ATOMIC PHYSICS
PHOTOELECTRIC EFFECT
Practical 1
STUDY OF THE PHOTOELECTRIC EFFECT

1 Introduction

The photoelectric effect is the phenomenon of electron emission from the material (metal) surface under absorption of the electromagnetic waves.

Vacuum or gas-filled devices which employ the external photoelectric effect to detect electromagnetic waves are called photocells. The gas-filled photocells are filled with an inert gas at a pressure of 0.005-1 mmHg.

The photocurrent of a vacuum photocell (under the condition of a constant light flux) reaches a saturation level with an increase of the anode voltage. While in the case of a gas-filled photocell, the photocurrent gradually increases with an increase of the anode voltage. At a sufficiently high voltage, the photocurrent sharply increases, initiating a stable glow-discharge begins. The appearance of the stable glow-discharge is unacceptable, since it destroys a photosensitive layer of the photocell.

The ratio of I - the photocurrent to Φ - the light flux incident on the photocell is called *the sensitivity of the photocell*:

$$\gamma=\frac{I}{\Phi}, \qquad (1)$$

The sensitivity of a photocell depends on the anode voltage and the spectral composition of light. The unit of sensitivity is $\mu A \times lm^{-1}$.

The ratio of the number of photoelectrons emitted from the cathode to the number of photons of the incident monochromatic light is called the *quantum yield* of the photoelectric effect.

The number of electrons emitted per second can be found by measuring the photocurrent I under the saturation conditions, while the number of photons can be determined from the light flux incident on the photocell Φ. The quantum yield is thus equal to:

$$\delta=\frac{\left(\frac{I}{e}\right)\cdot K_m}{\left(\frac{\Phi}{h\nu_0}\right)}, \qquad (2)$$

where e - is the charge of the electron, K_m = 683 lm / W – is the light efficiency of the radiation flux at λ_0 = 550 nm, $h\nu_0$ - is the energy of the given photon.

The light flux Φ shining on the photocell can be found from the indications of a luxmeter corresponding to the value of flux density S at a fixed distance r and from the given diameter of the photocell window d :

$$\Phi=\frac{\pi\cdot d^2}{4}S. \qquad (3)$$

2 Experimental setup

The experimental setup consists of a power source, two photocells: 1) СЦВ-4 – vacuum photocell with a antimony-cesium cathode, 2) ЦГ-4 – gas-filled photocell with a cesium cathode; a light source - incandescent lamp; a voltmeter and an ammeter.

The setup is assembled in accordance with the schematic, shown in Fig. 1, together with its general view.

Before the measurements, the photocells are placed on an optical bench in a movable carriage with a distance indicator from a light source.

The light source in this practical can be considered as a point source, since the filament size is small in comparison with the distance *r* from the incandescent lamp to the photocell. The luxmeter is used to measure the flux density.

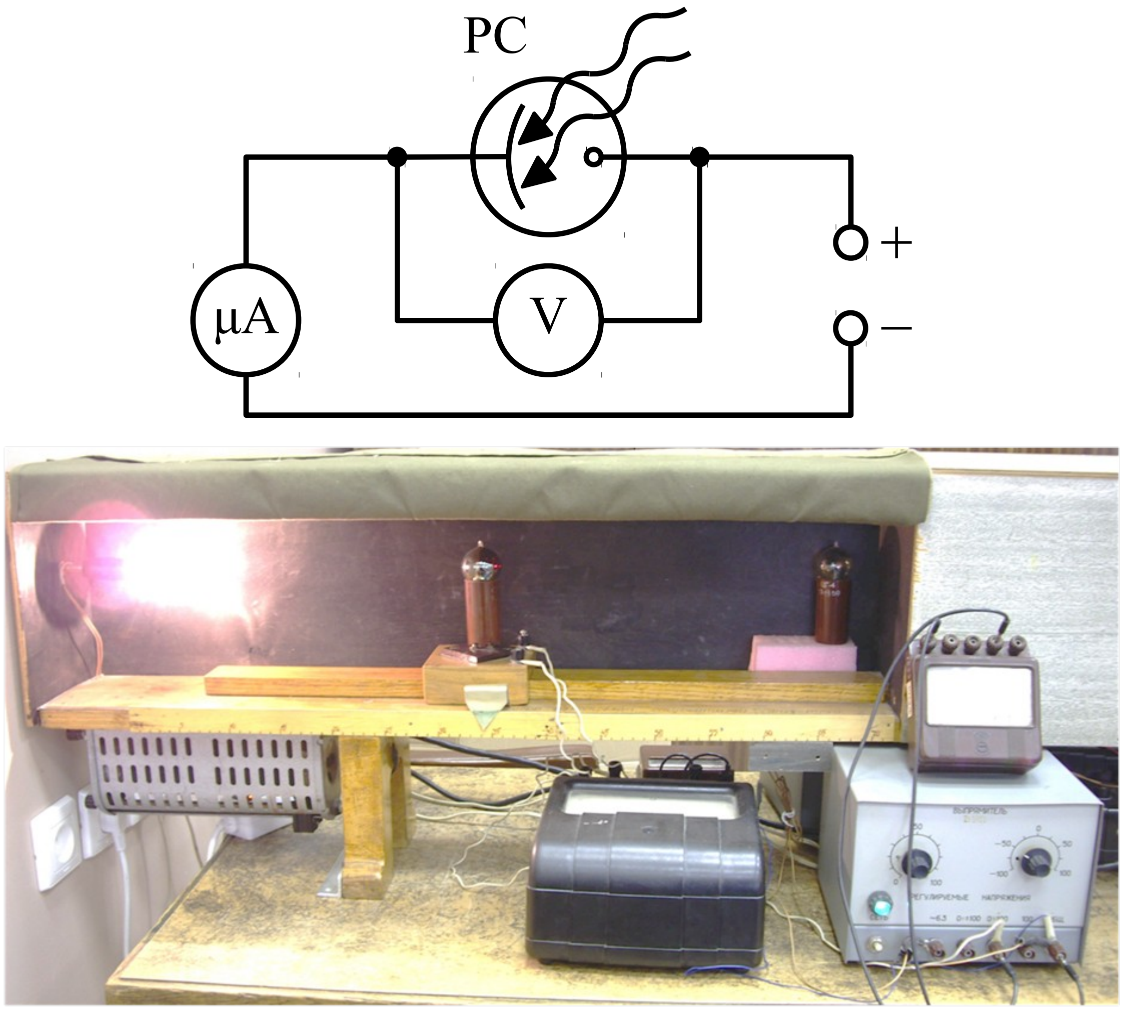

Fig. 1. The electric schematic and the general view of the setup.

3 Measurement and data processing

Task 1. Determination of the dependence of the photocell current on its anode voltage (IV curve) for the СЦВ-4 vacuum photocell.

To perform this task one needs to do the following steps:

1. Place the СЦВ-4 vacuum photocell in the carriage at a certain fixed distance away from the light source (20 or 25 cm).
2. Turn on the power supply.
3. At a constant light flux from an incandescent lamp, measure the photocurrent flowing through the photocell for 13 different values of the anode voltage (IV curve of the photocell). Change voltage from from 0 to 120 V with the step of 10 V.
4. Put down the results of measurements of the current *I* dependence on different values of the anode voltage *V* into table 1.
5. Plot IV curves *I = f (V)* for the given photocell.

Table 1.

V, V		0	10	20	30	40	50	60	70	80	90	100	110	120
СЦВ -4	*I*, μA													
ЦГ-4	*I*, μA													

Task 2. Determination of the dependence of the photocell current on the flux incident on the cathode for the СЦВ-4 vacuum photocell.

1. Place the СЦВ-4 vacuum photocell in the carriage at a certain fixed distance away from the light source (see task 1).
2. At a constant light flux from the incandescent lamp, apply an anode voltage to the photocell which corresponds to the saturation of the photocell (the current saturation).
3. Moving the carriage with a photocell on the optical bench with a step of 5 cm, measure the photocurrent at 8 different positions of the photocell.
4. Put down the results of measurements into table 2.
5. Plot the $I = f\,(1/r^2)$ dependence for the given photocell.

Table 2.

	r, cm								
	$1/r^2$, cm^2								
СЦВ-4	*I*, μA								
ЦГ-4	*I*, μA								

Task 3. Determination of the dependence of the photocell current on its anode voltage (IV curve) for the ЦГ-4 gas-filled photocell.

To perform this task one needs to do the following steps:

1. Place the gas-filled photocell ЦГ-4 in the carriage at a certain fixed distance away from the light source (20 or 25 cm).
2. Turn on the power supply.
3. At a constant light flux from an incandescent lamp, measure the photocurrent flowing through the photocell for 13 different values of the anode voltage (IV curve of the photocell). Change voltage from from 0 to 120 V with the step of 10 V.
4. Put down the results of measurements of the current *I* dependence on different values of the anode voltage *V* into table 1.
5. Plot IV curve $I = f\,(V)$ for the given photocell.

Task 4. Determination of the dependence of the photocell current on the flux incident on the cathode for the ЦГ-4 gas-filled photocell.

1. Place the gas-filled photocell ЦГ-4 in the carriage at a certain fixed distance away from the light source (see task 3).
2. At a constant light flux from the incandescent lamp, apply an anode voltage to the photocell which corresponds to the saturation of the photocell (the current saturation).
3. Moving the carriage with a photocell on the optical bench with a step of 5 cm, measure the photocurrent at 8 different positions of the photocell.
4. Put down the results of measurements into table 2.

5. Plot the $I = f(1/r^2)$ dependence for the given photocell.

Task 5. Calculation of the sensitivities of the photocells.

1. Using a luxmeter, measure the flux density at the photocell window. An effective diameter of the photocell window is equal to 3,7 cm. To do this, move the photocell carriage to the end of the optical bench, place the sensitive element of the luxmeter on the optical bench at a certain distance away from the light source. Use the same distance value as in the task 1. Set the luxmeter limit to 500 lux (with the matte cover removed). Measure the flux density at the chosen distance.

2. Using formula (1), calculate the sensitivities of the photocells. Calculation of the sensitivity for a vacuum photocell should be done at the current, which corresponds to the saturation regime.

Task 6. Evaluation of the quantum yield of a photoelectric effect for a vacuum photocell.

Using formulas (2) and (3) together with the saturation current value obtained in task 1, calculate the quantum yield of the photoelectric effect for the antimony- cesium vacuum photocell.

4 Questions

1. Why are light sensitive layers of photocells, which are designed for the visible range, fabricated from alkaline metals?
2. Explain the difference between the IV curves of vacuum and gas-filled photocells.
3. Explain the difference of the behavior of the dependence of the photocurrent on the flux incident on vacuum and gas-filled photocells.
4. Prove the statement that the dependence of the magnitude of the photocurrent on $1/r^2$ (r is the distance between the photocell and the point light source) should be linear.
5. At what current level/regime is the sensitivity of the gas-filled photocell calculated?
6. List the empirical relations of the photoelectric effect. Which relations can't be explained within the framework of the wave theory of light?
7. What is the threshold frequency of the photoelectric effect? What does define the value of the red border for any given case?
8. Why is the quantum yield much less than unity? Can the quantum yield of the photoelectric effect be greater than unity?
9. Explain the construction and the operation principle of a photomultiplier tube. What is the advantage of a photomultiplier tube over an ordinary photocell?
10. What experimental facts indicate the indivisibility of the energy of a single photon?
11. 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).