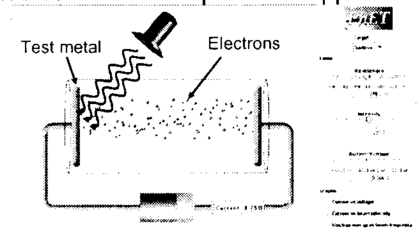
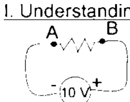
The Photoelectric Effect

Photoelectric effect experiment apparatus.



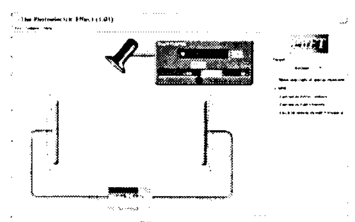
Two metal plates in vacuum, adjustable voltage between them, shine light on one plate. Measure current between plates.

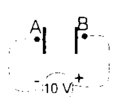
I. Understanding the apparatus and experiment.



Potential difference between A and B = +10 V
Measure of energy an electron gains going from A to B.

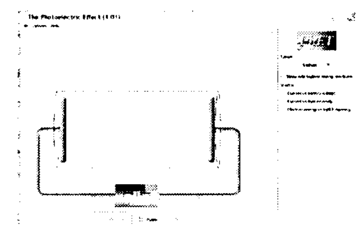
Photoelectric effect experiment apparatus.

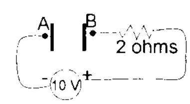




Potential difference between A and B =
a. 0 V
b. 10 V
c. infinite volts

Photoelectric effect experiment apparatus.

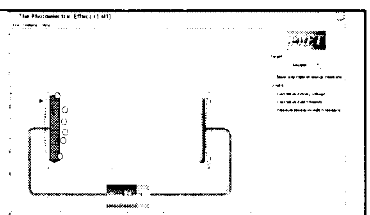


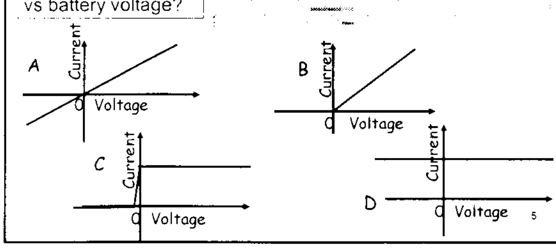


What is current from A to B?
a. 0 A
b. 5 A
c. 0.2 A

Hot plate.
A few electrons get enough energy to just barely "splash" out.

What is the current vs battery voltage?





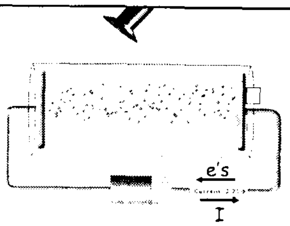
Further Predictions

How can you tell the high-energy waves on the ocean?

Should the colour of the light affect the current?

What will happen if we leave the light on longer?

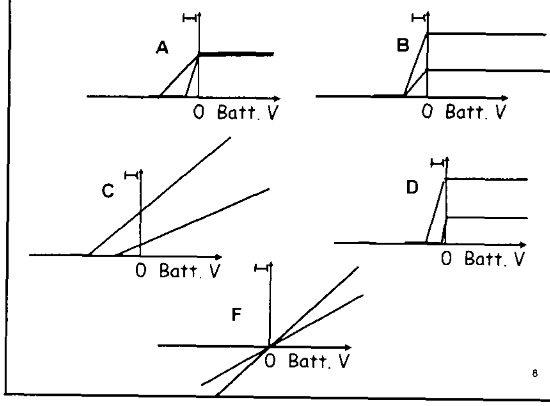
What will happen if we increase the intensity?



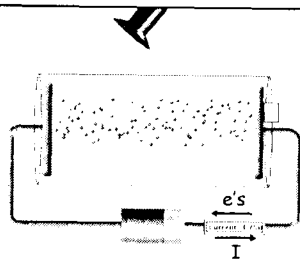
First experiment- I vs. V high intensity, low intensity
I vs. V two different colours

What happens?

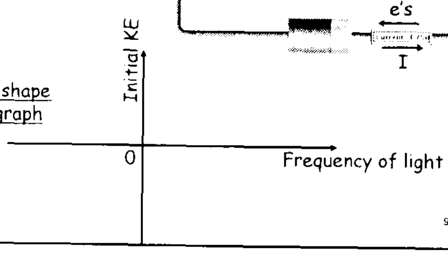
Which graph represents **low** and **high** intensity curves?

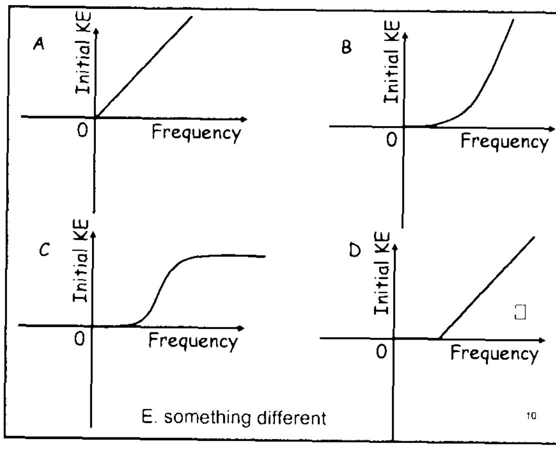


<u>Predict</u> what happens to the initial KE of the electrons as the *frequency* of light changes? (Light intensity is constant)



<u>Predict shape of the graph</u>





E. something different

<u>Classical wave predictions vs. experimental observations</u>

- Increase intensity, increase current.
- Current vs voltage step at zero then flat.
- Colour of light does not matter, only intensity.
- Takes time to heat up ⇒ current low and increases with time.

<u>Summary of what we know so far:</u>

1. If light can kick out electron, then even smallest intensities of that light will continue to kick out electrons. KE of electrons does not depend on intensity.
   (Light energy must be getting concentrated/focused somehow)
2. At lower frequencies, initial KE decreases & KE changes linearly with frequency.
   (This concentrated energy is linearly related to frequency)
3. There is a minimum frequency below which light won't kick out electrons.
   (Need a certain amount of energy to free electron from metal)

- *(Einstein)* Need "photon" picture of light to explain observations:
- - Light comes in chunks ("particle-like") of energy ("photon")
- - a photon interacts only with single electron
- - Photon energy depends on frequency of light, …
- for lower frequencies, photon energy not enough to free an electron

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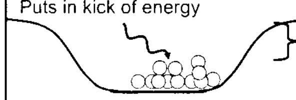
If photon has enough energy,
electron emerges with: KE = photon energy – work function

Photon…
Puts in kick of energy



energy needed to kick highest electron out of metal. "WORK FUNCTION" (ϕ)

Initial KE of electron as it comes out of metal = E_{photon} - energy needed to kick electron out of metal

Depends on type of metal.

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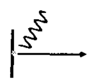
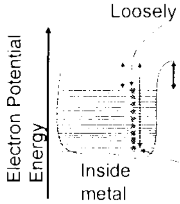
Photoelectric effect experiment: Apply Conservation of Energy

Energy in = Energy out

Energy of photon = energy needed to kick electron out of metal + Initial KE of electron as exits metal



Loosely stuck electron, takes least energy to kick out



work function (Φ) = energy needed to kick highest electron out of metal

Outside metal

Tightly stuck, needs more energy to escape

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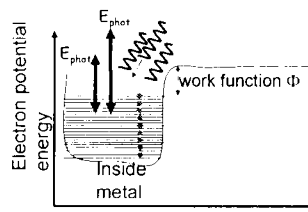
Electrons over large range of energy have equal chance of absorbing photons.



You initially have blue light shining on metal. If you change the frequency to violet light (at same # of photons per second), what happens to the number of electrons coming out?

a. fewer electrons kicked out
b. same # of electrons
c. more electrons kicked out
d. not enough information

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Typical energies

Photon Energies:

Each photon has: Energy = Planks constant * Frequency

(Energy in Joules)
$E=hf=(6.626*10^{-34}\ J\text{-}s)*(f\ s^{-1})$
$E=hc/\lambda = (1.99*10^{-25}\ J\text{-}m)/(\lambda\ m)$

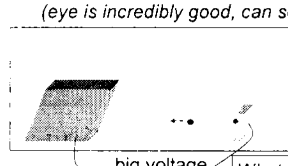
(Energy in eV)
$E=hf= (4.14*10^{-15}\ eV\text{-}s)*(f\ s^{-1})$
$E= hc/\lambda = (1240\ eV\text{-}nm)/(\lambda\ nm)$

Red Photon: 650 nm $E_{photon} = \frac{1240\ eV\text{-}nm}{650\ nm} = 1.91\ eV$

Work functions of metals (in eV):

Aluminum	4.08	Cesium	2.1	Lead	4.14	Potassium	2.3
Beryllium	5.0	Cobalt	5.0	Magnesium	3.68	Platinum	6.35
Cadmium	4.07	Copper	4.7	Mercury	4.5	Selenium	5.11
Calcium	2.9	Gold	5.1	Nickel	5.01	Silver	4.73
Carbon	4.81	Iron	4.5	Niobium	4.3	Sodium	2.28
						Uranium	3.6
						Zinc	4.3

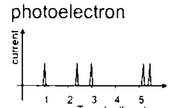
Photomultiplier tubes- application of photoelectric effect most sensitive way to detect visible light, see single photons
(eye is incredibly good, can see a few photons)



glass vacuum enclosure

big voltage

electron amplifier, gives pulse of current for each photoelectron



What would be the best choice of these materials to make this out of?

a. Platinum Φ = 6.35 eV
b. Magnesium = 3.68 eV
c. Nickel = 5.01 eV
d. lead = 4.14 eV
e. Sodium = 2.28 eV

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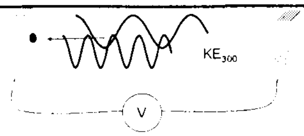
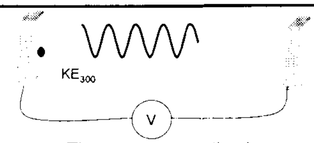


A photon at 300 nm will kick out an electron with an amount of kinetic energy, KE_{300}. If the wavelength is halved to 150 nm and the photon hits an electron in the metal with same energy as the previous electron, the energy of the electron coming out is

a. less than ½ KE_{300}.
b. ½ KE_{300}
c. = KE_{300}
d. 2 x KE_{300}
e. more than 2 x KE_{300}

(remember hill/kicker analogy, draw pictures to reason out answer, don't just pick answer without careful reasoning) 9



Shine in light of 300 nm. The most energetic electrons come out with kinetic energy, KE_{300}. A voltage diff of 1.8 V is required to stop these electrons. What is the work function Φ for this plate? (e.g. the minimum amount of energy needed to kick electron out of metal?)

a. 1.2 eV
b. 2.9 eV
c. 6.4 eV
d. 11.3 eV
e. none of the above

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Answers

11. 5.8×10^{14} Hz
12. 5.02×10^{14} Hz
13. 0.28 eV
14. 2.35 eV
15. 6.3×10^{5} m/s

Practice

Understanding Concepts

7. Create a graph of energy versus frequency for a photoelectric surface. Label the work function and the threshold frequency.

8. Explain why it is the frequency, not the intensity, of the light source that determines whether photoemission will occur.

9. Why do all the lines on the graph in **Figure 11** have the same slope?

10. Why doesn't classical wave theory explain the fact that there is no time delay in photoemission?

11. Calculate the minimum frequency of the photon required to eject electrons from a metal whose work function is 2.4 eV.

12. Find the threshold frequency for a calcium surface whose work function is 3.33 eV.

13. Barium has a work function of 2.48 eV. What is the maximum kinetic energy of the ejected electrons if the metal is illuminated at 450 nm?

14. When a certain metal is illuminated at 3.50×10^{2} nm, the maximum kinetic energy of the ejected electrons is 1.20 eV. Calculate the work function of the metal.

15. Light of frequency 8.0×10^{14} Hz illuminates a surface whose work function is 1.2 eV. If the retarding potential is 1.0 V, what is the maximum speed with which an electron reaches the plate?