Experimental Set for Measuring the Planck's Constant using LED

Jitlada Sunnu[1], Siriya Satsanapitak[1], Kheamrutai Thamaphat[1], Chutima Oopathump[2], Piyarat Bharmanee[1], Pichet Limsuwan[1]

[1]*Physics Learning Innovation Group, Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Thailand*
[2]*Division of Physics, Faculty of Science and Technology, Rajamangala University of Technology Krungthep, Thailand*

E-mail : s903607@yahoo.com

Abstract
The key parameter for determination of Planck's constant using LED is the voltage required to turn on an LED. Many experiments have been used a voltmeter to measure the voltage. The accuracy of voltage obtained depends on experience of experimenter in deciding when the LED stared to emit. Therefore, in this work, we have proposed a computer based approach that utilizes curve fitting to determine the voltage required to switch on an LED. The experimental setup consists of a circuit with a 6 V dc source, a 100 Ω resistor, a variable resistor (0-100 Ω), a capacitor (0.14 F), and five LEDs. A voltage probe connected to MultiLogPro Data Logger and a computer are used for monitoring the voltage across the capacitor during the discharge of capacitor through each LED. Then, the threshold voltage which is the minimum voltage to turn on the LED obtains from curve fitting. By plotting the graph of photon energy versus frequency for the five LEDs, the Planck's constant is achieved from its slope. The Planck's constant from our experiment was found to be $(6.625 \pm 0.003) \times 10^{-34}$ J•s. It can be concluded that this method is reliable and accurate with a percentage error of 0.015.

Keyword: Planck's constant, LED, physics education

1. Introduction

Quantum physics, which is also recognized as quantum mechanics or quantum theory, is largely the study of the microscopic world. Many quantities are found only in certain minimum (elementary) amounts or integer multiples of those elementary amounts. The elementary amount that is associated with such a quantity is called the quantum of that quantity [1]. In 1889, Max Planck introduced the concept of "quantum of action" (Planck's constant) in an attempt to explain the spectral distribution of blackbody radiation, which laid the foundations for quantum theory [2]. The Planck's constant (denoted h), also called Planck constant, is a physical constant reflecting the sizes of quanta in quantum mechanics. The Planck constant was first described as the proportionality constant between the energy (E) of photon and the frequency of its associated electromagnetic waves (f). The relation between the energy and frequency is called the Planck relation or the Planck-Einstein equation,

$$E = hf. \qquad (1)$$

Here h is Planck constant, which has the value $h = 6.626 \times 10^{-34}$ J·s $= 4.135 \times 10^{-15}$ eV·s.

In principle, the Planck constant could be determined by examining the spectrum of a black-body radiator or kinetic energy of photoelectrons, and this is how its value was first calculated in the early twentieth century. However, this method is moderately complex in laboratory activity for high school student. Consequently, determining the Planck constant using a simple electronic circuit has been created. The circuit is inexpensive and contains only a 6 V DC power supply, a light emitting diode (LED), a resistor, a variable resistor and a voltmeter. When the circuit is used to apply a potential difference across the LED, current flows once the potential difference is large enough. The electrical energy lost by each electron that crosses the LED is converted into the energy of an individual photon. The energy E of this photon is given by the formula in Eq. (1). By measuring the potential difference across a number of different LEDs, Planck constant can be revealed. This laboratory activity is accomplished within an hour with an accuracy of 20% [3].

From above, it means that the key parameter to be determined is the voltage required to switch on an LED of known optical frequency. There are two main methods for measuring this voltage, one uses a voltmeter to measure the minimum voltage needed to activate the LED, and the other determines the turn-on voltage from

the current-versus-voltage (I-V) curve of the LED. However, the value obtained for Planck constant is influenced by human judgment in deciding when the LED started to emit for the first method, and what feature of the I-V curve constituted the LED turn-on point for the second method. In this paper, the alternative approach to determine the voltage required to switch on an LED was presented. Computer software was utilized for curve fitting to determine the voltage. This idea was ignited by Zhou and Cloninger (2008) [4].
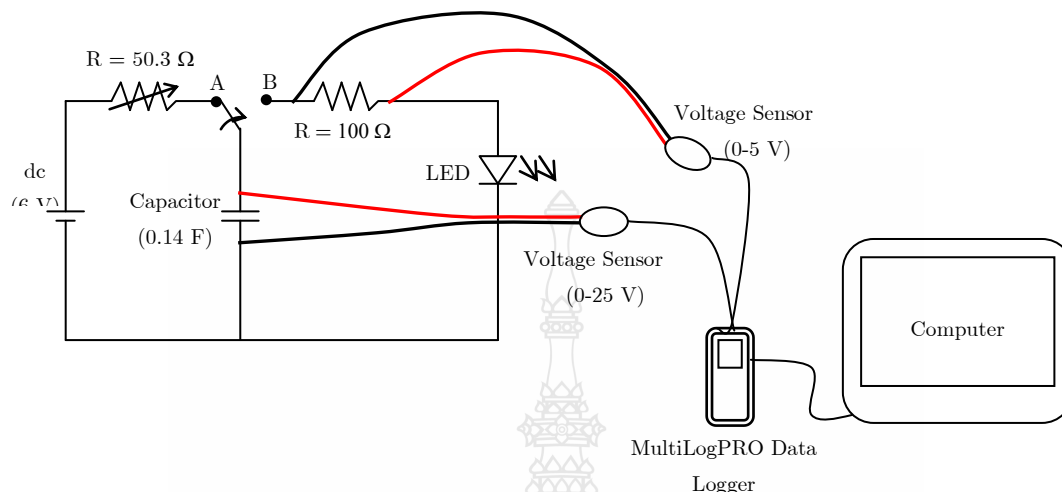

Figure 1 Diagram and photo of circuit used.

2. Experimental

In Figure 1, the experimental setup consists of a circuit with a 6 V DC source, a 100 Ω resistor, a variable resistor 0 - 100 Ω, a parallel connection of 0.1 F capacitor with four 0.01 F capacitors ($C = 0.14$ F), and 5-mm blue, green, orange, red, and infrared (IR) LEDs (from Electronics Source Co., Ltd.) with nominal emission wavelengths of 468 nm, 565 nm, 632 nm, 697 nm, and 940 nm, respectively. The first step, a capacitor of 0.14 F was fully charged by the dc source. After that, the switch was moved from the position A to B to begin the discharge with blue LED. The voltages across the capacitor and 100 Ω resistor were simultaneously monitored with voltage sensors attached to Data Logger, MultiLogPRO, interfaced to a computer. Then the same procedure was repeated for other LEDs.

Measuring the voltage across the capacitor during the discharge reveals an exponential decay curve that approaches a non-zero constant. This non-zero constant voltage (V_0) is the minimum voltage required for current to flow through the LED (threshold voltage) that is accurately determined by fitting the exponential decay curve with Origin 7 (OriginLab Corporation).
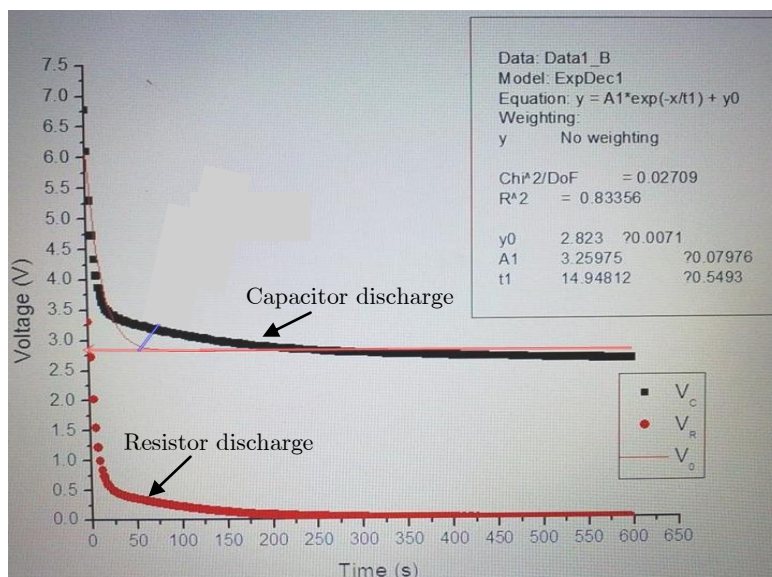
3. Results, Discussion and Conclusions

Figure 2 The example of voltage discharge curves for LED and the exponential decay curve fitting of the capacitor by Origin 7. From the table in the right hand side, it indicates that the fitted curve is governed by the equation of $y = A_1 e^{\frac{-x}{t_1}} + y_0$, where y_0 is V_0.

Figure 2 shows the example of discharge curves when two voltage sensors were used. It shows that the voltage across resistor is toward to zero and proportional to the current in the circuit while the capacitor voltage decays exponentially from its initial maximum to a lower limit. An exponential decay function is illustrated in the form of $y = A_1 e^{\frac{-x}{t_1}} + y_0$ where y_0 and A_1 is threshold voltage and arbitrary constant, respectively. Table 1 shows the threshold voltages that associate with different LEDs obtained from curve fittings and a photon generated by the LED possesses energy $E = hf = eV_0$, where $e = 1.6022 \times 10^9$ C is the charge of an electron, and V_0 is the turn-on voltage of the LED.

Table 1 The values of V_0 obtained from exponential curve fitting of the capacitor discharge voltage with five different LEDs. The results were collected from four repetitions.

Colour of LED	Wavelength λ (nm)	Frequency f (THz)	Voltage V_0 (V)	Energy E (10^{-19} J)
Blue	468	640.576	2.785 ± 0.002	4.462 ± 0.014
Green	565	530.602	2.086 ± 0.005	3.342 ± 0.017
Orange	632	474.351	1.828 ± 0.007	2.929 ± 0.019
Red	697	430.115	1.975 ± 0.005	3.164 ± 0.017
IR	940	318.926	1.159 ± 0.007	1.857 ± 0.019

From the values of E and f in Table 1, the Planck constant was revealed by plotting graph of photon energy E versus frequency f as shown in Figure 3. In this work, the experiment was repeated four times.
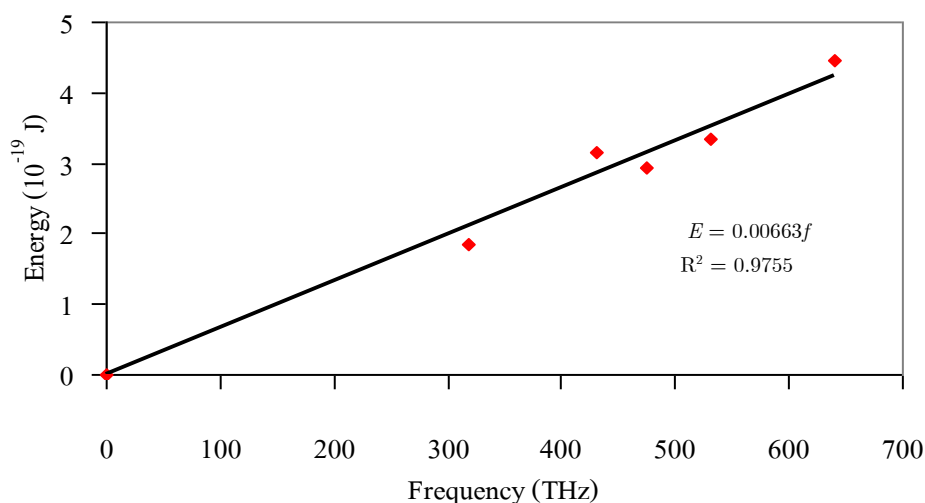

Figure 3 The relationship between photon energy and frequency for five LEDs. Planck constant is determined from slop.

Table 2 The obtained value of Planck constant from four experiments.

No.	Planck constant (J.s)
1	6.630×10^{-34}
2	6.630×10^{-34}
3	6.620×10^{-34}
4	6.620×10^{-34}
Average	$(6.625 \pm 0.003) \times 10^{-34}$

The Planck constant value of each experiment and average value are shown in Table 2. The average Planck constant is $(6.625 \pm 0.003) \times 10^{-34}$ J.s that is 0.015% below the known value. Source of error might be the fact that LEDs do not emit a single frequency of light. Instead, they emit a narrow spectrum with a width of approximately 70 nm. However, this method is reliable and consistent; generating more accurate value than the other reported methods using LEDs.

4. Acknowledgements

5. References

[1] Halliday, D., Resnick, R. and Walker, J. 2001. Fundamental of Physics, Wiley & Son, New York.
[2] Serway, R.A. and Jewett, J. 2004. Physics for Scientists and Engineers with Modern Physics, Brooks/Cole-Thomson Learning, Belmont.
[3] Perimeter Institute for Theoretical Physics. 2008. Measuring Planck's Constant: Teacher's Note, Conrad Entertainment, Ontorio.
[4] Zhou, F and Cloninger, T. 2008. Computer-Based Experiment for Determining Planck's Constant using LEDs. The Physics Teacher, 46; 413-415.