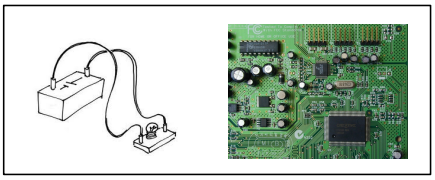
Electric circuits



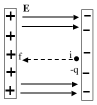
Lecture 21 :
Electric circuits

Reminders:
HW 9 due Monday 12th at midnight
MidTerm 3 coming up in a a week & a bit

A negative charge -q is released from position i to position f between the charged plates of a charged capacitor.

Did the potential energy (PE) increase or decrease?

Did the voltage (V) at the position of the test charge increase or decrease?



A: PE↑, V↑ B: PE↑, V↓
C: PE↓, V↑ D: PE↓, V↓
E: None of these.

Hint:
EPE = qΔV

Reading Quiz… should we have one?

1. An electric circuit is
   a. The circular path you follow scuffing your feet to build up a static charge.
   b. A car racing video game
   c. The description of how electrons disappear at some locations and are created at others in an electrical system.
   d. The closed path taken by electrons in running an electrical device.

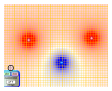
Electrostatics Summary

- Positive and negative charge: Like charges repel, opposites attract
- Coulombs law for point charges: $F = k \frac{q_A q_B}{r^2}$
  Force acts along line joining particles
- Conductivity:
  - Conductor: Electrons free to move around inside material
  - Insulator: All electrons remain bound to original atoms
- Voltage: Determines EPE of charge at that location in space
  Close to + charges voltage is more + and vice versa
  Grounded object is at 0V
  (Also called Electric Potential)
- EPE: = qΔV
  New form of potential energy
  Lots of analogies to GPE (ΔV↔Δh, q↔m)

Voltage is like the height of mountain

- Voltage
- Charge, q
- Electrical Potential Energy

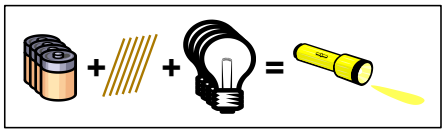
EPE = q Δ V



- Height (and gravity)
- Mass, m
- Gravitational potential Energy

GPE = m g Δh

Flashlights, circuits, batteries, and power



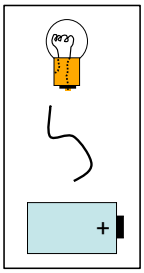
- Given batteries, light bulbs, and wire, how can we design a light bulb circuit
  a) that will burn brightest,
  b) that will last longer,
  c) that will be dim,
  d) that will turn on and off.
- How can you control and predict current and power in light bulbs?
- All this basic circuit stuff applies to home wiring, home electronics, heaters etc.
- Thursday lecture … help save lives … physics of dangers of electrocution.

Builds on electrostatics (like charges repel, opposite charges attract, voltage, EPE)
……but now electrons are moving……

…… **need to start thinking like an electron!**

light bulb circuit

- Start by looking at a really simple circuit containing
  - light bulb
  - Battery
  - Wires
- Each element made of metal containing electrons that are free to move
- What are the electrons doing in each element to ensure that the light bulb lights up?

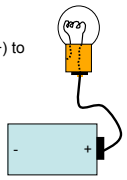


Using each of these three elements can you draw a picture where the bulb lights up?

light bulb circuit: Wiring

What will happen when hook up positive end of battery (+) to flashlight bulb with one wire?

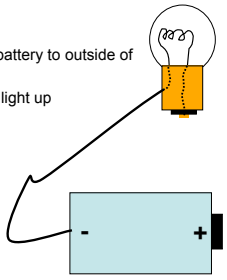
a. light up b. barely light up c. not light up



light bulb circuit: Wiring

What about hooking up negative end of battery to outside of flashlight bulb?

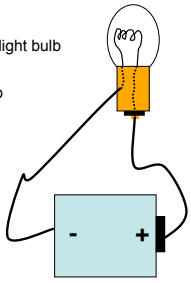
a. light up b. barely light up c. not light up



light bulb circuit: Wiring

What will happen when hook up battery to flashlight bulb with 2 wires as shown?

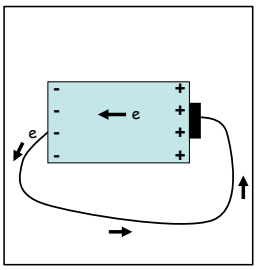
a. light up b. barely light up c. not light up



light bulb circuit: Battery

Voltage difference between ends of battery… 1.5 Volts, 9 Volts, 12 Volts

$\Delta EPE = q\,\Delta V$



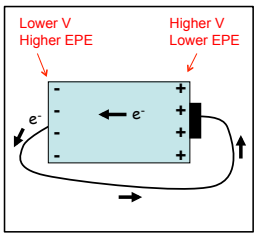
What happens to EPE of electrons as they flow around the loop?

a) EPE is always the same.
b) EPE increases through battery; EPE decreases through circuit.
c) EPE decreases through battery EPE increases through circuit.

light bulb circuit: Battery

Voltage difference between ends of battery… 1.5 Volts, 9 Volts, 12 Volts

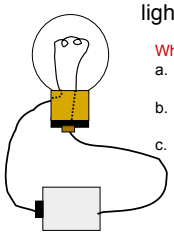
$\Delta EPE = q\,\Delta V$



What happens to EPE of electrons as they flow around the loop?

Battery of voltage (difference) V gives each electron eV of EPE to spend in circuit (→ KE → heat, light, etc).
Battery voltage also related to the force pushing e- round circuit
Think of as related to pushing up mountain, and then rolling down (hitting things)

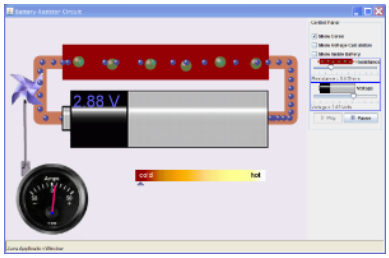
light bulb circuit: Bulb



What makes light bulb hot and bright?

a. Electrons pass through really fast, so they are moving fast, produce light.
b. Electrons run into stuff in filament, transfer energy.
c. Electrons in filament repelled by electrons flowing through so escape and produce light.

Simulate bulb



http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

Circuit elements summary

Wires: Make complete circuit necessary for steady flow of electrons
Usually have negligible (zero) resistance

Battery: Has positive charges piled up at one terminal and negative charges at the other
Provides voltage difference ΔV around circuit
Provides each electron with q ΔV= eV of EPE to spend in circuit
Provides push for electrons around circuit (bigger V, bigger push)

Bulb: Filament is a high resistance wire in which electrons lose their energy as heat

Energy changes in circuit

Battery: Chemical to EPE of electrons

In circuit wires: EPE to KE of electrons

In bulb: KE of electrons to thermal energy (random KE) of filament atoms

Filament surface: Thermal energy of filament atoms to radiated energy (light)

In Battery: heat and light

Really good question:

- I thought that the light bulb filament was just a piece of wire. But there are also wires connecting the bulb to the battery. Why don't the connecting wires get hot and glow like the light bulb filament?

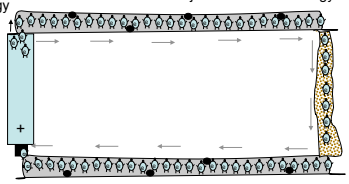
This is a task for Electron man!

Circuits – Think like an electron

Useful tip:
In questions, assume connecting wires have zero R and e^- lose zero energy in them, unless told otherwise

1. Start: Lots of energy

2. Wires: Not much to bump into – Low R. Lose just a little bit of energy

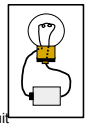


3. Filament
Lots to bump into
Higher R
(Like trudging through mudpit)
Lose lots of energy.

4. End: Exhausted! All energy used up getting through course.

- Same current through connecting wires and filament.
- $R_{filament} >> R_{wires}$
- Almost all energy lost in filament.

Circuits so far



Wires: Make complete circuit necessary for steady flow of electrons
Usually have negligible (zero) resistance

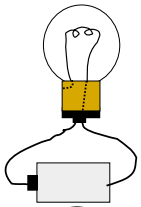
Battery: Maintains a voltage difference ΔV between terminals
Provides each electron with qΔV = eV of EPE to spend in circuit
Provides push for electrons around circuit (bigger V, bigger push)

Bulb: Filament is a high resistance wire
KE of electrons converted into heat via collisions

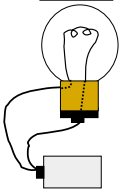
Electronman rules for analyzing circuits

a) No electron deaths/births
b) No passing of electrons
c) Electrons have energy (high at start, low at end)
d) Different conducting materials have different resistances

Think like an electron!



a. Light will not light up, No current will flow
b. Light will light up, Current will flow
c. Light will barely light up, Current will flow
d. Light will not light up, Current will flow
e. Light will light up, No current will flow.



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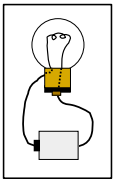
Circuit language



Resistance (R) of a circuit element is measure of how hard it is for electrons to pass through.
Units: Ohms (Ω)

Current (I) : charge per second flowing past a point in the circuit
(= # electrons per second × charge on electron)
Units : Amps (1 A = 1 C/s)

Voltage (difference) (ΔV)

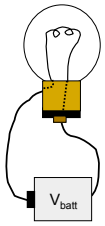
a) Across battery: Measure of EPE given to each e^- as it passes through battery. EPE given = eV. Related to pushing force on electrons in circuit

b) Across a resistor (wire, filament etc): Measure of EPE lost by each e^- as it passes through. EPE lost = eV.
Unless told otherwise voltage difference across connecting wire = 0.
Units: Volts (V)

Ohm's Law: ΔV = IR

Note: All quantities specific to one component.
Don't mix and match!

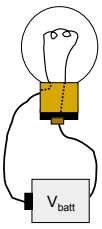
Resistance of component
Current through component
Voltage dropped across component



Resistance is measure of how hard it is for electrons to pass through an object … or how much stuff they will run into.

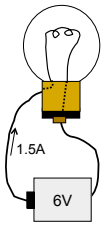
What if increase resistance (R) of filament… add more stuff for e^- to hit…

a. Rate at which electrons pass through filament stays the same
b. Rate at which electrons pass through filament decreases
c. Rate at which electrons pass through filament increases



What if increase voltage difference across battery?

a. Rate at which electrons pass through filament stays the same
b. Rate at which electrons pass through filament decreases
c. Rate at which electrons pass through filament increases



If the battery on the left has a voltage (difference) of 6V and it is pushing a current of 1.5 A through the bulb, what is the resistance of the bulb?

a) 9 Ω
b) 6 Ω
c) 4 Ω
d) 1.5 Ω
e) 0 Ω