Photoelectric Effect

In this lab you will do two different experiments, a photoelectric measurement and a half-life measurement.

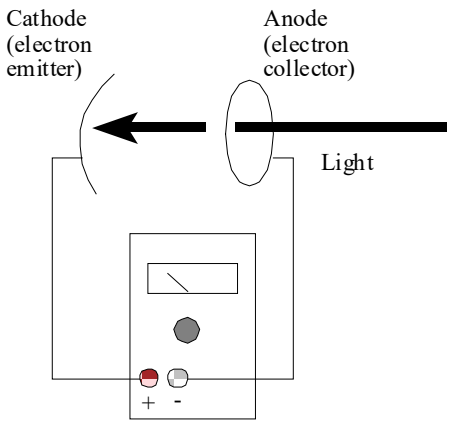
I want you to measure the photoelectric effect for our cell using several light sources, the three different He Ne lasers (red, yellow and green), the Argon ion laser, and the violet laser but you will have to measure the wavelengths for the argon ion laser with a diffraction grating. You should measure the stopping potential for each frequency (or energy) and plot stopping potential vs. frequency. The slope of that line should be h/e, where h = Plank's constant and e = charge on the electron. Find the slope using a linear regression technique. Compare that to the accepted value of h/e. (Note that you may get h or $h/2\pi$, depending on whether your frequencies are in Hz or radians/sec.) **Keep stray light to a minimum!**

You will measure the stopping potential by connecting an electrometer (high impedance voltmeter) between the anode and cathode and measuring the voltage. In this mode the anode and cathode act like a capacitor. When the light shines on the cathode and produces photoelectrons, they will travel to the anode and charge it up until the anode becomes negative enough to repel any 'new' electrons moving toward it. That potential difference is the stopping potential.

We have two different photoelectric cells. Cell A is a concave disk cathode (made of an alkali metal) and a platinum anode in the form of a wire ring. (See the figure below.) Cell B is somewhat similar, but has a built in electrometer. Cell B does not allow you to measure the current flowing between the cathode and anode, but you can do this with cell A. **You will use cell B**, but the description for cell A gives the background for the experiment, so you should read that first.

Directions for Cell A

You should try to adjust the light level reaching the cathode from each laser so that you have approximately the same short circuit current flowing. To do this, make the connections shown at the right and use the current range on the electrometer to measure the current. Adjust the light intensities from the lasers so that each produces about the same current. (See me about the current range to use.) The weakest lasers are the yellow and green He-Ne lasers, so you may want to choose a "standard" short circuit current based on those two. Note that this will not work if the photon energy is less than the work function of the cathode.



Electrometer

When you use the UV diode, you should put a mask with a small hole in it in from of the tube to keep light from the diode from hitting the anode. (The laser beams are narrow, so it isn't a problem with them.)

Use two different techniques to get the stopping potential.

1. Measure the voltage for no current flow by using the voltage scale on the electrometer. Here the anode will charge up to a voltage such that there is no net current flowing from the cathode to the anode. This is one estimate of the stopping potential.

2. Measure the voltage across a 10^{11} Ohm resister. Here you make the measurement on the current setting on the 10^{-11}A range. The reading on the meter is the voltage across a 10^{11} Ω resistor. There is some current flowing here, so it is not such a good estimate of the stopping potential, but it will give you an estimate whether leakage currents are a problem in your measurement.

Hopefully the difference between the voltages in 1 and 2 above will be small. If the differences are large, you are not getting much light on your sample or the energy of the photons is close to the cutoff energy. In this case small leakage currents might affect your measurement.

Note that the measurements are easy to make, but a little harder to interpret. The reason is that while most of the initial current is flowing from the cathode to the anode, at least until the anode charges, there is some current flowing in the reverse direction. When we make the voltage measurement in part 1, the "no current" condition does not mean that no current is flowing from the cathode to the anode, but rather that the two currents (cathode to anode and anode to cathode) cancel. Therefore this is not actually the "stopping potential" you talked about in Modern Physics. It should be close to the stopping potential, but it is hard to say exactly how close.

The difficulty is that the cathode material (a potassium coating) has a relatively low work function while the anode (a platinum wire) has a large work function. That would mean that scattered light hitting the anode would not produce photoelectrons there. However, some of the cathode material will "migrate" to the anode, and scattered light hitting that material will produce photoelectrons that will be drawn toward the more positive cathode producing the reverse current. It is very difficult to prevent the contamination of the anode by cathode material. One way to reduce the effect is to heat the anode and "boil" off this material. Unfortunately, you can easily heat the anode too much and soften it so that the wire sags. Also if you heat the anode at a low temperature for too long, the cathode can heat up and be damaged. However, heating the anode to a moderate temperature for a short time can get rid of some of the potassium there and yield better results.

A good reference for this laboratory is Melissinos' *Experiments in Modern Physics*. Pages 18-27 are particularly useful. I do not like their treatment of the data, but it raises some of the difficulties with the experiment. It is on reserve in the Library.

Directions for Cell B

Cell B is much like cell A, except that it has the "electrometer" inside the apparatus. It is a high impedance operational amplifier. However, it is not as good as a good as the electrometer, and there will always be some bias current flowing into the amplifier. Since the amplifier is inside the box, you cannot measure the current flowing from the cathode to the anode, but can only measure the "stopping potential". They claim their design minimizes the flow of electrons from the anode to the cathode.

Again you shine light from the different sources onto the window into the tube to produce a photocurrent and then measure the stopping potential. With this device you should also measure the stopping potentials when you partially attenuate the light using the filters provided. The stopping potentials should not depend on the intensity of the light. If it does, then you are not really measuring the stopping potential, i.e. the potential with no current flowing from the cathode to the anode.

Note that you will probably have to spread the beam with a glass cylinder to get it to

shine on the part of the tube where the cathode is. (You will need to do this for the He-Ne and argon ion lasers. The violet laser may have a wide enough beam to do this without spreading it more.)

Key Concepts and Devices

You should understand the processes or devices listed below. Know how they work and affect your measurements. Be prepared to explain them!

1. Photoelectric Effect
2. Diffraction Grating

You should also be prepared to explain how the photoelectric experiment works. Consult your Modern Physics text and Melissinos.

Radioactive Decay & Half-life Measurements

Radioactive decay

I want you to measure the half-life of Ba-137 and compare it to the commonly accepted value. (We could also use Po-210 abn Co-57 are other possibilities, but their half-lives are much longer, 138 days for Po-210 and 271 days for the Co-57. The barium's half-life is less than three minutes so it is easier to measure in a short time.) The barium is produced as a result of the beta decay of Cs-137. Radioactive decay is a random process and if there are a large number of radioactive atoms, the number, N(t), as a function of time is expected to be

$$N(t) = N(0)\exp\left(t/\tau\right) \qquad 1.$$

Where N(0) is the number present at t = 0, i.e. when you start the experiment. This comes from assuming that the probability of decay for all identical particles is the same in a given time interval. Then the number of decays in a short time Δt is proportional to the time interval, Δt, and proportional to the number of particles present. This results in a relation

$$dN = -\gamma N dt \qquad 2.$$

where γ is some constant of proportionality characteristic of the nucleus and dN is the change in the number of original particles present. (dN is negative because the number of original particles is decreasing. The number of counts you will measure in the Geiger tube is |dN|.) Solving this leads to equation 1 if we let $\gamma = 1/\tau$. τ is called the lifetime, because about 63% of the particles will decay in a time $t = \tau$. (Compare this to RC decay in electrical circuits and note that the equations look the same.) The count rate should vary according to the relation.

$$\frac{dN}{dt} = -\left(\frac{N_0}{\tau}\right)\exp\left(-t/\tau\right) = -\left(\frac{dN}{dt}\right)_0 \exp\left(-t/\tau\right) \qquad 3.$$

One defines the count rate, R(t) or just R, as |dN/dt|, which is the number of counts or decays per second. (Remember that dN/dt is <0 because the number of particles or nuclei is decreasing.)

$$R(t) = \left|\frac{dN}{dt}\right| = \left(\frac{N_0}{\tau}\right)\exp\left(-\,t/\tau\right) = \left(\left|\frac{dN}{dt}\right|\right)_0 \exp\left(-t/\tau\right) \qquad 4.$$

$(dN/dt)_o = -N_0/\tau$, so $R_o = N_o/\tau$ is the initial count rate. Then

$$R(t) = R_0 \exp\left(-\frac{t}{\tau}\right) \qquad 5.$$

Note that half of the particles will decay in a time $T_{1/2} = \tau \ln(2)$. $T_{1/2}$ is called the half-life. The lifetime is about 1.44 times the half-life; they are not the same! Most reference works give the half-life and not the lifetime.

You will try to determine the lifetime by measuring the count rate as a function of time. Measure the number of counts in a certain time interval that is much less than the lifetime. The count rate will be the number of counts divided by the time interval. You can estimate the lifetime by plotting the count rate vs. time and fitting it to equation 5 to determine τ. An easier way is to take the natural log of both sides of equation 5 to get

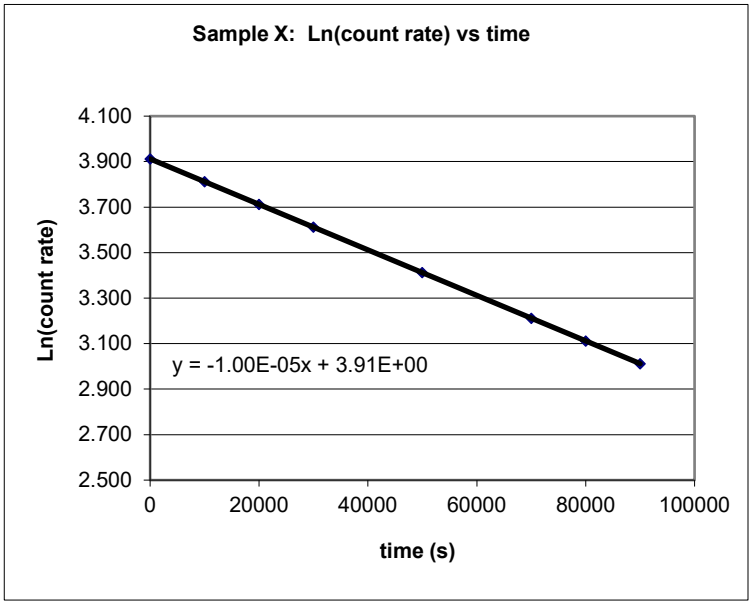
$$\ln\left(R(t)\right) = \ln\left(R_o\right) \; - t/\tau \qquad 6.$$

Now you can plot ln[R(t)] vs time and the slope is $-1/\tau$. That is what I want you to do.

I recommend a format like the one shown at the right, where the first column is the time when the measurements were taken and the third is the time interval over which you counted. The count rate is the ratio of the second and third columns. You would plot the ln(rate) vs. the time at which the measurement was made and the slope is $-1/\tau$.

time (s) measured	counts	time (s) interval	count rate	Ln(rate)
0	10,006	200	50.03	3.913
10,000	9,029	200	45.14	3.810
20,000	8,162	200	40.81	3.709
30,000	7,406	200	37.03	3.612
50,000	6,097	200	30.49	3.417
70,000	4,951	200	24.75	3.209
80,000	4,486	200	22.43	3.110
90,000	4,066	200	20.33	3.012

This plot is shown at the right for the data above. Here the slope is shown on the graph and is -10^{-5}/s. This means that τ would be 10^5s. (I made up this data. Yours will probably not look so nice.)



The decay process is random, so the number of counts you measure in a given time interval will vary due to the randomness of the decay process. If you measure n decays in a given time, e.g. 10s, and then remeasure it, you would expect to get a different number, even if the predicted count rate change was very small. You would expect to have an uncertainty, i.e. standard deviation, of $\sigma = (n)^{1/2}$. (Note that the number of decays n is **NOT** the same as the number of particles N.) This means that the fractional standard deviation, $\sigma/n = (n)^{-1/2}$. If you measure 10,000 counts your uncertainty is 100 counts or 1%. You need to measure enough counts so that the uncertainty is << than the change you would expect to get due to the decay of the count rate. For example, **if** you expect the count rate to decrease by 5% in 20s, according to equation 1, you want the fractional uncertainty in any of your counts to be much, much less than 5%; less by **at least** a factor of 10 and preferably by a factor of 50. The barium decays so fast that this might not be possible.

Background Radiation

One problem is that there is some ionizing radiation around us all the time due to cosmic rays and naturally occurring radioactive materials. (We are radioactive and about 5000 to 10,000 nuclei will undergo radioactive decay every second inside a typical person.) Therefore the detector will measure some counts or decays when no sample is present. You should measure this "background radiation" before you start your measurement and after you have finished your measurement at the very end. Unfortunately the count you measure with the sample present will also include this background radiation. This may have an effect on your computation of the half-life if the count rate for the sample present is not >> than the background. You would like to have a situation where the count rate for the sample is always 100 times as large as the background count rate. You may not be able to achieve that. You should be wary of using data where the count rate is less than 10 times the background.

Can you figure out how you could correct for the background radiation?

Detector Problems

You will use a Geiger-Mueller tube (GM tube) to measure the number of decays. When it measures a decay, it takes about 200μs before it can measure the next decay. This 200μs is called

the resolving time of the detector, because it cannot detect another decay during this time. Therefore you do not want very many counts occurring within 200μs, or 0.2ms, of each other. This will be the case if the count rate is less than 100 counts/s.

Because of this I **recommend** that you only use data from intervals where the count rate is less than100 counts/s. You can correct for the dead time, but to do so accurately we would have to measure the dead time. The tube manufacturer says the resolving time is ≤ 200μs, not that it equals 200μs, so we don't really know what it is.

Measure the half-life twice, once where you count for 20s intervals and once when you count for 40s intervals. Do they give the same result? What are your uncertainties? Did you try to correct for the background? Are you within ±1 standard deviation of the "book" value?

Key Concepts

1. Radioactive Decay and the concept of a Lifetime or Half Life for a particle. (Note the type of decay.)
2. Statistics of counting the number of decays, i.e. the uncertainty associated with the count.
3. Method of operation of a Geiger-Muller tube.

For information about the decay of Ba-137, see Wikipedia.

Read the GM tube discussion from "the Nucleus" manual.