ATOMIC PHYSICS

PHOTOELECTRIC EFFECT

Practical 3

STUDY OF THE EXTERNAL PHOTOELECTRIC EFFECT

1 Introduction

The external photoelectric effect is the emission of electrons (photoelectrons) from the surface of a metal under the influence of light. The electrons (called "photoelectrons") generate a current (called "photocurrent") when moving in an external electric field. The dependence of this photocurrent on the voltage applied to the photocell is nonlinear. The photocurrent increases with increasing voltage only up to a certain limiting value of I_{sat} (photocurrent of saturation).

According to Stoletov's law, under the condition of a constant spectral composition of light incident on the photocathode, the photocurrent of saturation is proportional to the light flux Φ:

$$I_{sat} \sim \Phi , \qquad (1)$$

The existence of a photocurrent at negative voltages at the anode means that the photoelectrons emerge from the cathode with a kinetic energy. If a negative voltage is applied to the anode of the photocell, the photocurrent gradually decreases, vanishing at a certain voltage V_0. Such negative voltage is called athe stopping potential. The maximum initial speed of the photoelectrons, υ_{max}, is related to this voltage V_0 as following:

$$\frac{m\upsilon_{max}^2}{2} = eV_0 , \qquad (2)$$

where e and m are the charge and mass of the electron.

For each photocathode, there is a threshold frequency (or, through $c = \lambda\nu$, threshold wavelength) of the external photoeffect - the maximum length of the light wave λ_{max}, at which the photoelectric effect is still possible. The wavelength λ_{max} depends on the photocathode material and the state of its surface. The threshold frequency of the photoelectric effect is related to the work function W of the metal by the equation:

$$h\nu_{min} = W , \qquad (3)$$

where h – is the Planck constant.

The Einstein equation for the external photoelectric effect reads:

$$h\nu = W + \frac{m\upsilon_{max}^2}{2} , \qquad (4)$$

or as written below, if equation (2) is taken into account

$$h\nu = W + eV_0 , \qquad (5)$$

As one can see from equation (5), the dependence of the stopping potential V_0 on the incident radiation frequency ν

$$V_0 = \frac{h\nu}{e} - \frac{W}{e} , \qquad (6)$$

gives an equation of a straight line (see Fig. 1).

The extrapolation of the straight line in Fig. 1 to the intersection with the vertical axis determines the work function of the metal, while the intersection with the horizontal axis gives the threshold frequency ν_{min} of the photoelectric effect. The gradient line is equal to the ratio of Planck's constant to the electron charge.

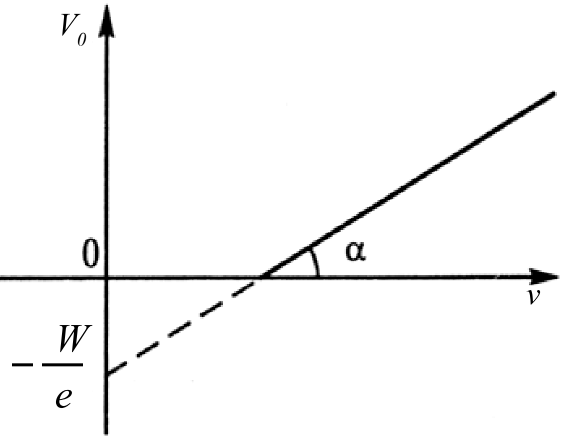

Fig. 1. The dependence of the stopping potential on the frequency of the incident radiation.

Equation (6) can be written for two different frequencies ν_1 and ν_2.Then the Planck constant can be derived from two known ν_1 and ν_2 and two measured stopping potential values V_1 and V_2 as

$$h = e\frac{V_2 - V_1}{\nu_2 - \nu_1}, \qquad (7)$$

while the work function is computed as follows

$$W = e\frac{V_2\nu_1 - V_1\nu_2}{\nu_2 - \nu_1}, \qquad (8)$$

2 Experimental setup

The experimental setup consists of a light source (mercury lamp with a filter unit) and a radiation detector (photocell), which are located on an optical bench. The setup also includes a measuring unit and a luxmeter. The general view of the setup and its schematic are shown in Fig. 2a and 2b.

The filter unit (2) is installed inside the illuminator housing (1) in front of the light source. It consists of a circular frame with four light filters. Behind the filter unit there is a device for adjusting the flux (3), which consists of two polarization filters. The upper part of the source has a switch of the position of the light filters (indicated by the arrow in Fig.2a), and an adjustment ring for changing the flux. The position "1" of the filter unit (see Fig.2c) corresponds to the passage of light without light filters, while the "5" position blocks the light flux from the lamp and can be used to set the zero current. The position "1" of the adjusting ring of illumination (on the yellow scale) corresponds to the maximum illumination, the position "5" - to the minimum. On the front panel of the measuring unit (6) there are two digital LED displays for outputting current and voltage measurement results (Fig. 2d). The "ПРЯМАЯ-ОБРАТНАЯ" button of the front panel of the measering unit is used to switch between the direct and reverse measurement modes, the "СБРОС" button, "+ " and "- " buttons are used to adjust the voltage across the photocell and reset it to zero.

The unit with the photocell (4) is fixed in the socket on the top of the current amplifier housing (5). On the side panel of the photocell amplifier housing there are two adjustment knobs "УСТАНОВКА НУЛЯ": "ГРУБО" and "ТОЧНО" to adjust the current value to zero before the measurements.

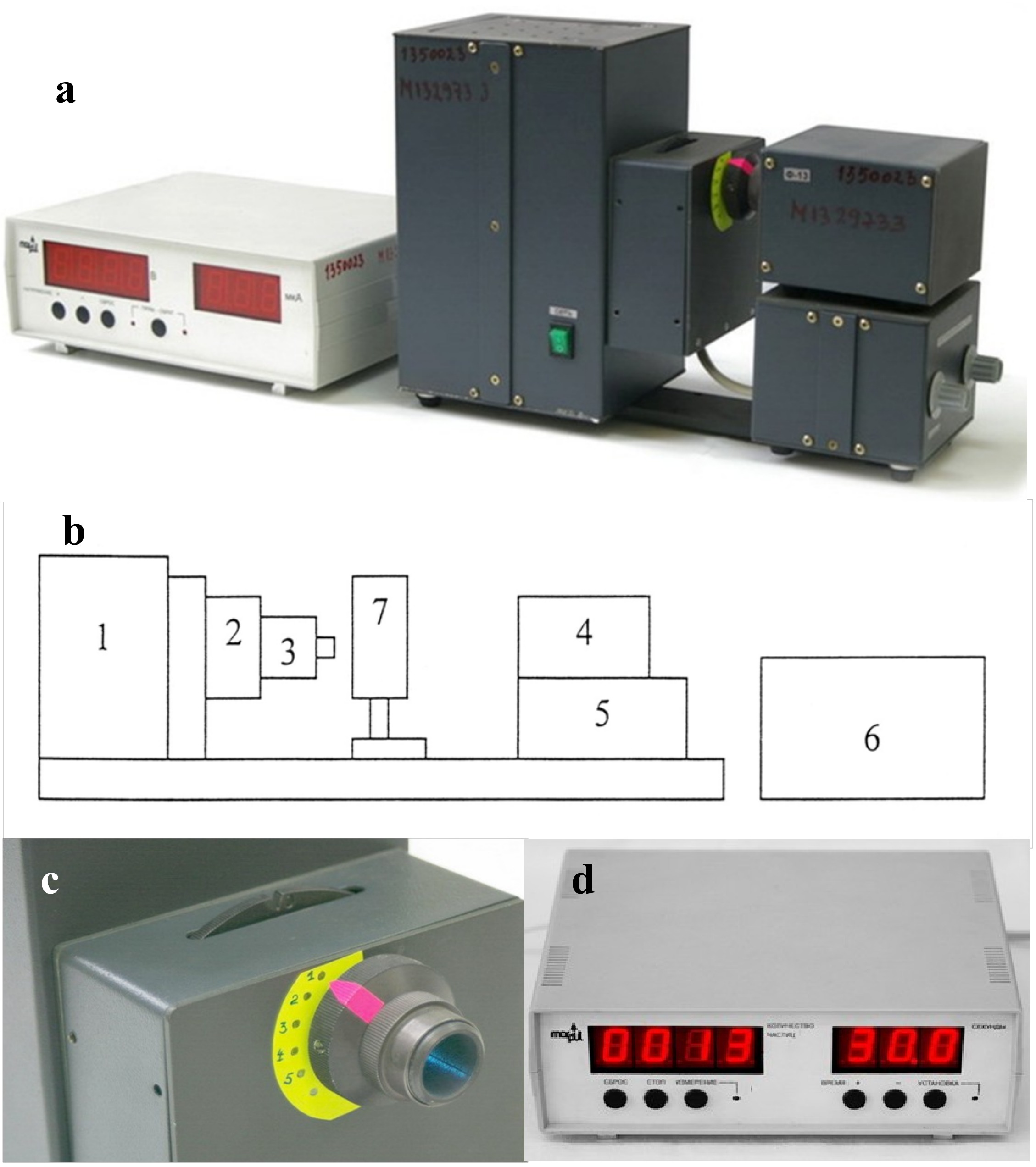

Fig . 2.a) A general view of the setup; b) A schematic of the setup; c) The light filter control system; d) The measuring unit of the setup.

The photocell together with the current amplifier unit can be moved along the optical bench by means of a special carriage. The holder (7) of the luxmeter receiver is located in the slider during the measurements, which is mounted and moved along the optical bench.

3 Measurement and data processing

Task 1. Estimating Planck's constant by the method of a stopping potential.

1. Switch on the measuring unit with the switch "СЕТЬ" on its rear panel. If everything is done right, the indicators "ОБРАТНАЯ", "В" and "мкА" on the front panel should light up. The indicator screen "В" should show four zeros. Wait 5 minutes while the unit warms up. Using the knobs "УСТАНОВКА НУЛЯ" (on the photocurrent amplifier unit) set the zero value on the "мкА" indicator screen.

2. Set the light filter switch (Fig.2c) to the position "5", which completely vanishes the light flux at the output of the source.

3. Turn on the mercury lamp with the switch "СЕТЬ" on the front panel of its' power supply unit. The "СЕТЬ" indicator should light up. Allow the lamp to warm up for 15 minutes.

4. Use the button "ПРЯМАЯ-ОБРАТНАЯ" on the front panel of the measuring unit to set the reverse measurement mode.

5. Position the unit with the photocell on the optical bench so that the input window of the photocell is no more than 0.5 cm away from the output window of the source. Push the movable blende (shutter, which blocks parasitic illumination of the photocell) of the source into the window of the photocell.

6. Place the violet light filter (λ = 4350Å) in front of the lamp, which corresponds to the "2 " position of the filter unit.

7. Set the maximum power of the light source by rotating the adjustment ring (Fig.2c).

8. Changing the voltage values with the help of the buttons "+ " and "- " in the range from 0 V to the voltage $V = V_0$, which completely blocks photoelectrons from reaching the anode, with a step of 0.05 V, record the IV curve of the photocell (negative voltages region on the IV curve). Get 15 data points. Put down the measurement results into table 1.

9. After the measurement is completed, use the button "СБРОС" to sets the voltage to zero.

ATTENTION!!! When determining the stopping potential, it is necessary to measure the current, changing the voltage from zero to the value of V_0 at which the current goes to zero, but not the other way about.

10. Place the green filter (λ = 5460Å) in front of the lamp, by switching the filter unit to the position "3". Repeat the measurements described in items 8-9 above. Put down the measurement results into table 1.

11. Place the yellow filter before the lamp (λ = 5784Å) by switching the filter unit to the position "4". Repeat the measurements described in items 8-9 above. Put down the measurement results into table 1.

Table 1.

λ = 4350Å															
V, V															
I, μA															
λ = 5460Å															
V, V															
I, μA															
λ = 5784Å															
V, V															
I, μA															

12. After the measurements are completed, switch the filter unit to the position "5".

13. Using the results of the measurements, plot the IV curves ($I = f(V_0)$) for three wavelengths.

14. Using formula (7) to estimate Planck's constant using three pairs of wavelengths. Find the average value of *h*.

15. Evaluate the measurement error and indicate possible causes of errors.

16. Using formula (8), estimate the work function.

ATTENTION!!! The mercury lamp should be switched on for no more than 45 minutes !!! After running for 45 minutes, the setup must be switched off for 15 minutes.

Task 2. Study of the IV curve of the vacuum photocell (positive voltages region on the IV curve).

1. Without changing the position of the unit with the photocell on the optical bench, use the button "ПРЯМАЯ-ОБРАТНАЯ" to set the direct measurement mode.

2. Under the condition of zero voltage value and blocked light flux, set the zero current value on the "мкА" indicator using the knobs "УСТАНОВКА НУЛЯ" (if necessary).

3. Switch the filter unit to the position "2", which corresponds to the violet light filter placed in front of the mercury lamp.

4. Set the flux to maximum by turning the dimmer ring.

5. Changing the voltage values in the range from 0 to 40 V (with a step of 2 V) using the "+ " and "- " buttons on the body of the measuring unit. Record the IV curve of the photocell with a constant value of the light flux (get 21 data points).

6. After the measurement in finished, switch the filter unit to the position "5".

7. Put down the measurement results into table 2.

Table 2.

V, V	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
I, μA																					

8. Plot the dependence $I = f(V)$. Note the voltage value at which the saturation current is reached.

Task 3. Verification of Stoletov's law for the photoelectric effect.

1. Without changing the position of the filter unit (violet light filter) and setting the voltage, which corresponds to the saturation current, measure the saturation current I_{sat} of the photocell, for 5 flux values E (corresponding to the fixed positions of the source adjustment ring). Put down the measurement results into table 3.

2. Move the unit with the photocell to the end of the optical bench and place the slider with the holder on the optical bench in front of the source. The luxmeter receiver is placed in the holder.

3. Position the unit with the photocell on the optical bench so that the input window of the photocell is no more than 0.5 cm away from the output window of the illuminator. Push the movable blende (shutter, which blocks parasitic illumination of the photocell) of the source into the window of the photocell.

4. Set the range limit of the luxmeter to 25 lx.

5. Measure the illumination E at the same 5 positions (see task 3, item 1) of the source adjustment ring. Put down the measurement results into the table 3.

6. After the measurements are completed, turn off the setup with the switch "СЕТЬ" (on the lamp and the measuring unit). Set the luxmeter range limit to 500 lx.

Table 3

Ring position	1	2	3	4	5
I_{sat}, μA					
E, lx					
F, lm					

7. Calculate the luminous flux according to the formula:

$$\Phi = \frac{\pi \cdot d^2}{4} E, \qquad (9)$$

where d - is the diameter of the window of the photocell.

8. Put down the results of the calculations into table 3.

9. Using the results of the measurements, plot the dependence $I_{sat} = f(\Phi)$.

4 Questions

1. What is the photoelectric effect?
2. What facts about the photoelectric effect cannot be explained with the wave theory of light?
3. What is called the threshold frequency of the photoelectric effect and what does its value depend on?
4. What is stopping potential?
5. How is Planck's constant determined by the stopping potential method? How is Einstein's equation used in this method?
6. Derive equations (7) and (8).
7. Can you specify the phenomenon opposite to the photoelectric effect?
8. Please, also see the questions after practical 2 "Determination of Planck's constant by means of the stopping potential method".
9. Make an electric schematic demonstrating operation (connection) of the photocell during the measurements (note the difference between the direct and inverse connection of the photocell).