Determination of Planck constant by a photoelectric cell

Problems: *External photoelectric phenomenon, photoelectric cell and its application, Einstein's theory pf photons, wave-particle duality, principle of determination of Planck constant and work function of electrons from photocathode by measurement of hindering voltage, linear regression.*

Instruments: *Photoelectric cell, SPEKOL photospectrometer, galvanometer, voltmeter, digital multimeter*

1. Introduction.

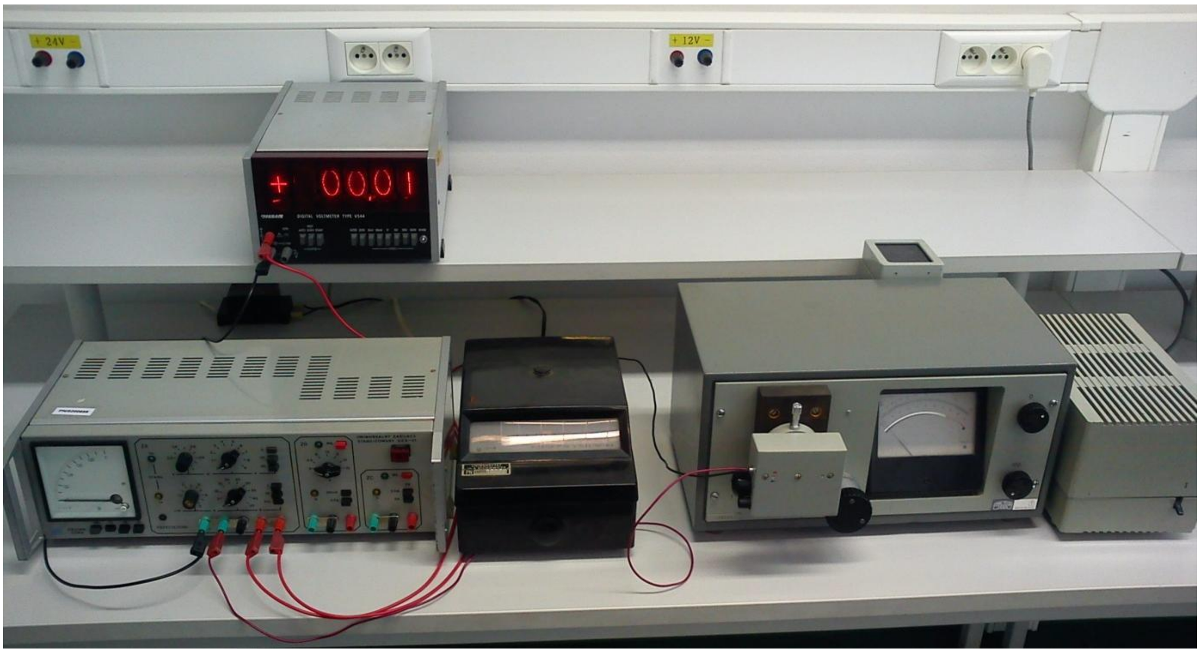

Figure 1. Measuring setup for Planck constant determination.

External photoelectric effect is the phenomenon of emission of electrons caused by light incident on metal surface. This phenomenon is studied with the use of a photoelectric cell whose scheme is presented in Fig. 2. The main element of a photoelectric cell is a cathode material capable of emitting electrons under the effect of light. Most often the photocathode is a layer deposited directly onto the inside wall of the glass tube of the cell. The glass tube has a special window through which light is directed onto the photocathode.

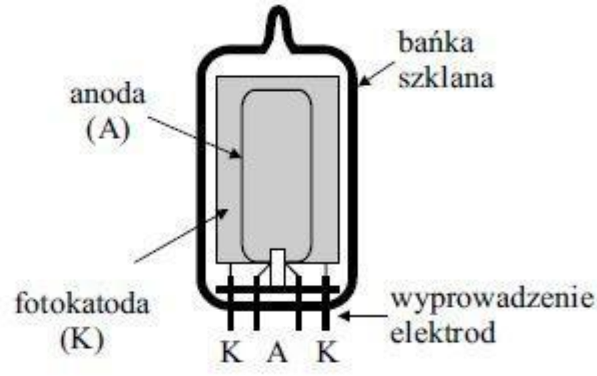

Figure 2. Scheme of a photoelectric cell [anode, glass tube, phtocathode, electrode output.

The electrons ejected from the photocathode by a stream of light are collected by the anode. The intensity of current flowing in the circuit depends on:

- stream of radiation ф incident on the photocathode,
- wavelength of incident light,
- voltage between the anode and the cathode.

If monochromatic radiation falls on the cathode of a photoelectric cell and if the stream of the radiation is constant, a constant number of electrons is ejected from the electrode in a certain unit of time. Under a low accelerating voltage, not all electrons that are ejected from the cathode can reach the anode. Thus, the cathode is surrounded by a cloud of electrons and a certain state of dynamic equilibrium is reached in which some of the electrons ejected from the cathode and not captured by the anode go back to the cathode.

On increasing the accelerating voltage, the current intensity increases fast until reaching a certain value known as the saturation current IS, which corresponds to the situation when all electrons emitted by the cathode are captured by the anode. When this situation is reached, an increase in the accelerating voltage cannot increase the current intensity any more.

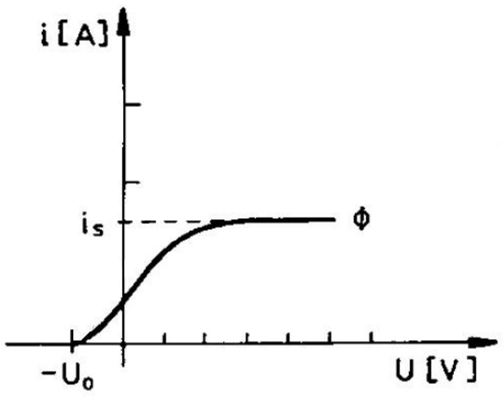

Figure 3. Current-voltage characteristics of a photocell.

The current flows in the system even when the sq voltage is negative (the anode potential is lower than that of the cathode). It means that some electrons have kinetic energy high enough to perform work against the electric field hindering force. At a certain value of voltage, even the electrons having the highest kinetic energy do not reach the anode and the current flow stops. This value of voltage is called the stopping potential, Uh**.** The knowledge of this potential permits determination of the maximum velocities v and kinetic energy EK of photoelectrons from the relation:

$$eU_h = \frac{1}{2}mv^2 = E_k \,. \tag{1}$$

The value of the stopping potential U_h does not depend on the stream of radiation incident on the photocathode. The relation between the stopping potential and the frequency of light ν incident on the photocathode is linear.

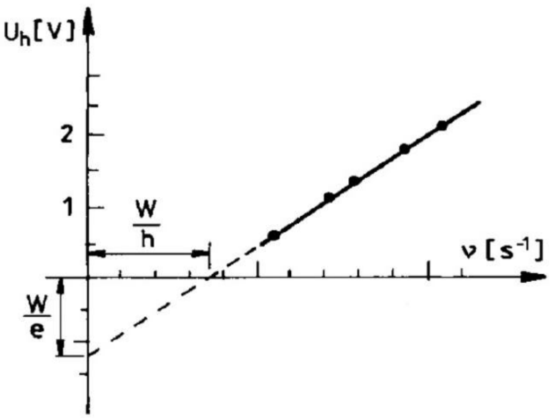

Figure 4. Voltage of hindering versus frequency of incident light.

The explanation of the photoelectric effect proposed by Einstein was based on the assumption that the energy of a light beam is absorbed and propagates in space in the form of finite portions of energy known as photons:

$$E = h\nu \, . \tag{2}$$

The photonic concept of Einstein's applied to the photoelectric effect can be written in the following way

$$h\nu = W + E_k \, , \tag{3}$$

where W is the work function. A photoelectron of energy hν on the metal surface can leave it at the cost of energy needed for the work function. If the electron does not lose energy in internal collisions on leaving the metal, its maximum kinetic energy is given by the formula:

$$E_k = h\nu - W \, , \tag{4}$$

$$eU_h = h\nu - W \, . \tag{5}$$

If the energy of an incident photon is smaller than the work function ($h\nu < W$) no photoelectric phenomenon is observed. The frequency limit ν_0 below which no photoelectric effect can be found from the relation:

$$h\nu_0 = W \, . \tag{6}$$

By transformation of eq. 6 the relation for the stopping potential is obtained:

$$U_h = \frac{h}{e}\nu - \frac{W}{e} \, . \tag{7}$$

2. The experiment.

A. Check if the experimental setup is connected as in Fig. 4.

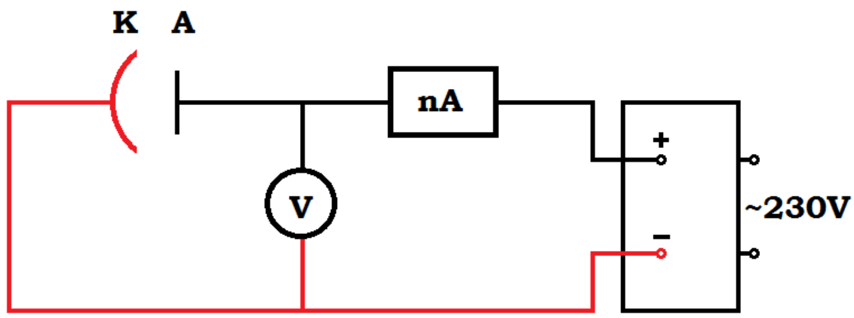

Figure 4. A scheme of experimental setup.

B. Prior to the measurements the activity of the SPEKOL monochromator can be observed. For this purpose, remove the photoelectric cell from the circuit and place a focusing screen against the output slit, switch on the lamp power supply and set the diaphragm switch to position 1. With the help of a monochromator drum it is possible to change the length of the wavelength. After the observation, place the photocell back in the circuit and set the diaphragm switch to position 0.

C. Nullify the mirror galvanometer. To do this, connect the galvanometer exits marked "+" and "-" (on the back of the galvanometer) with the help of a metal bar. Then, using the control knob on the main panel of the galvanometer set the light spot on zero. Attention: the procedure of galvanometer nullification should be carried out delicately and slowly to avoid excessive motion of the light spot.

D. Set the wavelength of 480 nm on the monochromator drum.

E. Switch on the power supply of the photocell.

F. With the use of potentiometers set the zero voltage.

G. Set the diaphragm switch to position 1, observe the movement of the spot on the galvanometer.

H. With the use of a potentiometer, slowly increase the voltage in the photocell until getting zero current intensity on the galvanometer. Read off the stopping potential and note the result in a table.

I. Close the exit slit of SPEKOL monochromator (set the switch to position 0) and set zero voltage on the power supply unit.

J. With the use of the monochromator drum, change the wavelength in the range 480–620 nm with a step of 10 nm. For each setting repeat the procedures 6-9.

λ [nm]	ν [Hz]	U_h [V]

K. For two selected wavelengths measure the current-voltage dependence, from the stopping potential to the maximum positive voltage, which requires a change in the voltage polarization. When the current intensity grows beyond the scale of the galvanometer, it should be replaced by a digital multimeter.

3. Analysis of results.

A. Making use of computer programs, calculate the slope of the line illustrating the dependence of U_h on ν. Calculate the Planck constant h from the slope of the line and the uncertainty of the result. From the intercept with the axis of ordinates calculate the work function W.

B. Plot the current-voltage characteristic of the photoelectric cell.

C. Estimate the uncertainties of results.

D. Compare the calculated Planck constant h with the tabulated value.

Table 1. Tabulated values of the physical constants needed.

c	2.99793×10^{8} m/s
e	1.60218×10^{-19}C
h	6.62608×10^{-34} Js

4. Literature.

R.Resnick, D.Halliday; „Fizyka”

H.Szydlowski; „Pracownia Fizyczna”

R.Eisberg, R.Resnick „Fizyka Kwantowa”