4/20

IB PhotoElectric Effect

Day ②

PhotoElectric Effect - When light strikes the surface of the material, electrons are emitted. The radiant Energy supplies the work necessary to free the electrons from the materials surface causing a current.

Photo Electric Characteristics

① The photocurrent is proportional to the intensity of the light

② The KE of the electrons is dependent on the freq., but not on intensity

③ No photoemission occurs for light with a freq. below a certain cutoff freq. f_0 regardless of intensity

④ Photocurrent is observed when the light freq. is greater then f_0, even if the intensity is low.

f_0 = Threshold Freq.

$f < f_0$ No photo Emission

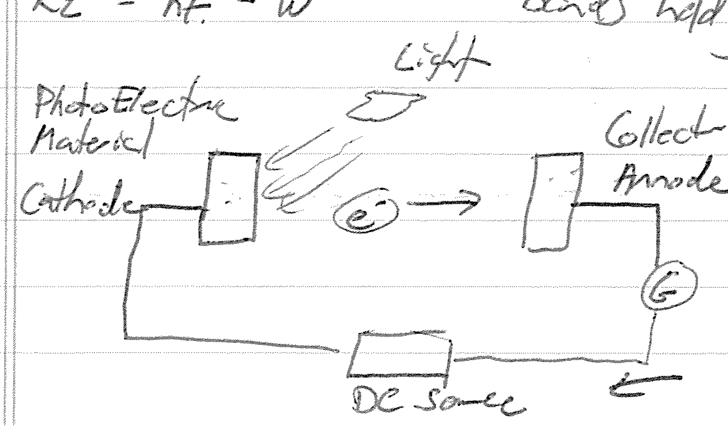
$f = f_0$ Electron freed, but no KE to move it

$f > f_0$ Photo Current

$KE = E - W$

$KE = hf - W$

W = Work/Energy needed to break the bonds holding the electron to the surface.



Pot. Diff is created causing e⁻ to move

Galvometer ammeter collect

Can be Stopping Potential

Ex1 A photon w/ a freq of 8×10^{14} Hz strikes a photoemissive surface whose work function is 1.7×10^{-19} J. Find
1) Max KE of the ejected photoelectrons
2) Threshold freq. of the surface

1) $KE = hf_0 - W$

$6.6 \times 10^{-34}\,JS(8 \times 10^{14}\,Hz) - 1.7 \times 10^{-19}\,J = 3.6 \times 10^{-19}\,J$

2) f_0 at which max KE of the photoelectrons is just 0

$0 = hf_0 - W$ $\quad 1.7 \times 10^{-19}\,J = (6.6 \times 10^{-34}\,JS)\,f_0$

$W = hf_0$ $\quad f_0 = 2.6 \times 10^{14}\,Hz$

Ex2 The work function of a metal is 2eV Find
a) The Threshold freq f_0 b) If the metal is illuminated w/ monochromatic light of wavelength (λ) 550 nm, Find max v of electrons

a) $KE = hf_0 - W$ (KE = 0) $\quad W = hf_0$ $\quad 2eV \times \frac{1.6 \times 10^{-19}\,J}{1eV} = 3.2 \times 10^{-19}\,J$

$3.2 \times 10^{-19}\,J = (6.63 \times 10^{-34}\,JS)(f_0)$

$f_0 = 4.8 \times 10^{14}\,Hz$

Find Energy of the photon

b) $E = hf$ $\quad v = f\lambda$ $\quad \lambda = \frac{c}{f}$

$E = \frac{hc}{\lambda}$ $\quad E = \frac{(6.63 \times 10^{-34}\,JS)(3 \times 10^{8}\,m/s)}{5.5 \times 10^{-7}\,m} = 3.6 \times 10^{-19}\,J$

Find KE

$KE = E - W$

$KE = 3.6 \times 10^{-19}\,J - 3.2 \times 10^{-19}\,J$

$.4 \times 10^{-19}\,J$

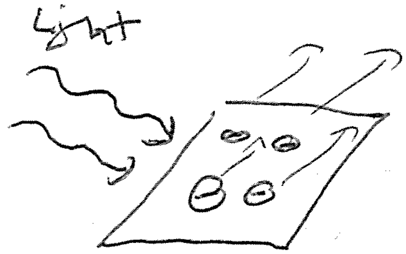
Find V

$2\,\frac{\frac{1}{2}mv^2}{m} = \frac{2(.4 \times 10^{-19})}{m}$ mass of Elect

$\sqrt{v^2} = \sqrt{\frac{.8 \times 10^{-19}}{9.11 \times 10^{-31}\,kg}} = 3 \times 10^{5}\,m/s$

Photo Electric Effect IB

JJ Thompson - Explained that when light was incident, electrons are emitted from the metal surface



Electrons are called photoElectrons & result in a small electric current - Photo-Electric Effect:
- Electrons in the surface of the metal absorb enough energy from the incoming radiation to overcome the electrostatic force of the protons in the nucleus

Key Findings

1. Photon-Electron Emission depends on the color or freq. of the light. $E = hf$
   ↑ freq ⇒ ↑ KE of Electrons $f > f_0$

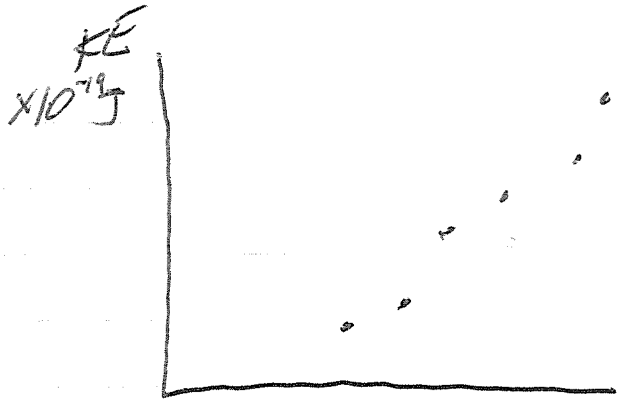
2. Intensity / Brightness
   No effect on KE of the photoelectrons, but had a proportional effect on the number emitted
   ↑ Intensity ⇒ ↑ # of Electrons

Could not be explained w/ wave theory
Einstein - photons (packets of light) collide & either rebound or transfer energy to the electrons

Explain Intensity — # of photons

Freq — ↑ F ⇒ ↑ KE

$f > f_0$



$E = hf$

$\frac{E}{f} = \frac{hf}{f}$

(A) Find slope of graph
h = Planks Const.

Use line of Best fit

(B) Find min Energy to Eject an electron from the surface

$\cancel{KE}^{0} = E - W$

$0 = hf_0 - W$

$W = hf_0$

w is also work function

W - work needed to free elect. from surface

E - Energy of photon

Explain why Einstein photoelectric theory accounts for no electrons emitted from the surface of this metal if ~~fo~~ is less than f_0

If $f < f_0$

$E = hf$ will be less than W

So KE will be neg which can not happen

Wave Nature of Matter IIB

Young's — Double Slit Experiment showed light as having a wave nature
Polarized & transverse

Einstein — Light as a Photon - Particle

Result: Wave-Particle Duality - Light behaves as both

DeBroglie - Any particle of matter with momentum p, has an associated wavelength. He called waves matter waves
Hypothesized electrons have a dual nature acting as both particles & waves

De Broglie Wavelength Eqn $p = \frac{h}{\lambda}$

p = momentum of particle Ns
h = Plank's Constant Js
λ = Wavelength m

* We use relativistic mass of particle. If particle moving is much less than the speed of light, we use rest mass

Ex. Find the de Broglie wavelength of an electron that is accelerated through a potential difference of 30V

Part I - Use Energy conversion to find velocity

$V = \frac{W}{q}$ $Vq = W$ $KE = \frac{1}{2}mv^2 \rightarrow$ ~~...~~ $W = \frac{1}{2}mv^2 \rightarrow Vq = \frac{1}{2}mv^2$

$30V \cdot 1.6\times10^{-19}C = \frac{1}{2}(9.1\times10^{-31}kg)\ v^2$ $v = 3.2\times10^{6}$ m/s

Part II - DeBroglie Wavelength

$p = \frac{h}{\lambda} \rightarrow \lambda = \frac{h}{p} \rightarrow \lambda = \frac{h}{mv}$

$\lambda = \frac{6.6\times10^{-34}\ Js}{9.1\times10^{-31}kg\ (3.2\times10^{6} m/s)} = 2.3\times10^{-10}$ m

Applicatin of DeBroglie Hypothesis

Electron Microscopes - Electrons have a shorter wavelength the visible light, that is why they are able to see deeper into matter than light microscopes

Heisenburg Uncertainty Principle IB

Mechanics - we know exact position & moment of a particl at any time

Wave-Particle Duality & quantum Mechanics - things are less certain

* we only know the probability of a particle being in a certain place or having a particular moment

Quantum Mechanics tells me that even w/ perfect equipment of ~~[illegible]~~ measurements, in the particle world there is still going to be uncertainty.

<u>Heisenburg Uncertainty Principle</u> - ~~[illegible]~~ Simultaneous measurement of position & momentum of a particle will always have uncertainty

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Δx - position uncertainty
Δp - momentum uncertainty
h = plank's constant

Ex. The velocity of an electron is $1\times10^6 \frac{m}{s} \pm .01\times10^6 \frac{m}{s}$.
Find the max. precision that can be given in a simultaneous measurement of its position

Uncert. of Velocity $\frac{.01\times10^6 m/s}{1\times10^6 m/s}\times100 = 1\%$

momentum ~~moment~~ of electron $p = mv$
$= 9.1\times10^{-31} kg\,(1\times10^6 m/s) = 9.1\times10^{-25} \frac{kg\,m}{s}$

Uncertainty of momentum Measurement $1\%\times9.1\times10^{-25}\frac{kg\,m}{s} = 9.1\times10^{-27}\frac{kg\,m}{s}$

Uncertainty Principle

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

So Best position measurement for the electron will have an uncertainty given by

$$\Delta x \left(9.1\times10^{-27} \frac{kg\,m}{s} \right) = \frac{6.6\times10^{-34}\ Js}{4\pi}$$

$$x = 5.8\times10^{-9} m$$