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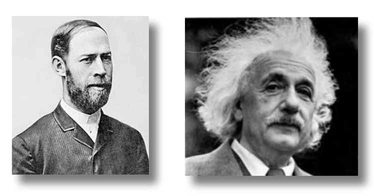
The Photoelectric Effect

Abstract

The goal of this experiment is to understand the physics of the photoelectric effect. By performing the experiment, students are able to measure the ratio between Planck's constant and the electron charge.

Background



H. Hertz* A. Einstein**

The photoelectric effect refers to the emission of electrons from matter (metals, non-metals, liquids, or gases) due to the absorption of energy carried by electro-magnetic radiation (see Figure 1).

The phenomenon was first observed by Heinrich Hertz in 1887. The physical explanation of the effect, was provided by Einstein in 1905, for which he was awarded the Nobel Prize in Physics in 1921.

According to the theory proposed by Einstein, light propagates as photons that have a characteristic energy $E_{photon} = h\nu$, where ν is the frequency. Photons that carry high energies, such as visible or ultraviolet light, produce an electrocurrent more easily. To observe the effect, an energy of a few eV to 1 MeV should be applied to an element with high atomic number (e.g. 19 for our Potassium cathode).

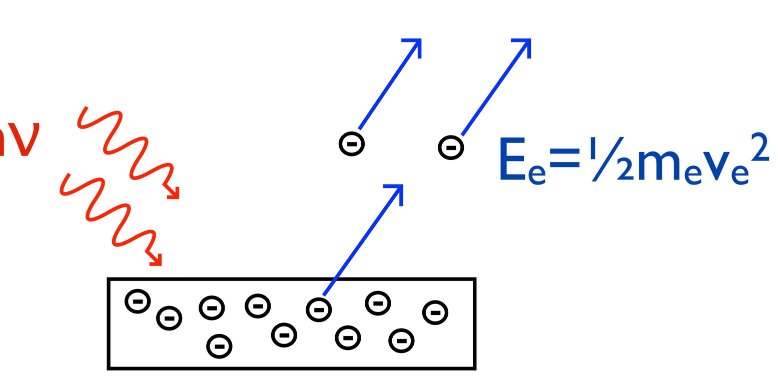


Figure 1

The difference between the photon's energy and the kinetic energy of the free electrons gives a measure of the work function $W = \phi \cdot e$, i.e. the barrier that electrons must overcome to leave the metal. The kinetic energy can be measured by applying a potential between the electrons (cathode) and a positive electrode (anode). There is a maximum kinetic energy attainable by the electrons for each specific light frequency:

$$e \cdot U_{max} = \tfrac{1}{2} m_e v^2_{e,max} = h\nu - W,$$

$$\text{-->}\ U_{max}(\nu) = h/e \cdot \nu - \phi.$$

By plotting the threshold stopping voltage as a function of the frequency, one can obtain the ratio h/e (from the slope) and the metals' work function (from the y-intercept).

Experimental Setup

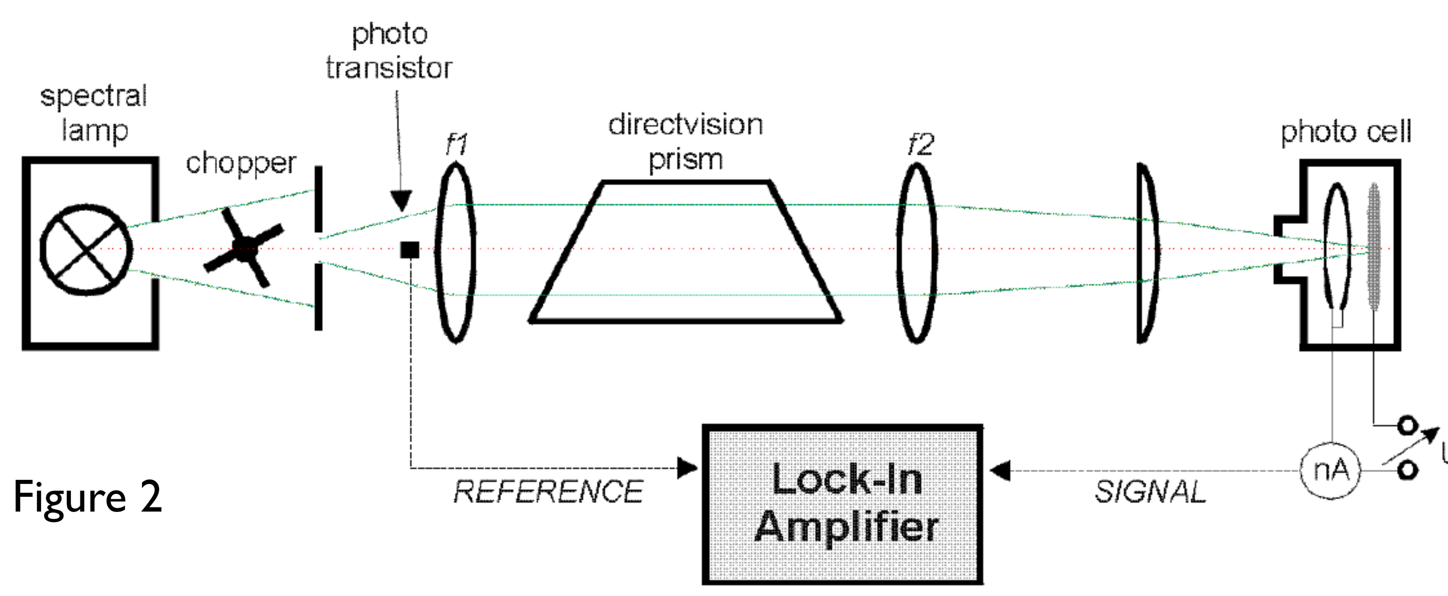


Figure 2

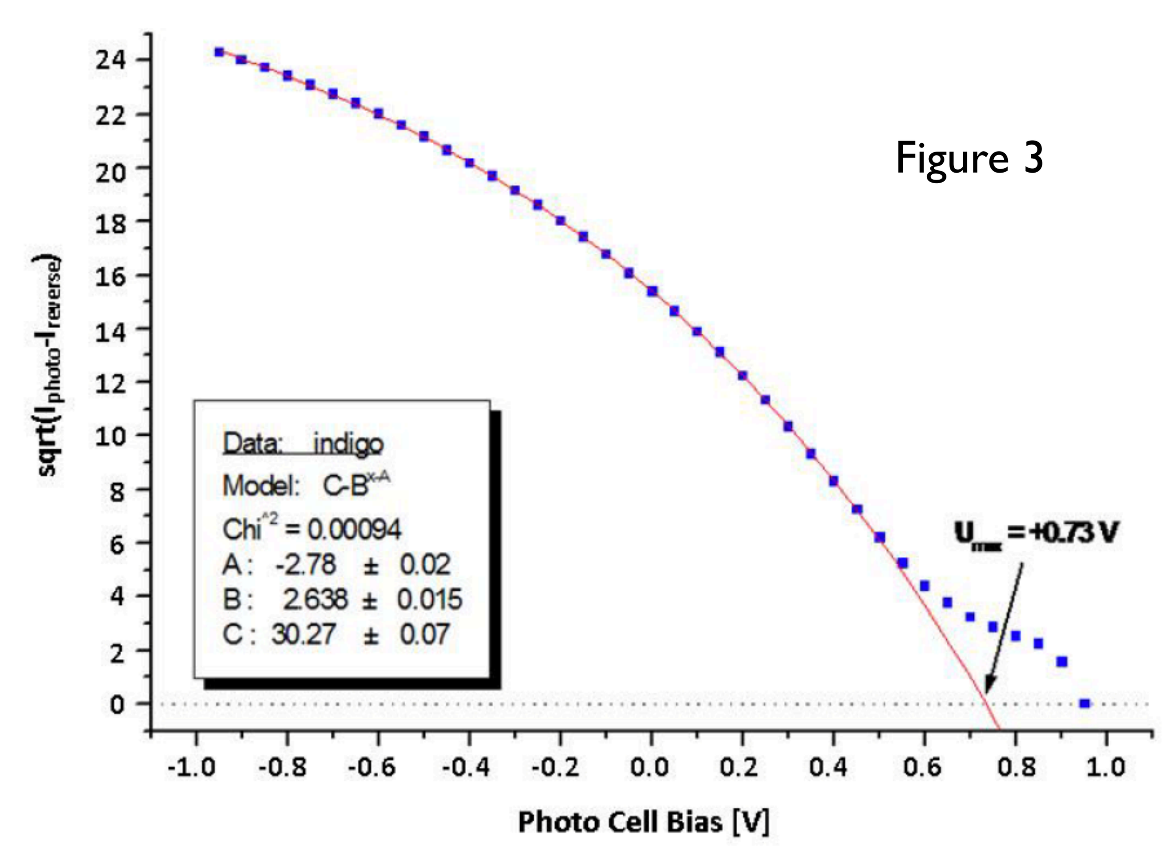
The experimental setup is shown in Figure 2. The source on the left is a spectral lamp of mercury and cadmium that produces light in a range of frequencies from ultraviolet to infrared. The light is dispersed by a prism and focused by a series of lenses into a photocell, which has an aperture of width 1mm in order to admit only one spectral line at a time.

Photons that have sufficient energy will expel electrons from the potassium cathode. However, if one applies the stopping voltage, no current can be measured. This value can be used to measure the work function of the cathode material. To measure the photo current, which is very small, we use a lock-in amplifier to modulate the incoming current with a reference signal, provided by the chopper on Figure 2.

Results

In order to determine the stopping voltage, one can plot the photocurrent, corrected for residual reverse current, as a function of photo cell voltage (see Figure 3). The shape of the curve depends on the geometry of the anode / cathode configuration.

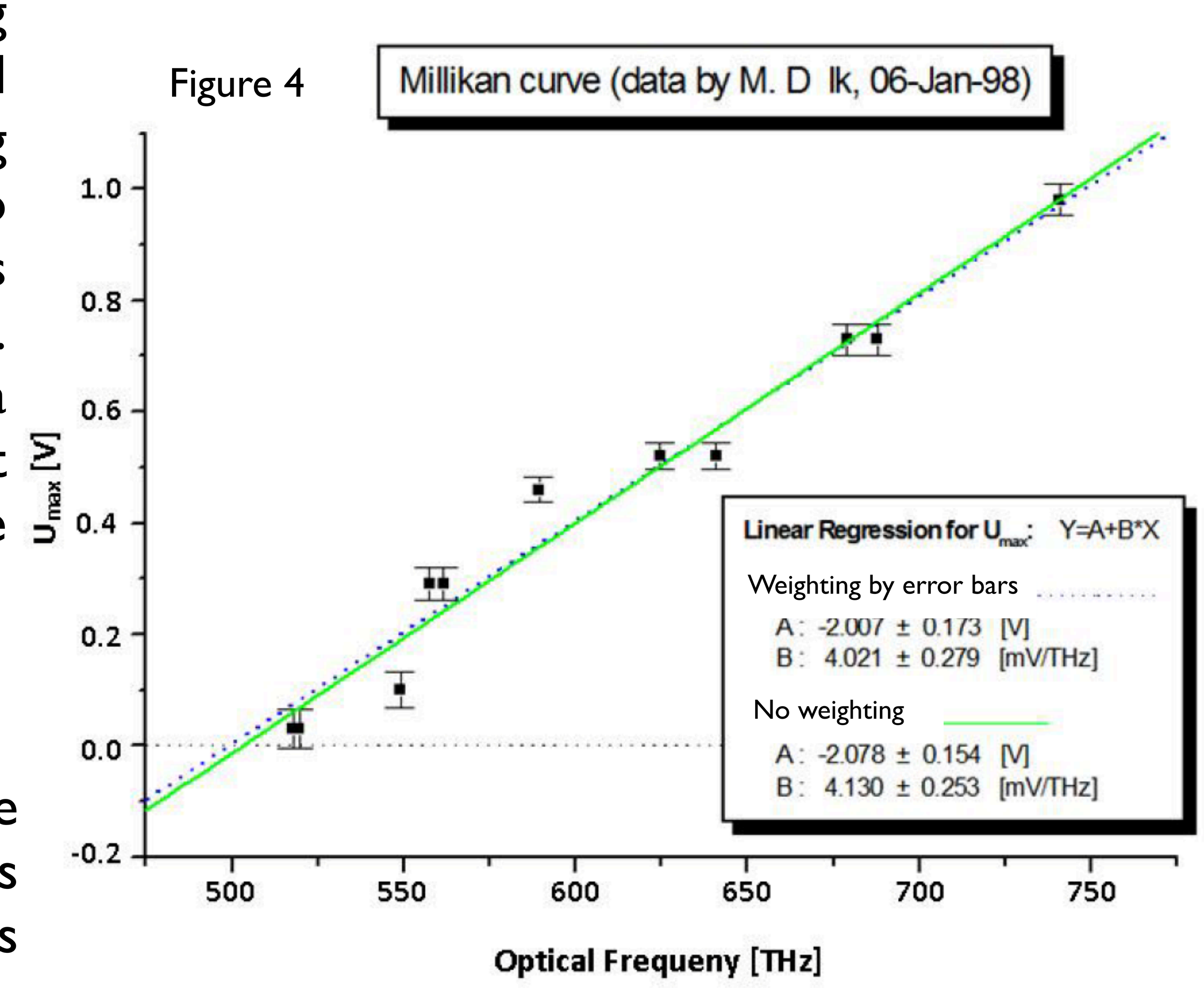
In the case of parallel plates, a straight line is obtained. To account for the details of the geometry, we fit a non-linear curve of shape $C\text{-}B^{x\text{-}A}$ to the data. The point at which the curve intersects the zero current value is our measure of the stopping potential.



After measuring the stopping potential for a series of spectral lines with frequencies ranging from 400-750 Hz (red to purple), we see that these values follow a linear trend (Figure 4). The slope of the curve has a value of h/e and the y-intercept is the work function of the material. The true value of h/e is

$$h/e = 4.13 \cdot 10^{-15}\,V / Hz$$

The experiment presented here and carried out by ETH students has yielded excellent results compared to the accepted value.



* Source: http://www.wix.com/theatom/evolution-of-the-atomic-theory/heinrich-hertz
** Source: http://www.eoearth.org/article/Einstein,_Albert

By Dr. Javiera Guedes
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