GDYNIA MARITIME UNIVERSITY
FACULTY OF MECHANICAL ENGINEERING

PHYSICS LABORATORY
DEPARTMENT OF PHYSICS

Theoretical Introduction

Experiment “M I L L I K A N”

Photoelectric phenomena are phenomena caused by the interaction of a substance with light radiation. They are connected with the transfer of photon energy to individual electrons. Photoelectric phenomena are used in photoelectric cells.

Photoelectric phenomena are divided into:

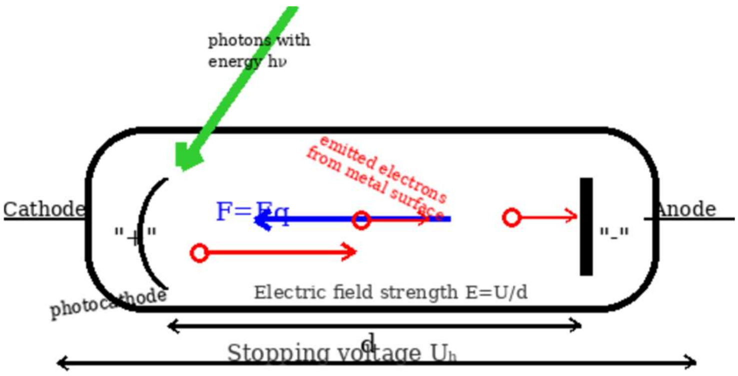
- **external** photoelectric phenomena, emission of electrons from a metal under the influence of light,

Electrons leaving the surface of a metal as a result of the photoelectric effect are called photoelectrons, and the current produced by their ordered motion in an external electric field is called photoelectric current.

- **internal** photoelectric phenomena, a change in the energy distribution of electrons in solid and liquid semiconductors and dielectrics caused by the interaction of light with a substance.

This manifests itself as a change in the concentration of charge carriers in the medium and, as a result, leads to photoconductivity or to the photoelectric effect in the barrier layer.

Research on the external photoelectric effect, the explanation of which required the introduction of the postulate of the quantum nature of light, Planck, Einstein, Millikan, was of great importance for the development of physics. According to the proposed model, the energy of the incident photon is transferred to the electron according to the equation:



$$hv = W + E$$

This is the so-called Einstein–Millikan equation, where:
hv– energy of the incident photon,
h– Planck’s constant,
ν– frequency of the light wave, or of the oscillator which is the source of the light wave,
W– the so-called work function, energy needed for an electron to escape from the surface of the metal,
E– kinetic energy of the emitted electron.

In optics, instead of frequency ν, Greek letter nu, the wavelength λ that the wave would have in vacuum is used, with good approximation also in air:

$$\lambda = c/v,$$

where c is the speed of light, approximately:

$$3 \cdot 10^8 \text{ m/s}.$$

Therefore, photon energy $h\nu$ is usually given as:

$$h\frac{c}{\lambda}.$$

The kinetic energy of photoelectrons emitted from the photocathode with initial velocity V, and moving towards the anode, can be expressed by determining the value of the stopping voltage, called the cut-off voltage

$$U_0 : \frac{mV^2}{2} = U_0 e,$$

where e is the elementary charge equal to: $1{,}602 \cdot 10^{-19}$ C.

“M I L L I K A N”

Preparation Questions:

1. What is the external photoelectric effect?
2. Are electrons different from photoelectrons?
3. Discuss the equation describing the photoelectric effect.
4. What is the work function?
5. In what units is the work function measured?
6. What is an electronvolt? Give the definition.
7. What are the values of the work function for typical materials, in electronvolts?
8. How can the maximum kinetic energy of photoelectrons be determined?
9. What is the relationship between the maximum energy of electrons in the photoelectric effect and the stopping voltage?
10. What is the unit and value of Planck’s constant?
11. What does the number of emitted photoelectrons depend on?
12. What is the threshold frequency, threshold wavelength, of a light wave?
13. The work function of electrons for a platinum plate is 6.35 eV, $1\ \text{eV} = 1.6 \cdot 10^{-19}$ J. What is the minimum frequency of a photon causing the external photoelectric effect? Planck’s constant is $6.6 \cdot 10^{-34}\ \text{J} \cdot \text{s}$.
14. The energy of a photon incident on the cathode is four times greater than the work function of an electron from this metal. What part of the photon energy is the kinetic energy of the photoelectron?
15. What does photon energy depend on?

Course of Activities:

1. With the instructor’s permission: turn on the voltmeters, turn on the lamp, open the photocell shutter and turn on the power supply.
2. Using the knob, set the wavelength of light λ to 400 nm.
3. Using the power supply knob, change the value of the stopping voltage U_0 until the photocurrent value is zero.
4. Read and record in the results table the value of the light wavelength and the cut-off voltage.
5. Increase the light wavelength by 10 nm.
6. Repeat steps 3 to 5 until ten values of light wavelengths λ and ten values of cut-off voltages U_0 are obtained.
7. After completing the measurements, tidy up the workstation.
8. Perform the calculations according to the instruction and prepare a trial graph in a spreadsheet. In the calculations, remember to use the basic SI units for light wavelengths and cut-off voltages.
9. Prepare a measurement protocol and measurement uncertainties.

NOTE:

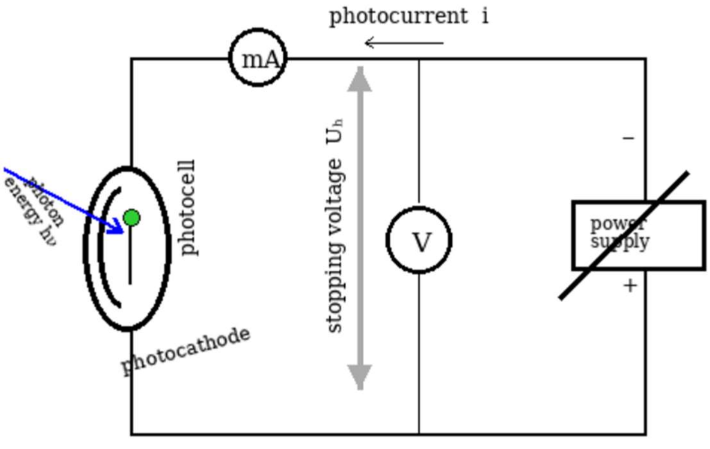
- Due to the very high sensitivity of the system, currents may be induced in the measuring system by the proximity of electrical devices and rapidly moving objects. Therefore, it is recommended that operating electronic devices, laptops, watches, be removed from the surroundings of the measuring system during measurements and that all movements be limited to the necessary minimum.
- The uncertainty of the cut-off voltage measurement should be determined on the basis of the range of stopping voltage values for which the photocurrent is zeroed.

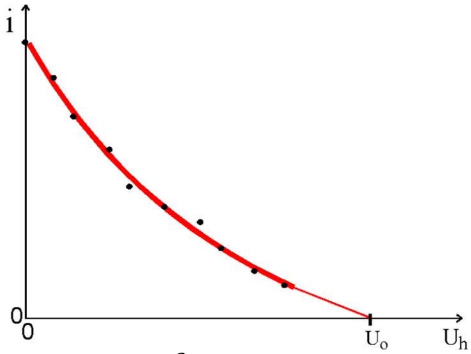
“MILLIKAN”

Methodological Template

Student 1: Determination of Planck’s constant using a photocell.
Student 2: Verification of the Einstein–Millikan equation.

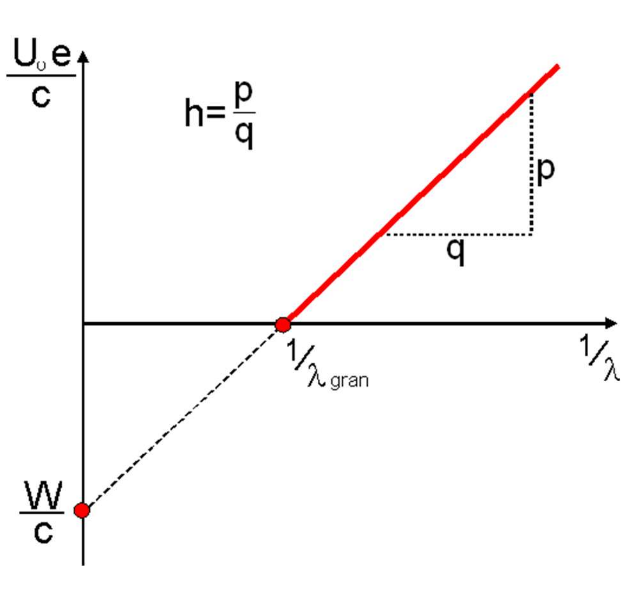
Theoretical Basis:





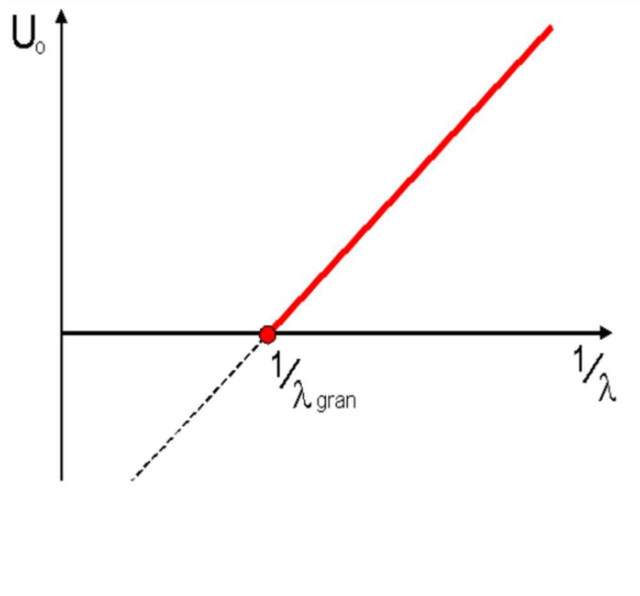
$$h\frac{c}{\lambda} = W + U_0 e$$

$$\frac{U_0 e}{c} = -\frac{W}{c} + h\frac{1}{\lambda}$$



Therefore, in order to determine Planck’s constant, one should:

- perform measurements of the dependence of the cut-off voltage U_0 on the wavelength of light,
- prepare a graph of the dependence: $\frac{U_0 e}{c}$ as a function of: $\frac{1}{\lambda}$
- read the value of Planck’s constant from it.



Therefore, in order to verify the Einstein–Millikan equation, one should:

- perform measurements of the dependence of the cut-off voltage U_0 on the wavelength of light,
- prepare a graph of the dependence: U_0 as a function of: $\frac{1}{\lambda}$
- analyse its linearity.

“M I L L I K A N”

Report Guidelines – Determination

Student 1: Determination of Planck’s constant using a photocell.

I. **Methodology** (conceptual plan of the exercise)
II. **Course of the exercise**
   II.1. Course of activities
   II.2. Sketch of the measurement setup
III. **Results**

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
λ	[nm]										
U_o	[V]										

$\Delta\lambda$= ...

ΔU_o = ...

2. Calculations (example calculations - referring, for example, to measurement no. 6)

$$\frac{U_0 e}{c} = \ldots$$

$$\frac{1}{\lambda} = \ldots$$

$$\Delta\frac{U_0 e}{c} = \frac{e}{c}\cdot\Delta U_0 = \ldots$$

$$\Delta\frac{1}{\lambda} = \left|\frac{1}{\lambda} - \frac{1}{\lambda + \Delta\lambda}\right| = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
$\frac{U_0 e}{c}$	[…]										
$\frac{1}{\lambda}$	[…]										
$\Delta\frac{1}{\lambda}$	[…]										

$$\Delta\frac{U_0 e}{c} = \ldots$$

4. Graph

- calculation of h, the slope of the “best-fit” straight line
- calculation of h', the slope of the deviated straight line
- calculation of: $\Delta h = |h - h'|$

5. Summary

The determined value of … is …
Accuracy of the method: …
Additional conclusions, observations, causes of measurement uncertainties.

“MILLIKAN”

Report Guidelines – Verification

Student 2: Verification of the Einstein–Millikan equation.

I. **Methodology** (conceptual plan of the exercise)
II. **Course of the exercise**
II.1. Course of activities
II.2. Sketch of the measurement setup
III. **Results**

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
λ	[nm]										
U_o	[V]										

$\Delta\lambda$= ...

ΔU_o = ...

2. Calculations (example calculations - referring, for example, to measurement no. 6)

$$\frac{1}{\lambda} = \ldots$$

$$\Delta\frac{1}{\lambda} = \left|\frac{1}{\lambda} - \frac{1}{\lambda + \Delta\lambda}\right| = \ldots$$

3. Calculation results

		1	2	3	4	5	6	7	8	9	10
U_o	[...]										
$\frac{1}{\lambda}$	[...]										
$\Delta\frac{1}{\lambda}$	[...]										

ΔU_o = ...

4. Graph

5. Summary

Since on the graph ... it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from the theory in the wavelength range from ... to ...

Alternatively:
The deviation from linearity in the range ... may result from ...
Additional conclusions, observations, causes of measurement uncertainties.