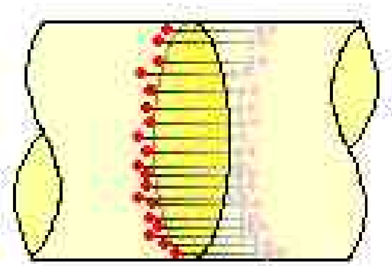
- **Remember:** positive charge moves from high potential to low potential

electric current III: what really happens

- When electrons move through a wire they undergo many collisions and a typical path looks like:



- Because of the collisions, the velocity is on average constant
- The drift velocity of the electrons is actually very slow (less than 1 meter per hour). So why can we have high currents?

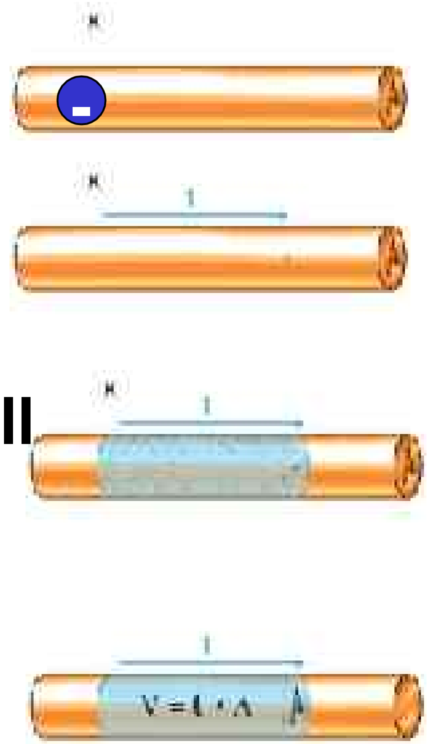


demo: model of resistance

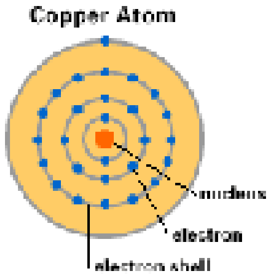
Because there are so many electrons!!!

electric current IV

- let's assume the average electron speed is ***v***
- consider one electron at point **x**
- after time **t** it will have moved….
- a distance **D = v t**
- in fact all the electrons over the distance D will have moved
- the volume of the cylinder V = A D = A v t
- if **n**: number of electrons per unit volume, the number of electrons moved is: nV=nAvt
- the charge ΔQ that has been moved: nAvtq
- current **I = ΔQ/t = n A v q**



$$I = nqvA$$



question

- A current of 1 A is running through a Copper wire with cross section 1mm². Each Copper atom produces 1 free electron.

c) How many free charge carriers per unit volume are there? (Given that the molar mass of Cu is 63.5 g and the density of copper is 8.92 g/cm²). b) What is the drift velocity?

- a) The volume taken by 1 mol of Cu atoms

$$V_{mol} = \frac{m_{mol}}{\rho} = \frac{63.5\ g}{8.92\ g/cm^3} = 7.12\ cm^3 = 7.12 \times 10^{-6}\ m^3$$

- the number of electrons is also 1 mol in this volume ($=N_A=6.02\text{x}10^{23}$) so:

$$n = \frac{6.02 \times 10^{23}}{7.12 \times 10^{-6}} = 8.46 \times 10^{28}\ m^{-3}$$

question…

- b) Use $I = nqvA$ so $v = \frac{I}{nqA}$
- with: $n = 8.46 \times 10^{28}\ m^{-3}$, $A = 1 mm^2 = 1 \times 10^{-6} m^2$
  $q = 1.6 \times 10^{-19}$ C and $I = 1A = 1C/s$
- so $v = 2.46 \times 10^{-5}$ m/s
- I.e. this is 0.089 m in one hour.

wait a second…

- Wasn’t charge supposed to be collected on the surface of a conductor?

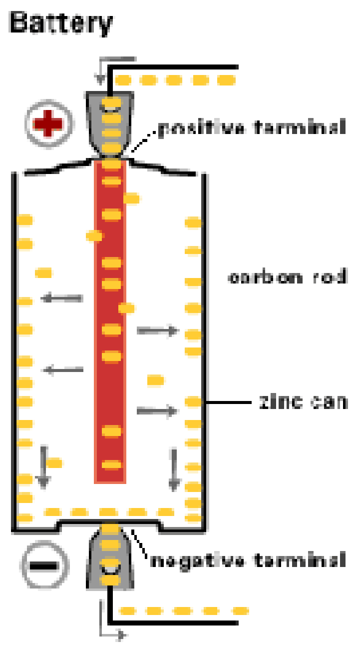
That only happens when the conductor has a Net Charge

(more electrons than protons or fewer electrons than protons).

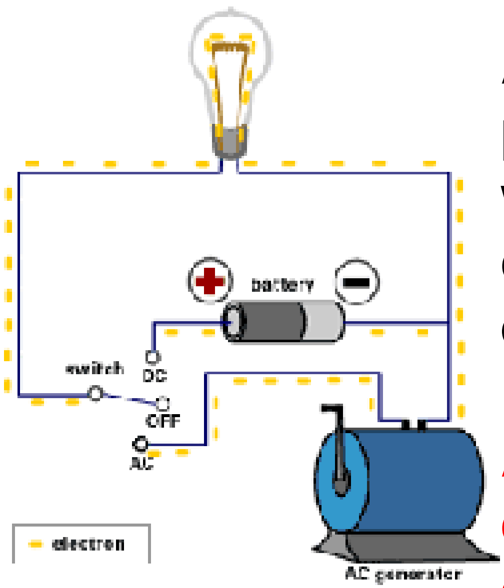
The conducting wires we are talking about are neutral.

batteries

- A battery can produce a potential difference between the anode (negative) and cathode (positive). When connected (I.e. using a wire or via a device) current can flow.
- The charge is created through chemical reactions. Once the chemical fuel is used, the battery is empty
- commonly used are zinc-carbon batteries.

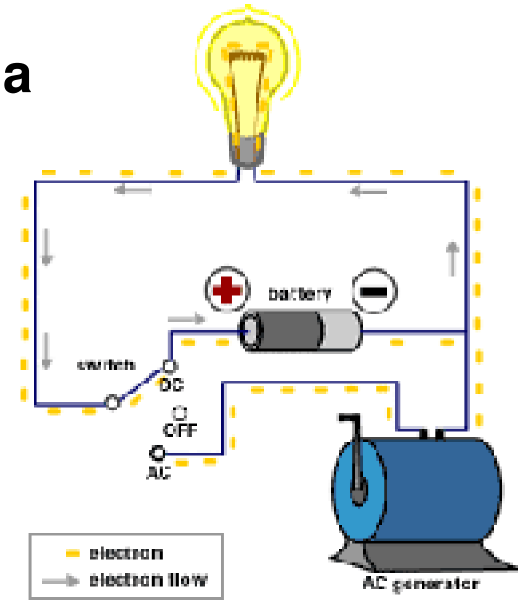


A simple circuit



A basic electric circuit consists of a power source (e.g. a battery) in which the + and – side are connected via a wire and some device.

As long as the circuit is open, no current will flow and hence the device not work.



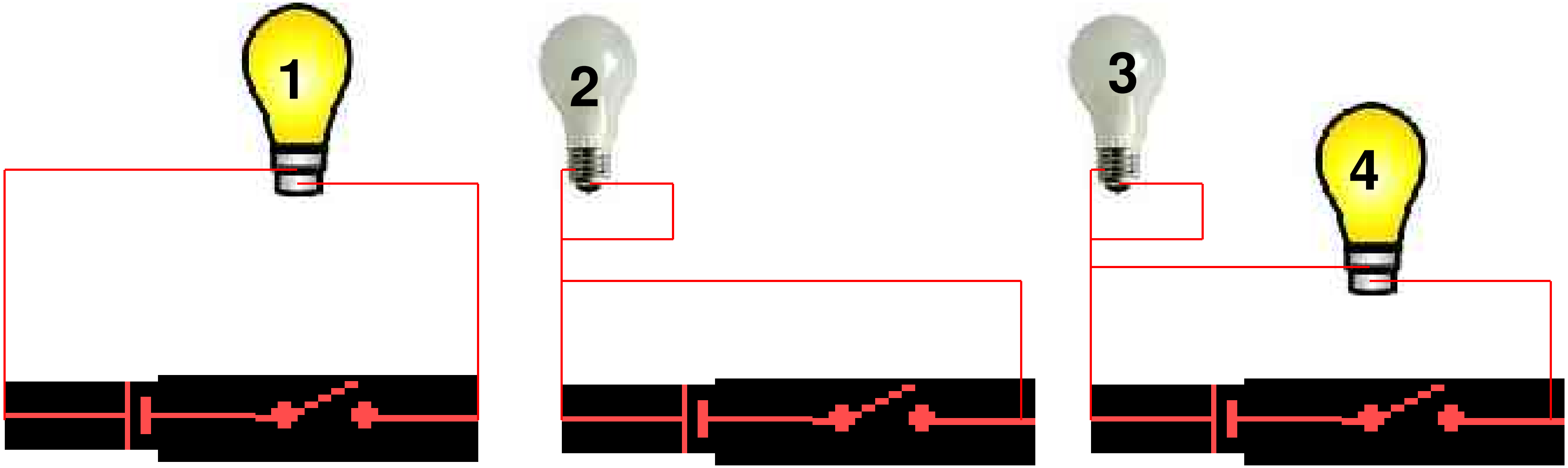
OFF

ON

Power sources can be DC (Direct Current) or AC (Alternating Current). We will deal with DC circuits first.

question

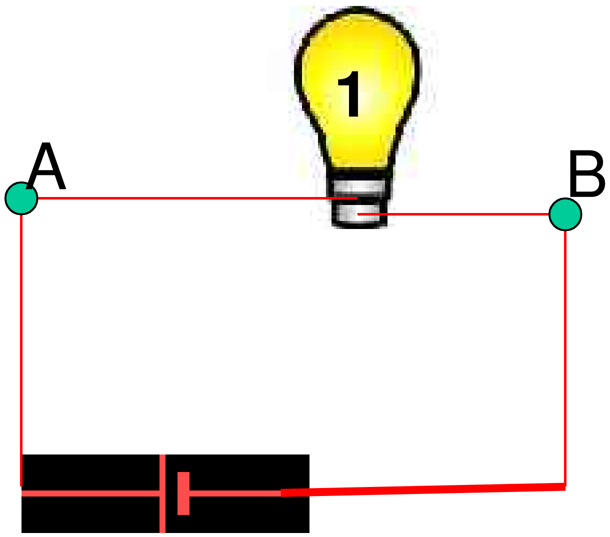
- Which of the following lights will not shine after the switches are closed?



a) 2
b) 2,3
c) 2,3,4
d) 1,2,3,4

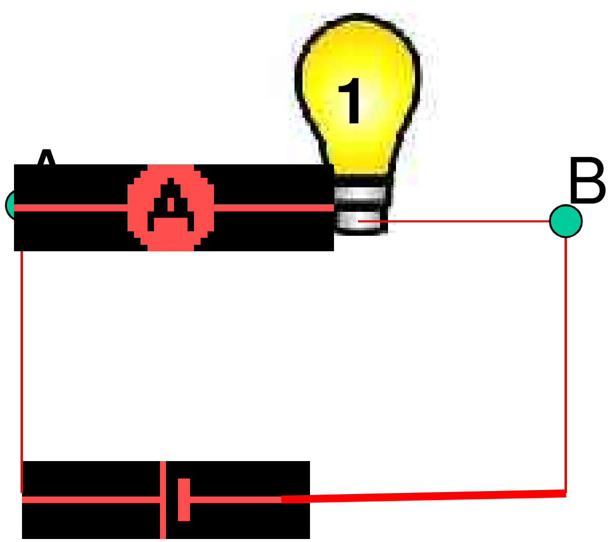
lights 2 and 3 will not shine since there is no potential difference over the contacts

how to measure current?

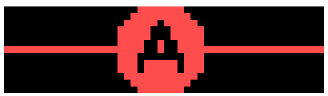


- The current anywhere between A and B must be constant, else electrons would accumulate at a certain point in the line

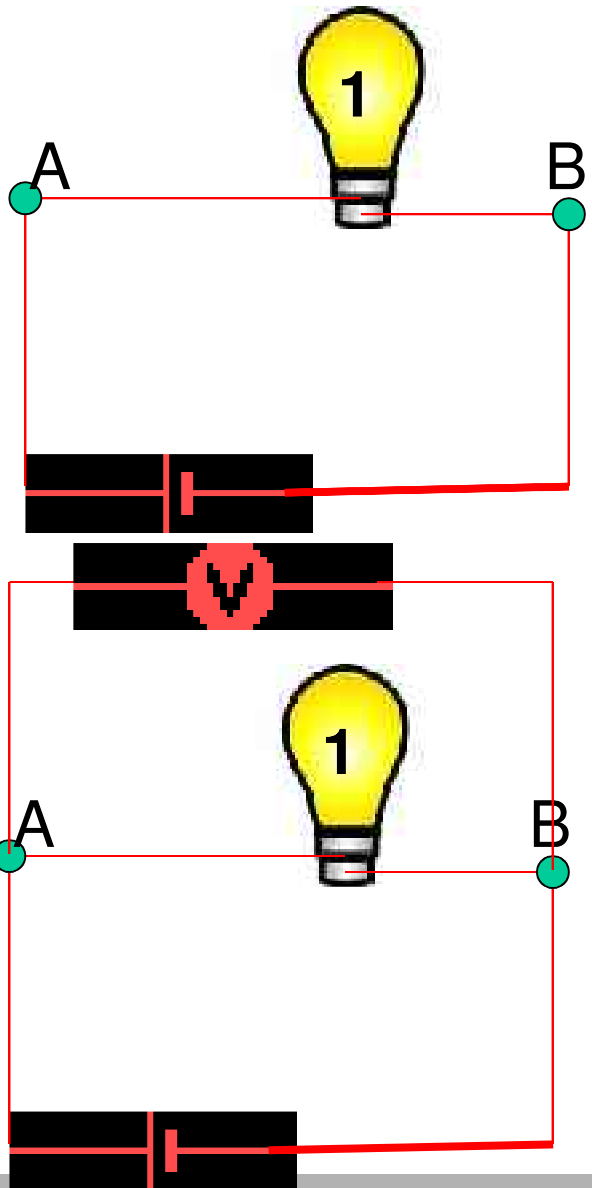
- A device to measure current in the light should therefore be placed in line (in series) with the light. Either side!!



- The device is called an Ampere meter (ammeter)



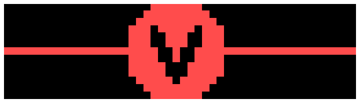
how to measure voltage?



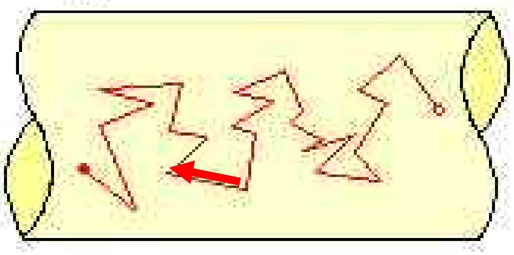
- To measure the voltage to the light, realize that we need to measure the potential difference between A and B

- A device to measure voltage to the light should therefore be placed in parallel with the light

- The device is called a Volt meter

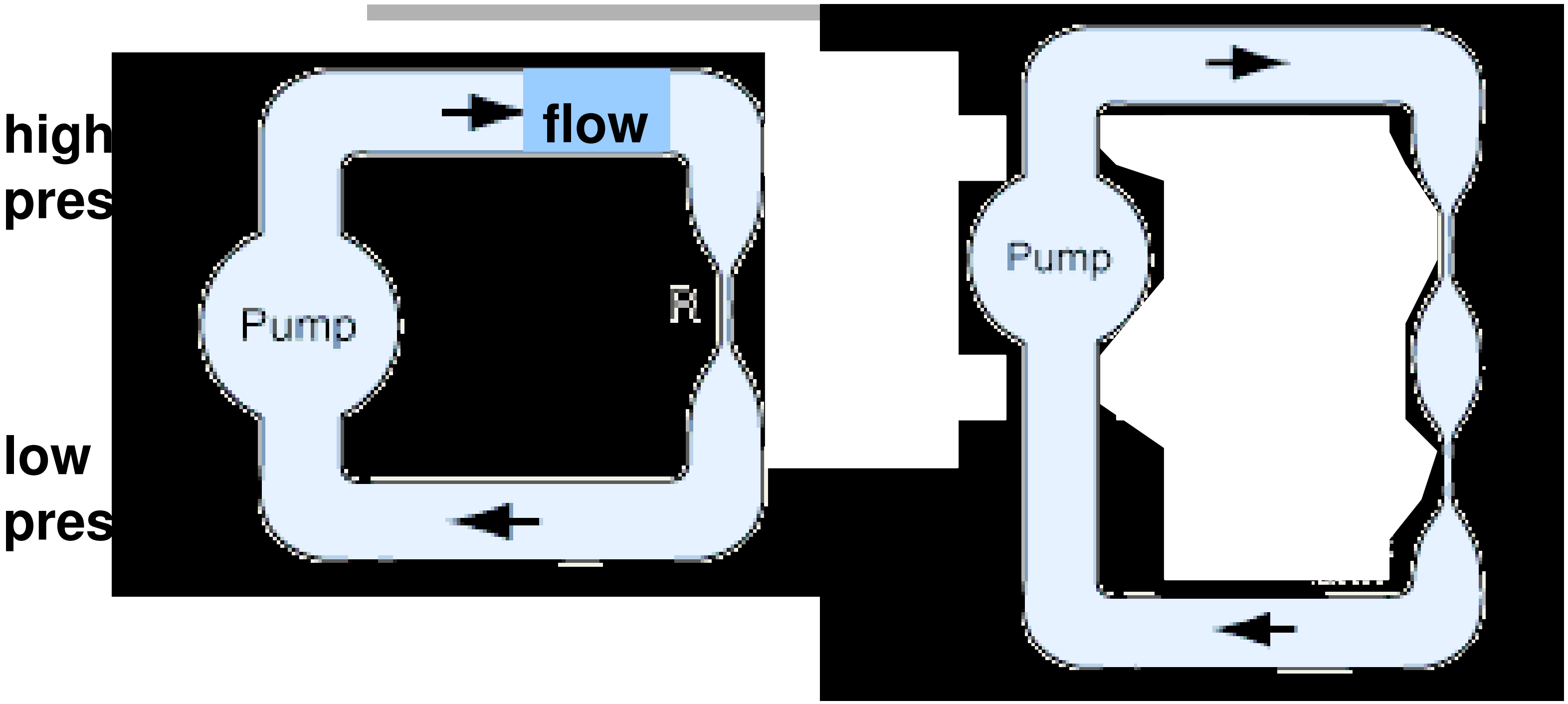


Resistance I



- When electrons move through a material, they undergo many collisions which hinders the motion (like friction).
- Without such collisions, the electrons would accelerate (since there is a force acting on them)
- The resistive force counterbalances the electric force so the drift velocity is constant
- When the resistive force is high, the current will go down if the voltage difference that drives the motion remains the same.

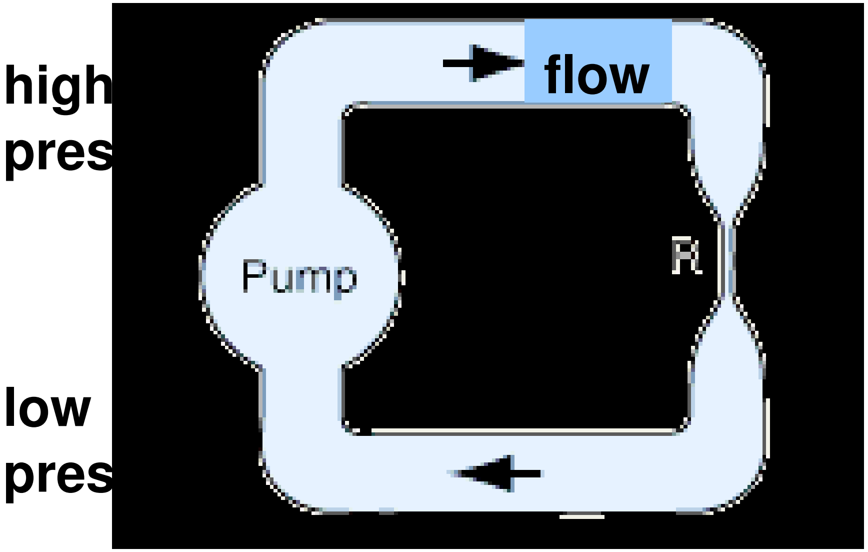
Resistance II

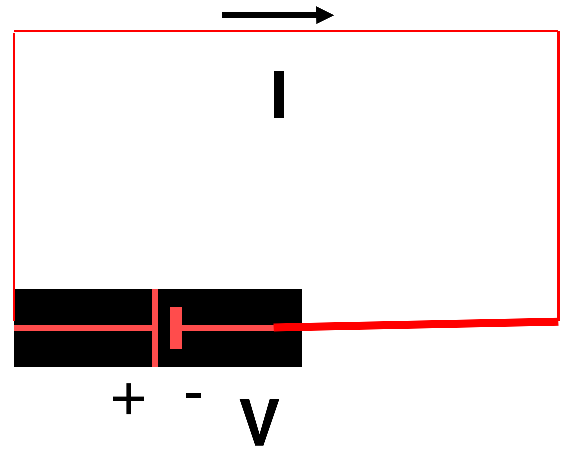


Compare with water flow through a pipe. If the pipe becomes narrow, flow is reduced. If the length over which the pipe is narrow becomes longer, flow is further reduced.

so resistance R : $R \sim \dfrac{l}{A}$

Resistance III





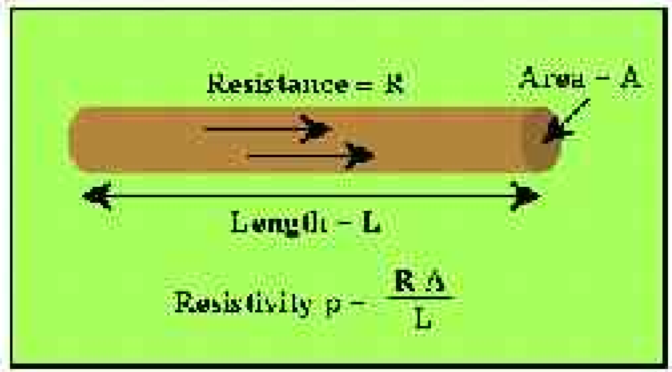
- voltage is the “equivalent” of pressure and current the equivalent of flow
- If pressure (voltage) difference increases, the flow (current) will increase
- If the resistance increases, the flow current will go down if the pressure difference remains the same

Ohm’s law and resistivity

- **Ohm’s law** $$V = IR \qquad I = \frac{V}{R} \qquad R = \frac{V}{I}$$

- **For a specific material, the resistance R can be calculated using:**

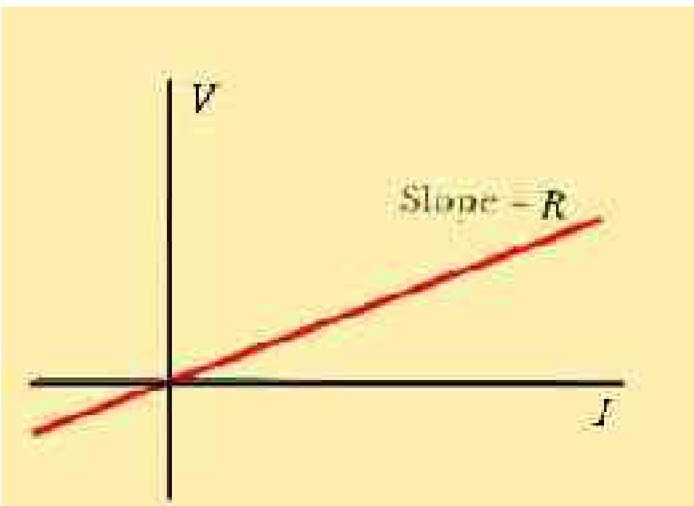
$$R = \rho \frac{l}{A}$$



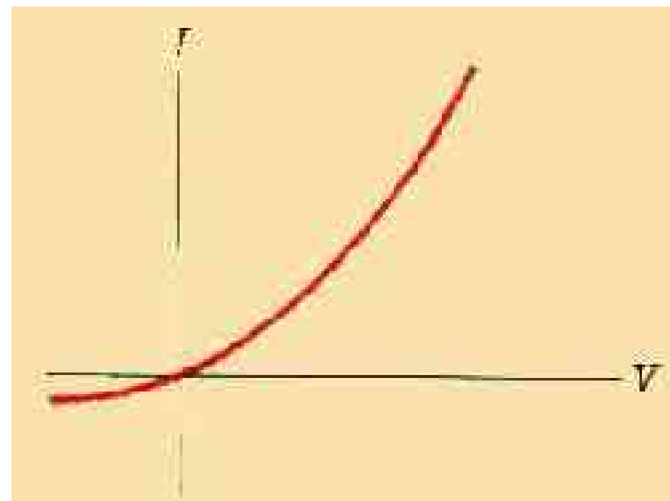
- **where R: resistance (in V/A=Ω (Ohm)), ρ the resistivity (material dependent in Ωm), l the length of the object and A the cross section of the object**

Ohm's law

- **Ohm's law implies that I is proportional to V, which is true for many materials but not for all:**



Ohmic resistance



Non-ohmic resistance

question

- **A voltage of 100V is put over a thick wire of unknown material. The current is measured is 4.5×10^3 A. The cross section of the wire is $1 cm^2$ and the length is 10m. What material is the cable made of?**

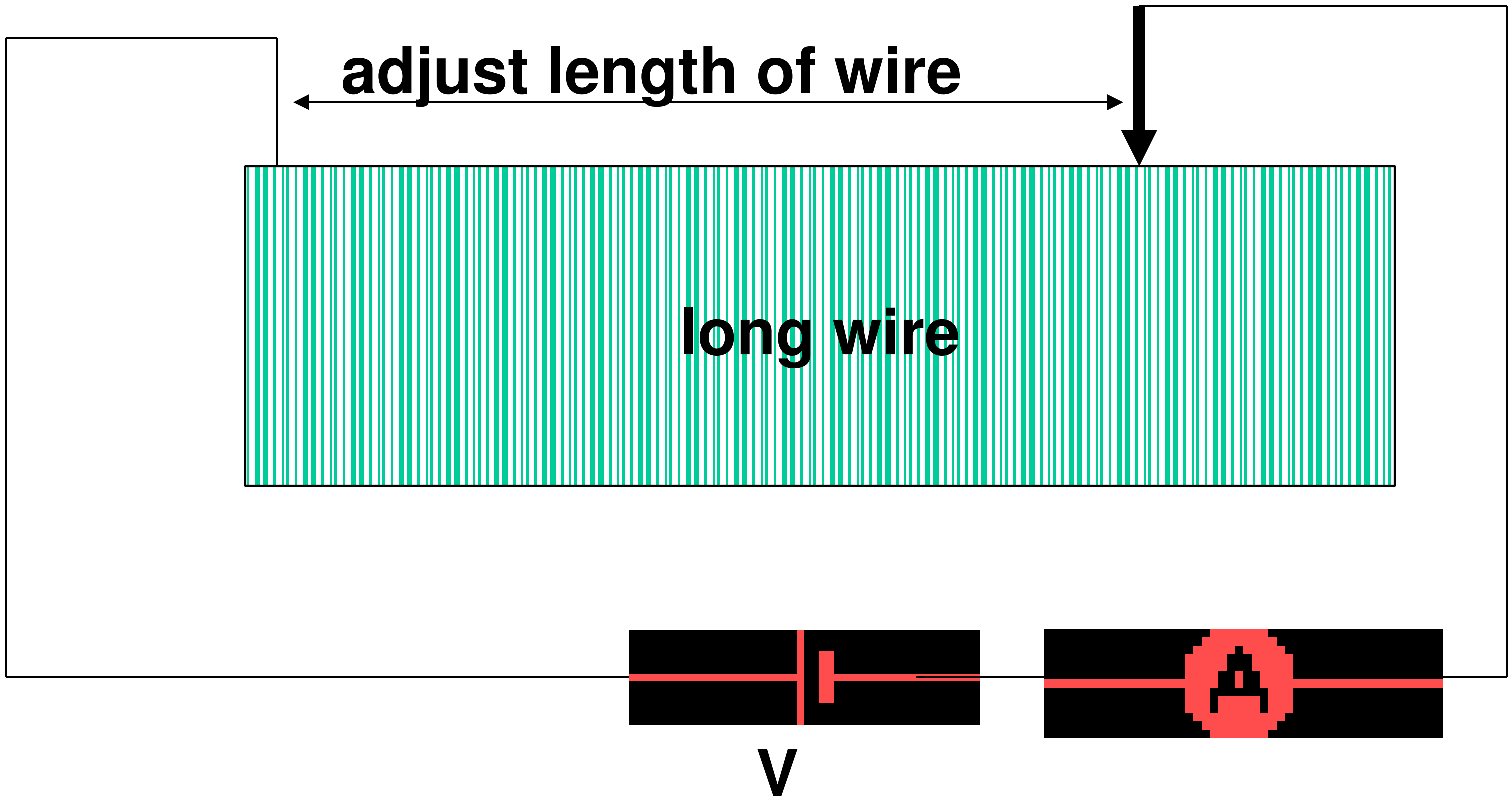
$R = V/I = 0.022 = \rho l/A$
so: $\rho = 0.022A/l$
$A = 1cm^2 = 0.0001m^2$
$l = 10$ m

$\rho = 2.2 \times 10^{-7}$ Ohm.m
Lead

Material	Resistivity (Ohm.m)
Silver	1.59×10^{-8}
Gold	2.44×10^{-8}
Lead	22×10^{-8}
Silicon	640
Quartz	75×10^{16}

a resistor bank..

- is an adjustable resistor



demo

question

- A person measures the resistance over a 10 m long cable through a measurement of V and I. He finds at V=10 V that I=1 A. A second cable made of the same material and length but with a radius that is 2 times larger than the original cable is then studied. At a voltage V=10V, what current is measured?

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

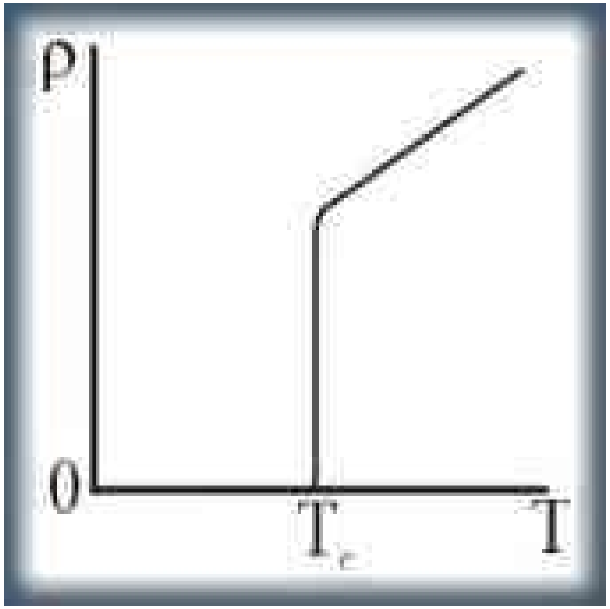
a) 1A
b) 2A
c) 4A
d) 8A

If radiusx2 then Ax4 and Rx0.25
I=V/R so Ix4 and thus 4A

superconductors

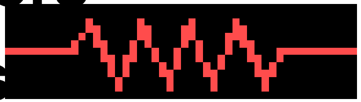
For some material the resistivity drops to near-zero below a certain temperature (the critical temperature)

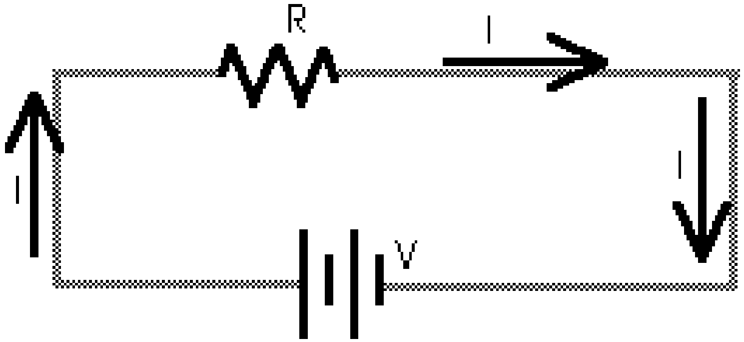
For such a material, current would continue to flow even if the potential is zero!

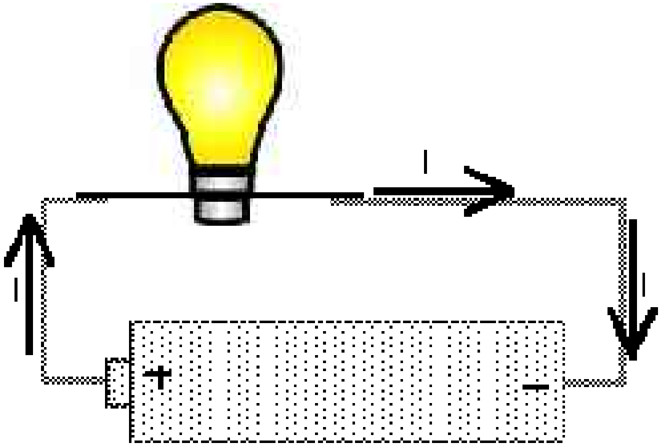


Element	T_c (K)
Mercury	4.15
Tin	3.69
Lead	7.26
Niobium	9.2
Aluminum	1.14
Cuprate Perovskite	138

resistors in a circuit

- resistors are commonly used in circuits
- their resistance is usually much higher than the resistance of the connecting wires and the wires are usually ignored.
- devices/lights etc are also resistors
- The symbol used for a resistor is 





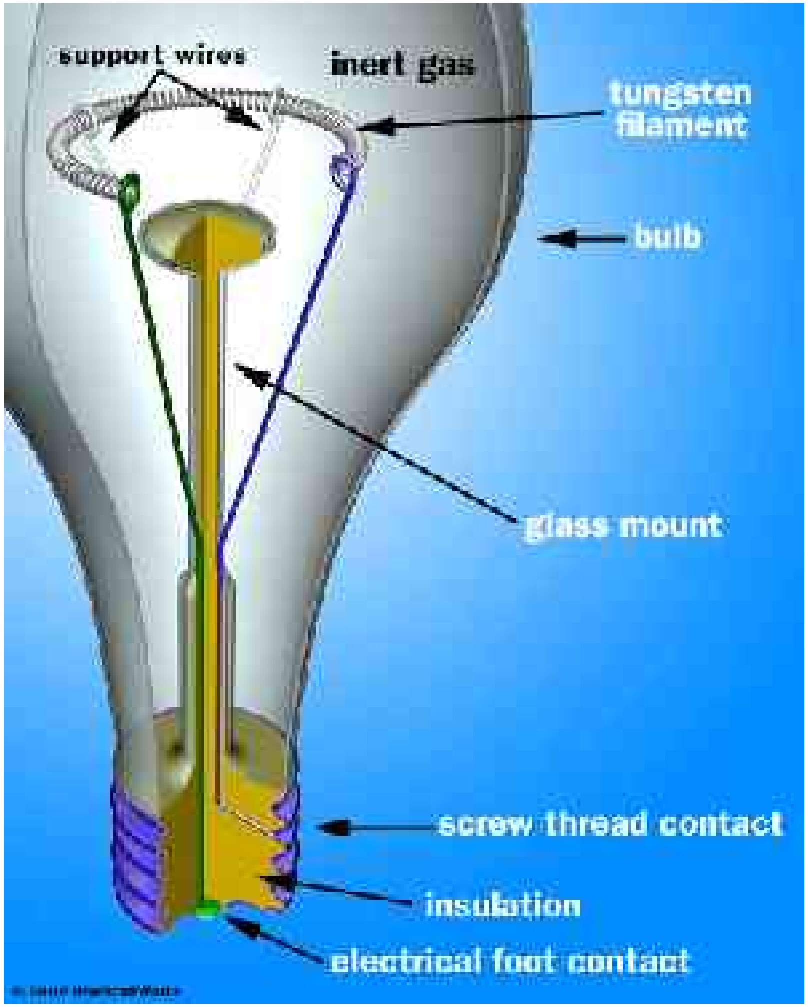
question

- **a resistor of 10 Ohm is put in a circuit. 10V is put over the resistor. The resistor is replaced by one of 100 Ohm. By what factor does the current through the resistor change?**
- **a) 0.1**
- **b) 1 (unchanged)**
- **c) 10**

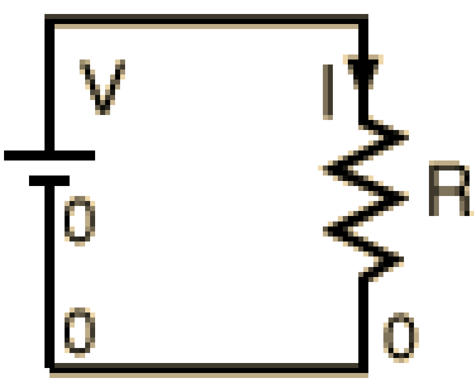
$$V = IR \qquad I = \frac{V}{R} \qquad R = \frac{V}{I}$$

If Rx10, then I/10 so a) 0.1

the lightbulb



electrical energy and power



- consider the circuit. The potential energy lost by a charge ΔQ falling through a potential difference V is

$$\Delta PE = V\Delta Q$$

- The energy lost per time unit (the power dissipated is:

$$P = \frac{\Delta PE}{\Delta t} = V\frac{\Delta Q}{\Delta t} = VI = I^2R = \frac{V^2}{R}$$

P: Watts (J/s)
For the energy consumed (E=Pxt) often kWh (kilowatt hour) is used
1 kWh: energy consumed in 1 hour at a rate of 1000 W
1 kWh=1000W x 3600 s = 3.6×10^{6} J

question

- A voltage of 10 V is put over a wire with cross section A and length l. The wire is then replaced with one of the same material that has cross section 2A and length 4l. At the same time the voltage is increased by a factor of 2. By what factor does the dissipated power change?
- a) the same
- b) doubles (factor of 2)
- c) quadruples (factor of 4)
- d) halves (factor of 0.5)

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

Ax2 and lx4 so Rx2.
Vx2 (note that I=V/R=constant)
$P=V^2/R$ so Px2

question

- **A 400 W computer is used for 8 hours per day. The electricity costs 10 cents per kWh. How much does it cost to run the computer for 1 year (8 hour each day)?**

400W=0.4kW
per day: 0.4kW x 8 hrs = 3.2kWh
per year 3.2kWh x 365 = 1168 kWh
cost per year: $0.10 x 1168 = $116.80