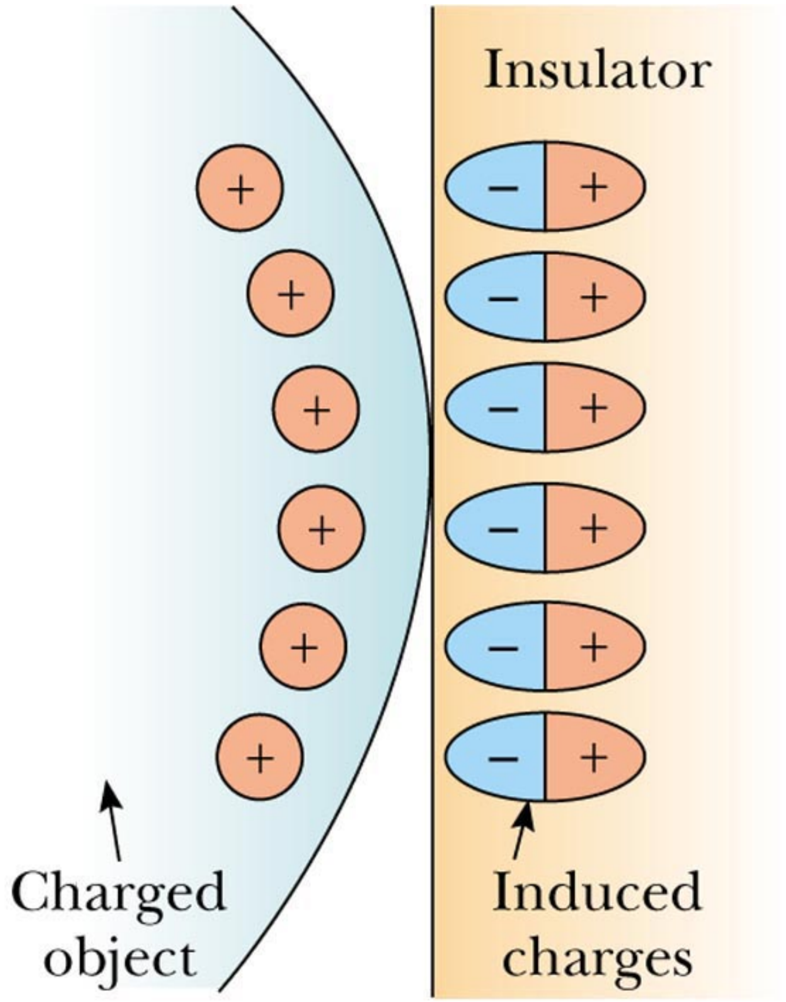
Announcements

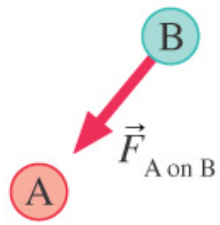
- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- LON-CAPA #6 due Oct. 18
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Electric dipoles

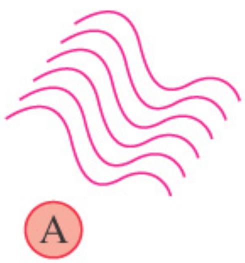
- The charged rod can attract an uncharged insulator if the insulator has electric dipoles inside it
- …or by inducing electric dipoles (separation of charges)



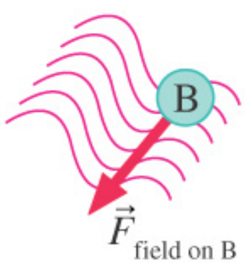
Compare action at a distance and field



In the Newtonian view, A exerts a force directly on B.



In Faraday's view, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)

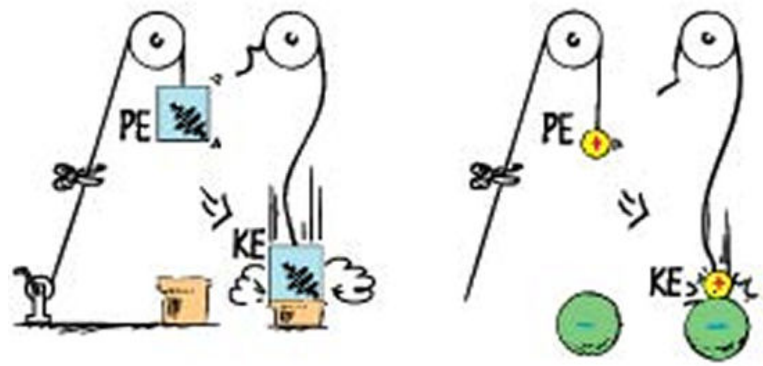


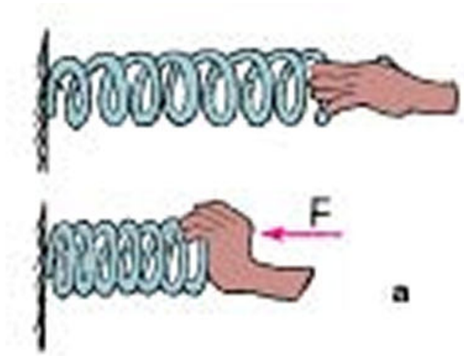
Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

- So we're going to replace the idea of action at a distance by the concept of a field
- Particles don't interact directly with each other
- They create fields which then interact with the other particles
  - we will need this when we start talking about dynamic situations
- We'll be dealing with electric and magnetic fields in this course

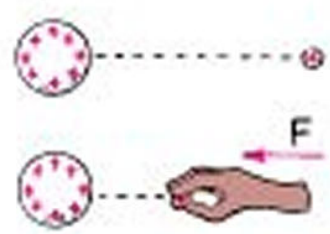
Electric potential energy

- When we talked about gravity, we learned that an object has gravitational energy because of its location in a gravitational field
- Just as work is required to lift a massive object against a gravitational field of Earth, work is required to push a charged particle against the electric field of a charged body
- The work change the potential energy of a charged particle
- Work done in compressing a spring increases the potential energy of the spring
- Work done in pushing a + charged particle towards a + charged sphere increases the potential energy of the charged particle





a



b

If I let go of the charged particle, it accelerates away to the right, changing potential energy to kinetic

Electric potential

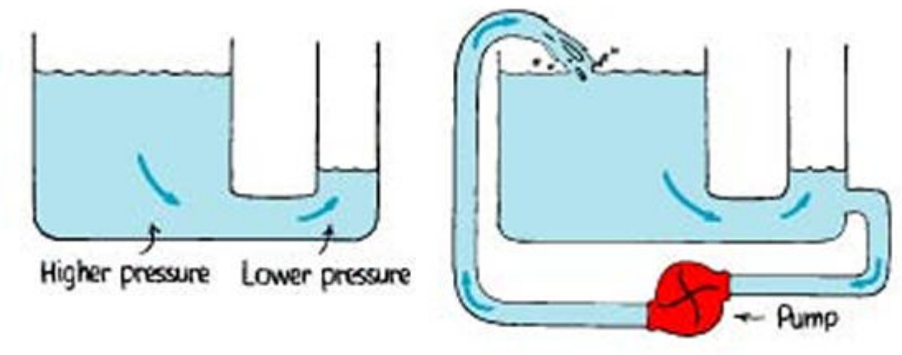
- It is convenient to define the electric potential energy per unit charge
- Simply divide the amount of energy by the amount of charge

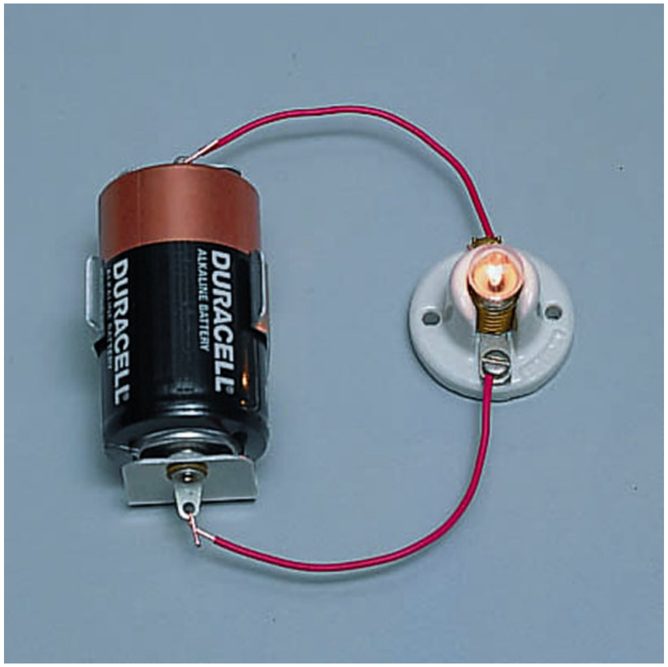
$$\text{electric potential} = \frac{\text{electric potential energy}}{\text{amount of charge}}$$

- The unit of measurement for electric potential is the Volt, so electric potential is often called voltage
  - 1 Volt = 1 Joule/Coulomb
- Thus a 1.5 Volt battery gives 1.5 Joules of energy to every 1 Coulomb of charge flowing through the battery
- The voltage can be defined at any point in space, whether a charge is present at that point or not
- When the ends of a heat conductor are at different temperatures, heat energy flows from the hotter end to the cooler end
- When the ends of an electrical conductor are at different electric potentials-when there is a potential difference-charges in the conductor flow from the higher potential to the lower potential
- Without a potential difference, no charge will flow

Potential differences

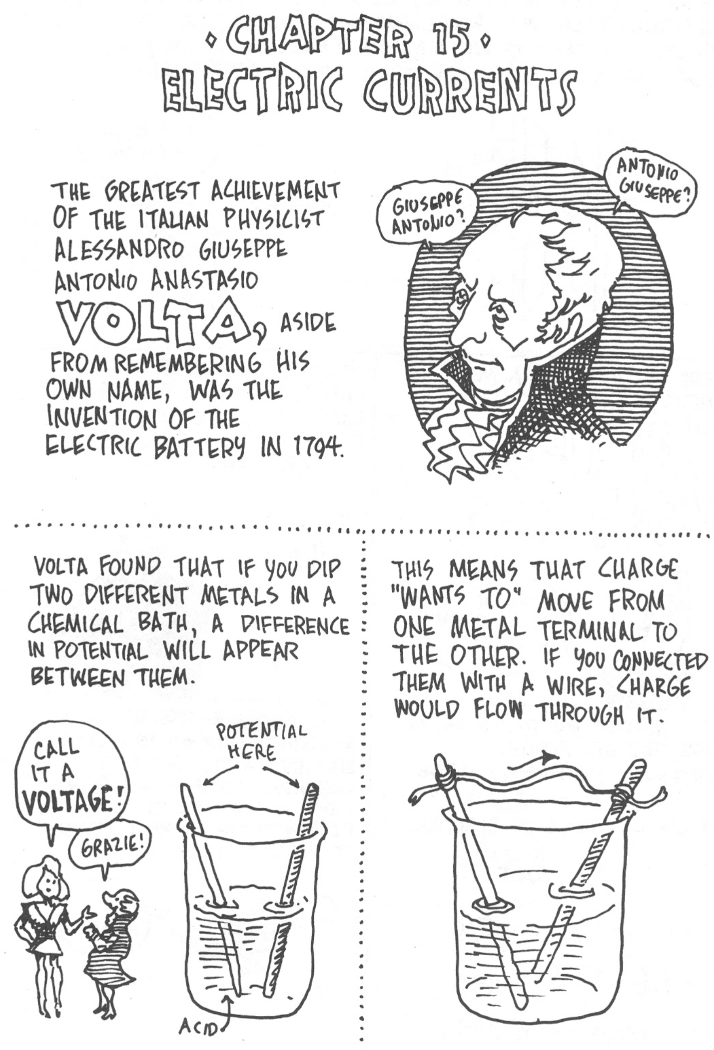
- Water will flow from a region of higher gravitational potential to lower gravitational potential, but not vice versa unless something does work to make it so
- That something could be a pump for example
  - with a pump, there can be a continuous flow of water
- Electric charge also moves naturally from a region of higher electric potential to lower electric potential
- To go the opposite direction, something has to perform work
- That something can be a battery for example
  - with a battery, there can be a continuous flow of electric current





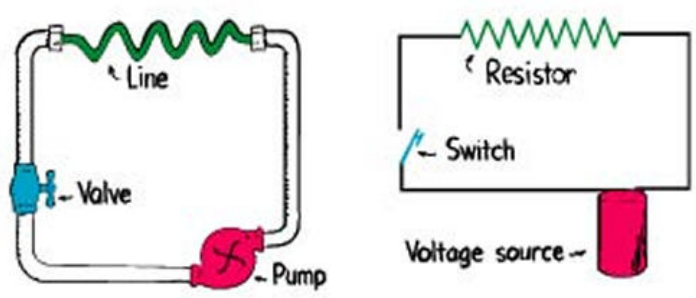
Batteries

- Volta found that when he stuck two dissimilar metals on his tongue, he got an electric shock
  - kids, don't try this at home
- He also found that he could create electric currents not using his tongue but with voltaic cells or batteries
- Galvani at this time also was performing experiments in which he showed that by touching a battery to dead frog legs, he could get them to move



Electric current

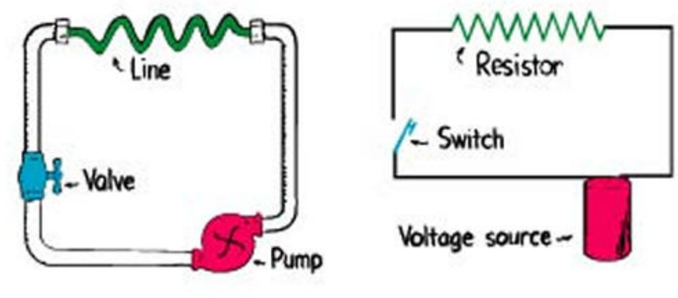
- Just as a water current is a flow of water molecules, so an electric current is a flow of charged particles
- In electric circuits, electrons make up the flow of charge
  - even though we often 'pretend' that it's actually a flow of positive charges, thanks to the convention started by Benjamin Franklin
  - whole cities in the US were wired for electricity before the electron was even discovered
- In electrical conductors, one or more electrons from each metal atom are free to to move throughout the atomic lattice

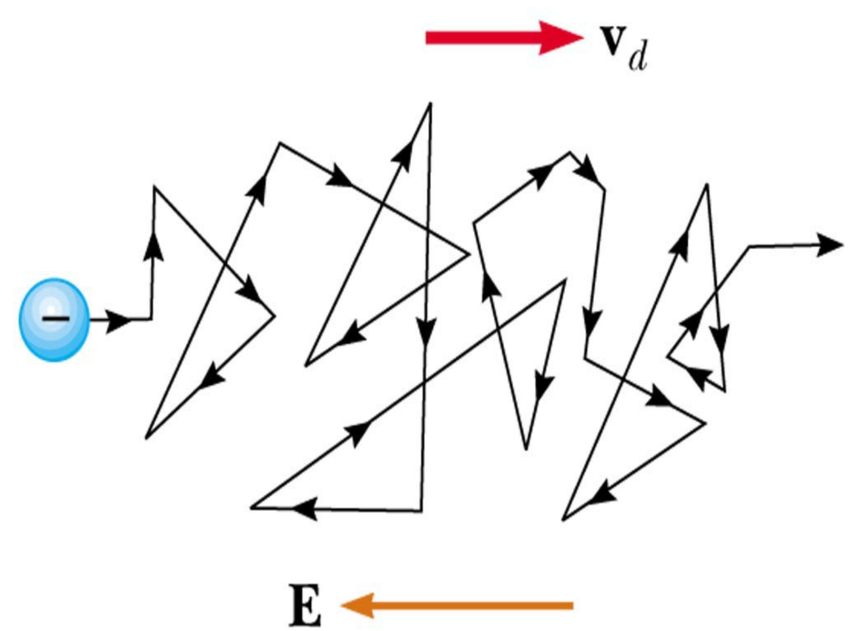


- Electrons flow around an electric circuit, driven by the battery
- The electrons are not supplied by the battery, they're already in the conductor
- The battery just supplies the work necessary to move the electrons from a lower potential to a higher potential

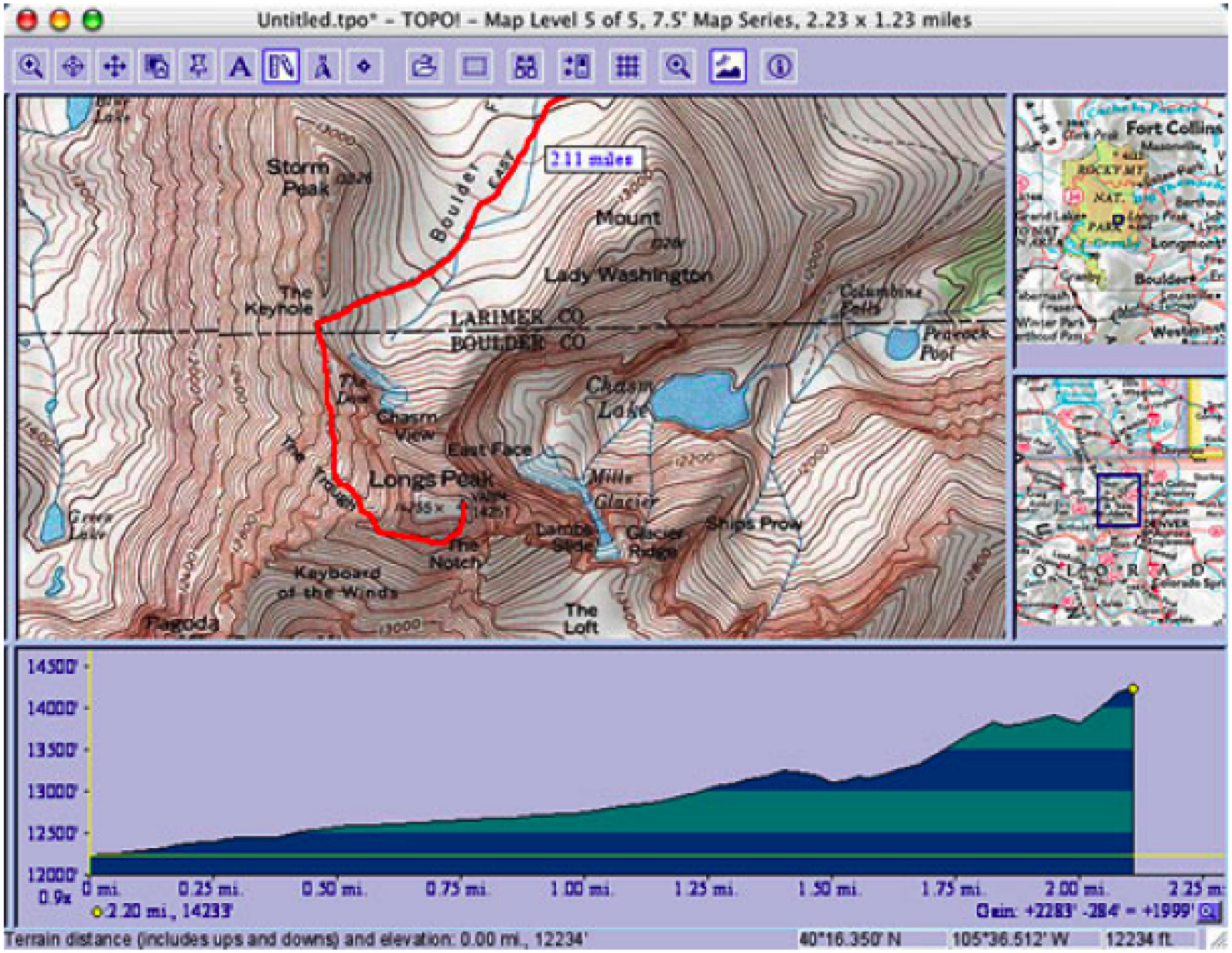
Current

- The rate of electrical flow is measured in Amperes (A), where 1 A is the flow of 1 C of charge per second
- Since each electron has a charge of $1.6X10^{-19}$ C, this means that a current of 1 A corresponds to 6.25 billion billion electrons flowing past a given point per second
  - household circuits can be 15-20 A
- The actual velocity of the electrons through the wire is very slow (typically <1 mm/s)
  - that’s because the electrons keep bumping into the atoms in the conductor
- But the electric signal itself travels at the speed of light





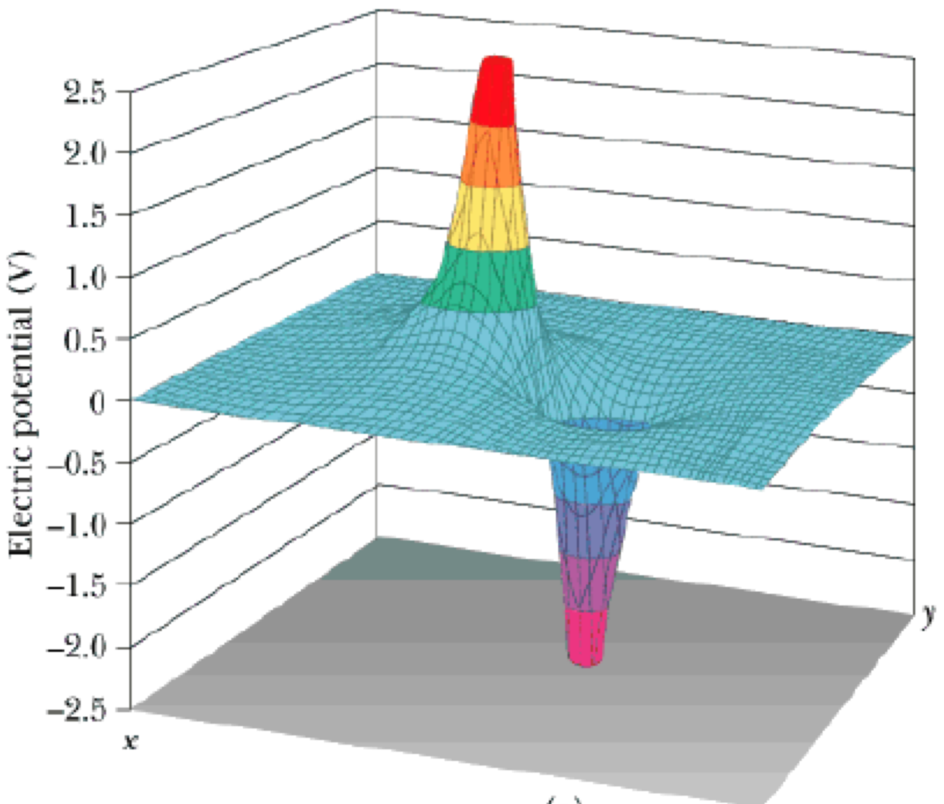
Electric field and potential



Sample from TOPO Maps

The slope gives a measure of the force and direction on a ball.

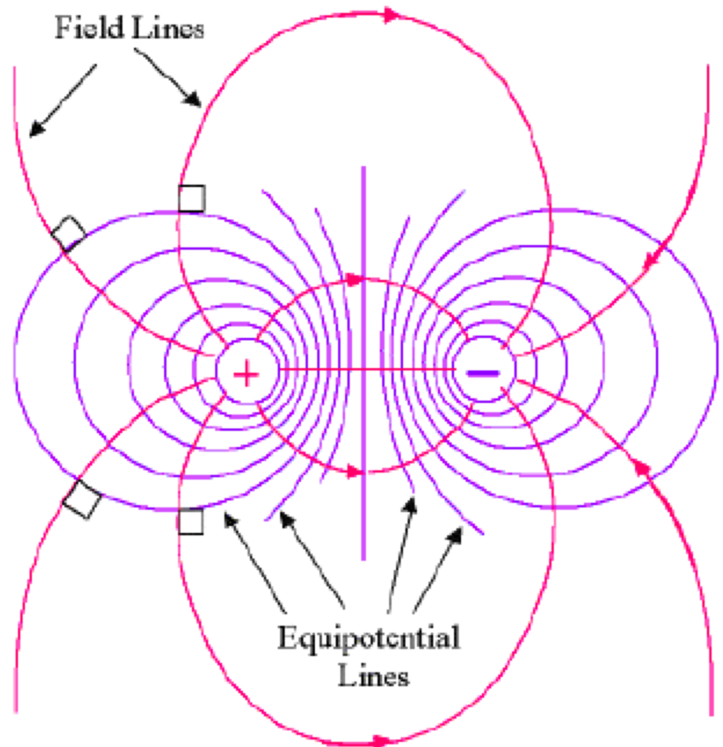
Electric field and potential



(a)

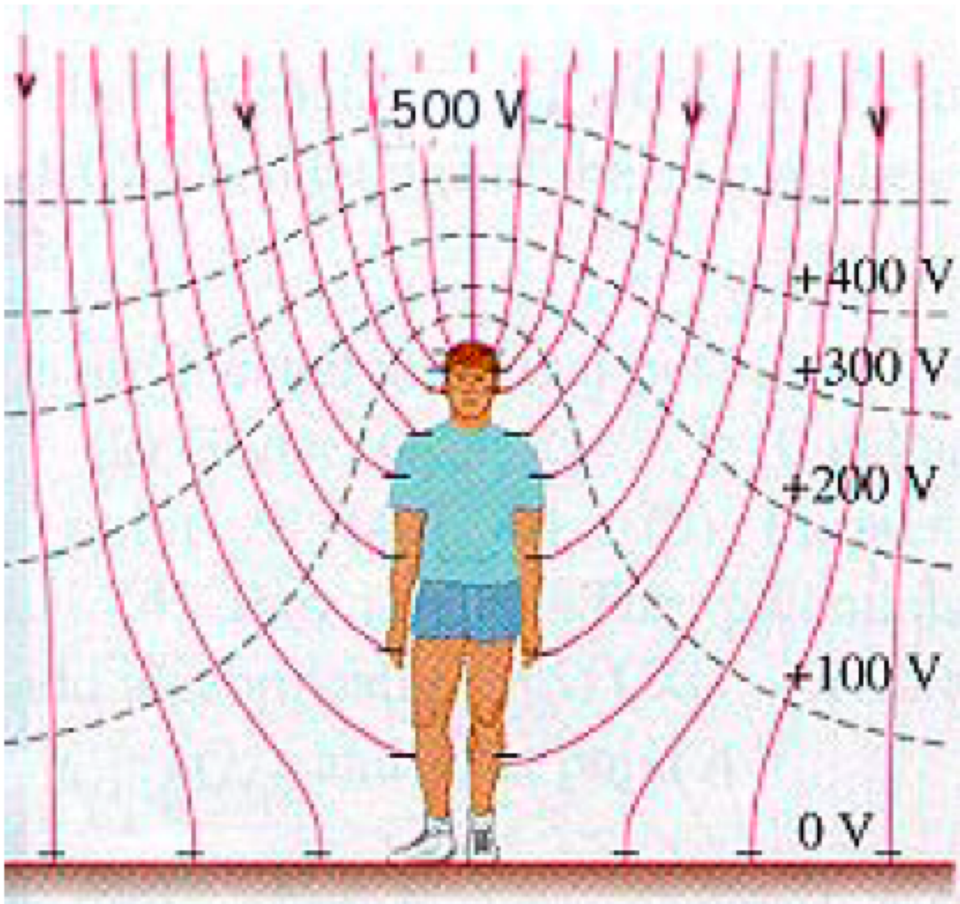
Serway, Physics for Scientists and Engineers, 5/e
Figure 25.8a Harcourt, Inc.

The height is electric potential, V, measured in volts



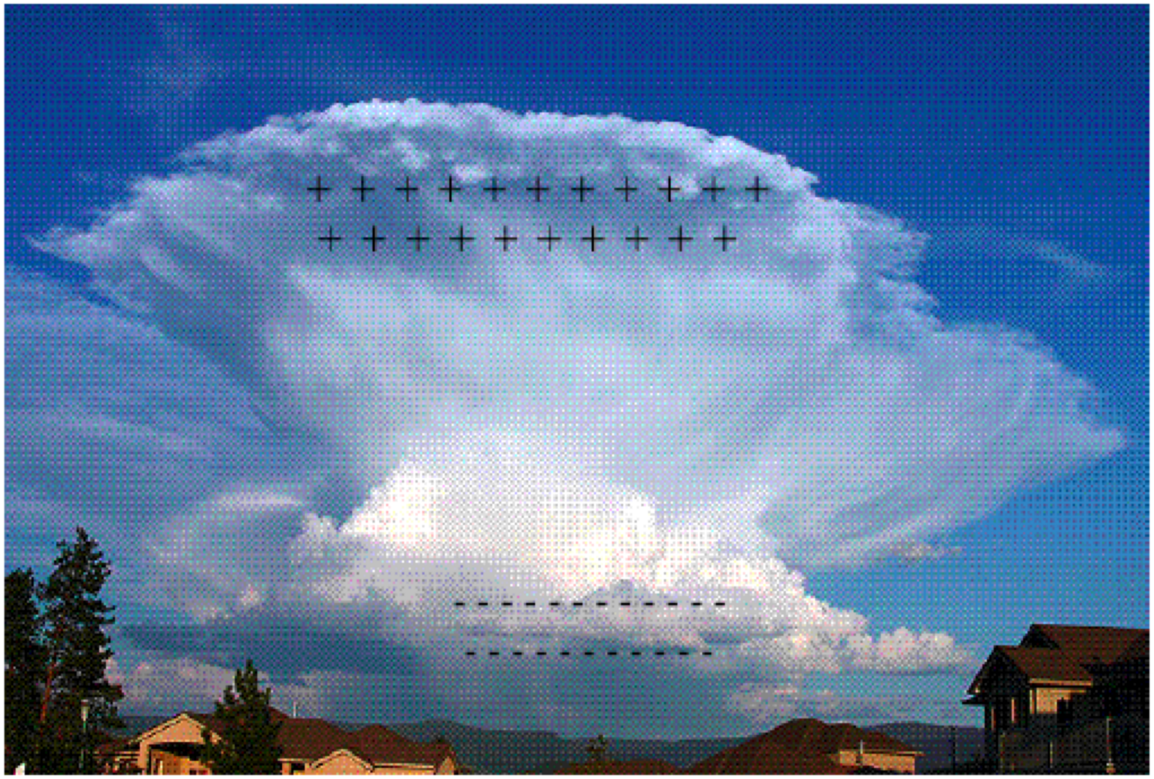
The slope gives a measure of the electric field.

Earth's electric field



The Earth's electric field is about 150 N/C (same as V/m)

Lightning



Potential difference of 100 MV is developed between cloud and ground. In the bolt about 5 C of charge are transferred (on average).

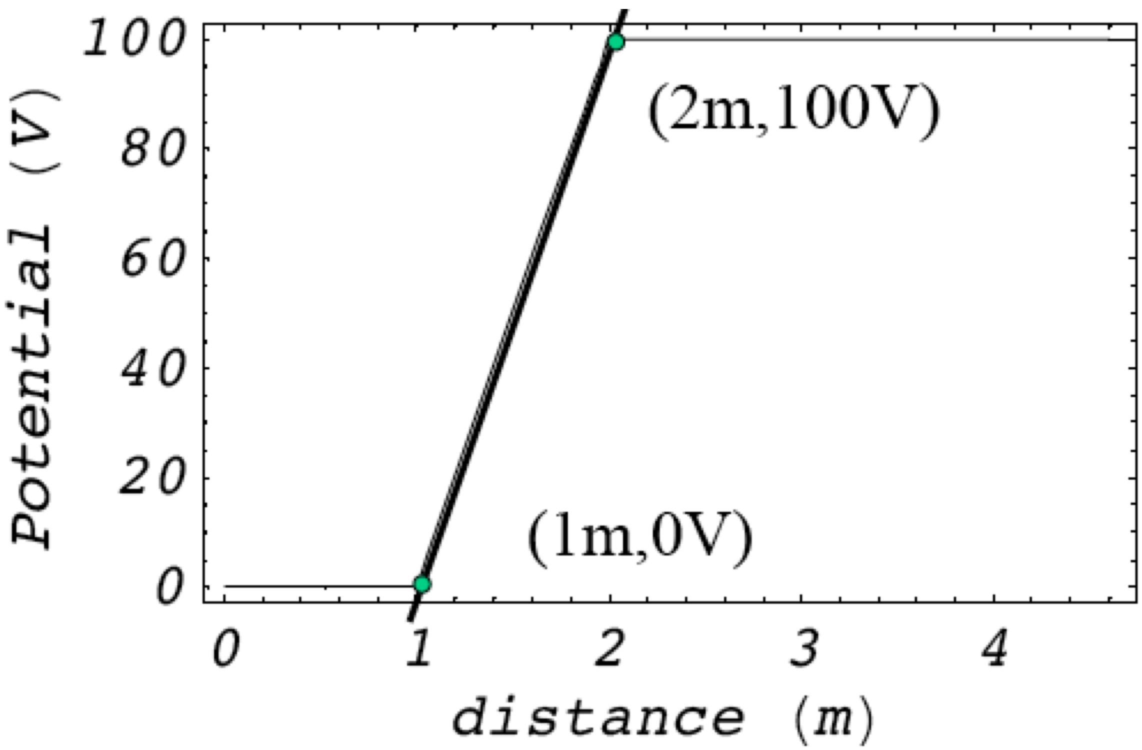
Electric field and potential

- Electric potential – SI unit is the Volt (V)
- Electric field is rate of change of potential

$$E = -\frac{\Delta V}{\Delta x}$$

- The minus sign means that electric fields point from + to – charge.

Example



What is the magnitude of the electric field at:

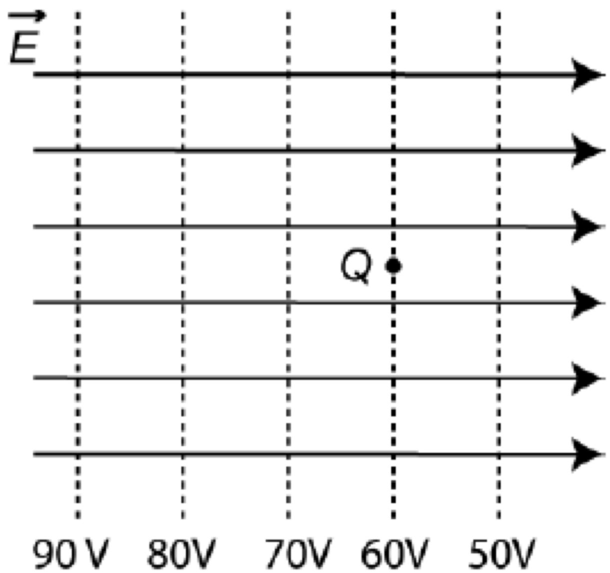
- 0.5 m?
- 1.5 m?
- 3.0 m?

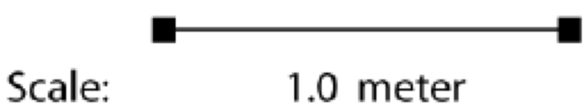
The field is 0 V/m at 0.5 m and 3.0 m since the slope is zero.

$$\left|E(\text{at } 1.5\text{m})\right| = \frac{\Delta \text{V}}{\Delta \text{x}} = \frac{(100V - 0V)}{(2m - 1m)} = 100\frac{V}{m}$$

Example

$Q = -0.5\ \mu C = -0.5 \times 10^{-6}$ C





What is the magnitude of the electric force on Q?

F = qE

F = 0.5E-6C x 40 N/C = 20 $\times 10^{-6}$ N

$$\vec{F} = q\vec{E}$$

Electric Field

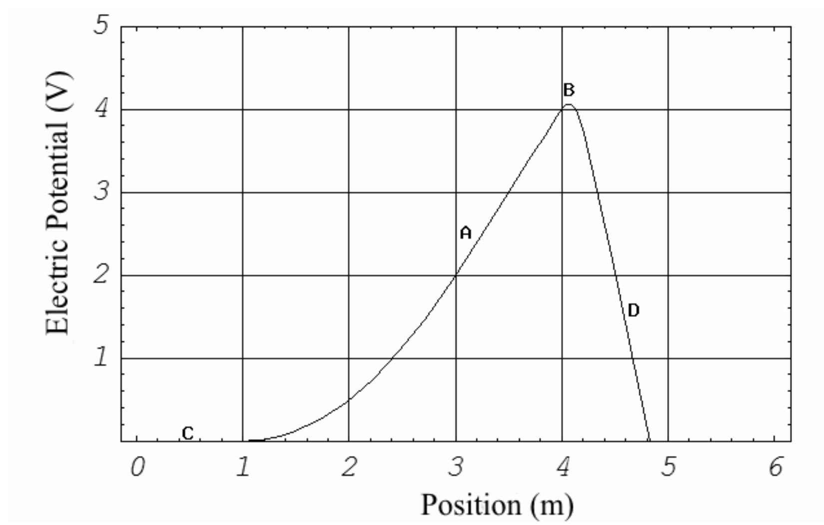
$E = -\Delta V/\Delta x = -(50V-90V)/1m = 40$ V/m

+ means to the right in this case

Where is E field the largest?

$$E = -\frac{\Delta V}{\Delta x}$$

- D has largest (magnitude) slope at D
  - so D has largest magnitude
  - points in direction of decreasing potential (to right)



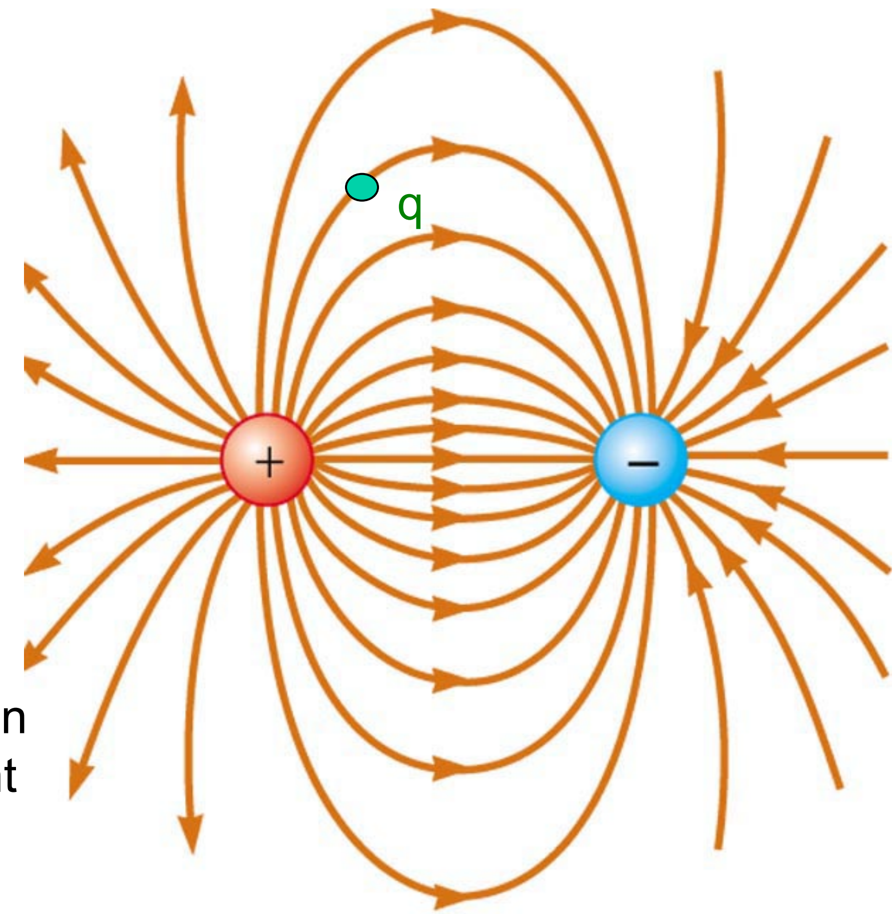
Force and Electric field

$$\vec{F} = q\vec{E}$$

Both F and E are vectors, i.e. have magnitude and direction

The force on a + charge (q) for the electric dipole shown to the right is always in the direction of the E field line at any point in space

If q were -, the force would be in the opposite direction



(a)

Clicker question

- q is a negative charge
- What is the direction of the force on q in the electric field shown on the right?

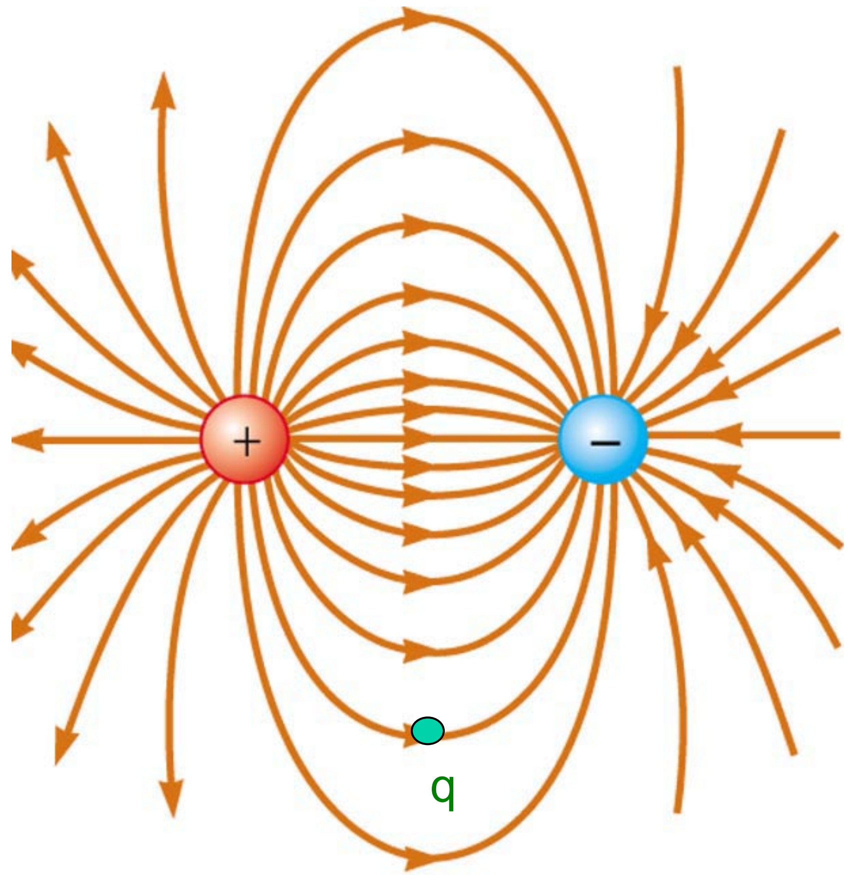
A) to the right

B) to the left

C) up

D) down

E) no force



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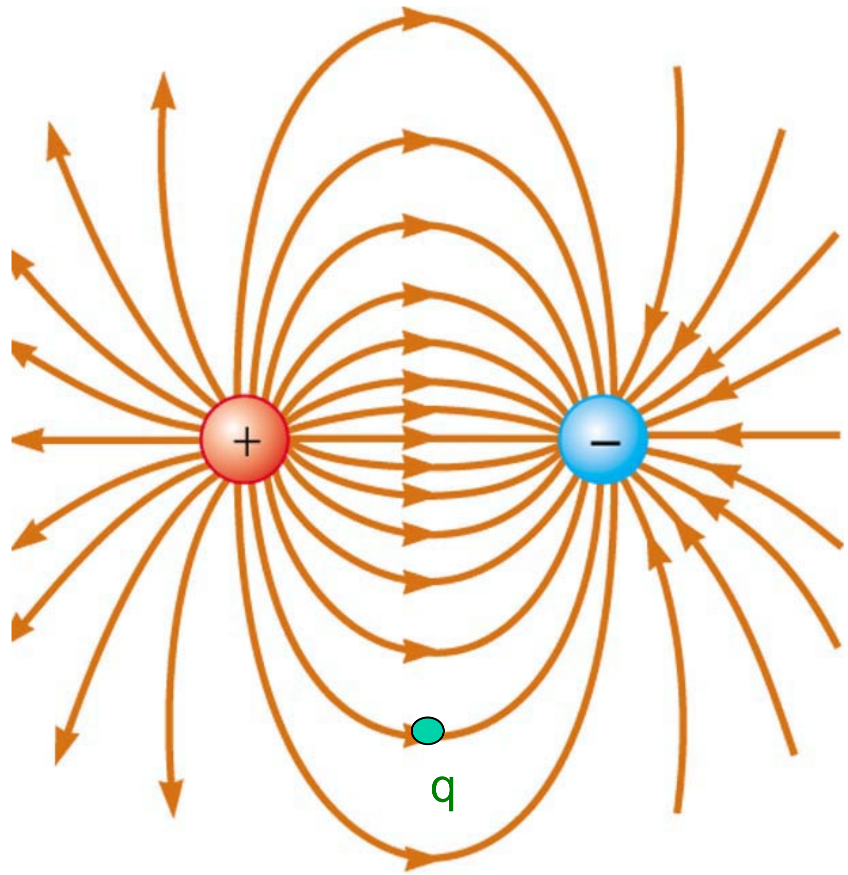

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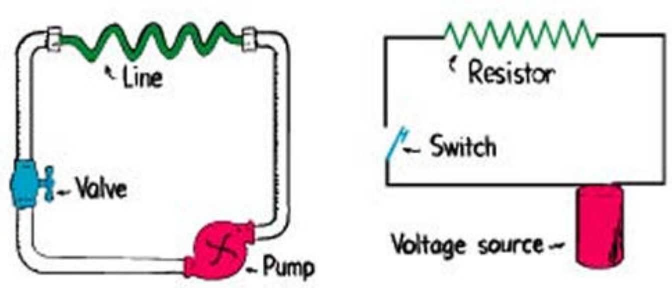
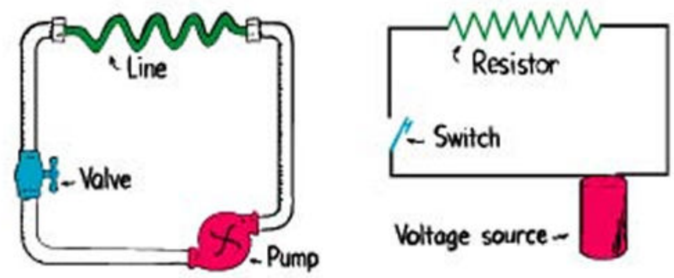
Electric currents

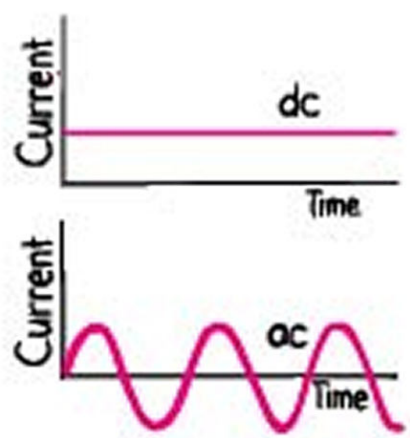
- Suppose I have an electric current flowing through a conductor
- What is the net charge in the conductor?
- Zero
- I haven't added any electrons to the circuit, only made use of the ones already there
- And for every electron,there's a proton with the same magnitude of charge, but opposite sign



AC/DC

- Electric current may be DC (direct current) or AC (alternating current)
- A battery produces a direct current
  - electrons are always moving away from the repelling - terminal of the battery and towards the + terminal
- An AC current alternates direction
  - electrons in the circuit are moved first one way, and then the opposite direction, alternating at a frequency that typically is 60 cycles per second (60 Hertz)
  - this switching is done by a generator periodically switching the sign of the terminals





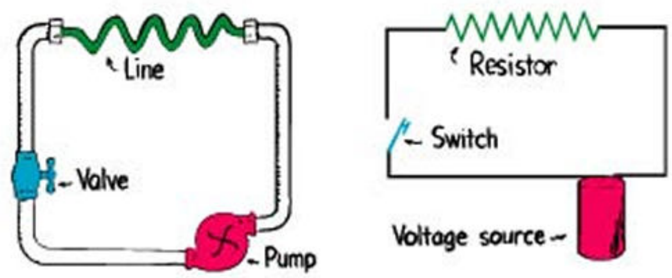
Why AC? Why 110 V?

- Electric energy in the form of AC can easily be stepped up to high voltages to be transmitted large distances with little heat loss, then stepped down to lower voltages where the energy is used

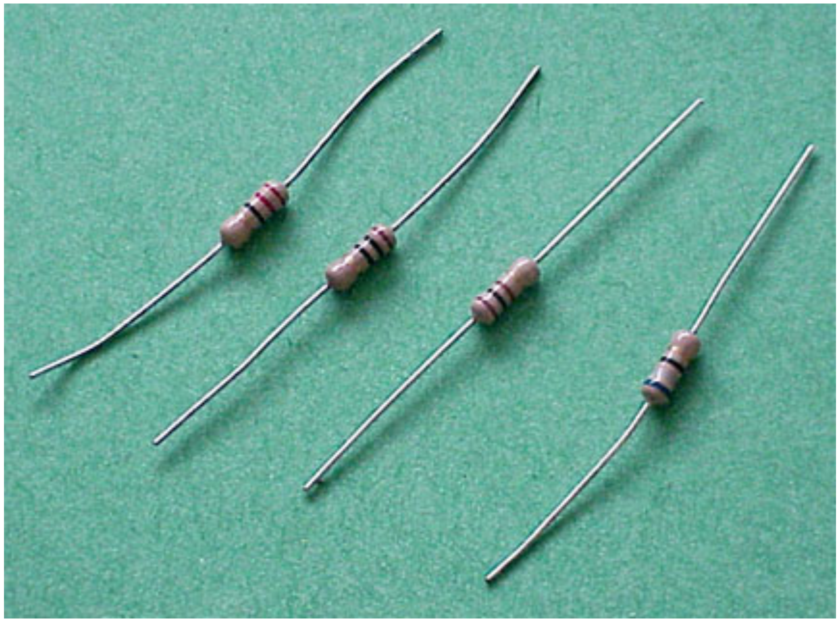
- In the early days of electrical lighting, high voltages burned out electric light filaments, so low voltages were more practical
- 110 V (now 120 V) was established because it made the bulbs of the day glow as brightly as gas lamps
- By the time electrical lighting made it to Europe, engineers had figured out how to make light bulbs that wouldn't burn out at higher voltages
- Since power transmission is more efficient at higher voltages, the Europeans adopted 220 V as their standard

Resistance

- The amount of current that flows in a circuit depends not only on the voltage but also on the electrical resistance of the circuit
  - thin pipes resist the flow of water more than thick pipes
  - long pipes resist the flow of water more than short pipes
  - the same is true for wires conducing a current
- It also matters what the wires are made of
  - copper for example is a very good conductor
  - wood is not
- Electrical resistance is measured in units of Ohms (Ω), after Georg Ohm



resistors used in circuit elements



Ohm's law

- Ohm found that, for some materials, the resistance is independent of the current, i.e. the current is directly proportional to the potential difference
  - these materials are said to follow Ohm's law
- Other materials are said to be non-Ohmic