Determination of Planck's Constant by Photoelectric Effect

Experiment No:

Date:

1 Aim

1. To determine the Planck's constant by photo electric effect.
2. To determine the work function 'ϕ' of a metal.

2 Definitions

2.1 Planck's Constant

Planck's constant (h) is a fundamental physical constant, which describes the behaviour of particles and waves on the atomic scale. It was introduced by German physicist Max Planck in the year 1900 in his work on black body radiation. The significance of Planck's constant is that radiation, such as light, is emitted, transmitted, and absorbed in discrete energy packets, or quanta, determined by the frequency of the radiation and the value of Planck's constant. The energy E of each quantum, or each photon, equals Planck's constant h times the radiation frequency (ν), i.e., $E = h\nu$.

2.2 Photoelectric Effect

The photoelectric effect refers to the emission, or ejection, of electrons from the surface of, generally, a metal in response to incident light. Energy contained within the incident light is absorbed by electrons within the metal, giving the electrons sufficient energy to be 'knocked' out of, that is, emitted from, the surface of the metal.

3 Theory

An electron in a metal can be modelled as a particle in an average potential well due to the net attraction and repulsion of protons and electrons. The minimum depth that an electron is located in the potential well is called the work function of the metal, ϕ. In other words, it is a measure of the amount of work that must be done on the electrons (located in the well) to make it free from the metal. Since different metal atoms have different number of protons, it is reasonable to assume that the work function (ϕ) depends on the metal. This is also supported by the fact that different metals have different values for electrical properties that should depend on the electron binding including conductivity. The shallower the well (i.e. the lower the work function 'ϕ'), less is the energy required to cause the emission of the electron. If we shine a light with sufficient energy then an electron is emitted.

When a photon with frequency 'ν' strikes the surface of a metal, it imparts all of its energy to a conduction electron near the surface of the metal. If the energy of the photon (hν) is greater than the work function (ϕ), the electron may be ejected from the metal. If the energy is less than the work function, the electron will simply acquire some kinetic energy that will dissipate almost immediately in subsequent collisions with other particles in the metal. By conservation of energy, the maximum kinetic energy with which the electron could be emitted from the metal surface T_{max} , is related to the energy of the absorbed photon hν, and the work function ϕ, by the relation,

$$T_{max} = \frac{1}{2}mv_{max}^2 = h\nu - e\phi \tag{1}$$

Now consider the case of electrons being emitted by a photocathode in a vacuum tube, as illustrated Fig. 1. In this case, all emitted electrons are slowed down as they approach the anode, and some of their kinetic energy is converted into potential energy. There are three possibilities that could happen.

1. First, if the potential is small then the potential energy at the anode is less than the kinetic energy of the electrons and there is a current through the tube.

2. The second is if the potential is large enough the potential energy at the anode is larger than the kinetic energy and the electrons are driven back to the cathode. In this case, there is no current.

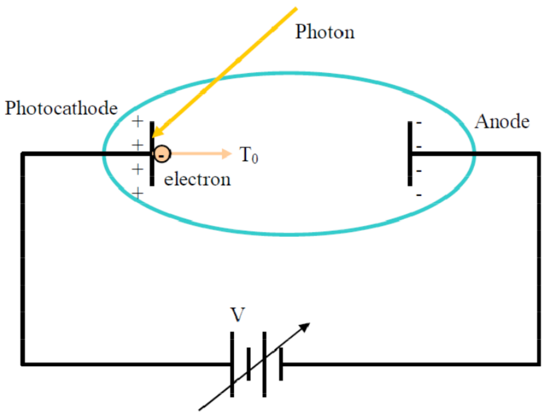

FIGURE 1

Schematic of a vaccum phototube

3. The third case is if the voltage just stops the electrons (with maximum kinetic energy T_{max}) from reaching the anode. The voltage required to do this is called the 'stopping potential' (V_0).

Thus Eq. 1 can be rewritten as,

$$eV_0 = h\nu - e\phi \tag{2}$$

$$V_0 = \frac{h}{e}\nu - \phi \tag{3}$$

The linear regression of Eq. 3 with experimental data can be used to calculate the h and ϕ values.

4 Apparatus

The present experimental set-up (Fig. 3) comprises of a tungsten light source with five different colour filters, a Cesium-type vacuum phototube, a built-in power supply and a current multiplier. The base of the phototube is built into a dark room and in front of it a receptor (pipe) is installed to mount filters.

5 Procedure

1. Plug in and switch on the apparatus using the red button at the bottom right corner of the set up.

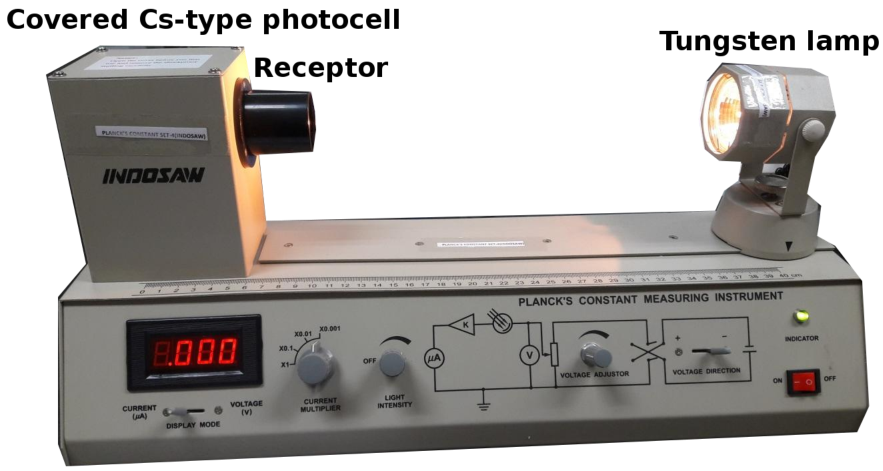

FIGURE 2

Experimental setup to measure photoelectric effect

2. Before the lamp is switched on, put the toggle switch in current mode and check that the dark current is zero.

3. Turn on the lamp source. Set the light intensity near to maximum. Note that the intensity should be such that the value of current should not exceed the display range. In case it happens, you need to reduce the intensity. You should not change intensity while taking data.

4. Insert one of the five specified filters into the drawtube of the receptor.

5. Now, set the voltage direction switch to '-ve' polarity. Adjust the voltage knob at minimum and current multiplier at X 0.001. Vary the voltage and record the current till the value of current becomes 0. Use the display mode switch to record the values of voltage each time.

6. Repeat the steps 4 and 5 for all the filters provided.

7. Fill up the observation tables and draw necessary plots. Determine the values of planck's constant and work function of the metal used in the phototube.

6 Formula's and constants

1. Standard Planck's constant = 6.626×10^{-34} Js

2. Frequency of light $\nu=\frac{c}{\lambda}$, where c is the velocity of light in vaccum (3×10^8 m/s) and λ is the wavelength of light

3. Charge of the electron (e) =1.602$\times$10^{-19} C

4. Linear regression formula: $y = mx + c$

5. Slope=b/a=$\frac{\Delta\nu}{\Delta V_0}$

6. From the linear fit of the experimental data in graph resembles Eq. 3.

   (a) So, h/e = Slope, and h = Slope $\times$ e and

   (b) The intercept of the graph equals to work function of the metal

7. 'h' Error $\%$ = (6.626-$h_{(calc)}$)/6.626)$\times$100 $\%$

7 Observations

7.1 Specification of filters

Colour	Blue	Green	Yellow	Orange	Red
Wavelength (nm)	460	500	540	570	635
Frequency (Hz)					

7.2 Stopping Potential

Colour	Blue	Green	Yellow	Orange	Red
Frequency (Hz)					
Stopping potential (V_0)					

7.3 Graph

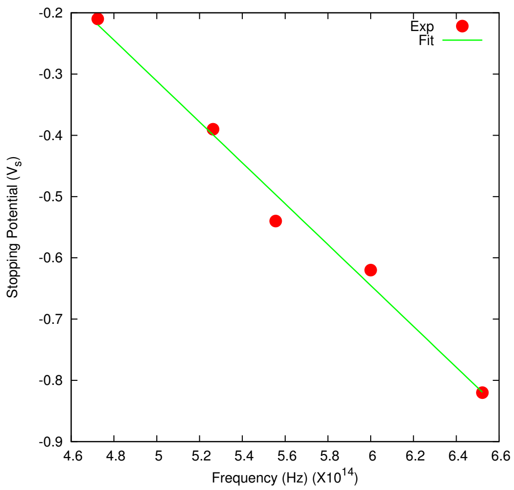

FIGURE 3

Sample graph for stopping potential vs. frequency

8 Results

1. Calculated Planck's constant value h=____________________

2. 'h' Error $\%$ =____________________

3. Calculated working function (ϕ) of the metal=____________________

Instructor comments:

Signature

9 Assignments

1. Does the calculated work function is accurate?

2. What would happen to current and voltage if you use a positive polarity as the voltage direction?

3. What would happen if you replace the photocell with a p-n junction LED light?

10 References

10.1 Basics

1. http://www.popularmechanics.com/science/news/a21490/what-is-plancks-constant/

2. https://youtu.be/vuGpUFjLaYE

10.2 Experiment

1. http://web.mit.edu/lululiu/Public/pixx/not-pixx/photoelectric.pdf

2. http://demoweb.physics.ucla.edu/content/experiment-6-photoelectric-effect

3. https://www.youtube.com/watch?v=pOBfwbu6VGQ