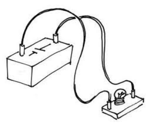
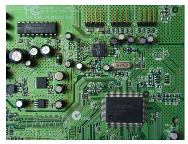
Electric circuits



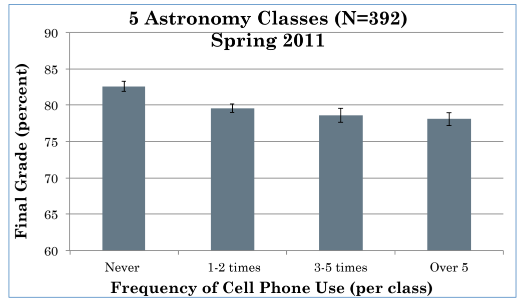


Why does water destroy my electronics?

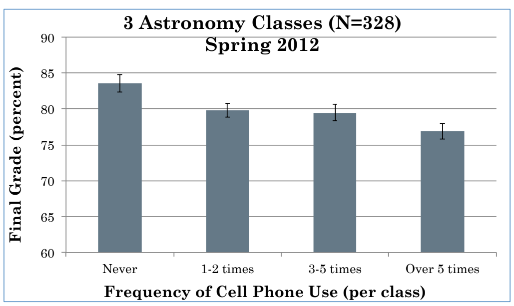
Lecture 21 :
Electric circuits

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

Digital Distractions reduce Final Grades



Digital Distractions reduce Final Grades RELIABLY



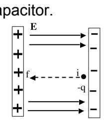
In other words …

Students who use report using their cell phones in class score nearly half a letter grade lower, on average, than students who report never using their phones.

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 = q∆V

A negative charge -q is released from position i to position f between the charged plates as shown.

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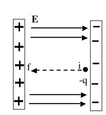

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E: None of these.

EPE = q∆V
Vf > Vi **∆V is bigger!**
EPE is q∆V
but q is **negative**
EPE gets smaller!

Reading Quiz.

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.

2. For a standard object with fixed resistance
   a. The voltage drop across the object is related to the current
   b. The voltage drop across the object is NOT related to the current
   c. It depends on the circumstances.

3. The power produced by a flashlight depends on
   a. Only the amount of voltage produced by the batteries.
   b. Only the amount of current flowing through the bulb.
   c. Both the voltage of the batteries and the amount of current through the bulb.
   d. None of the above.

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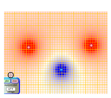
Voltage is like the height of mountain

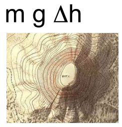
- Voltage
- Charge, q
- Electrical Potential Energy

EPE = q Δ V



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

GPE = m g Δh



Conservation of energy and EPE

ΔGPE = m g Δh

ΔKE = $\Delta(1/2mv^2)$

Work = F x $d_{parallel}$

and Friction

<u>Add:</u>

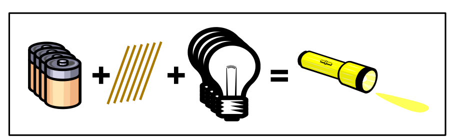
ΔEPE = q ΔV

$W_{ext} - |W_{friction}| = \Delta GPE + \Delta EPE + \Delta KE$
$= mg\Delta h + q\Delta V + \Delta(1/2mv^2)$

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: = $q\Delta V$
  New form of potential energy
  Lots of analogies to GPE ($\Delta V \leftrightarrow \Delta h$, $q \leftrightarrow m$)

Flashlights, circuits, batteries, and power



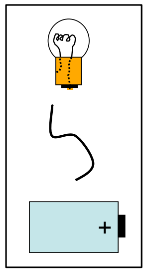
- Given batteries, light bulbs, and wire, how can we design a light bulb circuit
  a) that will burn brightest,
  b) that will last longer,
  c) that will be dim,
  d) that will turn on and off.
- How can you control and predict current and power in light bulbs?
- All this basic circuit stuff applies 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?

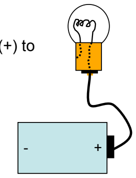


Using each of these three elements can you draw a picture where the bulb lights up?

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



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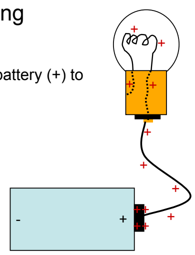
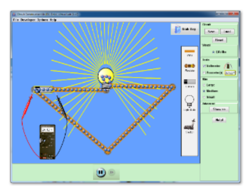


- Light requires steady flow of electrons through bulb
- But nowhere for electrons to flow!!!
  - Electrons in wire initially attracted to positive end of battery
  - This makes wire and filament positive
  - Electron flow stops when attractions to + end of battery and positively charged wire are equal. (technically they are at the same voltage!)

See this in action!

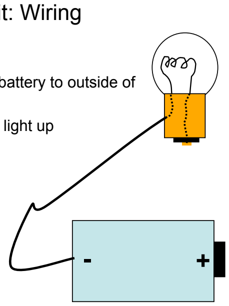


http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

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

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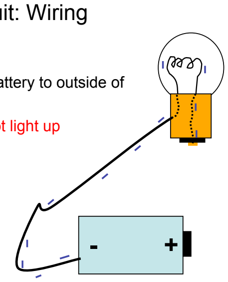
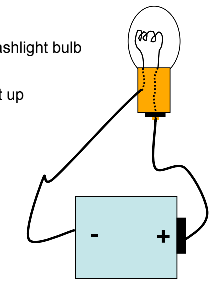


- Still no where for electrons to flow!!!
  - Some electrons pushed out of negative end of battery making wire and filament negatively charged
  - Flow stops when repulsion from negative end of battery equal to repulsion from negatively charged wire.

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



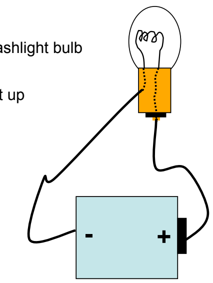
light bulb circuit: Wiring

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

Complete circuit: electrons are able to flow all the way around and back into battery, producing a steady current (I)

If there is a break in the circuit they will pile up at the break and push back(Coulomb's law) preventing any more from flowing (I=0)

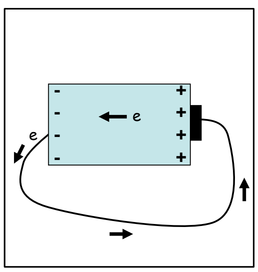


Electrons must have a complete conducting circuit to flow

light bulb circuit: Battery

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

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



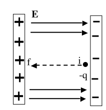
What happens to EPE of electrons as they flow around the loop?

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

A negative charge -q is released from position i to position f between the charged plates as shown.

Did the potential energy (PE) increase or decrease?

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



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E: None of these.

$EPE = q\Delta V$
$V_f > V_i$ **ΔV is bigger!**
EPE is $q\Delta V$
but q is **negative**
EPE gets smaller!

light bulb circuit: Battery

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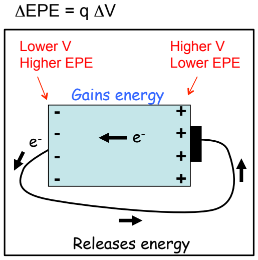


What happens to EPE of electrons as they flow around the loop?

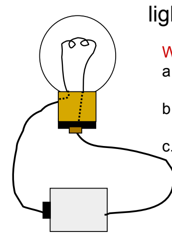
b) EPE increases through battery; EPE decreases through circuit.

As electron moves through battery:
- Goes from higher to lower voltage
  ⇒ ΔV is negative
- But electron has negative charge
  ⇒ change in EPE of electron is positive

- Battery has to do work pushing electrons towards negative terminal
- Work changes chemical energy to EPE of electrons

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



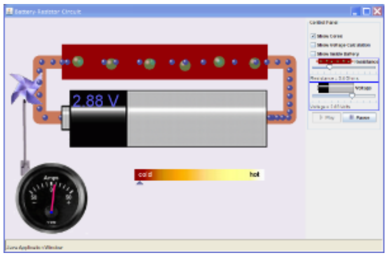
What makes light bulb hot and bright?

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.

Answer is b.
Electrons run into stuff in filament, collide …
EPE energy given by battery → kinetic energy of electrons in circuit → thermal energy of filament atoms

How much stuff they bump in to = RESISTANCE or R
(analogy: think of hitting rocks on way down the hill if I'm rolling a boulder down)

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

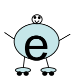
In bulb:
KE of electrons to thermal energy (random KE) of filament atoms

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?



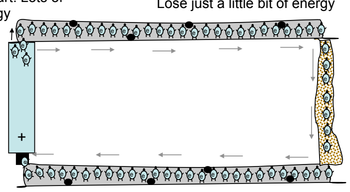
This is a task for Electron man!

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

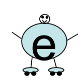
2. Wires: Not much to bump into – Low R. Lose just a little bit of energy



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.

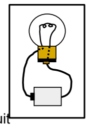


Circuits – Think like an electron

Rules: a) no electron deaths/births
b) no passing of electrons
c) electrons have energy
(high at start , low at end)
d) Material has resistance
(lets electrons pass easily or not)

See: resistor heating simulation

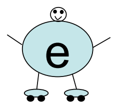
Circuits so far



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 $q\Delta V$ = eV of EPE to spend in circuit
Provides push for electrons around circuit (bigger V, bigger push)

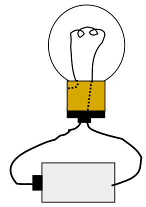
Bulb: Filament is a high resistance wire
KE of electrons converted into heat via collisions



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
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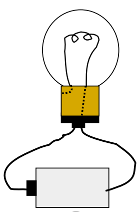
e. Light will light up, No current will flow.

d. Light will not light up, Current will flow … THINK LIKE AN ELECTRON!



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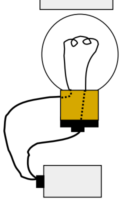

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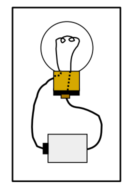
a. Light will not light up, No current will flow

back to signal and battery applets for review as needed

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)

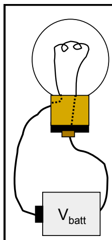
Voltage (difference) (ΔV)

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

- R: Resistance of component
- I: Current through component
- ΔV: Voltage dropped across component

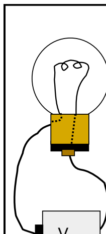
Note: All quantities specific to one component. Don't mix and match!



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



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What if increase resistance (R) of filament… add more stuff to hit…

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- Increase R ⇒ More stuff to run into, average speed slower, fewer e- per time.
- $\Delta V = IR \Rightarrow I = \Delta V_{batt}/R_{bulb}$