Exercise 91	INVESTIGATION OF EXTERNAL PHOTOELECTRIC EFFECT

Manuals

1. Equipment:

1. Phototube
2. Phototube power supply
3. Monochromator
4. Illuminator
5. Illuminator power supply
6. Voltmeter
7. Ammeter

2. Aim of the exercise:

- Measurement of the spectral dependence of the photocurrent ***i(λ)*** in the phototube (a kind of a photocell).
- Determination of the cutoff wavelength (related to the threshold frequency) of the external photoelectric effect.
- Determination of the work function of the metal the cathode in the phototube was made of.
- Calculation of the maximum kinetic energy of the electrons ejected from the cathode for a chosen wavelength.
- Measurement of the current-voltage characteristics *i(U)* of the phototube for two intensities of the incident light.

3. Scheme of the measurement system.

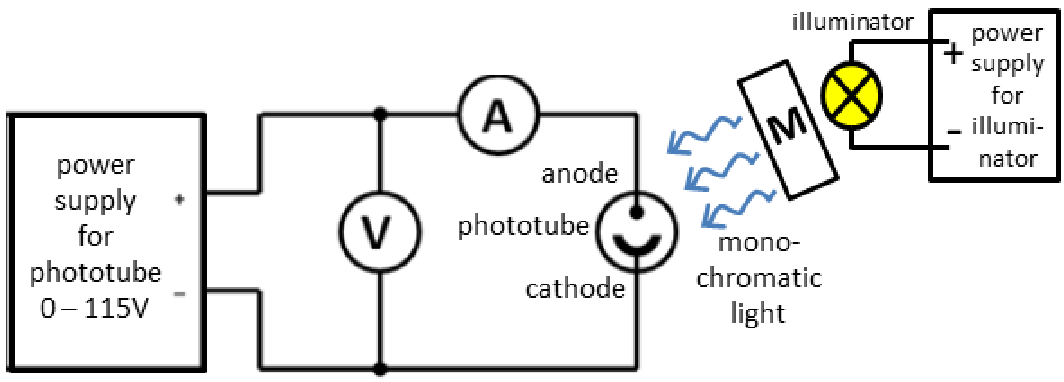


Fig. 1. The scheme of the measurement system (M- monochromator).

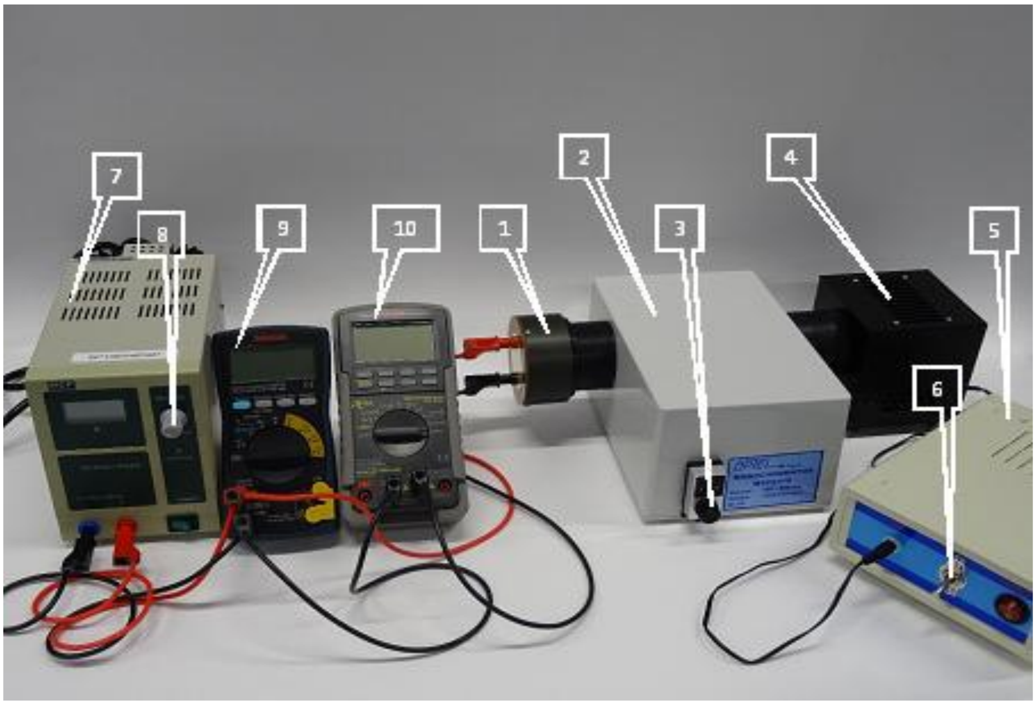


Fig2. Photo of the measurement system.

The measurement system consists of the following components (numbered in the photo):

1. phototube,
2. monochromator,
3. knob for setting the wavelength,
4. illuminator,
5. power supply for the illuminator,
6. light intensity switch (up – higher intensity, down – lower intensity),
7. power supply for the phototube,
8. knob for setting the voltage on the phototube,
9. voltmeter,
10. ammeter.

4. Measurements.

4.1. Measurement of the spectral dependence of the photocurrent i=f(λ).

1. Assemble the measuring system according to the scheme shown in fig. 1 and 2. For this purpose **+** terminal (red) of the phototube power supply (7) should be connected through the ammeter to the anode (red terminal) of the phototube (1), and **-** terminal (blue) of the phototube power supply should be connected to the cathode of the phototube (black terminal). The voltmeter should be connected in parallel to the output of the phototube power supply (**-** terminal of the power supply connect to the **COM** terminal of the voltmeter).
2. On the voltmeter select DC voltage measurement (**V**).
3. On the ammeter select DC current measurement (µ**A**).
4. Switch on the phototube power supply (7).
5. Using the knob (8) set the maximum voltage (about **115*V***) on the phototube power supply (7).
6. Read and note the value of the dark current i_{dark}, which is created in the phototube due to thermally excited electrons and because of scattered light.

7. Switch on the illuminator power supply (5). Set the switch (6) to the upper position (higher intensity of light illuminating the cathode).
8. Measure the spectral dependence ***i*(*λ*)** of the photocurrent flowing through the phototube in the range from 370nm to 700nm every 5nm. To do this, for each wavelength λ selected by the knob (3), note the value of the photocurrent ***i*** (reading it from the ammeter (10)).
9. After the measurements, use the knob (8) to turn down the voltage on the phototube power supply (7) to zero. Then switch off both the power supplies (7 and 5).

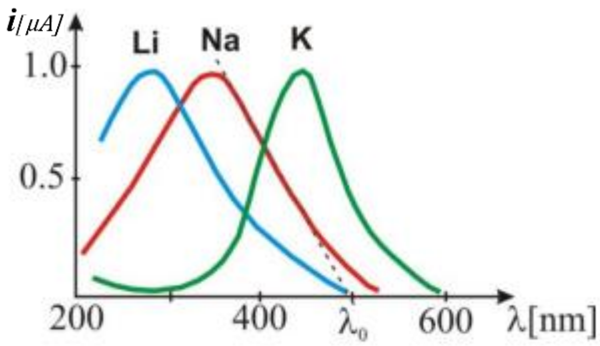
4.2. Measurements of current-voltage characteristics *i*=f*(U)*.

1. Repeat the points 4.1. 1 – 3.
2. Switch on the illuminator power supply (5). Set the light intensity switch (6) to the higher position (higher intensity of the light illuminating the cathode).
3. Using the results obtained in section 4.1. find the wavelength corresponding to the maximum value of the photocurrent and using the knob (3) set this value on the monochromator (2).
4. Switch on the phototube power supply (7).
5. Measure the current-voltage dependence ***i*=f(*U*)** of the phototube. To do this, using the knob (8) change the voltage on the phototube power supply as follows:
   from 0 to 10V every 1V,
   from 10 to 30V every 2V,
   from 30 to ~115V every 10V.
   For each voltage ***U***, read the value of the photocurrent ***i***. After measurements, turn down the voltage on the phototube power supply to zero.
6. Repeat the measurement of the current-voltage dependence (points 4.2. 1 - 5) for a lower illumination intensity of the phototube, i.e. with the switch (6) in the lower position.

5. Calculations and analysis of the results.

5.1. Analysis of the spectral characteristic of the photocurrent.

1. Plot the spectral characteristic of the photocurrent ***i*=f(*λ*)** of the phototube.
2. For several selected points, draw the error bars where $\frac{\Delta_p \lambda}{\sqrt{3}}$ is the horizontal bar (with the resolution of the monochromator $\Delta_p \lambda = 2nm$) and $\frac{\Delta_p i}{\sqrt{3}}$ is the vertical bar (with the maximum uncertainty of the ammeter $\Delta_p i$).
3. Approximating the long-wave edge of the spectral characteristic of the phototube to the background level i_{dark} determine the cutoff wavelength λ_o of the external photoelectric effect (fig. 3. - the dashed line on the long-wave edge of the spectral characteristic for **Na**). For this purpose, using linear regression, find the straight line ***i*=*aλ*+*b*** which is the best fit to the long-wave edge of the spectral characteristic. The cutoff wavelength of the external photoelectric effect



should be calculated from the equation $\boldsymbol{\lambda o} = \frac{\boldsymbol{i_{dark}-b}}{a}$.

4. Knowing the cutoff wavelenght calculte the work function of the material the cathode was made of:

$$W = h\frac{c}{\lambda_o} \qquad (1)$$

where: h – Planck's constant, c – speed of light.
Compare the obtained value to the values of work functions gathered in the table in section 7 and indicate the material the cathode in the investigated phototube was made of.
To convert the work function from **J** to **eV** use the formula:

$$W[\mathrm{eV}] = \frac{1}{1{,}6\cdot 10^{-19}} W[\mathrm{J}].$$

5. Calculate the uncertainty of the work function:

$$u_c(W) = \left|\frac{dW}{d\lambda_o}u(\lambda_0)\right| = \frac{hc}{\lambda_0^2}u(\lambda_o) \qquad (2)$$

6. For a chosen wavelength $\boldsymbol{\lambda}$ (shorter than $\boldsymbol{\lambda_o}$) calculate the maximum kinetic energy of the electrons ejected from the cathode:

$$E_{k,max} = h\frac{c}{\lambda} - W. \qquad (3)$$

7. Calculate the combined uncertainty of the maximum kinetic energy of the ejected electrons:

$$u_c(E_{k,max}) = \sqrt{\left(\frac{dE_{k,max}}{d\lambda}u(\lambda)\right)^2 + \left(\frac{E_{k,max}}{dW}u(W)\right)^2} = \sqrt{\left(\frac{hc}{\lambda^2}u(\lambda)\right)^2 + (u_c(W))^2} \qquad (4)$$

where: $\mathrm{u}(\lambda) = \frac{2nm}{\sqrt{3}}$.

5.2. Analysis of the current-voltage characteristics of the phototube.

1. Plot, in the same system of coordinates, the current-voltage characteristics ***i*=f(*U*)** for the two intensities of the light illuminating the phototube.
2. From the current-voltage characteristics determine the values of the saturated currents $\boldsymbol{i_s}$ for the both light intensities. The two values of the saturated currents calculate separately as the average values of the currents from the horizontal parts of the two curves in the range of high voltages.
3. Notice how the intensity of the phototube illumination affects the current-voltage characteristic and the value of the saturation current $\boldsymbol{i_s}$.
4. For several selected points, draw the error bars where $\frac{\Delta_p U}{\sqrt{3}}$ is the horizontal bar (with the maximum uncertainty of the voltmeter $\Delta_p U$) and $\frac{\Delta_p i}{\sqrt{3}}$ is the vertical bar (with the maximum uncertainty of the ammeter $\Delta_p i$).

6. Suggested tables for the results of measurements.

6.1. Table for the spectral characteristic *i*=f(*λ*):

i_{dark}	$u(i_{dark})$	i	$u(i)$	λ	$u(\lambda)$	λ_0	$u(\lambda_0)$	W	$u_c(W)$	E_{kmax}	$u_c(E_{kmax})$
$[A]$	$[A]$	$[A]$	$[A]$	$[nm]$	$[nm]$	$[nm]$	$[nm]$	$[eV]$	$[eV]$	$[eV]$	$[eV]$

6.2.Table for the current-voltage characteristics *i=f(U)* of the phototube:

illumination intensity	i	$u(i)$	U	$u(U)$	i_s	$u(i_s)$
	$[A]$	$[A]$	$[V]$	$[V]$	$[A]$	$[A]$
E_1						
E_2						

7. Table with work functions *W* for external photoelectric effect:

Element	Work Function(eV)
Aluminum	4.08
Beryllium	5.0
Cadmium	4.07
Calcium	2.9
Carbon	4.81
Cesium	2.1
Cobalt	5.0
Copper	4.7
Gold	5.1
Iron	4.5
Lead	4.14
Magnesium	3.68
Mercury	4.5
Nickel	5.01
Niobium	4.3
Potassium	2.3, 2.29**
Platinum	6.35
Selenium	5.11
Silver	4.26-4.73*
Sodium	2.28, 2.36**
Uranium	3.6
Zinc	4.3