Modern Physics Lab

Photoelectric Effect

Theory: When a photon hits a surface it can transfer its energy to a single electron and knock it out of the surface. The electron that is emitted is called a photo-electron and by measuring its kinetic energy we can learn about the surface where it came from. This technique is called photo-electron spectroscopy. It can also be applied to clusters, but before you build you own apparatus and start interrogating nature with this technique, we are going to run an experiment similar to the original ones that Albert Einstein explained in 1905.

The conundrum in 1905 was that according to the prevalent theory of electromagnetic waves at that time, energy would have to accumulate over some time before electrons would come out, but experiments showed they are ejected almost instantaneously. Also, it seemed odd that there was a maximum kinetic energy of the ejected electrons. Why would this happen if the accumulated energy was unbounded? Einstein interpretation was that light behaves like particles, where each photon acts as a bullet with a fixed amount of energy given by the equation:

$$E = \frac{hc}{\lambda}$$

When an electron is hit by a photon and ejected, the energy of the photon is used to pay a price to free the electron. This bail money has a minimum, which is called the work function, usually represented by the Greek letter phi (φ). In that case the rest of the photon energy becomes the kinetic energy of the electron, according to the equation of conservation:

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

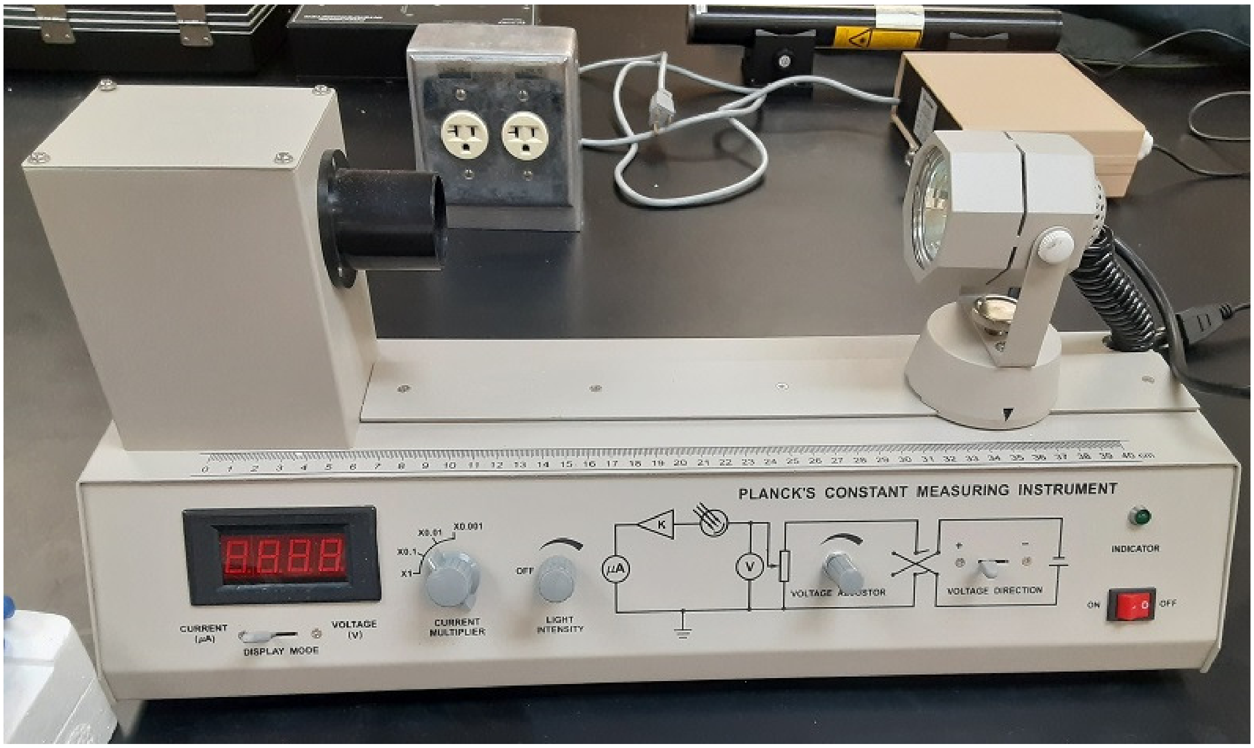
Where K.E. is the maximum kinetic energy of an ejected electron.

There are other interesting details of the experiment that require more elaborate explanations such as the dependence of the electron yield with temperature, angle of incidence and polarization, and the shape of the energy distribution of the emitted photoelectrons.

Also, notice that photoelectron emission is just one of the ways that energy can be absorbed from incident photons and in most metals is only a small fraction of the possibilities (~0.1%). In our experiment, the apparatus has a surface that has been selected for its large photoelectron yield and low work function, so the effect is easier to observe and measure.

Goal: We will measure the maximum kinetic energy of electrons emitted by light of different wavelengths and calculate the value of Planck's constant.

Procedure: We can first try a simple version of the experiment to extract the value of *h* rather quickly and later measure kinetic energy distributions and intensity yields in two additional, longer experiments.



Experiment 1:
Position the lamp at an intermediate distance from the phototube.
Select one of the filters and write down the wavelength. This is nominally the shortest wavelength that is allowed from the lamp, but of course the filters aren't perfect. Place the filter in front of the phototube.
Turn the light on and select negative acceleration voltage (this will repel the electrons).
By monitoring the photocurrent, change the voltage until the current is zero. Write down the voltage (V_{th}) at that point.
Repeat the same steps for the other filters.

Make a plot where the value of $-eV$ is on the *x*-axis and c/λ is on the *y*-axis. Then, according to the equation:

$$-eV_{th} = h\frac{c}{\lambda} - \varphi$$

In a linear approximation, the slope will be Planck's constant and the *y*-intercept will be the negative of the work function. Determine the two values from the graph, compare *h* to its accepted value of 6.626×10^{-34} Js, and confirm that the work function is around 2eV.

Experiment 2:

Select one of the filters used in the previous experiment and measure the photocurrent as a function of accelerating voltage. Do this from the negative threshold that you found before to zero and then invert the voltage and continue the measurements with positive voltages until you observe current saturation.

Make a graph of the obtained data and compare your results with the ones published in the literature. Can you explain the results?

Experiment 3:

With one of the filters used before, select a positive voltage where saturation happens and measure the photocurrent as a function of distance to the lamp. Make a graph of the obtained data and see if it can be explained by an inverse quadratic function.