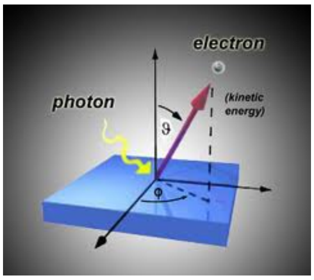
6.1 Quantum Physics: Photons and the Photoelectric Effect



EM Wave Equation Again!

In a vacuum:

$c = \lambda f$	c = speed of light (3.00 E 8 m/s) λ = wavelength (m) f = frequency (Hz = 1/s)

Quantum Cannonballs

Light can be thought of as particles that carry a frequency dependant quantity (a quantum) of energy.

An important energy unit is the electron-volt (eV):

1 eV = 1.602 E -19 J

It is the energy one electron has when accelerated through a 1.0 V potential difference:

$$E = Q \bullet V = 1 electron \bullet 1.0 V$$

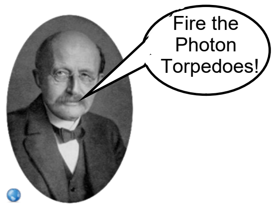
$$= 1.602 E-19 C \bullet \frac{1.0 J}{C} = 1.602 E-19 J$$

Note: you will sometimes convert between J and eV for unit agreement.

Energy of Photons

Max Planck predicted that photons carry a discrete amount of energy, dependant on frequency:

$E = hf$ AP Equation	E = Energy (J) h = Planck's Constant (6.63 E -34 J s OR: 4.14 E -15 eV s) f = frequency (Hz)



Photoelectric Effect

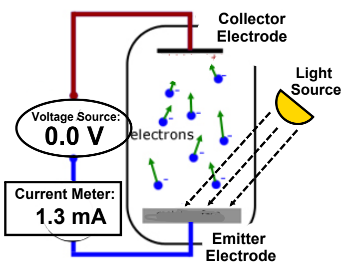
Einstein used photon concept to explain the <u>photoelectric effect</u> - ejection of electrons from a metal's surface when bombarded by light.

Electrons have kinetic energy, whose maximum value is related by the fundamental charge of an electron AND the electric potential needed to stop a photoelectric ejection (explanation follows):

$K_{max} = e \bullet V_0$	K_{max} = Kinetic Energy (J) e = 1.60 E -19 C V_0 = stopping potential voltage (V)

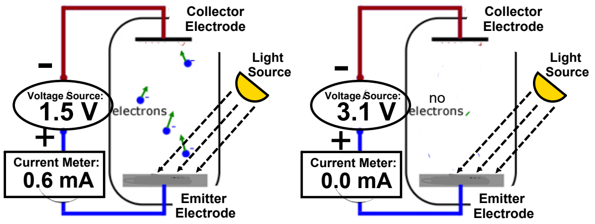
Stopping Potential Explanation 1

When a photon causes an electron to leave the surface of a metal, it reaches the other surface, is absorbed, and makes current flow through the circuit.



Stopping Potential Explanation 2

If a voltage is applied across the plates, with negative charge on the collector, current diminishes as some ejected electrons are stopped.



When the voltage is just right, no electrons make it to the plate and no current flows.

Kinetic Energy Details

There is a minimum amount of work needed to bump the electron from the surface of a metal (called the <u>work function:</u> φ_0).

When a photon hits a metal, some energy is used for this; the rest is in the kinetic energy of the ejected electron.

AP Equation	
$K_{max} = h \bullet f - \varphi$	Kmax = Kinetic energy (J) h = Planck's Constant (6.63 E -34 Js) f = frequency (Hz) φ = work function of a material (J).

Maximum Kinetic Energy of Freed Electron — **Incident Photon Energy** — **Minimum Work Needed to Free Electron**

Cutoff Frequency

The lowest frequency that will eject an electron is called the <u>cutoff frequency</u> (f_0):

$f_0 = \dfrac{\varphi}{h}$	φ = work function of a material (J). h = Planck's Constant: 6.63 E -34 Js

Photoelectric Characteristics

1. Photocurrent is proportional to light intensity (how many photons).
2. Maximum kinetic energy depends on frequency not intensity.
3. Below cutoff frequency, no photocurrent occurs, regardless of light intensity.
4. Photocurrent occurs as soon as cutoff frequency is reached, regardless of intensity.

Examples

A material has a work function of 2.1 eV. 1. What is the cutoff frequency of the material (what's the minimum frequency needed to produce a photoelectron)?

$$f_0 = \frac{\varphi}{h} = \frac{2.1eV}{4.14E-15eV\,s} = 5.07E14\,Hz$$

2. What energy (eV or J) does that photon have?

$$E = hf = 4.14E-15eVs \bullet 5.07E14Hz = \boxed{2.1eV}$$

$$E = hf = 6.63E-34Js \bullet 5.07E14Hz = \boxed{3.4E-19J}$$

3. What maximum energy would photo electrons have if 6.5 E 14 Hz light shines on the material (eV)?

$$K_{max} = h \bullet f - \varphi = 4.14E-15eVs \bullet 6.5E14Hz - 2.1eV = \boxed{0.59eV}$$

Homework 6.1

Problems 6.1 in your Booklet

Due: Next Class