Revision 10/30/01

Physics 307 Laboratory

Experiment 4: The Photoelectric Effect

Motivation:

The photoelectric effect demonstrates that electromagnetic radiation (specifically visible light) is composed of quanta called photons. This experiment, which was correctly interpreted by Einstein (Annalen der Physik 17 (1905)), was a key experiment in the development of modern physics. Volume 17 of Annalen der Physik also contains Einstein's paper on special relativity and Brownian motion!

Photoelectric effect (or photoemission) experiments are today used to study the structure of solids and surfaces. The University of Wisconsin Synchrotron Radiation Center is one of the great centers for this type of research.

References:

"Foundations of Modern Physics" by Tipler, Sec. 3.4.

"Experiments in Modern Physics" by Melisinnos, Sec. 1.4.

Theory:

Electrons in a metal are in a potential energy well. A minimum amount of energy, Φ, called the work function must be supplied to remove an electron. If a photon with energy hf is used to release the electron, then the emitted electron must have kinetic energy $1/2\ mv^2$ which is <u>less</u> <u>than</u> or <u>equal</u> to $hf-\Phi$. Not all the electrons in the metal have the same energy, hence the inequality in the expression $\frac{1}{2}mv^2 \leq (hf-\Phi)$. Note that if hf is less than Φ, then there is no photoemission current because kinetic energies cannot be negative.

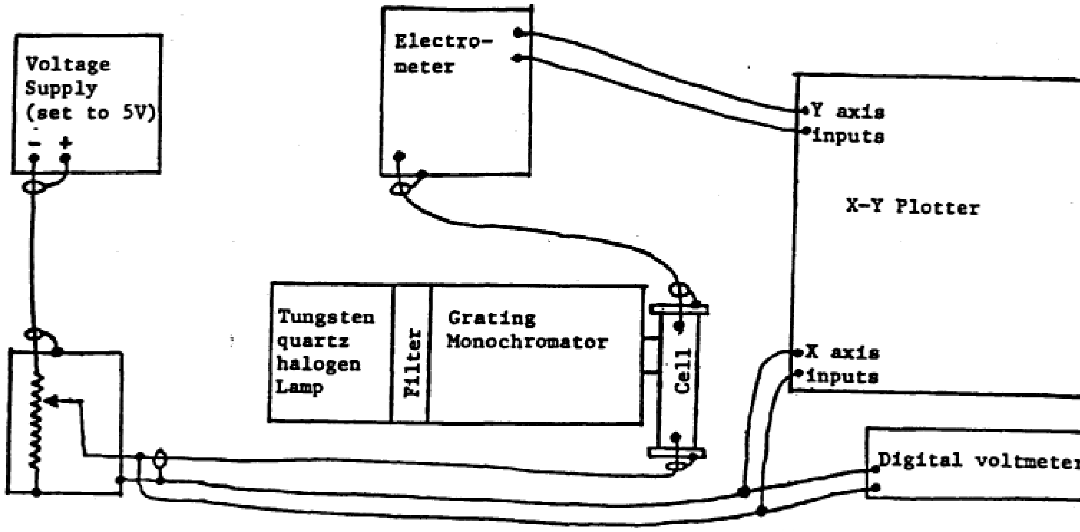
One could also reduce the photoemission current to zero by establishing an electrostatic potential, V, more negative than $(hf-\Phi)\ /\ |e|$ on the electron collector or anode. Such an electrostatic potential will reflect the photoelectrons. The stopping voltage V_S is $-(hf-\Phi)/|e|$. The slope of a plot of V_S as a function of f is, $h/|e|$. Planck's constant divided by $|e|$ is a fundamental constant of nature. The intercept $\Phi/|e|$ is the work function for the material divided by $|e|$. It may (see Melissinos) be necessary to correct the intercept for contact potential differences in order to determine the work function.

Experimental Procedure and Analysis

Part I Traditional Stopping Voltage Measurements

Turn on the incandescent light source which is built into the monochromator. Remove the photoelectric cell and observe the light from the exit slit by allowing the light to hit white paper. Tune the monochromator. Insert a narrowband interference filter between the source and monochromator and tune the monochromator. Check the monochromator wavelength calibration at six wavelengths against the filter wavelengths.

Leakage light at shorter wavelengths is often a problem in photoelectric experiments. This problem is minimized by performing the photoelectric experiments at selected wavelengths where you can use an interference filter and the monochromator in series to filter the light. A schematic of the traditional experiment for stopping voltage measurements is shown below.



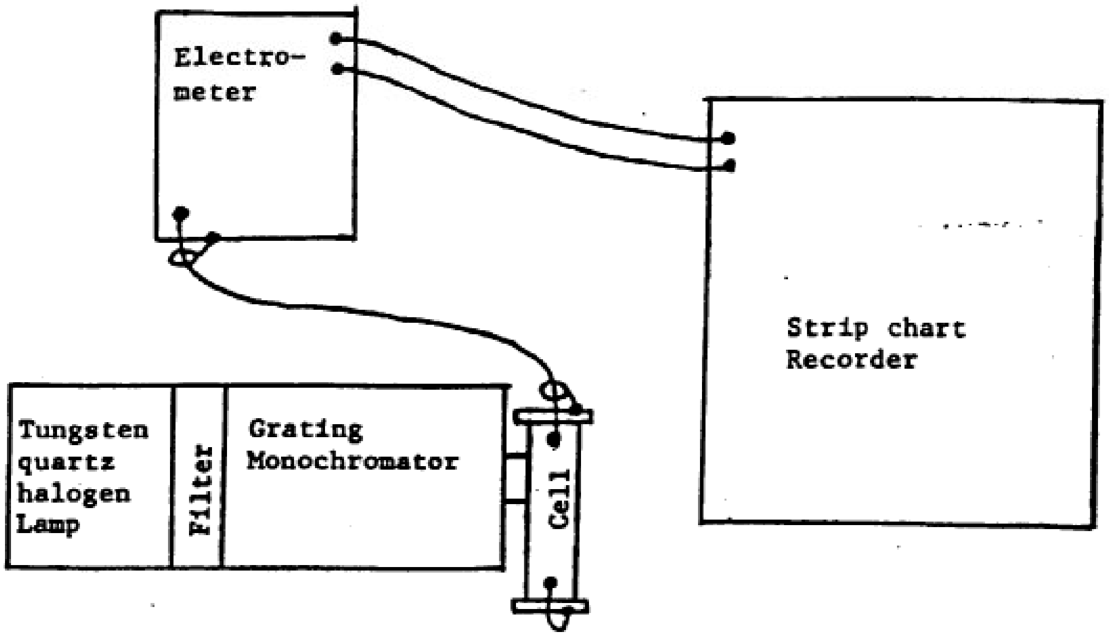
The voltage difference between the anode and cathode is varied using the multiturn pot while plotting the photocurrent as a function of the voltage. The voltage difference is measured and the voltage scale on your plots is calibrated using the Keithly multimeter. The absolute current scale is not important, but is vital to zero the electrometer carefully and to recheck the zero during the experiment. The curves must be plotted very slowly because of parasitic capacitance. It is also important not to disturb the various cables during the experiment because any change affects the parasitic capacitance. Avoid light leaks to the photoelectric cell and keep the room darkened during your measurements.

Plot V_S versus f for at least six values of f, and perform a linear least-square fit to determine h/|e|. Compare your result to the accepted value.

One of the difficulties in analyzing the photocurrent versus voltage plot is due to a reverse leakage current. The voltage at which the photocurrent vanishes is therefore difficult to define. The attached plot shows two possible values, labeled V_S'and V_S'', of the stopping voltage. Note that V_S'' depends on the pen width used to make the plot. Try several methods for analyzing your data.

Part II. <u>Photoelectric Battery Experiment</u>

A clever student developed an alternate version of the photoelectric experiment. In this version



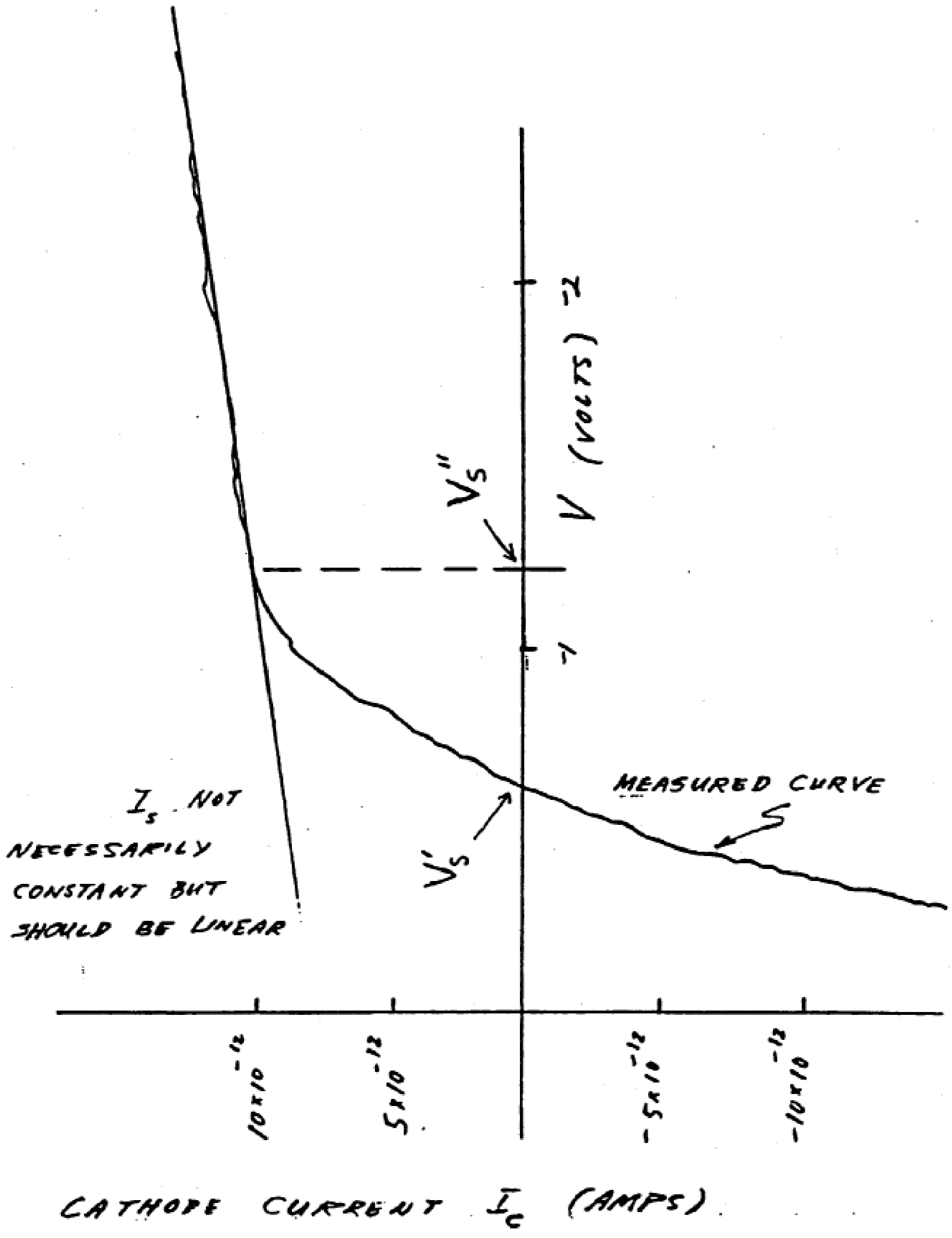
of the experiment the anode is grounded and the photocathode is allowed to charge up to a positive voltage with respect to the anode by photoelectron emission. The cathode voltage is measured using the Keithly electrometer as an extremely high impedance voltmeter. A schematic of the photoelectric battery experiment is shown above.

The data from this version of the experiment is recorded using a strip chart recorder. Use the zero button on the electrometer to ground the cathode. Simultaneously release the button and start the chart recorder. You should see the voltage rise rapidly, go through a well defined change in slope (knee), and then rise very slowly due to leakage UV light. The knee voltage, V_{knee} is easy to determine.

Plot V_{knee} versus f for at least six values of f and perform a least-square fit to determine h/|e|. Compare your results to the accepted value and to your result from Part I. Discuss uncertainties in both measurements.

Final Question:

1) What causes the reverse leakage current? Some scattered light hits the anode but the anode is made of platinum which has a very high work function.



CATHODE CURRENT I_c (AMPS)
V (VOLTS)
-1
-2
V_s''
V_s'
MEASURED CURVE
I_s NOT NECESSARILY CONSTANT BUT SHOULD BE LINEAR
10×10^{-12}
5×10^{-12}
-5×10^{-12}
-10×10^{-12}