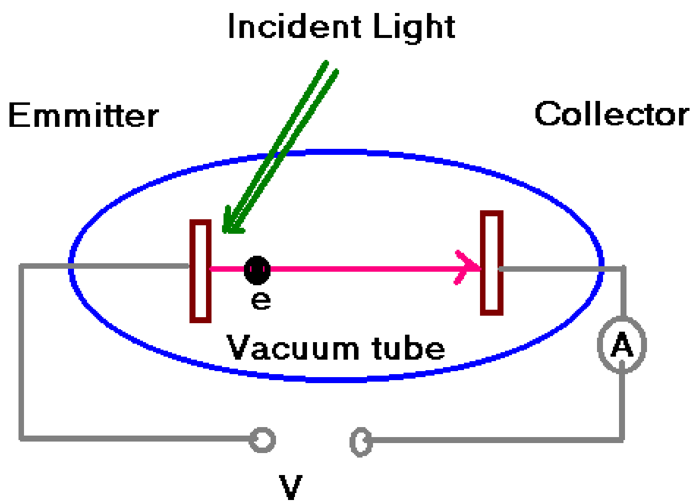
Photoelectric effect



observations:

(1) KE of photoelectrons are independent of the light intensity. Applying a sufficient stopping potential of $-V_0$ is sufficient to stop all photoelectrons no matter what the light intensity is.

(2) The maximum kinetic energy of the photoelecctrons, for a given emitting material, depends only on the frequency of the light. A different stopping potential $-V_0$ is required to stop the most energetic photoelectrons. This depends upon frequency, but not on the intensity.

If you read the red below, your life will be easier!

Important note: your text uses υ to represent frequency (f) which we are familiar with from general physics. This is quite common throughout the world of modern physics text books.

(3) The smaller the work function ϕ of the emitter material, the smaller is the threshold frequency of light that can eject photoelectrons. No photoelectrons are produced for frequencies below this threshold frequency, no matter what the intensity.

(4) When the photoelectrons are produced, the number is proportional to the intensity of light ... the maximum photocurrent is proportional to the light intensity.

(5) The photoelectrons are emitted almost instantly ($\leq$ 3x10^{-9}s) following the illumination of the photocathode, independent of the intensity of the light.

Einstein's Theory

(1) existence of photons:

$$E = hf$$

For n such photons, a total energy will be:

$$U = nE = nhf$$

You might also remember the energy for a photon gas:

$$U = pc$$

h is known as planck's constant (h=6x10^{-34} Js = 4.135x10^{-15} eV s)

Photons travel at the speed of light and have a wavelength given by:

$$f\lambda = c$$

due to a classical demonstration by Young in 1800, the wave nature of light was firmly established. Einstein, however, stated that photons also have clear particle like properties in his explanation of the photoelectric effect.

The postulate is this:

a photon delivers its entire energy to a single electron in the material.

The last 3 words are essential ...

an isolated electron can not completely absorb a photon.

The electron is not, however, ejected with this amount of kinetic energy because part of this energy must be lost in overcoming the work function of the material. Thus:

$$hf = \varphi + KE_{electron}$$

The maximum kinetic energy of the electrons (and hence the maximum velocity) will be given by:

$$hf = \varphi + \tfrac{1}{2}mv_{max}^2$$

The electrons result in a current. In order to stop this current, a retarding potential must be applied. Recall the definition for electric potential:

V=work per unit charge. Potential difference is the work required per unit charge to move a charge between 2 points in space.

The required retarding potential is thus given by:

$$eV_0 = \tfrac{1}{2}mv_{max}^2$$

We thus have:

$$\tfrac{1}{2}mv_{max}^2 = eV_0 = hf - \varphi$$

For a potential less than this, a current would be detected.

it's useful to plot a graph of this. To do so, consider a plot of frequency on the x-axis and eV on the y-axis. You then find that the slope of such a curve is h and the intercept with the (+x) axis is at the point when the work function is exactly equal to the energy of the photons hitting the material. I have a java applet that shows this experiment in a nice format.

Examples:

Light of wavelength 400 nm is incident upon lithium (work function is 2.9 eV). Calculate the photon energy and the stopping potential.

$$E = hf = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\,Js)(2.998\times10^{8}\,m/s)}{\lambda(1.602x10^{-19}\,J/eV)(1x10^{-9}\,m/nm)} = \frac{1.240\times10^{3}\,eV\ nm}{\lambda} = \frac{1.240\times10^{3}\,eV\ nm}{400} = 3.1eV$$

The maximum kinetic energy is then:

$$KE_{max} = hf - \varphi = 3.1eV - 2.9eV = 0.2eV$$

The stopping potential is then 0.2V.

What frequency of light is needed to produce electrons of 3eV from illumination of Lithium?

$$hf = \varphi + KE_{max} = 2.9eV + 3.0eV = 5.9eV$$

We can thus find the frequency as:

$$f = \frac{E}{h} = \frac{(5.9eV)(1.6\times10^{-19}\,J/eV)}{6.626\times10^{-34}\,J\,s} = 1.42\times10^{15}Hz$$