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Determination of Planck's Constant Using the Photoelectric Effect Experiment

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Abstract. Planck's constant experiment has been carried out to determine the value of Planck's constant using the regression analysis method. The steps are carried out using the scientific process outlined in the practical work steps. The specification of the experimental equipment uses the Planck constant experimental set with 12v/35w tungsten halogen light, 15v output, +-0.2% accuracy, 220V power requirement, 0.5A fuse rating and red, yellow 1, yellow 2, and red color filters, green and blue. Experiments using the concept of the photoelectric effect phenomenon began by irradiating metallic materials with light using a filter. The wavelength (635, 570, 540, 500, 460) nm is the light filter variation. The wavelength that hits the metal material is selected by placing a light filter on the light propagation path toward the metal material. So the light that passes through the filter is only light with a certain wavelength. After the metal material is irradiated by light with a certain wavelength, then the stopping potential voltage measurement is carried out on the metal material irradiated by light. From the variation of the light filter used, it is possible to calculate Planck's constant using the regression method with the value obtained 6.26x10^{34}. This value is very close to the actual Planck's constant value which is 6.62x10^{34} so an error value is obtained 4.23%. With 95.77% accuracy, Planck's constant value obtained from the calculation using the linear regression method can be said to be very close to the actual Planck's constant value.

1. Introduction.

In the last years of the 19th century, Planck investigated the black-body radiation problem which was first proposed by Kirchhoff about 40 years earlier. It is known that hot objects will shine [1]. The hotter the objects, the brighter the light. The electromagnetic field suits the laws of motion similar to the mass in a spring and reaches thermal equilibrium with hot atoms [2]. A hot object in equilibrium with light absorbs as much as it releases. If the object is black, it absorbs all incoming light, so the emission of thermal light leads into maximum [3]. Planck hypothesized that the equations of motion for light describe a group of harmonic oscillators, one for each possible frequency. He tested how oscillator entropy varies according to the object's temperature, tried to match Wien's law, and derived a mathematical function for the black-body spectrum [4]. Planck's constant is a set of measurement unit defined using only five universal physical constants and defined in such a way so that all these five constants are valued as 1 when expressed using these units. These units were proposed in 1899 by physicists Max Planck. Conceptual thought in classical physics with Planck's constant, a constant widely used in Quantum Mechanics. Planck concluded that atoms and molecules could emit or absorb only a certain amount of energy. The smallest amount or packet of energy that can be emitted or absorbed by atoms or molecules in the form of electromagnetic radiation is called quantum. Planck discovered that the energy of a photon (quantum) is directly proportional to the frequency of light. The principle of the photoelectric effect is used to get the value of Planck's constant [5]. So in carrying out the experimental steps in addition to using and referring to mathematical equations, there are aspects of science process skills that are applied. Science process skills are activities or activities that students must do in finding and processing the results obtained in the form of practicum to then be used as new knowledge for themselves [6]. The correlation between maximum photoelectron energy Kmax and the frequency of the incoming light can be expressed in the form:

$$K_{max} = h(V - V_o) = hV - hV_o \qquad \ldots\ldots(1)$$

Vo is the threshold frequency, there is no photoemission in the threshold frequency and h is a constant, that is:

$$h = 6.626 \times 10^{-34}\ J.s \qquad \ldots.(2)$$

Planck derived a formula that describes spectrum radiation, the spectrum of light, which is the relative brightness of the various wavelengths that exist. Planck's formula is:

$$E = h\nu \qquad \ldots\ldots(3)$$

Where h is Planck's constant, the value is 6.626×10^{-34} J.s [7].

when that surface absorbs electromagnetic radiation (like visible light and ultraviolet radiation) which is above the threshold frequency depending on the type of surface, electrons in the metal will be released [8]. The released electrons from the metal surface produce electric potential on the metal material . Because of the potential difference in the circuit (electric circuit including metal material in it), then electric current will be able to flow. Current flows from high potential to low potential [9]. Stopping potential is a voltage value that causes electrons to stop being released from the metal surface in the photoelectric effect. There is a voltage in the photoelectric effect circuit, where the positive pole is connected to the negative pole. Then there is a voltage value that causes the current to be zero .

2. Experimental Details.

In this experiment, a set of Planck's constants and a set of 5 light filters were used [10]. A set of Planck's constant has specifications for 12v/35 w halogen tungsten lamp; 15v output; +-0.2% accuracy; -10 °C to 60 °C relatively humidity storage; 0°C to 50°C operating temperature; 220 V power requirement; 0.5 A fuse rating; power cord with plug 3; red, yellow 1, yellow 2, green, and blue color filters. Experimental tools are shown in Figure 1.

Figure 1. Planck's Constant Experimental Tools Set

The first step in this experiment is to adjust the distance to the light source as far as 35 cm. The distance determines the distance between the light source and the light filter. There are five light filters used which are shown in Figure 1. The light filters used are red, yellow 1, yellow 2, green and blue. Which is where each filter has a different wavelength. Continue to adjust light intensity on medium level. Then calibrate the tools by providing a medium light intensity with the speed of light in a closed drawtube [11]. Illustration can be presented as shown in Figure 2.

Figure 2. Radiation towards Crawtube

In Figure 2 it is shown the second stage is measuring the stopping potential by installing a light filter starting with a wavelength of 635 with a red color filter [12]. The light filter is installed by opening the drawtube so that light enters and shines on the metal in the chamber cover as shown in Figure 3.

Figure 3. Experiment taking stopping potential data with a wavelength of 635 nm.

In Figure 2 it is explained when the light entered has been filtered so that only light with a wavelength of 635 nm hits the metal. After that, it will read the current in the display mode, then change the direction of the voltage to (-), and then adjust the voltage until get a current value of 0 μA. Continue to change the display mode to voltage mode so that the voltage value is obtained as shown in Figure 4.μA

Figure 4. Changing the Display Mode to Voltage Mode.

In Figure 4, it is obtained that the stopping potential value is -0.29 Volts. The minus sign is a picture of the opposite direction to the current [13]. The next step is to conduct a similar experiment using 4 different filters with wavelengths of 570, 540, 500, 460 nm. After the experimental results are obtained, the fourth stage is data processing by calculating the frequency of light. After obtaining the light frequency value of each wavelength and potential stopping value, a graph is made based on the data. From the graph, the linear regression value will be obtained with the equation:

$$y = mx + b \quad \text{......(4)}$$

This equation will be used to calculate the value of Planck's constant. Graph uses to determine the value of gradient (m). where the x-axis is the value of frequency (f) and the y-axis is the value of stopping potential (V_s)[13]. From the data on graph, the equation can be obtained:

$$m = \frac{\Delta V_s}{\Delta f} \quad \text{........(5)}$$

$$E_{cahaya} = W + Ek_{elektron} \quad \text{........(6)}$$

$$hf = hf_o + eV$$

$$eV = hf - hf_o$$

$$V = \frac{h}{e}f - \frac{h}{e}f_o$$

From the equation above, it can be seen that it forms a straight line equation same as equation 4. So it can be concluded that the gradient of a straight line is equal to $\frac{h}{e}$ or written as follows:

$$m = \frac{h}{e} \quad \text{........(7)}$$

$$h = m\,e \quad \text{........(8)}$$

The steps in this experiment are described in Figure 5.

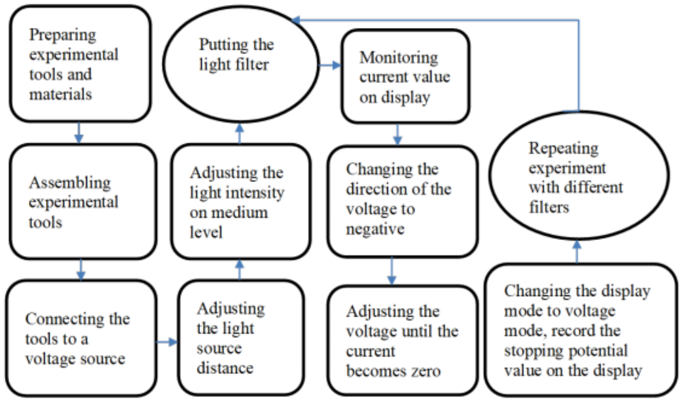


Figure 5. Flow chart of Work steps

3. Results and Discussions.

Based on experiments that have been carried out using variation of light filters with wavelengths (635, 570, 540, 500, 460) nm, the light filter colors used are red, yellow 1, yellow 2, green and blue. From this experiment, the value of current and stopping potential (Vs) are obtained [14]. The data can be seen in Table 1:

Table 1. Experimental Data Using Light Filter Variations

Filter colours	Wavelength (nm)	Current (A)	Stopping Potential Vs (Volt)
Red	635	0,189	-0,34
Yellow 1	570	0,507	-0,52
Yellow 2	540	0.772	-0.66
Green	500	0.802	-0.84
Blue	460	0.817	-1.07

From the data obtained, it can be analyzed that the current obtained from the light filter variation experiment with a wavelength of (635, 570, 540, 500, 460) nm, the resulting current will increase if a filter with a shorter wavelength is used. With this, it can be said that the resulting current is inversely proportional to the wavelength. The ratio of current to stopping potential is directly proportional, the greater current generated then the larger stopping potential required. Stopping potential value is negative (-) because it is a reverse stopping voltage in the opposite direction to the current generated. Stopping potential value varies depending on how much current is generated by the metal irradiated by light with various wavelengths [15]. To get the value of Planck's constant, the first calculation is carried out to get the frequency value of each light that has passed through the light filters. The frequency calculate using the following equation:

$$\text{Frequency} = \frac{c}{\lambda} \qquad \ldots\ldots(9)$$

Example of the frequency calculation:

Frequency = 3.10^{8}/ 0.000000635

= $4.72\ 440944.10^{14}$

The results of the data calculations are in Table 2:

Table 2. Light Frequency Using Filter Variations

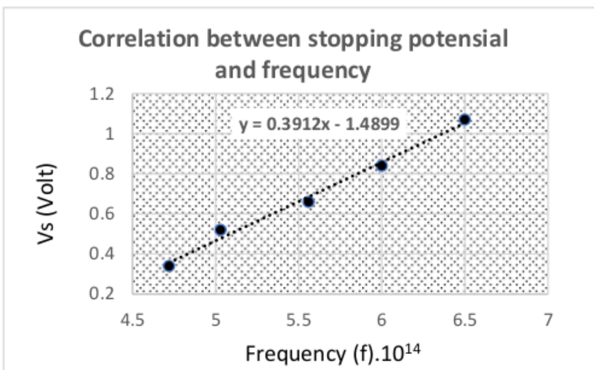
Filter colours	Wavelength (nm)	c ($x10^8$ m/s)	Frequency (x 10^{14} Hz)
Red	635	3	4.72
Yellow 1	570	3	5.03
Yellow 2	540	3	5.56
Green	500	3	6.0
Blue	460	3	6.5

From the table above, the frequency values for different wavelengths of light are obtained. To get the Planck's constant value, a calculation using linear regression is carried out based on the data in Table 3 below:

Table 3. Linear Regression Calculation Data

Filter colours	Wavelength (nm)	Frequency (x 10^{14} Hz)	Stopping Potential Vs (Volt)
Red	635	4.72	-0,34
Yellow 1	570	5.03	-0,52
Yellow 2	540	5.56	-0.66
Green	500	6.0	-0.84
Blue	460	6.5	-1.07

Variation of the filter colors used are red, yellow 1, yellow 2, green and blue.



Graph 1. Stopping Potential vs Frequency

In the graph above, the result of linear regression value is $y = 0.3912x - 1.4899$. For example the linear regression is $y = mx - b$ [16], the electron charge is $1.6.10^{-19}$ [17]. Then the result is $m = 0.3912 . 10^{-14}$. By combining this result with equations (, the Planck's constan is obtained as follows:

$h = m\ e$
$h = 0.3912 . 10^{-14}.-1,6 . 10^{-19}$
$h = 0.633744 . 10^{-33}$
$h = 6.34 . 10^{-34}$

In this experiment, the Planck's constant value is $h = 6.34 . 10^{-34}$. This constant value obtained also indicate that the phenomenon of the presence of light energy is greater than the work function of the metal, resulting the release of electrons from the metal. The constant value obtained from this experiment is very close to the value of Planck's constant, which is $h = 6,62.10^{-34}$ [18]. The correlation between stopping potential and frequency forms a linear regression line. To find out the accuracy of the Planck's constant value from the experimental results, use the following calculations:

$$\text{Error} = \frac{|h \text{ value obtained by experiment} - \text{Planck's constant value}|}{\text{Planck's constant value}} \times 100\%$$

$$\text{Error} = \frac{|6.62 \times 10^{-34} - 6.34 \times 10^{-34}|}{6.62 \times 10^{-34}} \times 100\%$$

Error = 4.23% with an accuracy value of 95.77%.

Based on calculation above, the error value is 4.23% with an accuracy value of 95.77%. So it can be analyzed that the error value is low because it is less than 10%.

4. Conclusions.

This experiment was carried out to get the value of Planck's constant using a set of experimental tools with the principle of the photoelectric effect. The steps of experimental activities begin with preparing tools and materials, then take stopping potential data from the current that occurs due to the release of electron from metal that is irradiated by light with a certain wavelength. The experimental result in the form of Planck's constant value of 6.34 . 10^{-34} with an error value of 4.23%.

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