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Exercise 374

Study of the photoelectric cell

Dependency research of the photoelectric current from the distance between light source and photoelectric cell surface

r	[m]											
r^{-2}	[m^{-2}]											
I_f	[μA]											

Verification the light absorption law

Number of plates, n		0	1	2	3	4	5	6
I_f	[μA]							
$\ln I_f$								

Exercise 374. Study of the photoelectric cell

Principles of Photoelectric cell operation

The *internal photoelectric phenomenon* is used in photoelectric cells, which consists of the release of valence electrons from atomic bonds in semiconductor crystals. The liberated electrons remain inside the crystal and can move freely in it. The site after the released electron can be taken by an electron from the adjacent bond. Then the lack of an electron in the bond, i.e. the so called *electron hole (simply called a hole),* moves to the adjacent binding. Thus, both photoelectrons and holes can move through the crystal and thus conduct electricity. The effect of the internal photoelectric effect is therefore an increased electrical conductivity of the crystal.

The valence electrons have energy only in a certain range of energy values called the *valence band.* Likewise, conduction electrons can only assume certain energy range values from the *conduction band* (lies above the valence band). In a semiconductor, the conduction band and the valence band are separated by a *band gap* or *energy gap (E_g).* The width of band gap is equal to the binding energy of valence electrons. The E_g value define the minimum frequency of light ν_g that can be transferred by an electron from the valence band to the conduction band. The condition for the release of an electron is that the energy of the photon $E_f = h\nu_f$ is equal to or greater than the band gap E_g:

$$h\nu_f \geq E_g = h\nu_g \, , \tag{1}$$

where h is a Planck constant. For example, band gap of selenium is equal 2 eV. This mean that the maximum wavelength of light capable of releasing a valence electron in this semiconductor is about 620 nm (orange light). This value is calculated from the relationship between the wavelength and frequency, given as: $\lambda_{\max} = c/\nu_g$.

When electron and hole are in the same place in the semiconductor, then electron occupy the empty state associated with a hole. With this action both carriers disappear. This process is called *Recombination*. The number of recombination per time unit depends on the concentration of charge carriers, with the time of light incidents on semiconductor surface, the number of carriers increases, which causes an increase of recombination. Over time, a dynamic equilibrium is established, in which the additional number of carriers depends on the number of generated electron-hole pairs per time unit, so on the illumination intensity. The light only reaches the subsurface layers of the semiconductor, thus to increase the effect of lighting, the photosensitive material should be as thin and as large as possible.

The internal photoelectric effect in the double layers, each of which is characterized by another type of conductivity, manifests itself in the form of the *photovoltaic effect*. This effect consist in the fact that double layers upon exposure to light, e.g. a metal-semiconductor junction, can generate electric current. Photosensitive double layers are called *photoelectric cell*, *solar cell or photovoltaic cell.*

A schematic diagram of a selenium photoelectric cell is shown in Figure 1. It consists of a thin layer of selenium placed below a thin film of lead or gold, which fulfils the role as an electrode. The combination is placed over on iron plate, which is also the electrode of the photoelectric cell.

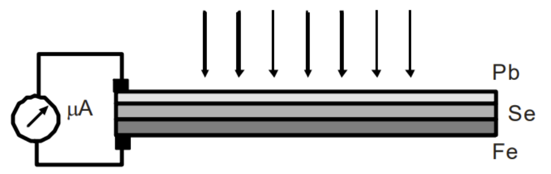

Figure 1. Selenium photoelectric cell structure

A thin barrier layer is formed at the metal-semiconductor junction of positive charges on the metal side and negative charges on the semiconductor side. It is the result of the diffusion of electrons from the metal into the semiconductor under influence by a significant difference in the concentration of charge carriers in metal and semiconductor. The barrier layer prevents the further flow of electrons into the semiconductor.

When light falls on the surface of junction from the side of the thin lead layer, it cause the release of additional free electrons from the selenium layer. Under the influence of the potential difference in the barrier layer, electrons immediately pass into the sputtered lead layer, negatively charging it, concerning to the lower iron electrode, which is not reached by light. As a result, an electric current I_f will flow in the circuit obtained by connecting the poles of the photoelectric cell, which is proportional to the illuminance *E* of the photoelectric cell surface.

Dependence $I_f = \mathrm{f}(E)$ can be easily estimated in the case of a point light source. Illuminance of a surface from a point source is inversely proportional to the square of the distance from the light source:

$$E = \frac{I}{r^2}\cos\alpha , \tag{2}$$

where *I* is intensity of a light source (power radiated by a point source per unit solid angle), α is light incident angle (the angle between the direction of the incident light and the normal to the plane). *E* is proportional to r^{-2}, the graph of the dependence of the photoelectric current I_f on r^{-2} is also a graph of the dependence on the illuminance *E* of the photoelectric cell surface. Dependence $I_f = \mathrm{f}(r^{-2})$ should be a straight line (at distances for which the linear dimensions of the light source can be disregarded).

Absorption of electromagnetic radiation

The attenuation of light passes through transparent media is mainly caused by absorption. According to the Beer-Lambert law, the intensity of light *I* decreases exponentially with increasing thickness of the absorbing medium:

$$I = I_0 e^{-kx} , \tag{3}$$

where I_0 is the intensity of the incident light, *k* is the absorption coefficient. Here, the light intensity is defined as a power of the radiation passing through unit area perpendicular to the direction of the light.

Equation (3) can be checked by placing glass plates of the same thickness in path of light incident on the photoelectric cell. Photoelectric current I_f is directly proportional to the intensity of light *I*, so the function $I_f = \mathrm{f}(n)$ (where, *n* is number of plates), should be an exponential curve. Thus, the graph of the natural logarithm of the current I_f on the number of plates n along the path of the light beam, should be straight line.

Performance of the task

Investigation of the dependence of the photoelectric current from the distance between light source and photoelectric cell surface

1. Mount the photoelectric cell on the optical bench and place it far from the light source, at the beginning of the optical bench.
2. Connect the photoelectric cell to the microammeter ("plus" to "plus" in the case of a pointer meter). In a digital microammeter, we use the " **COM**" and " **mA**" inputs and set the range switch to "**μA**" (DC values from a few to several dozen microamperes will be measured).
3. Turn on the lamp and carry out measurements of the photoelectric current I_f at different distances *r* of the photoelectric cell surface from the **bulb filament**. We reduce these distances, every 0.05 m, from the maximum value (1 m) to not less than 0.5 m.
4. Calculate for each *r* value r^{-2} and plot the graph $I_f = \mathrm{f}(r^{-2})$.

Verification the law of light absorption in transparent medium

1. Place the photoelectric cell at a distance of 40÷50 cm from the light source.
2. Place a tripod with a frame filled with a glass plates in front of the photoelectric cell.
3. Record the initial readings of the microammeter and also after each removed glass plate.
4. Plot the graph between the natural logarithm of the current I_f and the number of plates *n* along the path of the light beam, $\ln I_f = \mathrm{f}(n)$.

Analyze the obtained charts.

Calculation of the uncertainties

Dependency research $I_f = \mathrm{f}(r^{-2})$. The absolute error Δr^{-2} we calculate using the total differential method:

$$\Delta\left(r^{-2}\right) = \left|\frac{\partial r^{-2}}{\partial r}\right| \cdot \Delta r \quad \Rightarrow \quad \Delta\left(r^{-2}\right) = \frac{2 \cdot \Delta r}{r^3}, \qquad \Delta r = 5 \cdot 10^{-3}\,\mathrm{m}.$$

The measurement of ΔI_f is determined based on the accuracy of the used device.

- In the case of a pointer meter $\Delta I_f = \dfrac{K \cdot Z}{100}$;

  Z - maximum current value for a given measuring range, K - meter class given in the measurement window.
- In the case of a digital meter, the accuracy is given in the manual of the device. Here, you can assume that the accuracy is equal 0,5 μA.

Verification the law of light absorption For a given *n*, we mark the absolute errors $\Delta \ln I_f$ on the graph $\ln I_f = \mathrm{f}(n)$ (determined by the total differential method),

$$\Delta \ln I_f = \frac{\Delta I_f}{I_f}.$$

If we use an digital meter, due to not very large changes in the current intensity a relative error can be assumed $\dfrac{\Delta I_f}{I_f} = 0{,}02$ for all measurements I_f.

Calculate the errors for *two* or *three* measurement points and mark them on the graph as an error rectangles around these points.