Determining Planck's Constant

References

Am. J. Physics, *Concerning a widespread error in the description of the photoelectric effect,* Vol. 4, No. 8, August, 1976.
Any Intro Physics Text!
Optics, Klein, M. (for info on monochromators)
On the Web: www.phys.virginia.edu/classes/252/photoelectric_effect.html
theory.uwinnipeg.ca/physics/quant/node4.html
American Journal of Physics Home Page Search Engine
(www.phy.nau.edu/ danmac/AAPTDB/index.html)

1 Brief Background

The Photoelectric Effect was one of the first major failures of the wave theory of light. When light incident on a metal plate ejects electrons, the wave theory makes three main predictions:

1. An increase in the intensity of the incident light would proportionately increase the kinetic energy of the ejected electrons.
2. The photoelectric effect should occur for *any* frequency, provided that the light sufficiently intense.
3. An appreciable time delay should exist for incident light of sufficiently low intensity.

All of these three predictions of wave theory completely fail in the photoelectric effect; increasing the light intensity has no effect on the energy of the ejected electrons, there is a definite cutoff frequency below which no photoelectric effect occurs, and the electrons are ejected from the metal with no measurable time delay.

2 Experimental Setup

In this experiment, light hits a positively charged metal plate (the cathode) and electrons are ejected with kinetic energy K, heading towards a nearby negatively charged collector (the anode) which is held at a potential V relative to the cathode (see Figure ??). Only the electrons with sufficient kinetic energy can overcome the existing electrostatic potential "hill" and strike the anode, thus registering a current in the ammeter. By adjusting the voltage V until the photocurrent just goes to zero, one can measure the maximum kinetic energy of the ejected photoelectrons.

For incident photons with frequency ν, the ejected photoelectrons have a maximum kinetic energy, $K_{\max}$, given by

$$K_{\max} = h\nu - \phi_c,$$

where ϕ_c is the work function associated with the cathode (see **AJP**, 1976). If we now pick a particular frequency of light, then the maximum kinetic energy of the photelectrons can be

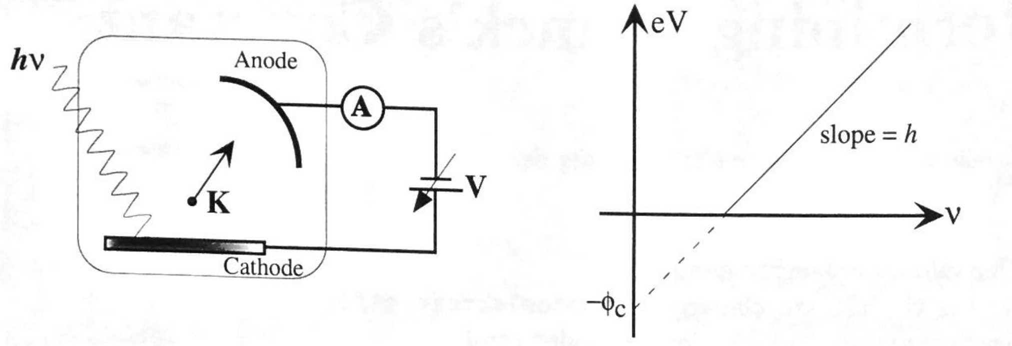

Figure 1: Simplified setup for the photoelectric effect.

directly measured by increasing the voltage V until the photocurrent goes to zero. At this point,

$$K_{\text{max}} = eV_0,$$

and by repeating this process for different frequencies of light, one can plot K_{max} versus ν to obtain Planck's constant, h (Figure ??).

2.1 More Detail

Our light source is a high pressure mercury lamp whose light is passed through a monochromator to allow us to select out different frequency lines from mercury's spectrum (see Table ??). The frequency of output light is simply dialed in on the front of the monochromator; however, the monochromator does not do a perfect job of frequency selection, so we have some high frequency cutoff filters to help reject unwanted high frequency lines.

The light exits from the monochromator/filter combination and enters the phototube striking the potassium photocathode. Ejected photoelectrons of sufficient kinetic energy are then collected at the anode. The resulting photocurrent is measured by the picoammeter. A sketch of the apparatus is shown in Figure ??.

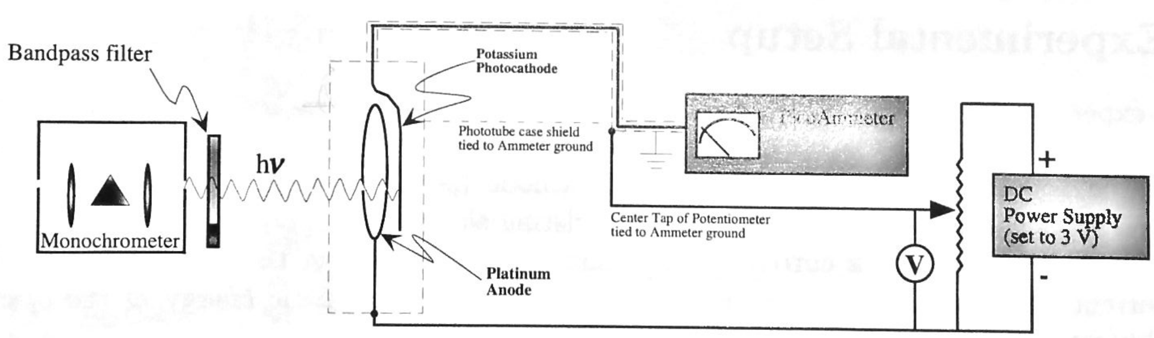

Figure 2: Experimental setup for this lab (mercury light source is not shown).

There are two ways to go about measuring Planck's constant, h.

2.1.1 Simple Method

The first is the simplest: simply pick a particular line in the mercury spectrum, and then adjust the stopping voltage until the photocurrent drops to zero. After performing this for as many different lines that you can find, make a plot of stopping potential energy vs frequency and the slope of the best fit line should be h.

2.1.2 Alternate Method

The second method is more complicated; since we are looking for a null current (lying in the *picoamp* range), we have to worry about small effects such as leakage current within the phototube, or stray light (either from the room or the monochromator). For a specific frequency of light, we measure the photocurrent, I, as a function of bias voltage, V, which is adjusted through use of the precision voltage divider seen in Figure ??. You will have to plot (for each wavelength of light) I .vs. V and extrapolate appropriately to obtain the correct stopping voltage (Incidentally, it would be interesting to see what effect the bandpass filters have on the I .vs. V at a particular frequency).

After gathering I .vs. V data for several (the more the better!) different frequencies, you should be able to plot eV .vs. ν to get an estimate of Planck's constant, h.

Your lab report should definitively answer which of these two methods gives the best value for Planck's constant.

Intensity (relative scale)	Wavelength nm
2800.0	365.02
300.00	365.48
80.000	366.29
240.00	366.33
30.000	370.14
35.000	370.42
30.000	380.17
20.000	390.19
60.000	390.64
1800.0	404.66
150.00	407.78
40.000	410.80
250.00	433.92
400.00	434.75
4000.0	435.83
5.0000	488.30
5.0000	488.99
80.000	491.61
5.0000	497.04
5.0000	498.06
20.000	510.27
40.000	512.06
20.000	513.79
20.000	529.07
5.0000	531.68
60.000	535.41
30.000	538.46
1100.0	546.07
30.000	554.96
160.00	567.59
240.00	576.96
100.00	578.97
280.00	579.07
140.00	580.38
60.000	585.92
20.000	587.20
20.000	607.27
30.000	623.40
160.00	671.64
250.00	690.75
250.00	708.19
200.00	709.19

Table 1: Wavelengths in air for prominent visible lines in the mercury spectrum. Only lines resulting from transitions in neutral mercury are given. The intensities given here are to be taken as a rough estimate of the relative brightness of lines. There are lines for singly ionized mercury which are not listed here but may be found in the CRC Handbook of Chemistry and Physics, from which this data is taken.