**Determination of Planck's Constant with LEDs**

## What do we need

LEDs, power suply, multimeters, variable resistor, (current limiting) resistor, cables for connections.

## Introduction

Light Emitting Diodes (LEDs) are semiconductor devices characteristically defined by their ability to emit electromagnetic radiation in the visible and infrared spectrum when a voltage is applied. LEDs are composed of p-type (electron acceptor) and n-type (electron donor) semiconductor materials that form a physical connection named p-n junction. Electrons from the n-type region and holes from the p-type region recombine in the vicinity of the p–n interface and these regions lose their neutrality and most of their mobile carriers, forming the space charge region or depletion layer (Fig.1). Thus, in a p–n junction without an external applied voltage appear a potential difference called built-in potential.

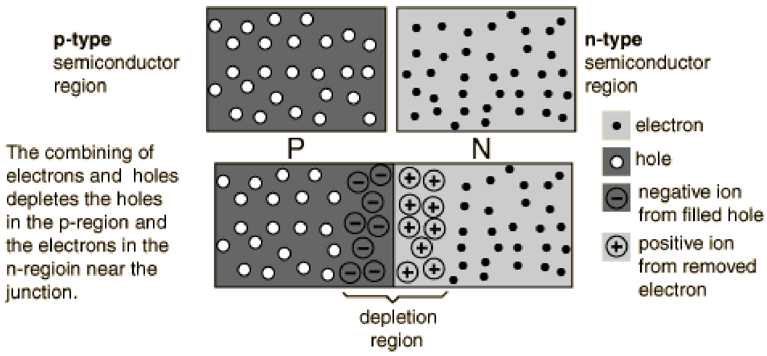


Fig.1

As in other diodes, current flows easily from the p-semiconductor (anode) to the n-semiconductor (cathode) under forward-bias above a minimum threshold value ($U_0$) but not in the reverse direction under reverse bias. Note that when LED is forward biased, little current will flow until the diodes threshold voltage is exceeded.

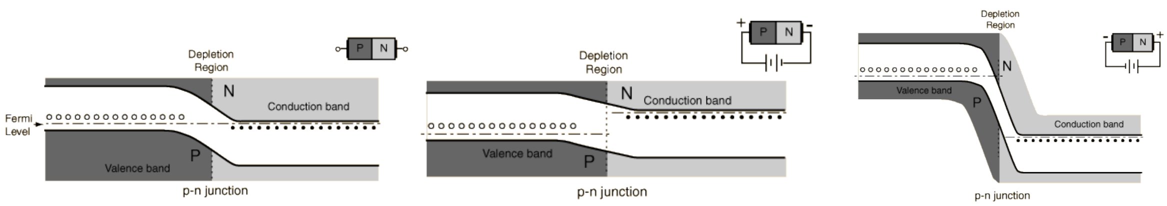


Fig.2

When an excited electron meets a hole, it falls into a lower energy level (from the conducting band down to the valence band Fig.3), and releases a quanta of energy (electroluminescence) equal to that of the quanta required to create the electron hole pair as a photon of discrete energy. The quanta of energy or photon has an energy

$$E = h\nu = \frac{hc}{\lambda} \tag{1}$$

with $h$ the Planck constant and $c$ the speed of light.

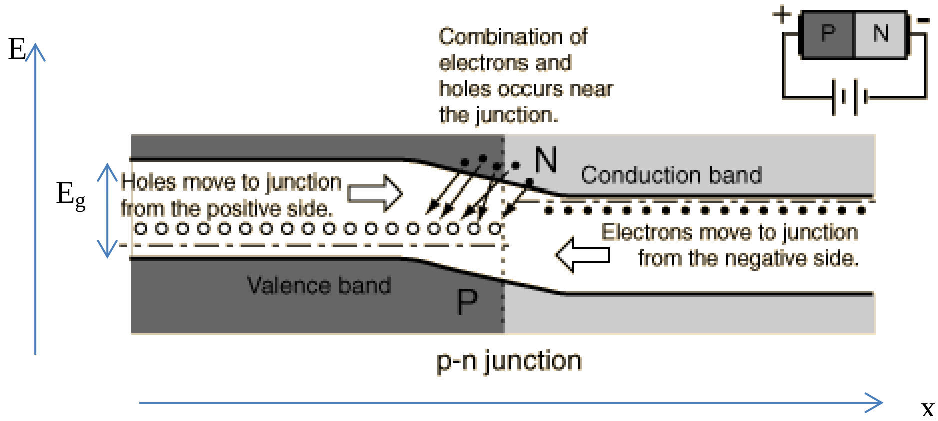

Fig.3

The wavelength of the light emitted (2), and thus its color depends on the band gap energy $E_g$ of materials forming the p-n junction. In silicon or germanium diodes, the electrons and holes recombine by a non-radiative transition, which produces no optical emission.

$$h\nu = \frac{hc}{\lambda} \cong E_g \tag{2}$$

LED development began with infrared and red devices made with gallium arsenide (GaAs), and the advances in materials science made possible the production of devices with even shorter wavelengths, emitting light in a variety of colors.

**Operating principle**

In this experiment, we will use the current-voltage relationship of a set of LEDs to measure Planck's constant. The main component of the experimental set-up is a circuit board containing five LEDs, each with a different emission wavelength, a variable resistor P and a current limiting resistor $R_{p.}$ A particular LED can be connected to the circuit shown in Fig. 3, the current through the LED is measured by the ammeter and the voltage across the LED is measured with the voltmeter (Fig.4).

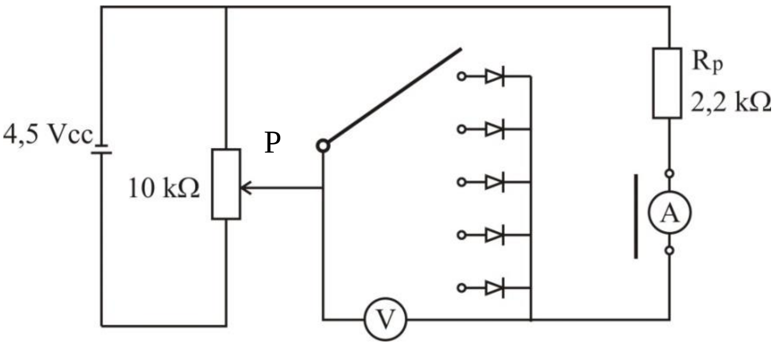

Fig.3


Fig.4

For a LED a typical current–voltage curve is drawn in fig5. Once the LED turns on (at the threshold voltage $U_0$), the current increases very quickly with increasing voltage.

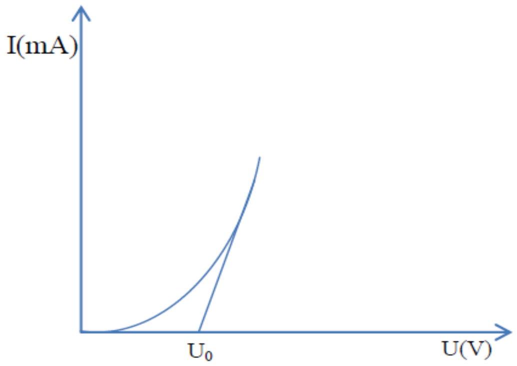

Fig5.

The relationship between the wavelength of the emitted photon $\lambda$, the threshold potential $U_0$ and discrete quanta of energy

$$eU_0 = h\nu = \frac{hc}{\lambda} \qquad (3)$$

allows to calculate the Planck's constant if the threshold potential is found from experimental data and the elementary charge $e=1.6\cdot10^{-19}$C, respectively the speed of light $c=3\cdot10^{8}$ m/s are known.

**What to do**

1. Connect the multimeters using the appropriate range and apply 4.5V DC to the input terminals using the power supply.
2. Choose a LED and adjust the voltage across it using the potentiometer P. Take readings of 0.03V (DC digital voltmeter) and record the corresponding current I(mA) through the LED.
3. Use all five LEDs and complete the Table 1.
4. Using data from table 1 represent for each LED the I-V characteristic curve I=f(U).
5. Approximate the diode characteristic curve with a sloped line segment (tangent to the diode curve) and at the intersection with the voltage axis read the threshold voltage (the piecewise linear method for the diode characteristic curve) for each LED.
6. Use relation (3) in order to obtain the Planck constant.
7. Find the mean value of Planck's constant and its uncertainty from the experimental values. Compare to the best current value for Planck's constant.
8. Represent $U_0=f(\nu)$ and find the Planck constant from the slope.

Table 1

| $\lambda =$ $nm$ | | |
|---|---|---|
| | U (V) | I (mA) |
| 1 | | |
| 2 | | |
| 3 | | |
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| 9 | | |
| 10 | | |
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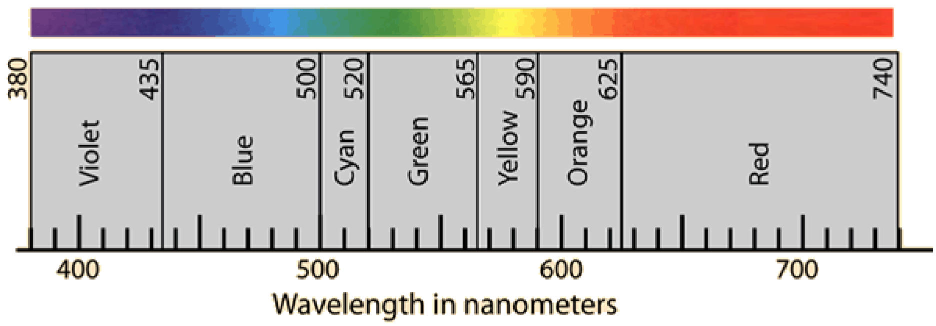
Table 2

| | Color | $\lambda$(nm) | $\nu$(THz) | $U_0$(V) | h(J·s) | $h_{av}$(J·s) | $\Delta h$(J·s) | $\sigma_h$(J·s) | $h_{av} \pm \sigma_h$ (J·s) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Blue | 475 | | | | | | | |
| 2 | Green | 550 | | | | | | | |
| 3 | Yellow | 590 | | | | | | | |
| 4 | Orange | 625 | | | | | | | |
| 5 | Red | 720 | | | | | | | |

**Appendix**




Typically, the forward voltage of an LED is about 1.8–3.3 volts; it varies by the color of the LED. A red LED typically drops 1.8 volts, but voltage drop normally rises as the light frequency increases, so a blue LED may drop around 3.3 volts.

**References**

Damian I., Popov D., Fizică - teme experimentale -, Ed. Politehnica,Timişoara, 2002.
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