Electric Current and Resistance

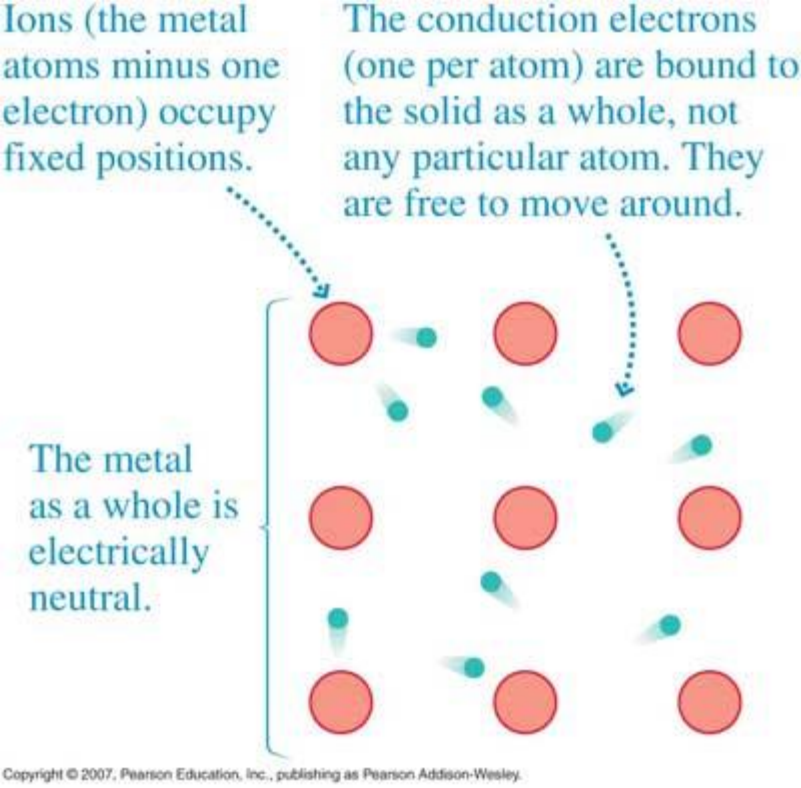
- Current
- Parts of a circuit
- Resistivity
- Ohm’s Law
- Ohmic and Nonohmic materials
- Energy and Power

Electric Current

- Electric current is the movement of electric charge
- Very important in our lives – we use it to deliver energy and information

Current in Conductors

- Current in conductors is produced by electrons moving through a lattice of fixed ions
- Current is a drift of the sea of electrons through the lattice
- Lattice is not charged



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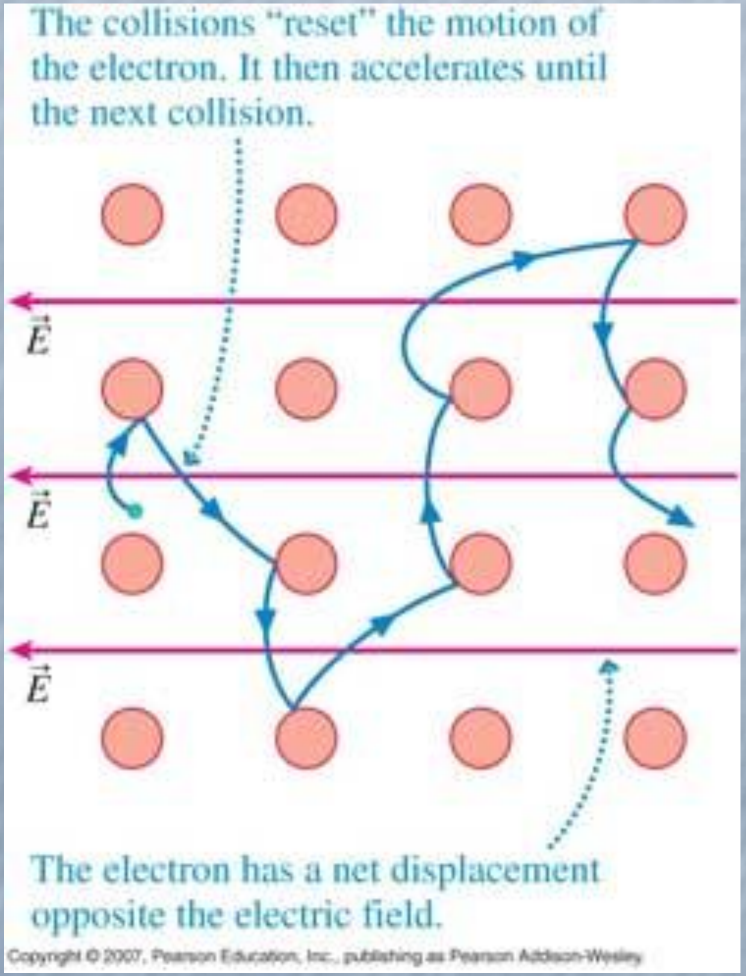
Creating a current in a wire

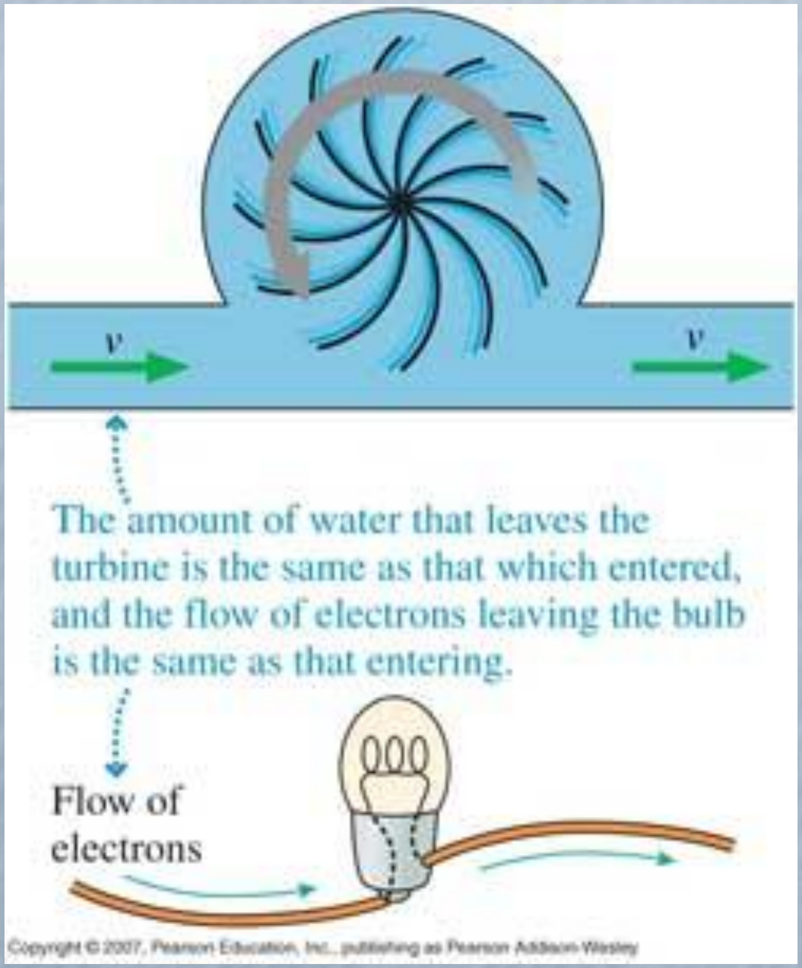

The collisions "reset" the motion of the electron. It then accelerates until the next collision.

The electron has a net displacement opposite the electric field.

- Currents are created by an electric field pushing the electrons along a wire
- The electric field is produced by a potential difference along the length of the wire like a capacitor or a battery

Conservation of current

- Follows from the conservation of charge
- The current is the same at all points along a wire
- Similar to a water turbine, same amount of water in as water out

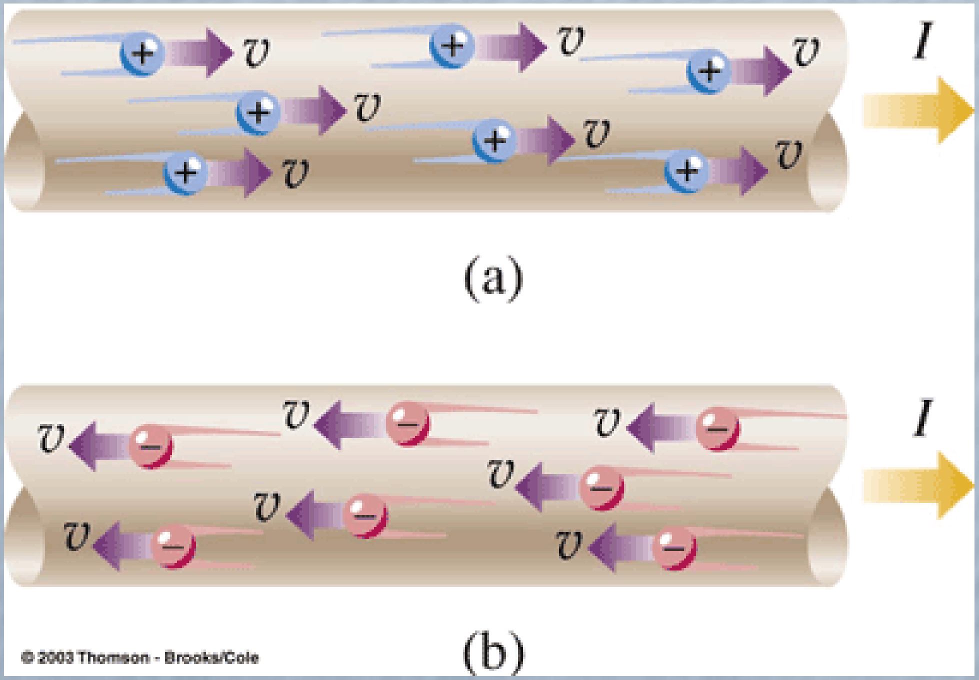


The amount of water that leaves the turbine is the same as that which entered, and the flow of electrons leaving the bulb is the same as that entering.

Definition of Current

Current, I, is defined as the rate of change of **positive** charge:

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



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Units: Coulombs/second or Amperes or Amps

Definition of Current

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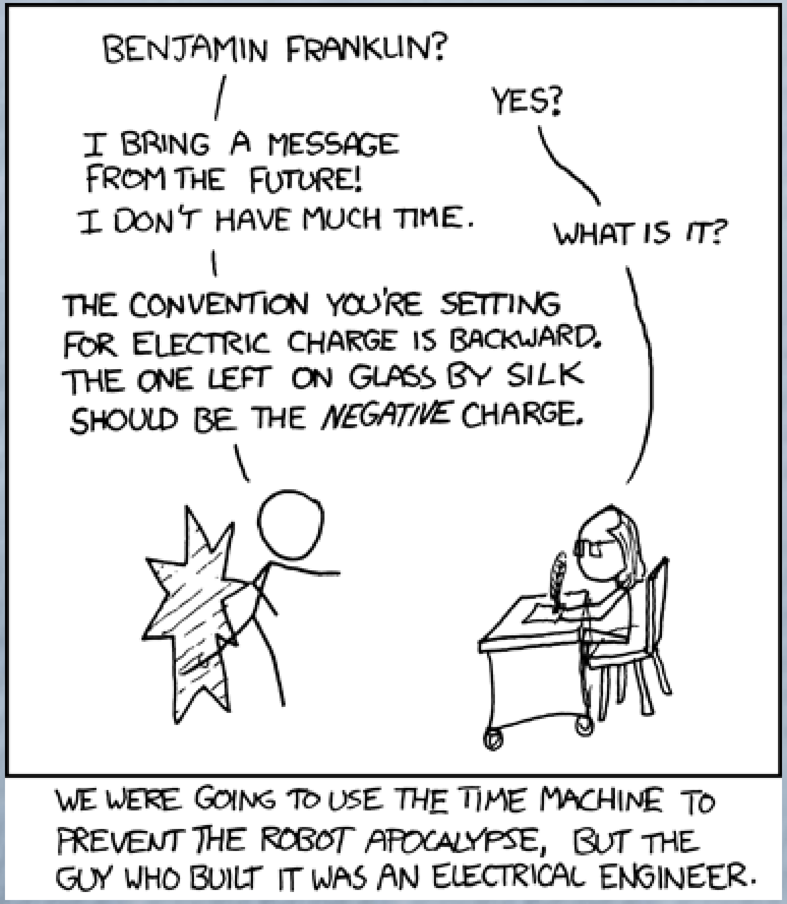
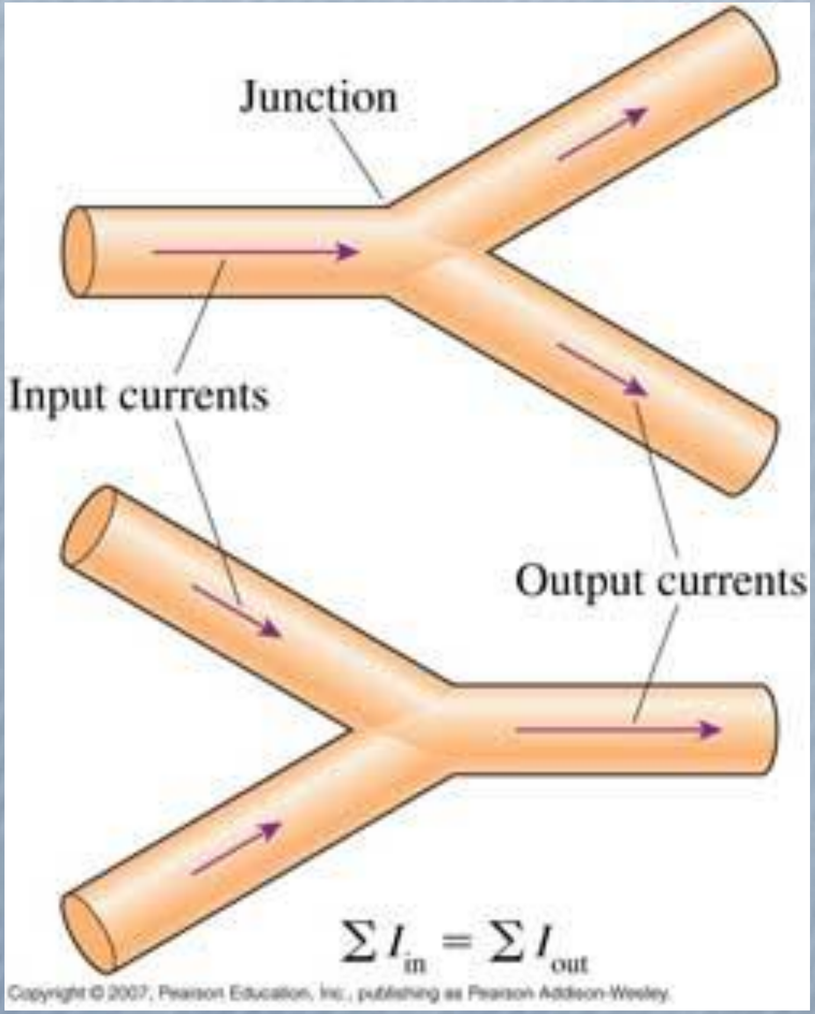


WE WERE GOING TO USE THE TIME MACHINE TO PREVENT THE ROBOT APOCALYPSE, BUT THE GUY WHO BUILT IT WAS AN ELECTRICAL ENGINEER.

Conservation of current: Kirchhoff’s Law



The sum of currents into a junction must equal the currents flowing out of it

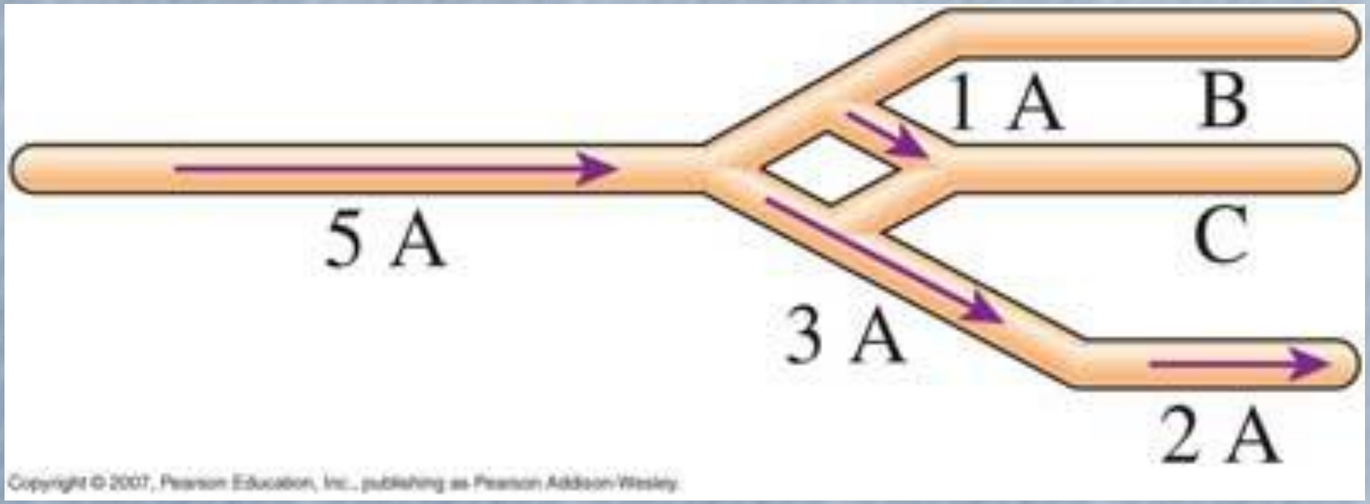
$$\sum I_{in} = \sum I_{out}$$

Sometimes expressed as:

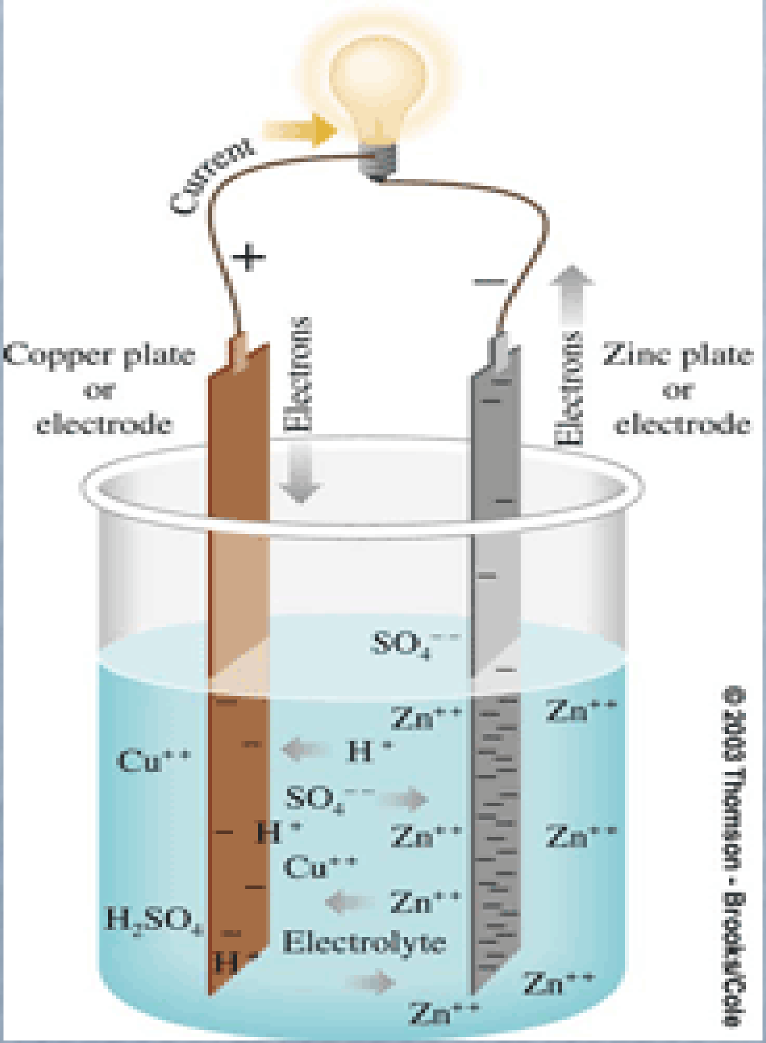
$$\sum_j I_j = 0$$

Example of Kirchhoff’s Law

What are the currents in B and C ?



Batteries



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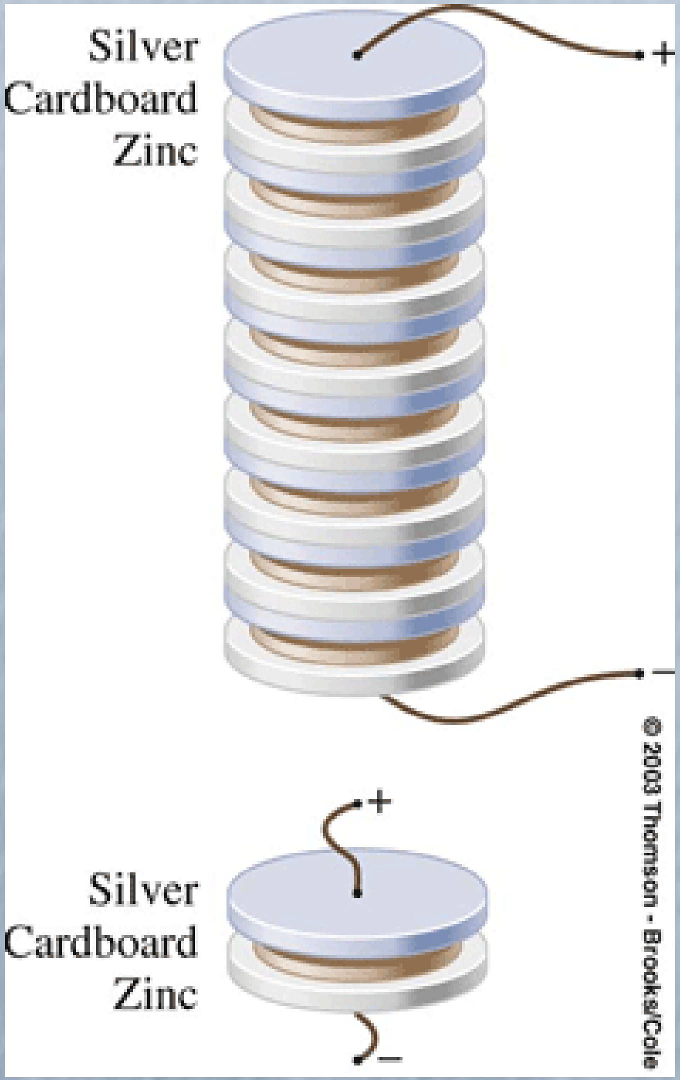
- Batteries produce a potential difference from chemical reactions in electrolytes
- Chemical energy from breaking bonds, force the separation of ions and electrons

E.M.F

- The chemical reaction creates a voltage between the electrodes, called the **emf** (electromotive force)
- The value of the emf depends on the chemicals in the battery – 1.2V NiCad, 1.5V alkaline
- The emf is also called **terminal voltage**
- Capacitors cannot “move” or recharge the electrons between electrodes, they have ZERO emf



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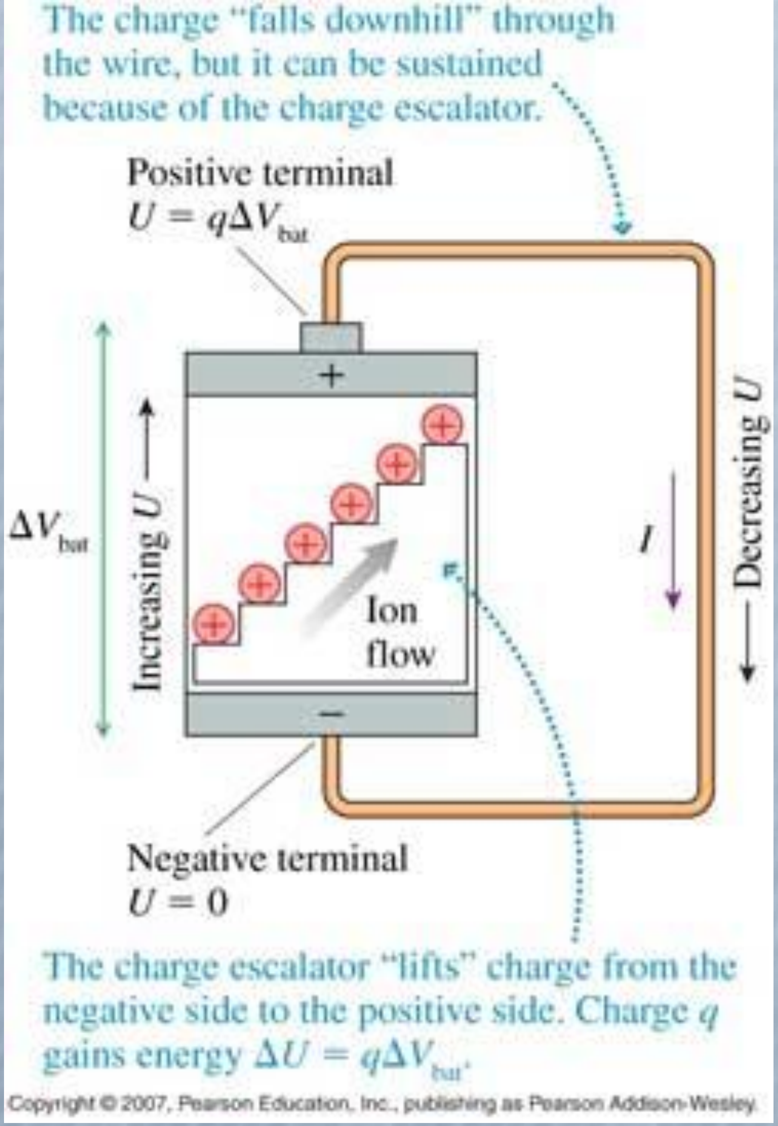
Inside a battery

- Can be thought of as a machine increasing the potential of positive ions
- Competing a circuit will drain the energy of the battery

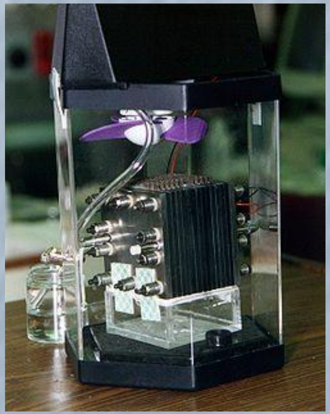


The charge "falls downhill" through the wire, but it can be sustained because of the charge escalator.

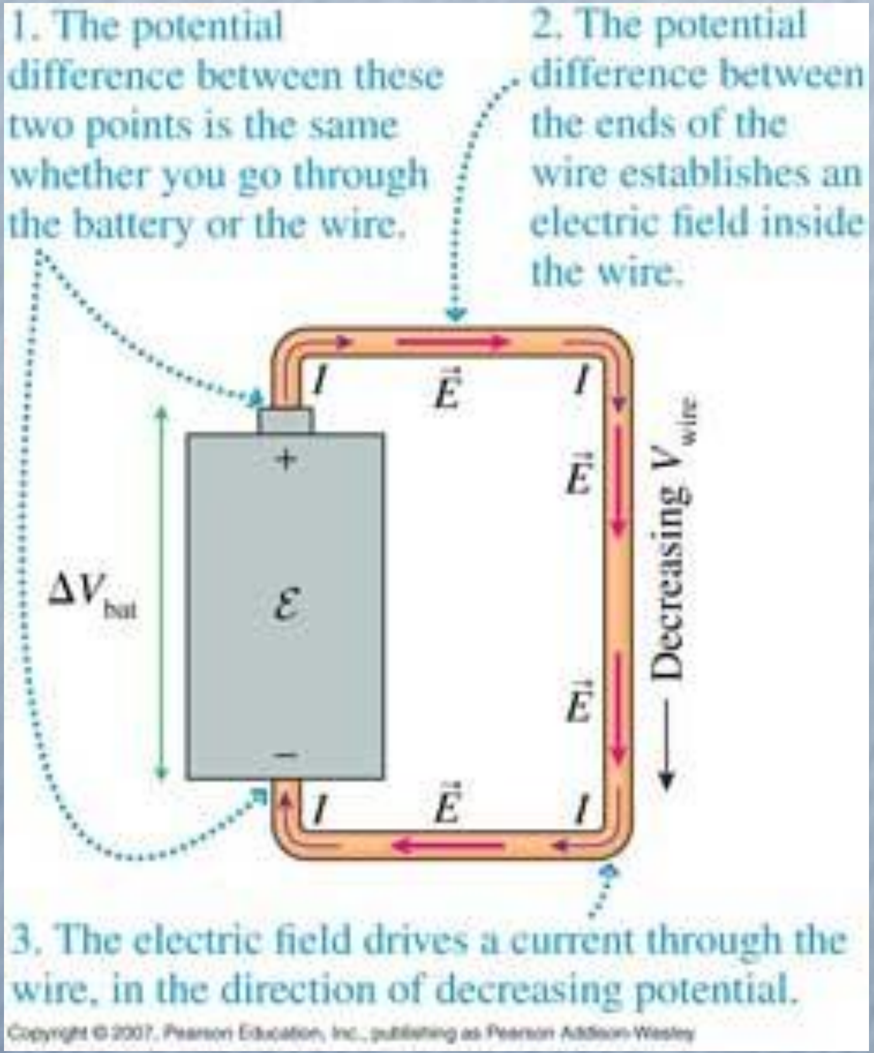
The charge escalator "lifts" charge from the negative side to the positive side. Charge q gains energy $\Delta U = q\Delta V_{bat}$.

Other types of current generators

- Electricity generators (Nuclear, Coal, Oil)
- Fuel Cells – mixing H_2 and O_2 with Polymer membrane electrolytes
- electric eel (*Electrophorus electricus*)



A simple circuit



1. The potential difference between these two points is the same whether you go through the battery or the wire.

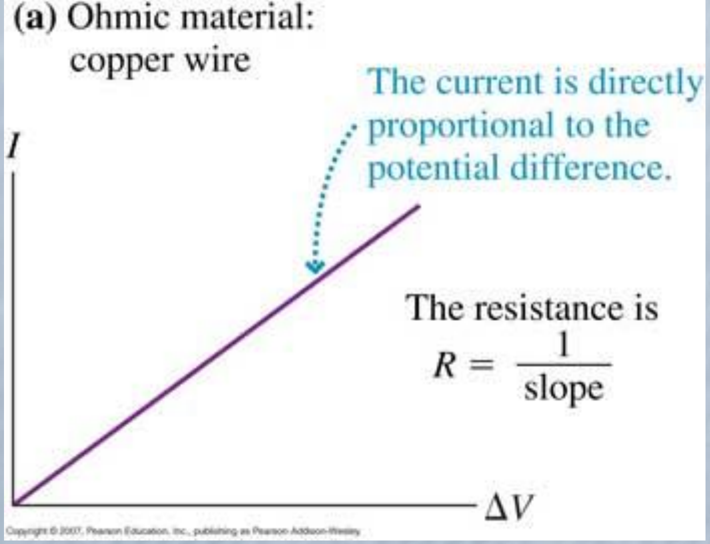
2. The potential difference between the ends of the wire establishes an electric field inside the wire.

3. The electric field drives a current through the wire, in the direction of decreasing potential.

- The potential difference along the wire is the same as the emf

Ohm’s Law

- In many conductors – such as copper wire, the voltage V, required to drive a current I is linear
- Materials which are linear are said to obey Ohm’s Law
- Leads to a useful concept called **resistance**



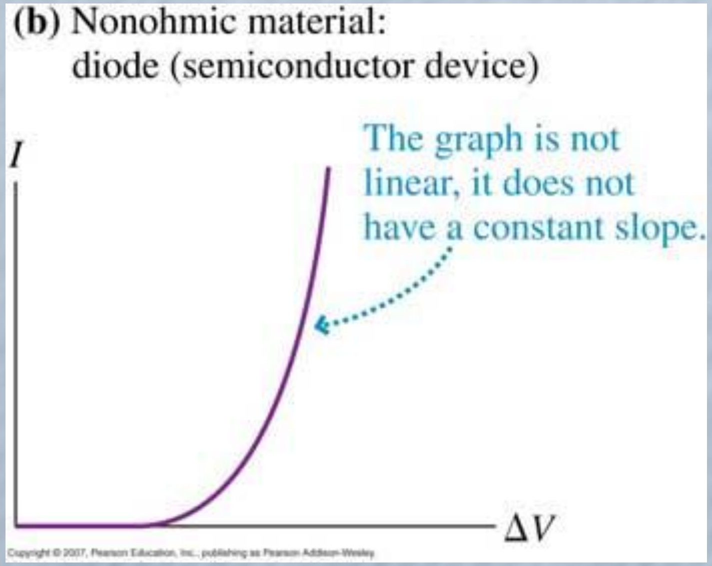
$$V = IR$$

$$V \propto I$$

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

Resistance

- Resistance is a useful concept, and is applied to materials which are nonohmic (I vs. V is not linear)
- Units of volts/amp or ohms (Ω)
- Nonohmic materials include batteries, capacitors, air, semi-conductors in an electric field and superconductors



(b) Nonohmic material:
diode (semiconductor device)

The graph is not linear, it does not have a constant slope.

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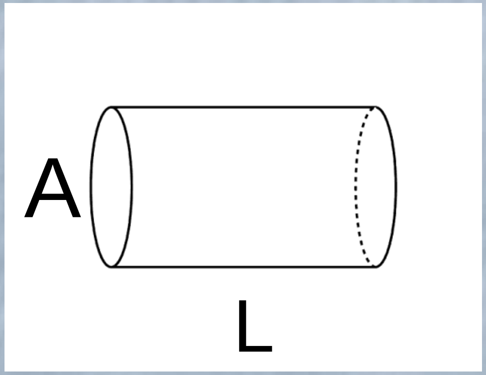
$$R = \frac{V}{I}$$

Resistivity

Experiments with wires made with metals such as copper, show that the resistance, R, of a wire depends on the cross sectional area, A, and its length, L

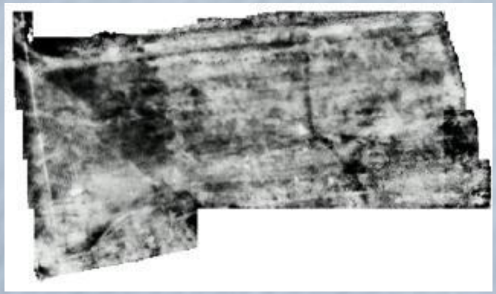
$$R = \rho \frac{L}{A}$$



- This defines ρ, the **resistivity**, with units Ωm.
- It is a property of the material – copper is 1.7×10^{-8}, muscle is 13, fat is 25 Ωm

Uses of Resistivity

- Measure the spreading of a gap with a thin wire
- Measure the fat to muscle ratio in the human body
- Testing drinking water
- Mapping resistivity in soil to look for archeological features



Review of yesterday

Please answer the problem number 21 (a) and (b) on page 745 while we are waiting to start.

“What is the resistance of

(a) A 1.0m long…

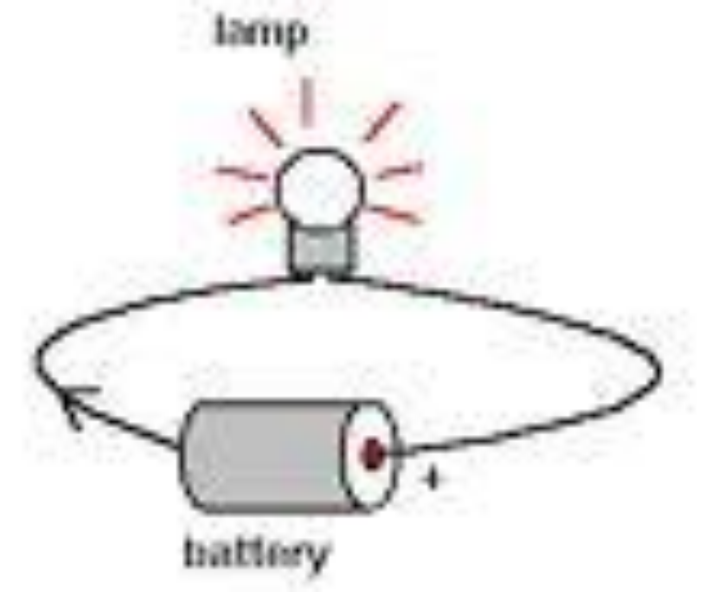
(b) A 10cm long…”

Note the **resistivities** of Copper and Iron can be found in the inside end cover of Knight.

Ideal Circuits

In circuits we will use, it is normal to make the following assumptions:

- Ideal wires – thick copper wires, with zero resistance
- Ideal batteries – that never run down, or have an emf dependent on the load
- Ideal bulbs – resistance does not change with time



Ideal Circuits

In circuits we will use, it is normal to make the following assumptions:

- Ideal resistors – always follow Ohm’s Law perfectly

Voltage drop across the resistor is ΔV. The Electric field along the resistor will be

$$E = \frac{\Delta V}{L}$$

Energy from a moving charge in a field

Energy transferred by a moving charge is

$$\Delta U = q\Delta V$$

- ΔU is the change in energy (Joules)
- q is the charge (Coulombs)
- ΔV is the change in potential (Volts)

Energy from a moving charge in a field

Energy transferred by a change in charge through a potential V

$$\Delta U = \Delta q V$$

- ΔU is the change in energy (Joules)
- Δq is the change in charge (Coulombs)
- V is the potential the charge has been moved (Volts)

Definition of Power from charge moving through a field

Power, P, is defined as the rate of change of energy

$$P = \frac{\Delta U}{\Delta t}$$

- P is power (Joules per second, or Watts)
- ΔU is the change in energy (Joules)
- Δt is how long the change in energy lasts (seconds)

Definition of Power from charge moving through a field

$$P = \frac{\Delta U}{\Delta t} = \frac{\Delta q}{\Delta t} V_{emf} = I V_{emf}$$

- P is the power, Joules per second or Watts
- I is the current, Coulombs per second or Amps
- V_{emf} is the change in potential (Volts)

Power and Resistance

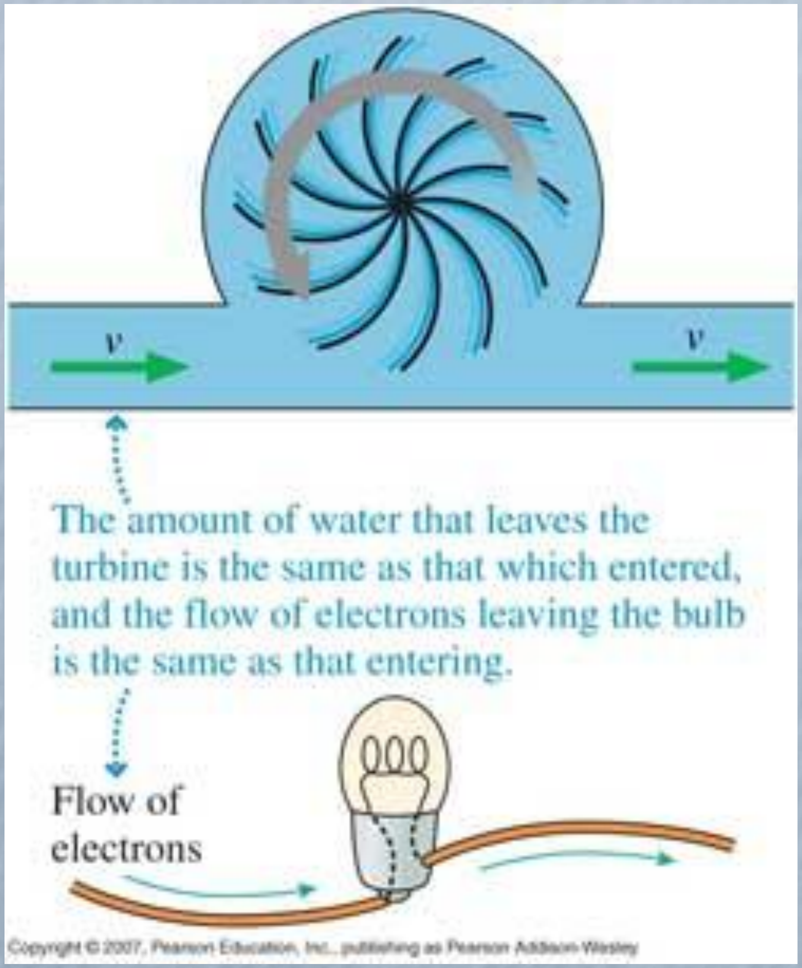
- Using P=VI and V=IR we get 2 important equations
- Power dissipation increases quadratically with either current or voltage at constant resistance

$$P = I^2 R$$

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

Power in circuits

- Where does the power come from ?
- Current is conserved!



The amount of water that leaves the turbine is the same as that which entered, and the flow of electrons leaving the bulb is the same as that entering.

Summary

- Current
- Parts of a circuit
- Resistivity
- Ohm’s Law
- Ohmic and Nonohmic materials
- Energy and Power

Homework

Knight Chapter 22, page 747

53, 54, 55, 56, 58, 59, 60 ,62

Review question on Currents

While we are waiting please try question 7 on page 745

“A capacitor is charged to 6.0×10^{-4} C, then discharged….”