# Measurement of Planck Constant by using LEDs

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# Introduction

Planck's constant ($h = 6.63 \times 10^{-34}$ Js) is a universal constant that lies at the heart of quantum physics.
With an easy-setup experiment in a laboratory, we can measure the value of Planck constant, by using several different colored LEDs.
Details of the procedure and the steps of experiment is explained in this presentation.

- What is an LED
- Colors of LED
- Emitting light
- I-V Characteristics
- Photon energy
- Experimental setup
- Current-Voltage results
- Determining activation voltage
- Semi-logarithmic I-V Characteristics of LEDs
- Wavelength of photon measurements
- Table of Voltage VS Frequency
- Calculation of Planck constant from the slope
- Conclusion
- References

[1]

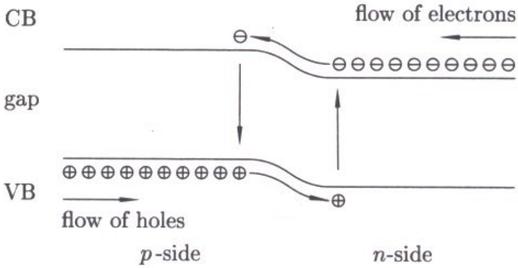
An LED (Light emitting diode) is a semiconductor device that emits photon at some frequencies, and it is usually made from GaAs, GaP or SiC. [2]

# Colors of LED

| Color | Wavelength | Voltage drop | Semiconductor material |
|---|---|---|---|
| Infrared | $\lambda > 760$ | $\Delta V < 1.63$ | Gallium arsenide (GaAs)<br>Aluminium gallium arsenide (AlGaAs) |
| Red | $610 < \lambda < 760$ | $1.63 < \Delta V < 2.03$ | Aluminium gallium arsenide (AlGaAs)<br>Gallium arsenide phosphide (GaAsP)<br>Aluminium gallium indium phosphide (AlGaInP)<br>Gallium(III) phosphide (GaP) |
| Yellow | $570 < \lambda < 590$ | $2.10 < \Delta V < 2.18$ | Gallium arsenide phosphide (GaAsP)<br>Aluminium gallium indium phosphide (AlGaInP)<br>Gallium(III) phosphide (GaP) |
| Green | $500 < \lambda < 570$ | $1.90 < \Delta V < 4.00$ | Traditional green: Gallium(III) phosphide (GaP)<br>Aluminium gallium indium phosphide (AlGaInP)<br>Aluminium gallium phosphide (AlGaP)<br>Pure green: Indium gallium nitride (InGaN)<br>Gallium(III) nitride (GaN) |
| Blue | $450 < \lambda < 500$ | $2.48 < \Delta V < 3.70$ | Zinc selenide (ZnSe)<br>Indium gallium nitride (InGaN)<br>Silicon carbide (SiC) as substrate<br>Silicon (Si) as substrate-under development |

[3]

When 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. [4]




[2]

Above the threshold value, the current increases exponentially with the increase of bias voltage across the diode. [5]

$$I = I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

where:

I = Current flowing through the diode.

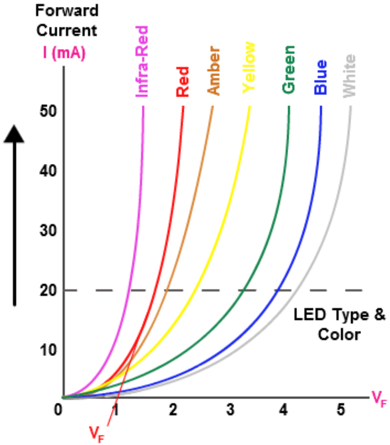
$I_0$ = Saturation current.

V = Voltage across the diode.

q = Absolute value of electron charge.

k = Boltzmann's constant.

T = Absolute temperature (K).




[6]

## Photon energy

The relation between the photon energy and the activation voltage is;

$$eV_0 = hf = \frac{hc}{\lambda}$$

where:

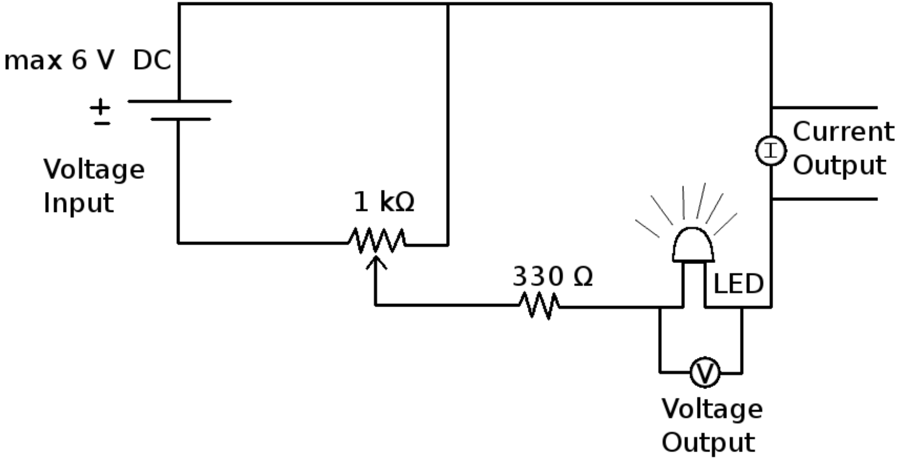
$V_0 =$ Activation voltage.

f = Frequency of the emitted photons.

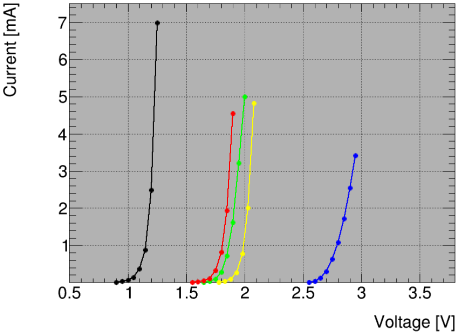
$\lambda =$ Wavelength of the emitted photons.

c = Velocity of light 299 792 458 $ms^{-1}$

e = Electron charge 1.602 176 6208(98) x$10^{19}$C [7]


max 6 V DC
±
Voltage
Input
1 kΩ
330 Ω
LED
Current
Output
I
V
Voltage
Output

# Current-Voltage Results

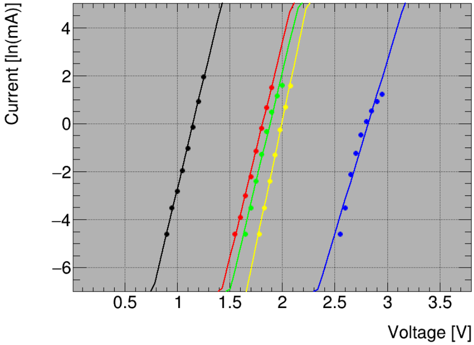



Current values as a function of voltage across the LED.
Infrared, Red, Green, Yellow, Blue respectively.

| Infrared | | Red | | Yellow | | Green | | Blue | |
|---|---|---|---|---|---|---|---|---|---|
| **V** | **mA** | **V** | **mA** | **V** | **mA** | **V** | **mA** | **V** | **mA** |
| 0.90 | 0.01 | 1.55 | 0.01 | 1.78 | 0.01 | 1.65 | 0.01 | 2.55 | 0.01 |
| 0.95 | 0.03 | 1.60 | 0.02 | 1.83 | 0.03 | 1.70 | 0.03 | 2.60 | 0.03 |
| 1.00 | 0.06 | 1.65 | 0.05 | 1.88 | 0.09 | 1.75 | 0.09 | 2.65 | 0.12 |
| 1.05 | 0.14 | 1.70 | 0.11 | 1.93 | 0.27 | 1.80 | 0.28 | 2.70 | 0.29 |
| 1.10 | 0.36 | 1.75 | 0.32 | 1.98 | 0.77 | 1.85 | 0.72 | 2.75 | 0.63 |
| 1.15 | 0.87 | 1.80 | 0.82 | 2.03 | 2.00 | 1.90 | 1.61 | 2.80 | 1.08 |
| 1.20 | 2.49 | 1.85 | 1.94 | 2.08 | 4.82 | 1.95 | 3.21 | 2.85 | 1.71 |
| 1.25 | 6.98 | 1.90 | 4.55 | | | 2.00 | 4.99 | 2.90 | 2.54 |
| | | | | | | | | 2.95 | 3.41 |

- One of the main points of this experiment is to determine the activation voltage.
- A method for that is to try finding the voltage when the led just turns on and starts emitting light by increasing the voltage across on it.
- But this seems rather hard to make a good determination.
- Another method could be the use of the advantage of making semi-logarithmic graph hence transforming the exponential relationship between the current and the voltage to linear.
- Hence our data would be useful for a linear fit, and the activation voltage is to be determined as the root of the fit function.

# Semi-logarithmic I-V Characteristics of LEDs

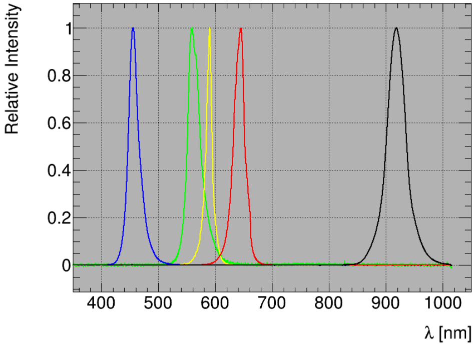



By using the linear fit function results, activation voltages are calculated as the root of the fit functions, including the errors of parameters of the fit.

Roots of the fit functions

| **Color** | **Voltage [V]** | **Error $\pm$ [V]** |
|---|---|---|
| Infrared | 1.151 | 0.032 |
| Red | 1.815 | 0.041 |
| Yellow | 1.998 | 0.050 |
| Green | 1.886 | 0.138 |
| Blue | 2.821 | 0.366 |

# Wavelength of photon measurements




Wavelengths of the emitted lights are measured by using a spectrometer. Distributions are normalized.
Iterative Gaussian Fit algorithm is applied for each distribution to measure mean values .

| **Color** | **Mean [nm]** | **Error $\pm$ [nm]** |
|---|---|---|
| Blue | 456.739 | 0.064 |
| Green | 562.677 | 0.076 |
| Yellow | 589.109 | 0.059 |
| Red | 642.367 | 0.042 |
| Infrared | 918.546 | 0.055 |

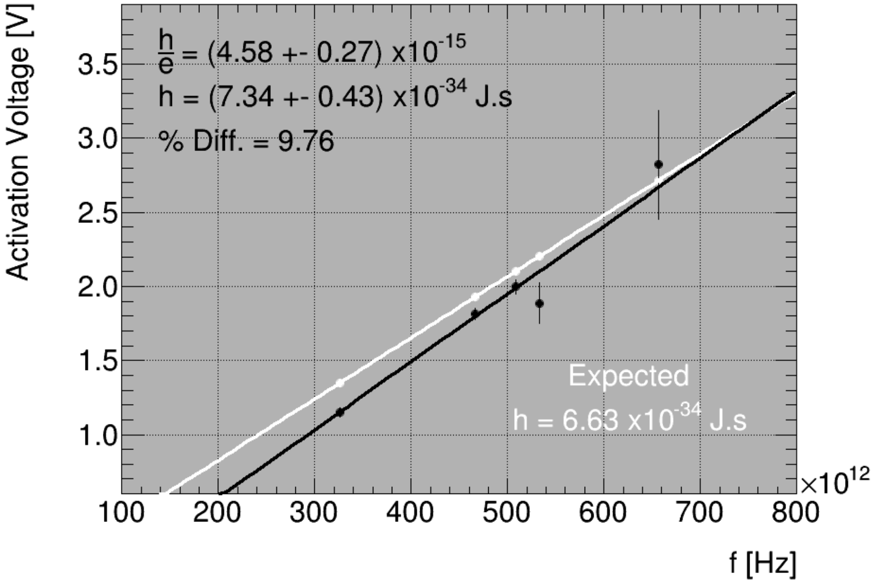
Voltage and wavelength values taken from the separately fit results for each individual led, are tabulated below.

| **Color** | **Voltage [V]** | **Frequency [Hz]** |
|---|---|---|
| Infrared | $1.151 \pm 0.032$ | $3.264 \times 10^{14}$ |
| Red | $1.815 \pm 0.041$ | $4.667 \times 10^{14}$ |
| Yellow | $1.998 \pm 0.050$ | $5.089 \times 10^{14}$ |
| Green | $1.886 \pm 0.138$ | $5.328 \times 10^{14}$ |
| Blue | $2.821 \pm 0.366$ | $6.564 \times 10^{14}$ |

Linear relationship between Voltage and the frequency can be shown as given and the slope of this function can be measured by using a linear fit method on these data points. Hence the slope of the fit function will represent h/e.

$$eV = hf \quad \rightarrow \quad V = \frac{h}{e}f \qquad Slope = \frac{h}{e}$$

# Voltage VS Frequency



# Calculation of Planck constant from the slope

The calculation of the Planck constant will be simply multiplying the slope with the electron charge as the final step.

$$h = Slope * e$$
$$h = 4.58x10^{-15} * 1.60x10^{-19}$$
$$h = 7.34x10^{-34} J.s. \ (difference : 9.76\ \%)$$

68% Confidence level: [6.91 - 7.77] ($\pm$ $1\sigma$)
95% Confidence level: [6.48 - 8.20] ($\pm$ $2\sigma$)

As a conclusion, it can be said that since the behavior of leds are not as expected as they would be ideal and the characteristics of them are not known accurately, it is expected that the current and voltage measurements will include some errors.
The effect of temperature is not taken into account in the calculations hence it is another addition to the experimental errors.
After all, measuring the Planck's Constant with such an easy experimental procedure and getting the result with less than 10 % error, is said to be not a bad achievement I guess.

[1] http://www.rayennur.com.

[2] http://www.phys.uconn.edu/~hamilton/phys258/N/led.pdf
I-V Characteristic of an LED.

[3] https://en.wikipedia.org/wiki/Light-emitting_diode.

[4] https://www.perimeterinstitute.ca.

[5] http://www.pveducation.org/pvcdrom/diode-equation.

[6] http://physics.tutorcircle.com/.

[7] C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016).

Special Thanks to Mehmet Adıyaman for helping me with the setup of the circuit using Arduino and the collection of the data points.