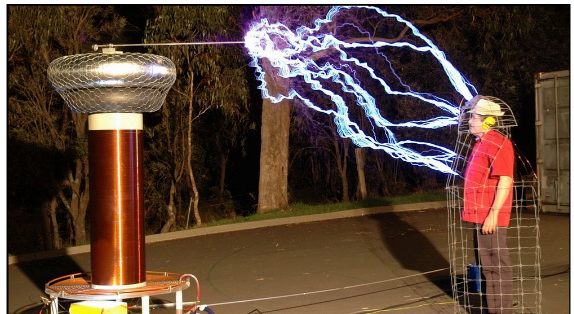
Midterm 3 review

Day 23:
Questions about circuits
Review

Reminders:
No new HW this week!
Wed special help room?
SURVEY ONLINE



Where's the circuit?

Is this a doctored photo?

Where do electrons flow?

Could we possibly do this here?

Mid term 3 on Thursday

- 30 multiple choice questions, worth 40 points.
  An optional long answer will be a take home on the next HW (after break).
- Exam will be closed book.
- THREE 3 by 5 inch formula cards. You can WRITE anything on it BY HAND. Please write your student ID on your formula card.
- Calculator and pencil/eraser
  - Calculator cannot connect to outside world. No calculators on cell phones or laptops allowed.
  - No sharing of calculators.
  - A limited supply of spare calculators are available (no guarantees they work though!)
- Exam scores and solutions will be posted after the exam on D2L.
- There will be no early or late exams given and no make-up exams.
- Balcony areas will be CLOSED on Thursday

Midterm preparation

- Prepare by applying the principles we have learned – practice.
- You CANNOT memorize answers to specific questions.
- Make a formula card now with the important equations.
- Go over homeworks, class clicker questions, questions in the book (see 1010 website).
  - Not sure how to get the answer – take it to the helproom.

Topics Covered

Light and EM Radiation:
Blackbody:
Atoms / electric charge and electric Force:
Voltage:
Circuits:

See details on web

Formula Sheet provided

Practice problems (don't span topics but give feel of materials)

Review Topics

Light and E/M Radiation

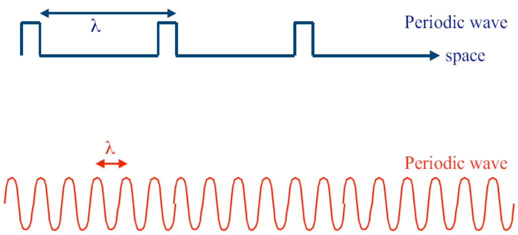
Blackbody spectrum
- Introduction to EM waves and the EM spectrum
- Kelvin temperature scale
- Stefan-Boltzman law
- Shape of BB spectrum at different temperatures –
  ⇒ why the sun produces visible light efficiently and incandescent light bulbs don't.

Static electricity
- Coulomb's law for force between point charges
- Voltage and electric potential energy (EPE)

Electric circuits
- Ohm's Law
- Power dissipation law
- Batteries in series and Parallel

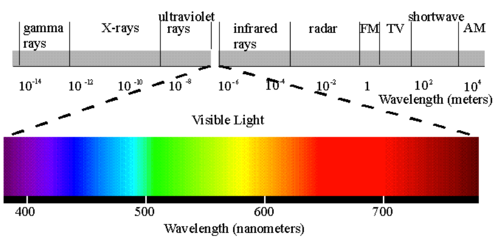
Wavelength

For *periodic* waves, we can identify a *wave length*, λ, by measuring the *distance* between unique points



Electromagnetic waves can have any wavelength

Scientific notation is useful!



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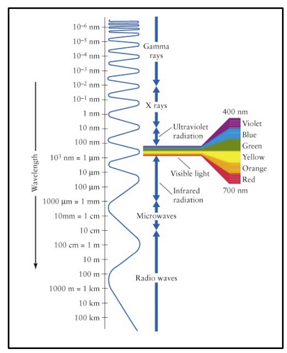
The electromagnetic spectrum



- All EM radiation is a periodic modulation of the electric field
- All EM radiation travels at speed $c = 3 \times 10^8$ m/s
- $c = \lambda \times f$
- Visible light is just one part of the electromagnetic spectrum with specific range of λ (and f)

Purple light has a wavelength of 400 nm. What is its frequency?
(1 nm = 1×10^{-9} m)

a. 7.5×10^5 Hz
b. 7.5×10^{14} Hz
c. 1.3×10^{-6} Hz
d. 1333 Hz
e. 400×10^9 Hz

$f = c/\lambda$

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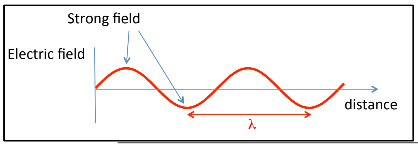
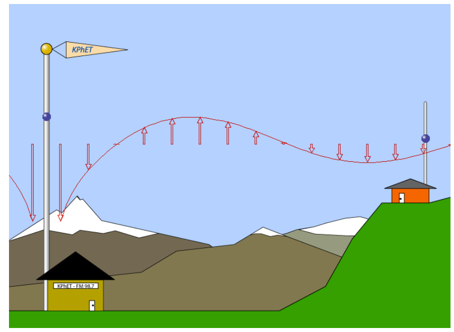
$f = c/\lambda$
Use standard units!

What is Electric field?

- Light is periodic modulation of "electric field"



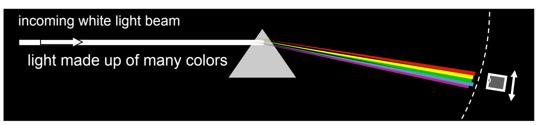
- Electric field exists everywhere in space
- Describes the force on a charged particle at each point in space
- Vector – has a magnitude and direction
- Units: Newtons/Coulomb
- Contains energy
- Created by charges (and created in other ways)
- Analogy: Like gravitational field describes the force on a particle with mass
- Balloon demo

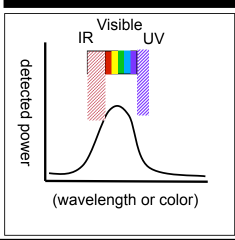


http://phet.colorado.edu/en/simulation/radio-waves

The spectrum of white light?

A spectrometer measures the spectrum (range of wavelengths or frequencies) in light





White light

- Defined as the spectrum of EM radiation emitted by the sun
- All visible λ present with roughly equal intensity

Blackbody spectrum and temperature

- Everything that has a non-zero temperature emits a spectrum of EM radiation
- The spectrum of EM radiation coming from a black object is called the "blackbody spectrum."
- Black object: Absorbs and emits all EM λ easily
- Go to the blackbody spectrum simulation
- BB spectrum determined by temperature only.
- The temperature of the object affects both
  - The total power of EM radiation emitted by the object
  - The range of wavelengths emitted (the spectrum)

Temperature and total emitted power (brightness)

Stefan-Boltzman law gives total electromagnetic power (energy/second) out of a hot object at temperature T

Power $= e \times \sigma \times T^4 \times a$

Area of surface

Temperature of object (in Kelvin!)

Stefan-Boltzmann constant,
$\sigma = 5.67 \times 10^{-8}$ J/(s m^2 K^4)

e = "emissivity"; how well the light gets out

What is 2400 degrees C in degrees K?

a. 2127 K
b. 2400 K
c. 8.8 K
d. 2673 K
e. None of the above

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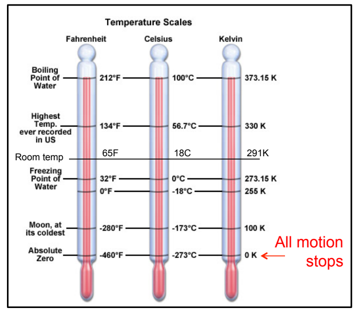
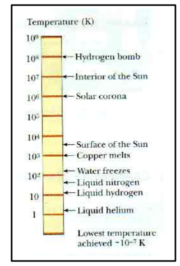
Temp (K) = Temp (C) + 273

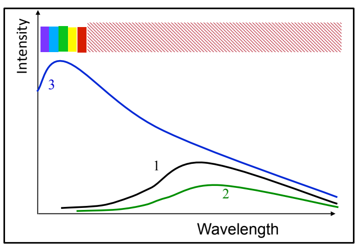
The Kelvin Temperature Scale: Links T to motion





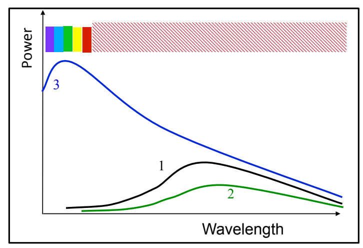
- 1 degree Kelvin = 1 degree Celsius = 9/5 degree Fahrenheit
- 0 degree Celsius = 273 K

Identify spectrum of radiation given off by person (37 C) and a block of barely frozen ice (0 C).



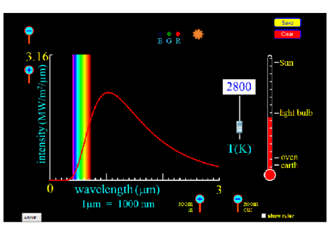
a. 2 is person, 1 is ice,
b. 1 is person, 2 is ice,
c. None, because ice gives off no thermal radiation,
d. 1 is both ice and person because they are almost identical
e. 3 is person, one of the others is ice.

Identify spectrum of radiation given off by person (37 C) and a block of barely frozen ice (0 C).



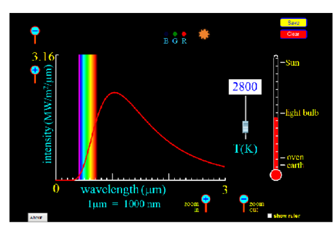
b. 1 is person, 2 is ice,

Anything with a non–zero temperature emits EM radiation. The ice and the person are both so cold that the radiation is not visible. The person is a bit hotter than ice, so gives off more radiation ($\propto T^4$), and has peak power at a slightly shorter λ ($\propto 1/T$).



The plot above shows the BB spectrum of an object at the temperature of a typical lightbulb. Why is the lightbulb <20% efficient?

a. Not all of the electrical power going into the lightbulb gets converted into EM power
b. Less than 20% of the electrical power in gets converted to IR power
c. All the electrical power going in gets converted to EM power but less than 20% is at visible wavelengths
d. Visible light is at shorter wavelengths and therefore doesn't contain EM energy
e. The surface area of the lightbulb filament is too small for an efficient conversion of electrical power to visible EM power.



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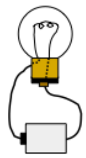
d. Visible light is at shorter wavelengths and therefore doesn't contain EM energy
e. The surface area of the lightbulb filament is too small for an efficient conversion of electrical power to visible EM power.

How much power from bulb.

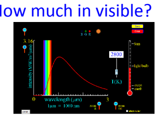
How much power in bulb (or circuit):
ΔV = 12V (given)
R = 15 Ohms
I = ???



I = ΔV / R= 12 V/ 15 Ohms =0.8 Amps
P= ?

P = I ΔV
= 0.8 A x 12 V = 9.6 W

How much in visible?



10%-20%
~ 1 Watt!!

What type of EM radiation is emitted from the surface of the earth?
a. Primarily UV
b. Primarily visible
c. Primarily IR
d. IR and visible
e. All parts of the EM spectrum at roughly equal intensities

$\lambda_{max} \sim 1/T$

Remember to use T in K

What type of EM radiation is emitted from the surface of the earth?
a. Primarily UV
b. Primarily visible
c. Primarily IR
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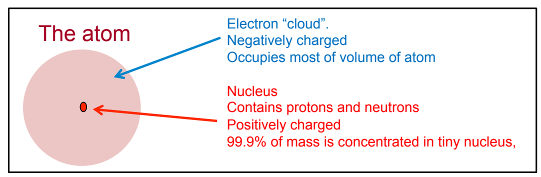
e. All parts of the EM spectrum at roughly equal intensities

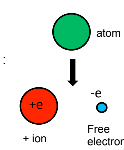
Look at BB phet at temperature of earth

Atoms, Electrons and Ions

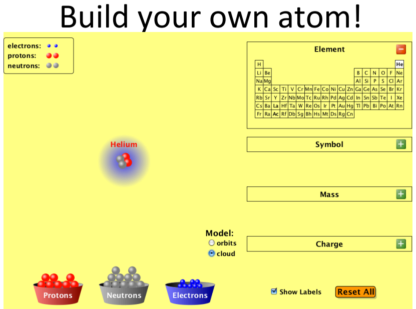


Atoms have equal number of protons and electrons, so total charge is *zero*.
⇒*They are electrically neutral*
The same is true of most ordinary objects (made of atoms.)

You can pull electrons off atoms. This leaves 2 *charged* particles :
- Unbound (free) electrons (negatively charged)
- Positively charged ions
(ion = atom with unequal number of protons and electrons)



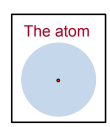
Build your own atom!



http://phet.colorado.edu/en/simulation/build-an-atom

Source of electricity: Electric charges

Everything (earth, you, the table etc) made of tiny particles called atoms
Atoms are made up of 3 even tinier particles:
Electrons, neutrons and protons

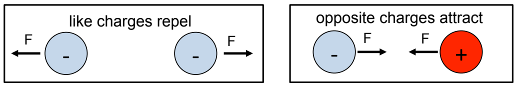


Particle	Charge	Mass
Electron	-e	9.11×10^{-31} kg
Proton	+e	1.67×10^{-27} kg
Neutron	0	1.67×10^{-27} kg

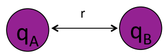
e = 1.6×10^{-19} Coulombs
Coulomb (C) is the unit of charge

Static electricity: What happens when charges are stationary
Electricity (and electric currents): What happens when charges (usually electrons) are moving

Putting this together: Electric Force



Consider 2 'point' charges, A and B. What force does charge A feel?



Observed behavior:
- Force depends on q_A and q_B : More charge, more force
- Force depends on distance between them (r) : less distance, more force

Coulomb's Law:
$\text{Force}_{\text{of B on A}} = \frac{kq_Aq_B}{r^2}$

- Describes the force between 2 point charges
- k is Coulomb constant = 8.99 x 10^9 N m^2/C^2
- q_A and q_B are amount of charge in coulombs (C)
- r is separation in m

1 Coulomb = 6 x 10^{18} electron charges!

Electric Hockey Simulation!

$\text{Force}_{\text{of B on A}} = \frac{kq_Aq_B}{r^2}$

Place charge (B) 2cm from charged puck (A). See charged puck fly away

Now place charge (B) 1 cm away from charged puck (A).
Compared to previous situation force on A will be:

a. half as large, b. same size, c. twice as large, d. four times larger
e. something else.

d. four times larger since force depends on $1/r^2$
⇒ distance smaller, force larger

Place charge (B) 1cm away from charged puck (A) as in previous Q.
Add a second charge to B, right on top of first.
Compared to previous question, force on A is:

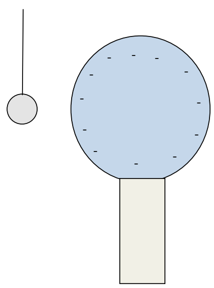
a. ½, b. same, c. x 2, d. x 4, e. something else.

c. x 2 because force on A goes like (charge of A x charge of B),
… in this Q we doubled the charge on B

Bring uncharged metalized mylar balloon up to Van de Graaff.

Predict what will happen:

1. Before it touches
2. After it touches



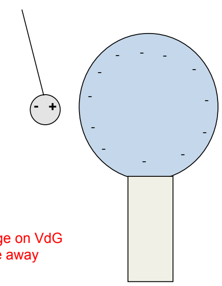
1. Before touching
   a. Not affected by VdG
   b. Attracted to it
   c. Repelled

2. After touching
   a. Not affected by VdG
   b. Attracted to it
   c. Repelled

Bring uncharged metalized mylar balloon up to Vandergraff.

Predict what will happen:

1. Before it touches
2. After it touches



1. Before touching
   a. Not affected by VdG
   b. Attracted to it
   c. Repelled

- Charges in neutral ball are polarized by – charge on VdG
- \+ charges move closer to VdG, - charges move away
- Force between charges = $\frac{kq_Aq_B}{r^2}$
- \+ charges on ball are closer to VdG, so force of attraction is strongest

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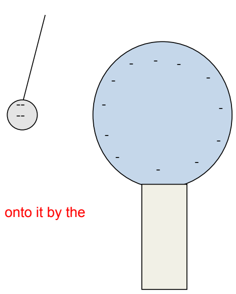
Bring uncharged metalized mylar balloon up to Vandergraff.

Predict what will happen:

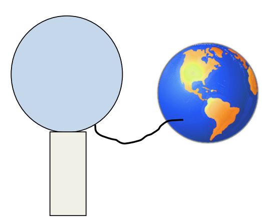
1. Before it touches
2. After it touches



2. After touching
   a. Not affected by VdG
   b. Attracted to it
   c. Repelled

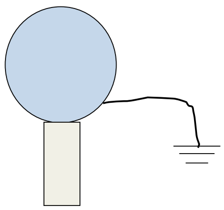
- When balloon touches, - charges are pushed onto it by the other – charges on the VdG
- Now balloon is negatively charged like VdG
- Like charges repel

What is electrical ground?



- A grounded object is connected by a wire to the earth
- The earth is like a big reservoir for supplying or receiving excess + and – charges
- So big that it can gain or lose a few charges and always remain essentially neutral
- Wire provides an easy path for charges to/from the earth
- Grounded object is always at zero volts

What is electrical ground?



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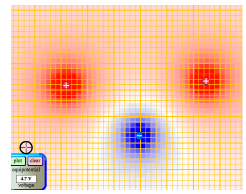
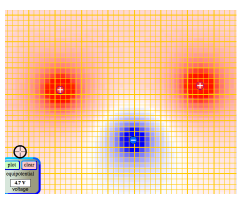
Voltage has to do with conditions of system

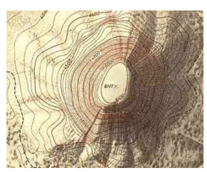
- Amount of charge
- Distance from that charge
- Like the electric force (related but different)



Voltage is like the height of mountain

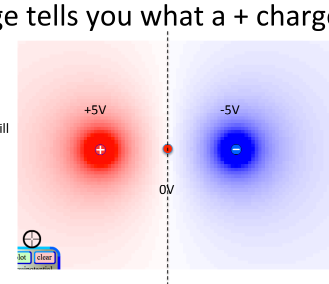
- Think Topographical maps





Voltage tells you what a + charge will do

+V is like top of hill
-V Is like valley



Where is 0 V?

What will a +q do at 0V:
a) Be attracted to higher voltage
b) Be attracted to lower voltage
c) Not be impacted

b) Just like a ball rolls down hill

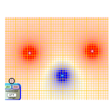
Voltage is like the height of mountain

- Voltage
- Charge, q
- Electrical Potential Energy

$EPE = q\ \Delta V$

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

$GPE = m\ g\ \Delta h$



Electrostatic potential energy and voltage

New force: Electrostatic force between charges
New PE: Electric Potential Energy (EPE)

Forces and PE go in pairs - Remember gravitational force:
- Do work against gravitational force (mg) to raise an object's GPE (mgh)
- Similarly, do work against electric force to raise an object's EPE

EPE = q ΔV, where q = charge of object and ΔV is voltage difference
Like GPE with q ↔ m and ΔV ↔ Δh

Voltage (V)
- tells you EPE of any charge at that location in space
- Tells you work required to bring a unit charge from V = 0 to that location
- Determined by surrounding charges.
  Closer you are to + charge the more + the voltage
- A grounded object is always at V = 0
- Usually most interested in ΔV: voltage difference between 2 locations

Best understood by doing practice questions!

Two metal plates connected by a battery.
Battery maintains a voltage difference of V between the plates

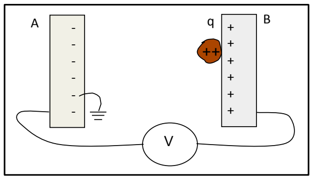


Plate A is grounded (set to zero V)
What is the voltage of plate B?

a) 0
b) +V
c) -V
d) Can't determine from information given

Two metal plates connected by a battery.
Battery maintains a voltage difference of V between the plates

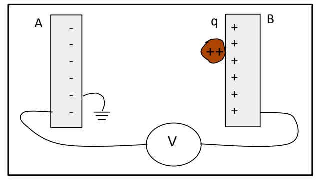
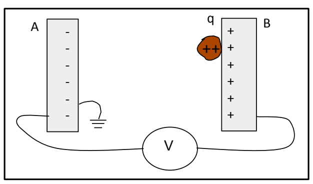


Plate A is grounded (set to zero V)
What is the voltage of plate B?

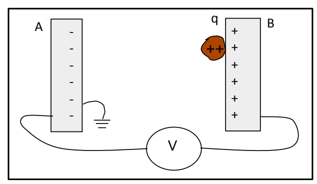
a) 0
b) +V
c) -V
d) Can't determine from information given

Note: Conductors (bits of metal, wires etc) are a constant voltage all over



What will happen to the charge q if we let go of it (ignore gravity)?

a) Nothing
b) It will fly over to plate A
c) Sparks will fly
d) Something else



What will happen to the charge q if we let go of it (ignore gravity)?

a) Nothing
b) It will fly over to plate A
c) Sparks will fly
d) Something else

q has a + charge. It will be repelled by + charges on plates B and attracted to - charges on plate A

Conservation of energy and EPE

Remember conservation of energy equation:

Work Done on object = Change in Energy of object

$W_{ext} - |W_{friction}| = \Delta PE + \Delta KE$

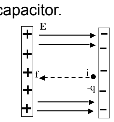
Now we can add another PE term to this equation:

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

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?

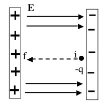
Did the voltage (V) at the position of the test charge increase or decrease?



A: PE$\uparrow$, V$\uparrow$
B: PE$\uparrow$, V$\downarrow$
C: PE$\downarrow$, V$\uparrow$
D: PE$\downarrow$, V$\downarrow$
E: None of these.

Hint:
EPE = $q\Delta V$

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?

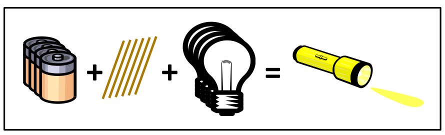
A: PE $\uparrow$, V $\uparrow$
B: PE $\uparrow$, V $\downarrow$
C: PE $\downarrow$, V $\uparrow$
D: PE $\downarrow$, V $\downarrow$
E: None of these.

EPE = qΔV
Vf > Vi **ΔV is bigger!**
EPE is qΔV
but q is **negative**
EPE gets smaller!

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
- 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 ($\Delta V \leftrightarrow \Delta h$, $q \leftrightarrow m$)

Flashlights, circuits, batteries, and power



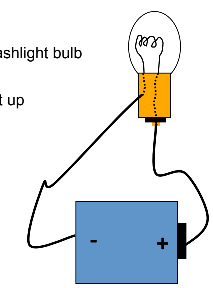
- Given batteries, light bulbs, and wire, how can we design a light bulb circuit
  a) that will burn brightest,
  b) that will last longer,
  c) that will be dim,
  d) that will turn on and off.
- How can you control and predict current and power in light bulbs?
- All this basic circuit stuff applies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



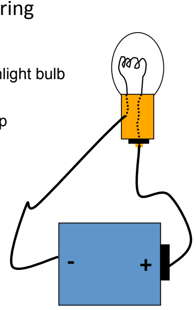
light bulb circuit: Wiring

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)

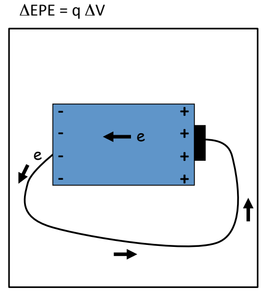


Electrons must have a complete conducting circuit to flow

light bulb circuit: Battery

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

ΔEPE = q ΔV



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.

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

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

Energy changes in circuit

<u>Battery:</u>
Chemical to EPE of electrons

<u>In circuit wires:</u>
EPE to KE of electrons

<u>In bulb:</u>
KE of electrons to thermal energy (random KE) of filament atoms

<u>Filament surface:</u>
Thermal energy of filament atoms to radiated energy (light)

<u>In Battery</u>:
heat and light

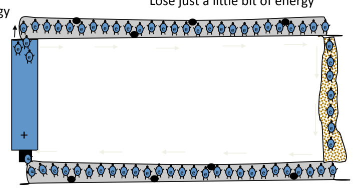
This is a task for Electron man!

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

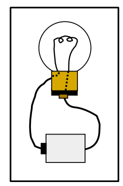


3. Filament
Lots to bump into
Higher R
(Like trudging through mudpit)
Lose lots of energy.

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.

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)

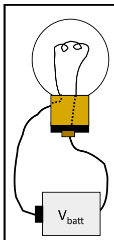
Voltage (difference) (ΔV)

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: $\Delta V = IR$
- R: Resistance of component
- I: Current through component
- ΔV: Voltage dropped across component

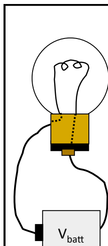
Note: All quantities specific to one component. Don't mix and match!



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

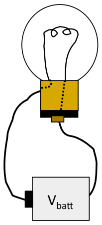


Resistance is measure of how hard it is for electrons to pass through … how much stuff will they run into.

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

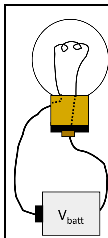
a. Rate at which electrons pass through filament stays the same
b. Rate at which electrons pass through filament decreases
c. Rate at which electrons pass through filament increases

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



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



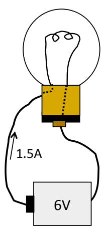
What if increase voltage difference across battery?

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

More EPE given to electrons in battery …electrons have more KE in circuit … higher average speed ….more electrons per time.

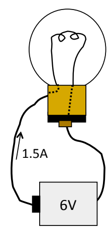
Electrons have bigger pushing force around circuit……more KE……higher average speed……more electrons per time

$\Delta V = IR \Rightarrow I = \Delta V_{batt}/R_{bulb}$



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



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

$\Delta V = IR \Rightarrow R = \Delta V/I$
Voltage across bulb = 6V
(no energy/voltage lost in connecting wires)
Current through bulb = 1.5A
$\Rightarrow$ Resistance of bulb = 6/1.5 = 4Ω

Electrical Power

What is the electrical power used up by each component in circuit?
POWER tells us how HOT something gets or how BRIGHT a bulb is

P = I ΔV
- ΔV: Voltage dropped across component
- I: Current through component
- P: Electrical power dissipated (used up) in component

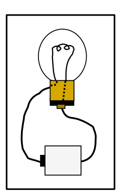
Don't mix and match!

Also Ohm's Law: Δ V = IR
Substitute into power law to get different forms:

P = I²R
- Useful if you know I and R but not V (series circuits)

P = ΔV²/R
- Useful if you know V and R but not I (parallel circuits)

P = I ΔV
- Useful if you know I and V but not R

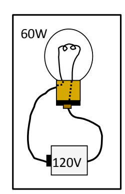


Power question

I have a 60W bulb plugged into the mains.
Assume that the mains supply is like a 120V battery

What current flows through the bulb?

a) 120 A
b) 60 A
c) 0.5 A
d) 2 A
e) 7200 A



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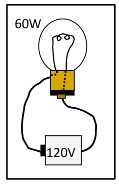


Know P and V and want I
⇒Use P = I ΔV
⇒I = P/ΔV = 60/120 = 0.5A

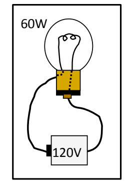
Power question

I have a 60W bulb plugged into the mains.
Assume that the mains supply is like a 120V battery

What current flows through the bulb?
0.5A

What is the resistance of the bulb filament?

a) 240 Ω
b) 2 Ω
c) 0.5 Ω
d) 30 Ω
e) Can't determine



Power question

I have a 60W bulb plugged into the mains.
Assume that the mains supply is like a 120V battery

What current flows through the bulb? 0.5A

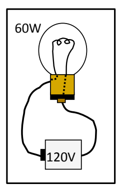
What is the resistance of the bulb filament?

a) 240 Ω

Method 1:
- Know P and ΔV, want R
- Use: $P = \Delta V^2/R$
- $R = \Delta V^2/P = 120*120/60 = 240\Omega$

Method 2:
- Know ΔV and I (from previous question)
- Use ΔV = IR
- $R = \Delta V/I = 120/0.5 = 240\Omega$

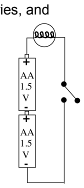
Often several ways to calculate circuit answers:
- Useful for checking your answers
- Practice enables to you choose quickest method



Batteries in series

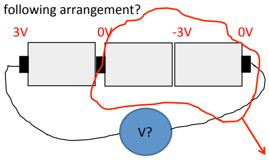
A flashlight requires 2 AA (1.5V) batteries, and is arranged as shown. The bulb…

A: has 1.5 V across it, & glows
B: has 3 V across it, & glows
C: has 3 V across it, & is dark
D: has 0 V across it, & is dark
E: has 0 V across it, &glows



Batteries in series

Batteries provide a voltage difference between their terminals
If each battery below is an identical 3V battery, what is the total voltage across the following arrangement?

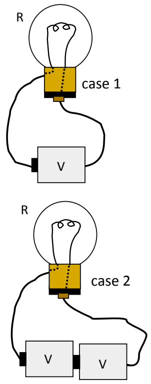


a) 3V
b) 0V
c) 9V
d) 6V
e) Other

- Tail to tail (or nose to nose) configuration of batteries not a good idea
- Voltage differences cancel out
- Could cause explosion of a non-rechargeable battery
  (current is being forced through 3rd battery in the wrong direction)

First we have 1.5 V across a bulb, later we put 3 V across the SAME bulb. What happened to the POWER dissipated by the bulb?

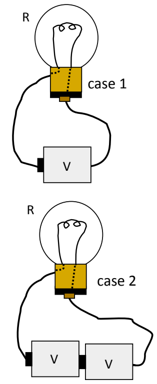
A) Stayed the same
B) Doubled
C) Quadrupled
D) Not sure/something else



Batteries in series (nose to tail)

Compare the brightness of the bulbs in case 1 and case 2.
All bulbs and batteries are identical

a. Case 2 twice as bright as case 1
b. Case 2 same brightness but runs twice as long
c. Case 2 **more** than twice as bright as case 1
d. Case 2 produces no light



Batteries in series (nose to tail)

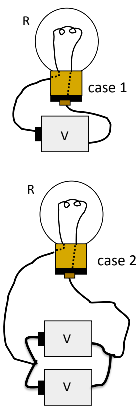
c. case 2 is more than twice as bright

Electrical power into bulb = EM power out.

Method 1: $P_{in} = \Delta V_{bulb}^2/R$
Case1: $P_{in} = \Delta V^2/R$
Case 2: $P_{in} = (2\ \Delta V)^2/R = 4\ V^2/R$

(In addition, since filament is hotter in case 2 a greater fraction of the radiated EM power is in visible range.)

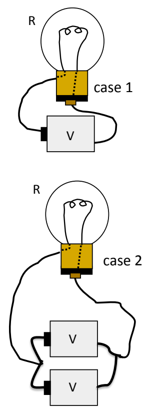
Method 2:
$P_{in} = I_{bulb} \times \Delta V_{bulb}$
Both I and V double in case 2 $\Rightarrow P_{in} = \times 4$



Batteries in parallel

Compare the brightness of the bulbs in case 1 and case 2.
All bulbs and batteries are identical

a. 2 twice as bright as 1
b. 2 same brightness
c. 2 more than twice as bright as 1
d. 2 produces no light



Batteries in parallel

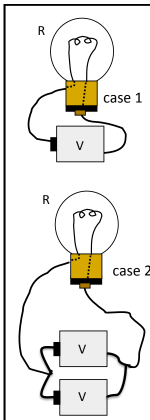
Compare the brightness of the bulbs in case 1 and case 2.
All bulbs and batteries are identical

a. 2 twice as bright as 1
b. 2 same brightness
c. 2 more than twice as bright as 1
d. 2 produces no light

Why?
Think like an electron.
In either battery in case two, the electron has the same Electric potential energy = EPE = q ΔV

Note: an electron doesn't get to go through both batteries, it's one or the other

Same energy to deposit in identical bulbs
What is the difference then?



Batteries in parallel

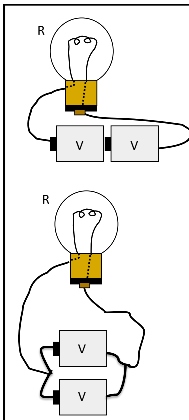
What is the difference then?

Each battery can produce a given amount of Current (electrons/ second) for a certain amount of time

Note: rating on batteries is in Amp-Hours! (what is an amp-hour?)

Zoinks.. With two batteries I have a greater reservoir of electrons to draw from.

Case 2: last twice as a long!



Summary:
- **Series:** more energy for each electron! (brighter)
  how you make a 9 V out of D-Cells, or AAAs

- **Parallel:** longer lasting
  difference between AAAs and D cells