timeter or CASSY Input B to the output of the plug-in board.

- If it is necessary to reduce electrical noise connect the optical bench (and possibly the rod of the photocell holder) to the ground connection of the measurement amplifier, in extreme cases connect this terminal to the external ground of the distribution box. Usually these connections are not required.

Carrying out the experiment

Notes:

If potassium from the light-sensitive layer of the cathode becomes deposited on the anode ring, this can cause an electron flux which will interfere with the experiment. If necessary, bake out the photocell as described in the Instruction Sheet.

Dirt on the photocell can cause leakage currents between the anode and the cathode which can affect the measurement of the limit voltage U_0. Clean the photocell with alcohol.

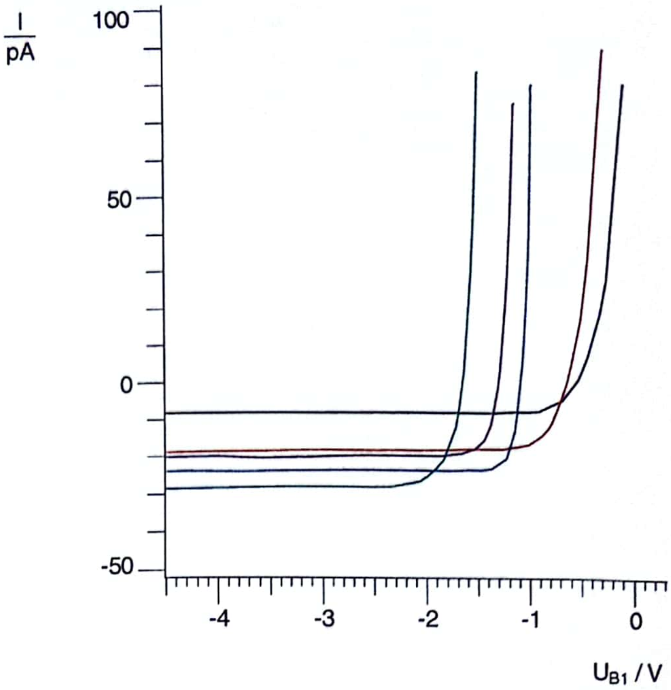
You do not need to darken the room; this has no effect on the measurement results.

- Switch on both multimeters and set the range switch to +-10 V DC or start CASSYLab on the computer connected to the CASSY, select the 10 V range for both inputs A and B.
- Turn the interference filter for yellow light (λ_{Hg} = 578 nm) into the beam path.
- Set the potentiometer for the maximum counter voltage, something like - 4.5 Volts.
- Observe the photocurrent, note that in the most sensitive setting of the I-Amplifier D the transimpedance Rg is 100 GΩ. So a photocurrent of 10 pA will be equivalent to 1V output. In CASSYLab create a formula for a Symbol "I", with Unit "pA" and the formula "UA1*10", meaning 1 V is worth 10 pA
- In CASSYLab, select "Measuring parameters / manual recording", and change the axis assignment to x-axis = "UB1", y-axis= "I"
- Adjust the setting of the iris behind the interference filter (d) to achieve approximately the same reverse photocurrent at all wavelengths, starting with a full open iris for the yellow line, as this is the weakest in intensity. If possible, do not vary the setting of the other iris (b), as this would change the illuminated area on the photocell.
- Reduce the counter voltage stepwise (for example in 0.5 V steps) and record the resulting photocurrent. When the photocurrent starts to rise, use smaller steps and wait before reading the values until the photocurrent has settled. In CASSYLab use "F9" to record one value.
- Turn the interference filter for green light (λ_{Hg} = 546 nm) into the beam path and repeat the measurement. In CASSYLab select "Measuring parameters / Append new meas. Series" to start a new curve in a different color.
- Repeat the measurement with the blue (λ_{Hg} = 436 nm), violet (λ_{Hg} = 405 nm) and ultraviolet (λ_{Hg} = 365 nm) interference filters.

Note: If the iris diaphragm is closed too far, this may affect the uniform illumination of the light spot on the cathode. Also, leakage currents will play an increasing role.

If there is no photocurrent at all observable, check if the photocell is fully screwed into the socket.

Measuring example

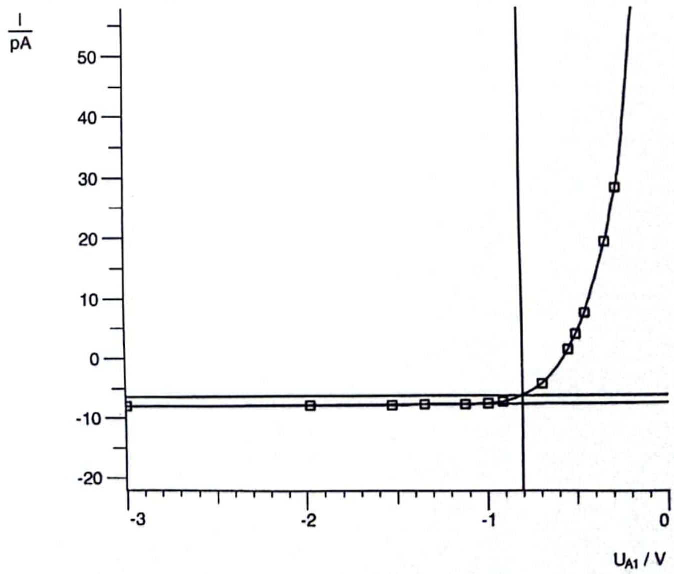


Below a sufficiently negative counter voltage, all the recorded curves show a constant current, which is independent of the counter voltage but depends on the intensity and wavelength of the incident light. This reverse current is generated by stray light on the anode ring. There is no ohmic component in this example, so the cell was clean of dust and dirt on the outside.

Depending on the wavelength of the incident light, the photocurrent starts to rise at different counter voltages. For the ultraviolet line, this happens at –2 Volt, for the yellow one at –0.6 Volt, and the other wavelengths in between.

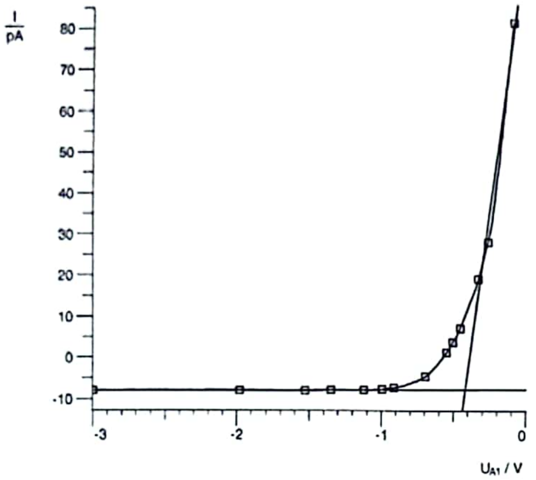
Evaluation

There are several ways in the literature to evaluate the measured data and determine at what counter voltage exactly the photocurrent starts.



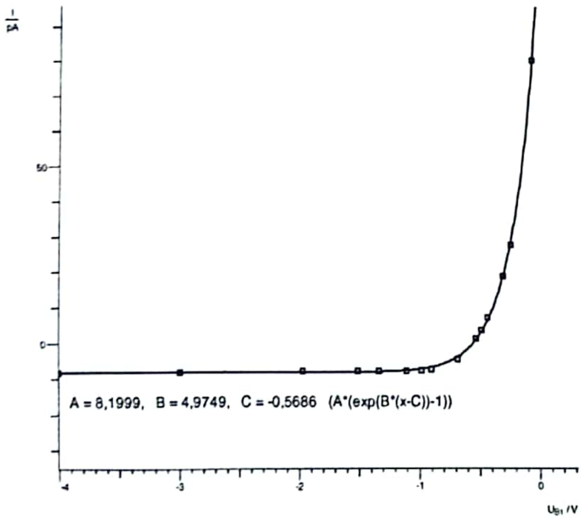
The easiest approach is to draw a line through all the measurement points on the left side before the photocurrent start, then draw a parallel line a few pA apart and take the crossing of the photocurrent with this line, in the image above at –0.81 V.

Another approach is to take again a best fit line through all the points on the left, and then another best fit line through all the data points at high photocurrents and look for the intersection of both lines, here at –0.4 V.



A third approach, which requires much more measurements, would measure the current-voltage curves for the same wavelength but at different intensities, and take the point where the curves intersect as "the" counter voltage, see [1]

A fourth, purely mathematical approach fits an exponential function to the measured values.



A function similar to Shockley's Diode equation $I(U) = A \cdot \left(e^{B(U-C)} - 1\right)$ is used, where A is the dark current, B somewhat related to light intensity times photocathode response and C is the counter voltage. In CASSYLab, press the right mouse key in the diagram, select "Fit function", "Free fit"; in the dialog box type the formula "A*(exp(B*(x-C))-1)", make some rough estimations for A(=10), B(=7) and C(=-1) and mark the data points to start the free fit. A few seconds later, CASSYLab will display the optimum values for A, B and C, and C is our result, where $I(C)=0$. Therefore this evaluation is very similar to P6.1.4.3, in that experiment we are simply measuring the voltage where $I=0$

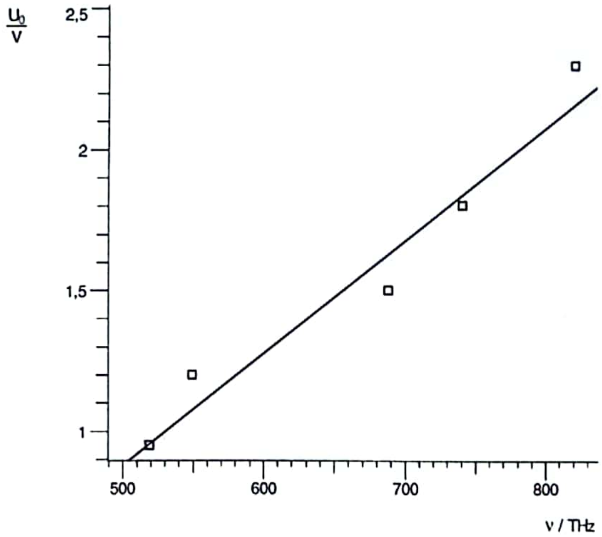
In the end, all the different evaluations give quite similar results for Planck's constant as it is calculated only from the slope of the threshold voltage versus photon energy. Similar as the work function cancels out, so does any offset error from the data evaluation.

For simplicity we have chosen to use the first method described and look at the point where the photocurrent starts to barely rise above the baseline on the left side of the diagram from the other currents.

This gives us the values of the limit voltage versus frequency of light:

λ / nm	ν / THz	U_0 / V
578	519	0,95
546	549	1,2
436	688	1,5
405	741	1,8
365	822	2,3

Plotting the data in a diagram gives us this result



The plotted measurement points lie on a straight line with close approximation.

A line fitted to the measurement points has a slope of

$$\frac{\Delta U_0}{\Delta \nu} = 0{,}00398\,\mathrm{V/THz} = 3.98 * 10^{-15}\,Vs$$

According to (V), multiplying with $e = 1.6 \bullet 10^{-19}$ As gives a value of Planck's constant

$h = 6.37 \bullet 10^{-34}$ Js

Literature value: $h = 6.62 \bullet 10^{-34}$ Js

Results

In the photoelectric effect, the kinetic energy E_{kin} of the liberated electrons depends on the frequency, and not on the intensity of the incident light.

Planck's constant h can be determined by measuring the limit voltage U_0, above which the electrons can no longer escape, as a function of the frequency ν.

Acknowledgment

Special thanks to Dr John Fry, Department of Physics, University of Liverpool for very helpful discussions and the idea of fitting with an exponential function.

References

[1] Langensiepen, Fritz; „Ein verbessertes Verfahren zur Bestimmung des Planckschen Wirkungsquantums mit in der Schule vorhandenen Mitteln."; Praxis der Naturwissenschaften. Physik, 30 (1981) 11, S. 321-328