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 a major center for this type of research.

References:

Experiments in Modern Physics, by Melissinos, Sec. 1.4.

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

Theory:

Electrons in a metal are in a potential energy well. A minimum amount of energy, $\phi$, 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 $\frac{1}{2}mv^2$ which is less than or equal 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 $\phi$, 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.

Equipment: Keithley electrometer, Pasco Interface, Function Generator, Digital Voltmeter, 5 V DC Power Supply, multi-turn "pot" for varying the anode-cathode voltage, Monochromator with photocell attached.
Procedure:

Part I: 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 one of the interference filters and the monochromator in series to filter the light. A schematic of the experiment for stopping voltage measurements is shown below.

The voltage difference between the anode and cathode is varied using the function generator (or the 5 V power supply) while plotting the photocurrent as a function of the voltage. Use the D.C. power supply to set up the experiment initially but the triangle waveform on the function generator works best for actually taking data. Pull out the DC offset knob to move the waveform to cover the desired voltage range. You can check the Pasco calibration with the digital multimeter using either the 5 V supply or the function generator with the amplitude set to zero and varying the offset voltage.

The absolute current scale is not important, but it is vital to expand the region critical to fitting a line and finding $V_s$. The vertical expansion should be the largest possible consistent with the noise level. The curves must be plotted slowly because of parasitic capacitance. There will be a vertical shift between the scan up and scan down because the sign of the charging current changes, but both traces can be analyzed for $V_s$ values. Disturbing cables during the experiment will affect the parasitic capacitance and cause shifts in the output. 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 $\frac{h}{|e|}$. 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 plot below shows two possible values, labeled $V_s'$ and $V_s''$, of the stopping voltage. Note that the value you derive for $V_s''$ may depend on the scale used in the plot and on the amount of noise on the trace. Try several methods for analyzing your data, and discuss uncertainties in your measurements.

\[ \text{Part II: Photoelectric "Battery" Measurement} \]

This version of the experiment was invented by a student. Turn off the Voltage Supply and disconnect the multi-turn pot. Ground the photocell anode to the electrometer ground. Use the electrometer as an "ultra high impedance" voltmeter. Press and release the zero button of the electrometer. The cathode of the photocell should charge positive due to the photo electron emission. Verify that this charging is due to radiation. Record the saturation voltage $V_{batt}$.

Plot $V_{batt}$ 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.

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.
Using the PASCO Science Workshop 750 Interface

Although the X-Y plotters are, in many ways, simpler than using the PASCO interface for data acquisition this device streamlines the data recording process and allows subsequent data processing (through spreadsheet software) and analysis (through curve fitting software). There should be icons on your desktop or in the "Apps" file for (1) DataStudio (which is new Science Workshop program), (2) Microsoft Excel, and (3) CurveExpert. These latter two programs allow you to work up your data.

The PASCO DataStudio program works primarily through its GUI (graphical user interface) and its drag and drop features. In this experiment you will need to record (1) the accelerating voltage and (2) the counter-electron current vs. time using two of the three available inputs. After double clicking on the DataStudio icon you should:

1. Drag and Drop twice (Part I) or once (Part II) from the Analog Plug Sensor onto the A, B and/or C Analog Channel icons. You will be given a choice of inputs; choose the Voltage Sensor.
2. Drag and Drop twice from the Graph icon onto the two respective Analog Channel icons. With two graphs you can plot either voltage vs. time or voltage vs. photocurrent (remembering, of course, the output to the Pasco interface will actually be a voltage signal from the electrometer).
3. Drag and Drop twice from the Table icon onto the two respective Analog Channel icons. You can increase the number of columns by clicking on the proper icon (and then use only one table).
4. Click on the Start icon to begin data acquisition without creating a permanent data set.
5. Don’t forget to Save your data.
6. To remove an icon or data set click once on said item and then use the Delete option.
7. NOTE: You should also adjust the sampling rate by clicking on the Sampling Options icon. Sampling rates in excess of 20/sec often give unsatisfactory results.
8. To move a data set to Excel it is easiest to use the mouse to highlight a region of interest and then Copy (CTRL+C) into the cut and paste buffer. Once copied you can use the Paste feature to import it into Excel.

Excel has relatively limited curve fitting capabilities but is relatively easy to use, especially for manipulating/processing data.

CurveExpert is very easy to use if you again use the mouse highlight feature to move the data from Excel through a Cut and Paste procedure.

You may save the results on the computer if you create a subdirectory with your lab section identified. Copying the data to floppy disk is also a good idea.