Modern Physics

Photoelectric Effect

$$\frac{hc}{\lambda} = \phi + eV_{stop}$$, where ϕ is the work function.

Problem 1.- Consider the photoelectric experiment with an atomic gas instead of a metallic surface, what differences can you imagine?

Solution: Here are some differences between these two experiments:

To remove an electron from an atomic gas, the photon must have at least the ionization energy, which in general is larger than the work function of the same metal. Example: for sodium the work function is 2.36 eV and the ionization energy is 5.1eV.

Ionizing an atom will leave a positive ion behind (plus the free electron) which in principle can be detected.

There is no way to connect leads to an atomic gas, so the potential would have to be provided in a different way. A Faraday cage for example.

Can you think of any other difference?

Problem 2.- Light of wavelength 532 nanometers is incident on sodium, with workfunction 2.28 eV. What is the maximum kinetic energy of the ejected photoelectrons?

Solution: We use the equation proposed by Einstein to solve this problem:

$$\frac{\mathrm{hc}}{\lambda} = \phi + KE \rightarrow KE = \frac{\mathrm{hc}}{\lambda} - \phi = \frac{4.14\times10^{-15}\,\mathrm{eVs}\times3\times10^{8}\,m/s}{532\times10^{-9}\,m} - 2.28eV = 0.05eV$$

Problem 3.- Calculate the work function of a metal if when illuminated with monochromatic light of 248nm wavelength, we need to apply a voltage of 1.33 volts to stop all the photoelectrons.

Solution: Using Einstein's equation:

$$\frac{hc}{\lambda} = \phi + qV_{stop} \rightarrow \phi = \frac{hc}{\lambda} - qV_{stop} = \frac{(4.14\times10^{-15}eV)(3\times10^{8}m/s)}{248\times10^{-9}m} - 1e(1.33V) = \mathbf{3.68\ eV}$$

Problem 3a.- Calculate the work function of a metal if when illuminated with monochromatic light of 157nm wavelength we need to apply a voltage of 1.22 volts to stop all the photoelectrons.

Solution: In the photoelectric effect, the energy of the photon is shared by the kinetic energy of the emitted electron and the work function of the metal, so:

$$\frac{hc}{\lambda} = \phi + K.E.$$

But if we apply a potential to stop the electrons the kinetic energy can be calculated from

$$K.E. = eV_{stop} \rightarrow \frac{hc}{\lambda} = \phi + eV_{stop}$$

With the values of the problem:

$$\phi = \frac{hc}{\lambda} - eV_{stop} = \frac{4.135\times10^{-15}\,eVs(3\times10^{8}\,m/s)}{157\times10^{-9}\,m} - 1.22eV = \mathbf{6.7\ eV}$$

Problem 4.- The second harmonic generator of an yttrium-aluminum-garnet (YAG) laser emits 100mJ pulses of green light (wavelength = 532nm). Calculate the number of photons emitted per pulse.

Solution: To get the number of photons we just need to divide the energy of the pulse by the energy of one photon:

$$\#of\ \ photons = \frac{100mJ}{\frac{hc}{\lambda}} = \frac{100\times10^{-3}\,J\times532\times10^{-9}\,m}{6.62\times10^{-34}\,Js\times3\times10^{8}\,m/s} = \mathbf{2.67\times10^{17}}$$

Problem 5.- Calculate the minimum frequency to generate photo electrons out of a material whose work function is 2.93eV. Then calculate the stopping potential when the same material is illuminated with light of 400nm wavelength.

Solution: The threshold frequency will happen when the energy of the photon is exactly the work function, so:

$$\mathrm{f} = \frac{2.93\mathrm{eV}}{\mathrm{h}} = \frac{2.93\mathrm{eV}}{4.1357\times10^{-15}\,\mathrm{eVs}} = 7.08\times10^{14}\ \mathrm{Hz}$$

To get the stopping potential, remember that the kinetic energy will have to be converted into potential energy to stop the electron.

Maximum Kinetic Energy

$$= \frac{\mathrm{hc}}{\lambda} - \varphi = \frac{(6.62\times10^{-34}\,\mathrm{Js})(3\times10^{8}\,\mathrm{m/s})}{400\times10^{-9}\,\mathrm{m}} - 2.93\mathrm{eV}\frac{1.6\times10^{-19}\,\mathrm{J}}{1\mathrm{eV}} = 2.77\times10^{-20}\mathrm{J}$$

Stopping voltage

$$V = \frac{2.77\times10^{-20}\,\text{J}}{1.6\times10^{-19}\,\text{C}} = \mathbf{0.17\ V}$$