The Photoelectric Effect: Measurement of Planck's Constant

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To determine Planck's constant and the work function of an alkali metal surface by measurement of the maximum kinetic energy of electrons ejected from the metal as a function of the frequency of the light.

PREPARATORY QUESTIONS

1. If a certain metal with a work function of 2.0 eV is illuminated by monochromatic light of wavelength 3500$\mathring{A}$, what is the maximum kinetic energy of the electrons ejected in the photoelectric effect?
2. What are the principal lines in the spectrum of a mercury discharge lamp (consult Melissinos)?
3. How does a narrow-band optical interference filter work?
4. Plot the expected curves of current against retarding voltage when the cathode of the tube is illuminated with light of wavelengths 3650$\mathring{A}$, 4035$\mathring{A}$, 4360$\mathring{A}$, 5460$\mathring{A}$ and 5775$\mathring{A}$, respectively.

INTRODUCTION

In 1895 Heinrich Hertz observed that UV light from the sparks of the generator of the radio waves he had recently discovered, falling on the negative electrode of his radio wave detector, induced the flow of electricity in the gap between the electrodes. Pursuing the phenomenon in detail, he discovered the photoelectric effect whereby light of sufficiently short wavelength causes the ejection of electrons from a metal surface. Lenard made improved measurements and demonstrated by determination of their charge to mass ratio that the ejected particles are identical with the electrons that had recently been discovered by Thomson in experiments with cathode rays.

Crude though the early data were, the qualitative fact of the dependence of the critical cutoff voltage on the wavelength of light emerged with sufficient clarity to induce the young Einstein, working as a patent examiner in the Swiss Patent Office in 1905, to link the effect with the recent idea, introduced by Planck in 1900, that matter radiates its energy in quanta of energy hν. He postulated that light delivers its energy to an absorber in quanta with energy hν. Thus, if it takes an amount of energy W to lift an electron out of the surface and away from its image charge, then the residual kinetic energy K of the ejected electron is

$$K = h\nu - W \tag{1}$$

It was not until 1912 that the technical problems of making precision measurements of the photoelectric effect were overcome by Richardson and K. T. Compton (former MIT president) to the point where the Einstein photoelectric equation could be tested to high accuracy and used in precise determinations of h. In this experiment you will measure the photoelectric current from an alkali metal surface as a function of a retarding potential that opposes the escape of the electrons from the surface. From the data you will be able to derive the value of Plank's constant and the work function of the metal.

EXPERIMENT

Connect the phototube cathode to the Keithly electrometer operating as an ultra-sensitive ammeter. Note that the input connector to the electrometer requires a *triaxial* cable. Make sure the center conductor of the cable is the one connected to the cathode. Illuminate the photocathode with light of the various spectral lines of mercury transmitted by the interference filters mounted on the filter wheel. You may want to start with the more energetic spectral lines. Rigorously convince yourself that the current you are measuring is a photoelectric current caused by the mercury lamp.

The cathode of the photocell is built up on a silverlayer (for transporting the charges), which is oxidized, so that it has a large surface area (viewed under a microscope, this surface is not flat). Onto this surface is deposited a very thin layer of potassium which is the source of the photo-emmission electrons in this experiment. It is not possible to precisely determine the work function for removing an electron, because the cathode surface interacts with the remaining gases in the photocell as a getter, so that the surface characteristics change a little from the ideal case. The anode ring is made from platinum.

Use the variable voltage DC Power supply as the source of the retarding voltage between the anode and the cathode. Measure, tabulate, and plot the phototube current as a function of the the retarding voltage for each filter. Repeat the series of measurements at least five times to obtain the data necessary for a reliable estimate of the random errors of measurement.

The following are practical problems with which you must contend:

1. Light striking the anode ring can produce photo-

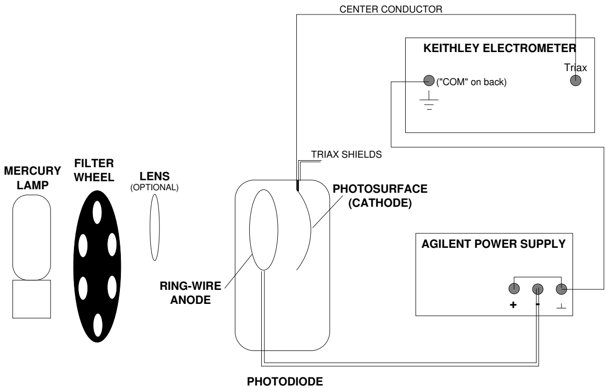

FIG. 1: Experimental arrangement for measuring the photoelectric effect

electrons that cause a reverse (negative) current in the electrometer and confuse the identification of the critical cutoff voltage. It is therefore important to focus the light beam so that it passes cleanly through the ring without illuminating it.

2. Proper grounding of the apparatus is essential to obtaining reliable data. When the grounding is proper, the electrometer readings should be unaffected by touching or moving your hand near the equipment.

3. Because you are measuring such small currents (the currents you obtain with no retarding voltage should be on the order of hundreds of picoamps), the ammeter will be prone to pick up induced currents from ambient magnetic fields. You can avoid such interference by keeping the connecting wires as short and direct as possible and free of loops. For instance, you might want to use a short piece of copper wire to ground the positive terminal of the power supply as shown in Figure 1. You may also find it useful to twist some of the cables together.

4. Your measurement chain may be sensitive to ambient light. Check to see if the current you are measuring is affected when you cover the experiment with black cloth.

ANALYSIS

Determine the cutoff value of the retarding voltage for each of the filters, and assess the random and systematic errors of each determination. Plot the cutoff voltages against the center frequency of the filter bandpass. Suggestion: You can probably make more reliable determinations of the change in cutoff voltage from one wavelength to the next if you normalize your current data so that the zero-voltage values are all the same. Plots of normalized current versus retarding voltage will then show clearly the effect of photon energy on the cutoff voltage. Compute h and W from your plots and estimate the random and systematic errors, taking account of the effects of the errors in the cutoff determinations on your evaluation of the slope and intercept.

1. The wave-particle duality of photons and electrons.
2. The potential energy in eV of an electron as a function of distance from a smooth conducting plane.

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[1] Melissinos, A.C., Experiments in Modern Physics, Academic Press, 1966

UV SAFETY

UVR, which is emitted from low pressure mercury vapour. The mercury vapour emits UVR when an electrical discharge is passed through it most of the energy emitted is at a wavelength of 254 nm. This lies in the UVC portion of the spectrum (180280 nm). In the case of fluorescent lighting, the 254 nm radiation is used to excite a phosphor which coats the inside of the glass envelope of the lamp. The phosphor will re-emit at visible wavelengths (different phosphors produce different colours), and any UVC which is not absorbed by the phosphor will be absorbed by the glass wall of the lamp. However, the mercury discharge will also emit at other wavelengths notably at 365 nm, which lies in the UVA (315400 nm). This UVA radiation may not be absorbed by the phosphor, and much of it will pass out through the lamp walls into the environment.

Good Overview of UV Radiation from the Health Physics Society

http://www.hps.org/hpspublications/articles/uv.html