**Study of Photoelectric Effect. Determination of Planck 's constant.**

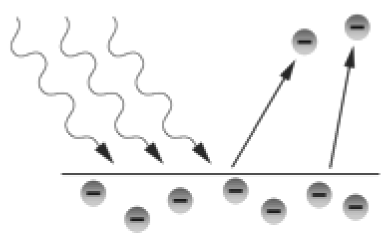
## 1. Photoelectric Effect

The dual nature of light, that light exhibits characteristics of waves and particles at different times is connected to the photoelectric effect. The photoelectric effect is explained considering the light made by photons, so light has characteristic of particles.

The *photoelectric effect* is the emission of electrons from matter upon the absorption of electromagnetic radiation, such as ultraviolet radiation or X-rays.

The photoelectric effect was explained mathematically by Albert Einstein, who extended the work on quanta developed by Max Planck. Einstein established the equation of photoelectric effect, also called the Einstein equation for photoelectric effect. The light is made by photons. Photon (quanta of light) interacts with substances. The absorption of single quanta of light explains the photoelectric effect. The idea of light quanta was motivated by Max Planck's law of black-body radiation. Einstein's explanation of the photoelectric effect won him the Nobel Prize in 1921.

Exposing a metallic surface to electromagnetic radiation, the photons are absorbed and electrons are emitted, and current is produced.



Photoelectric Effect*

The electromagnetic radiation must have the frequency equal or bigger than the *threshold frequency* $\nu_{threshold}$. The threshold frequency is specific to the type of surface and material.

No electrons are emitted for radiation with a frequency below that of the threshold, as the electrons are unable to gain sufficient energy to overcome the electrostatic barrier presented by the termination of the crystalline surface. This electrostatic barrier is the material *work function*

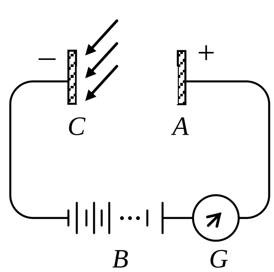
$L_{function}$, the minimum energy required to remove an electron from atomic binding. Alkaline metals have the smallest values for work function. Some values for the work function are given in the table below.

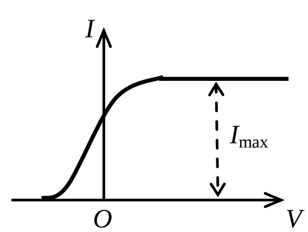
| **Metal** | Li | Na | K | Rb | Ce |
|---|---|---|---|---|---|
| **Work Function (*eV*)** | 2,5 | 2,1 | 2 | 1,5 | 1,4 |

Photoelectric cells work in visible, UV or infrared in function of the values of the work function. Some cells (with Na and K) work in UV and others (with alloy of Cs) in infrared.

The emitted electrons are called *photoelectrons*. The energy of the photon is absorbed by the electron and, if sufficient, the electron can escape from the material with a finite kinetic energy. A single photon can only eject a single electron, as the energy of one photon may only be absorbed by one electron. The photons of the light beam have a characteristic energy given by the wavelength of the light. In the photoemission process, an electron can be ejected from the material if absorbs the energy of one photon and has more energy than the work function. If the photon energy is too low, however, the electron is unable to escape the surface of the material. Increasing the intensity of the light beam does not change the energy of the constituent photons, only their number. The energy of the emitted electrons does not depend on the intensity of the incoming light.

Photoelectric effect is studied with a photoelectric cell and the variation of photoelectric current intensity with respect voltage is given in the figure below. The photoelectric current intensity increased from zero, has some values and reaches the maximum value $I_{max}$.




**2. Laws of Photoelectric Effect**

1. The photoelectric current intensity is proportional to the intensity of the light.

2. The energy of the photoelectrons increased with increasing frequency of incident light (1905).
3. The photoelectric effect occurs only for frequencies equal or bigger than the *threshold frequency* $\nu_{threshold}$. The threshold wavelength is in visible for alkaline metals and in UV for the majority of the other metals. Some examples of threshold wavelength are given in the table below.

| **Metal** | Li | Na | K | Ta | Hg | Au | Fe | Ag |
|---|---|---|---|---|---|---|---|---|
| $\lambda_0$ (Å) | 5000 | 5400 | 5500 | 3050 | 2735 | 2650 | 2610 | 2610 |

4. The photoelectric effect occurs in a very small time $10^{-9}$ s.

## 3. Einstein's equation for photoelectric effect

Enunciation of Einstein's equation (1905) for photoelectric effect is: *the energy of photon is equal to the energy needed to remove an electron plus the kinetic energy of the emitted electron.*

Einstein's equation for photoelectric effect was in good concordance with Millikan's experiments (1916).

The mathematical statement is given by:

$$h\nu = L_{\text{function}} + \frac{1}{2}mv^2, \tag{1}$$

or

$$h\nu = eV_0 + \frac{1}{2}mv^2, \tag{2}$$

where $h\nu$ is the energy of photon, the expression of the work function is replaced by $eV_0$ which is the energy needed to overcome the electrostatic barrier, $h$ is Planck's constant, $\nu$ is the frequency of the incident photon, $\frac{1}{2}mv^2$ is the maximum kinetic energy of ejected electrons, $e$ is the electric charge of electron, $m$ is the mass of the ejected electron, $v$ is the velocity of the ejected electron.

Furthermore, one gets:

$$\frac{1}{2}mv^2 = eV_s, \quad (3)$$

where $V_s$ is the *sticking voltage* – the value of voltage corresponding to the zero value of the photocurrent. The Einstein equation becomes:

$$h\nu = eV_s + L_{\text{function}}. \quad (4)$$

Einstein explained the equation of photoelectric effect considering that light is made by photons. More quanta generate bigger values for energy. Some effects for UV and X-rays are highlighted by the light characteristic of particles. Einstein's equation for photoelectric effect was studied by Millikan (1916) who won the Nobel Prize in 1923, and after this by Lukirski (1928). The Planck's constant was obtained from studies.

**Apparatus and Equipment**

Photoelectric cell, filter for frequency with six positions, source of light, galvanometer.

**Measurements**

1. Determining the sticking voltage by changing the position of the filter and applying the light.
2. The values of the frequency are known.
3. Determining $a$ and $b$ of the straight line $V_b = \frac{h}{e}\nu - \frac{1}{e}L_{function}$, with $V_b$ the *sticking voltage*. Making the graph with $\nu$ on x-axis and $V_b$ on y-axis, and calculating the points using $a$ and $b$.
4. Calculating Planck's constant from $b = \frac{h}{e}\nu$ and the work function from $a = \frac{1}{e}L_{function}$.

**Results**

| No. crt. | $\nu \cdot 10^{14}$ $(Hz)$ | $V_0$ $(V)$ | $h\,(J \cdot s)$ | $L_{function}$ $(eV)$ |
|---|---|---|---|---|
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