EXPERIMENT 5
MEASURMENT OF PLANCK CONSTANT USING LEDs

PURPOSE

Planck's constant (h = 6.626x10^{-34} J.s) is a universal constant that lies at the heart of quantum physics. The aim of this experiment is to measure the value of Planck constant by using several different colored LEDs.

EQUIPMENT

4 visible LEDs, DC source, spectometer, multimeter, potentiometer.

THEORY

LED is p-n junction made up of suitable materials that emit spontaneous radiation when forward biased. The energy supplied to the LED is almost radiative. We will ignore non-radiative effects.

If the LED is connected to a voltage source, current flows when the potential difference is large enough to overcome the barrier. After crossing the barrier, electrons will move from higher-energy states to lower-energy states, hence, the light will be emitted as the energy loss by the electrons, Figure 1.

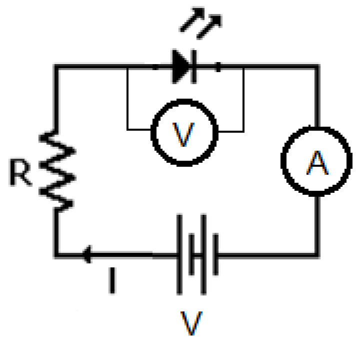

Figure 1: Forvard bias circuit

Above the threshold value, the current (I) increases exponentially with the increase of bias voltage across the diode (V) as follows:

$$I = I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \quad (1)$$

where

I_0 = Saturation current
e = Absolute value of electron charge (e = 1.6 x10^{-19} C)
k = Boltzmann's constant (k = 1.38x10^{-23} J/K)
T = Absolute temperature in Kelvin

Thypical I-V curves for different colored LEDs are shown in Figure 2.

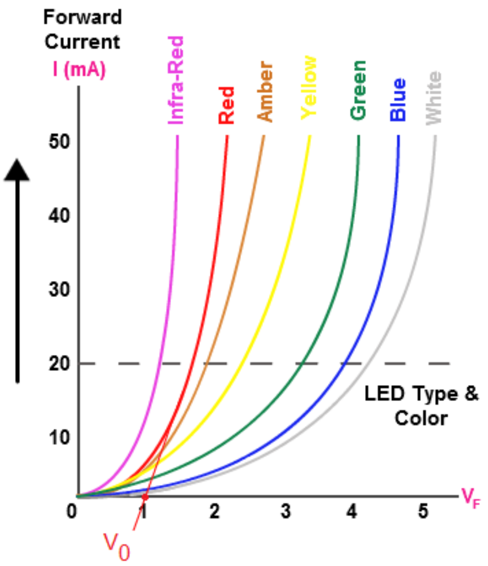

Figure 2: I-V cureves for several LEDs.

If V_0 is the minimum voltage (turn on voltage) required for the emission of light, then we can write:

$$eV_0 = \frac{hc}{\lambda} \quad (2)$$

Here, h is the Planck constant, c is the speed of light in vacuum and λ is the wavelength of the light. If you plot a tangent line to the I-V curve (for relatively large values of V), then V_0 can be obtained simply by evaluating the intercept of the line with the x-axis as indicated in Figure 2.

Equation (2) is very nice connnection among three fundamental constants in physics; e, c and h. By measuring wavelegth and turn on voltage, we can extract one of the constant by knowing other two. The pricise values of these constants are as follows:

Table 1: Very precise values of three fundamental constants in physics.

Constant	Symbol	Value
Electronic charge	e	$1.602\,176\,634 \times 10^{-19}$ C
Planck constant	h	$6.626\,070\,150 \times 10^{-34}$ J.s
Speed of light	c	299 792 458 m/s

Note that we will use spectro-photo-meter to extract the spectral power distribution (intensity) of colored LEDs as a function of wavelength. An example, that we have used in lab, is shown in Figure 3. The light data can be taken via a fiber cable. The wavelength range covers UV to NIR (200-1000 nm).

Figure 3: A CCD spectro photo meter its fiber. It is directly connected to a computer via USB cable.

PROCEDURE

Part 1 ***Spectral Light Distribution of LEDs***

Setup is shown in Figure 4. First connect spectrophotometer (SPM) to computer via USB. Then, turn on the red LED and direct its output to the SPM. Finally, acquire the spectral light data via computer. Repeat the experiment for other colors. Fill Table 2.

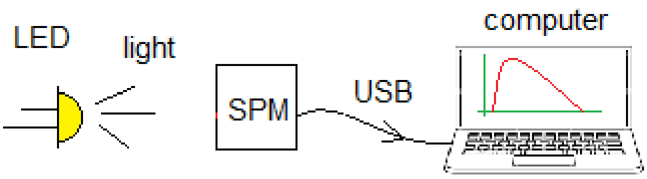

Figure 4: Exp. 1

Part 2 ***Turn on voltage measurement***

You can use a bread board to set up the circuit as shown in Figure 5. LED and potentiometer is connected to DC source. The aim is to measure turn on voltages of each LED (red, yellow, green, blue). While you are changing the resistance of potentiometer, you can measure current (*I*) in the circuit and voltage (*V*) across LED via multimeter. Repeat experiment for all colors and fill Table 3. Also, take a note the turn on voltage values observed directly by your eye and multimeter. Write down the values in Table 4.

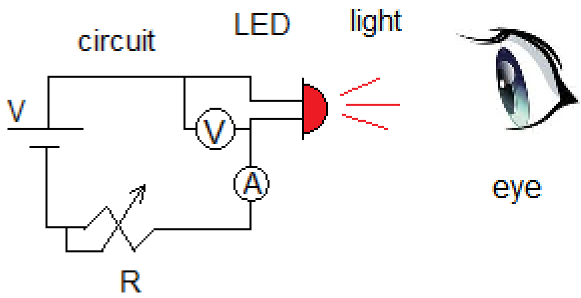

Figure 5: Exp. 2

QUESTIONS

For each question, write down your conculusion briefly.

1. Explain the physics of Equation (2).
2. Plot I-V curve of each LED using Table 3.
3. Determine the turn on voltage of each LED using data in Table 3. Plot tangent line for high voltage values and find the intersection of the line with the x-axis which is V_0. An example plot is shown in Figure 6.
4. Compare turn on voltages obtained in part (2) and the values in Table 4.
5. Plot $1/\lambda$ vs V_0. An example is shown in Figure 7. Fit the data to a stright line and extract its slope. From Equation (2), $V_0 = (hc/e) / \lambda$ = slope / λ. Therefore, the slope of the curve can be used to extract the value of h. Namely, h = slope * (e / c). Hence, determine the value Planck constant and its uncertainty using fitting. What is the R^2 value of the fit?
6. Finally, compare your result with its precise value of Planck constant in Table 1.

Table 2: Spectral Data for LEDs of different color used Exp 1

Color of LED	Peak vavelength (λ)	1 / λ
Red		
Yellow		
Green		
Blue		

Table 3: I-V Data for LEDs of different color used Exp 2

Red		Yellow		Green		Blue	
I (mA)	V (Volt)	I (mA)	V (Volt)	I (mA)	V (Volt)	I (mA)	V (Volt)

Table 4: Turn on voltage observed directly by eye for LEDs of different color used Exp 2

Color of LED	Turn on Voltage
Red	
Yellow	
Green	
Blue	

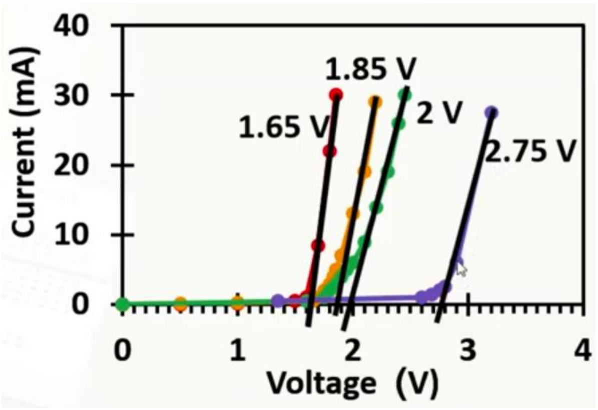

Figure 6.

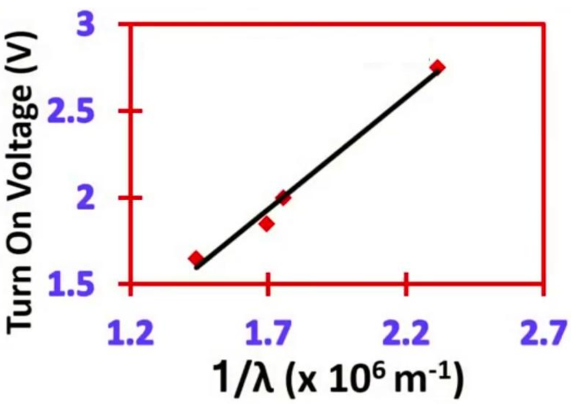

Figure 7.