Politechnika Wrocławska
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Laboratorium Podstaw Fizyki

Physics Laboratory - Report #2

Experiment: 48

Determination of the Planck constant using electroluminescent diodes

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Introduction

Light-emitting diodes (LEDs) convert electrical energy into light energy. They emit radiation (photons) of visible wavelengths when they are "forward biased" (i.e. when the voltage between the p side and the n-side is above the "turn-on" voltage). This is caused by electrons from the "n" region in the LED giving up light as they fall into holes in the "p" region.

APPARATUS

- Tunable power supply
- Electroluminescent diode
- Digital multimeters
- Monochromator
- Photoresistor

3.Experimental setup

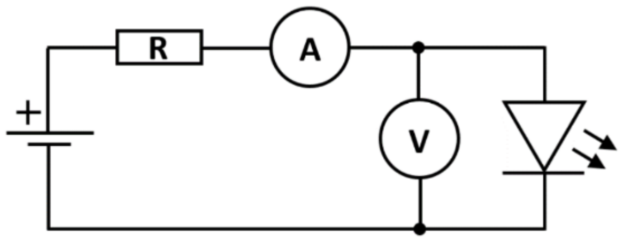


Fig. 1. The electrical circuit used to measure the current-voltage characteristic for forward-biased diodes.

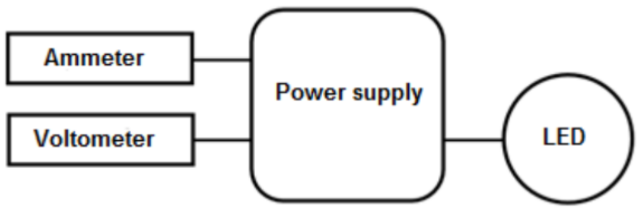


Fig. 2. The block-diagram of the experimental setup used for determination of the current-voltage characteristic of a LED diode.

Determining of the Planck constant from the I-V characteristic of LED

When we connect the LED to an external voltage in the forward bias direction, the height of potential barrier across the p-n junction is reduced (see Fig. 8a). At a particular voltage the height of the potential barrier becomes very low and the LED starts glowing, i.e. in the forward biased condition electrons crossing the junction recombine with the holes moving in the opposite direction and the excess energy is emitted as photons. The light energy emitted during forward biasing of LED is given by the equation:

$$E = \frac{h \cdot c}{\lambda}$$

The relationship between the light energy emitted from LED and the applied voltage is the following:

$$E = e \cdot U_b$$

where e = 1.602 × 10^{-19} C is the magnitude of the electron charge, U_b – a voltage referring to the potential barrier of a diode, determined from the I-V curve (cf. Fig. 8b). The experimental determination of Planck's constant is then easily obtained by measuring the wavelength of the emitted radiation from an LED and applied voltage over the LED concurrently, by combining the equations to get h:

$$\frac{h \cdot c}{\lambda} = e \cdot U_b$$

Rearranging Eq. 4 we get:

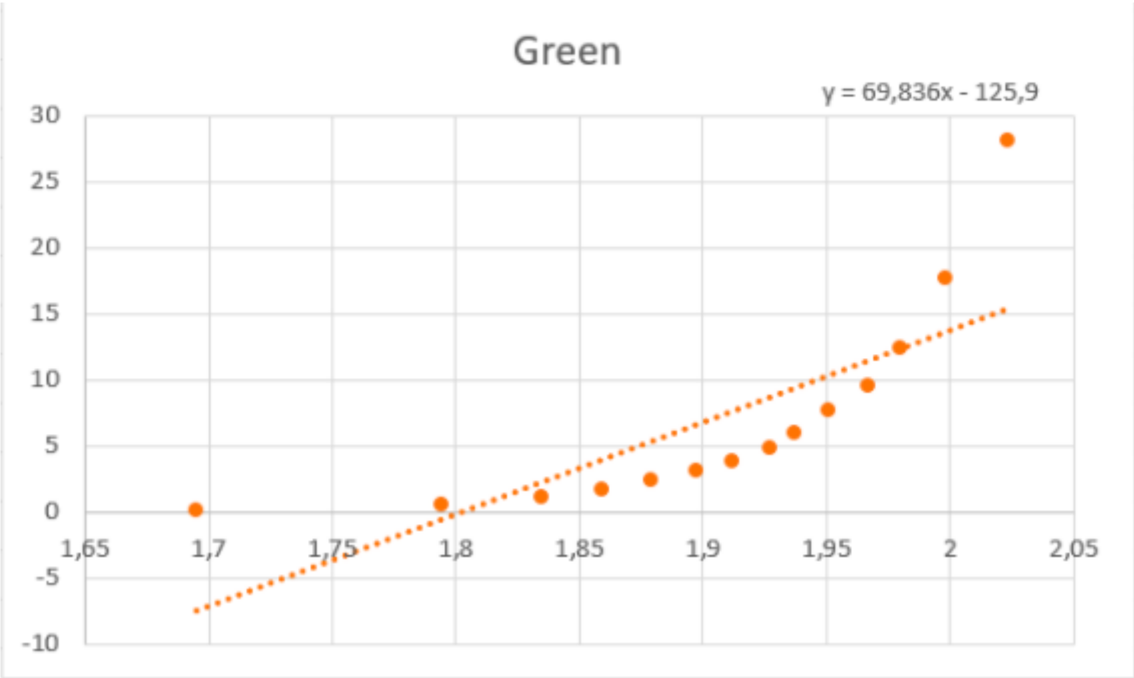
$$h = \frac{e}{c} \cdot \lambda \cdot U_b$$

REFERENCE

Laboratorium Podstaw Fizyki, Politechnika Wroclawska, "http://lpf.wppt.pwr.edu.pl/opisy.php"

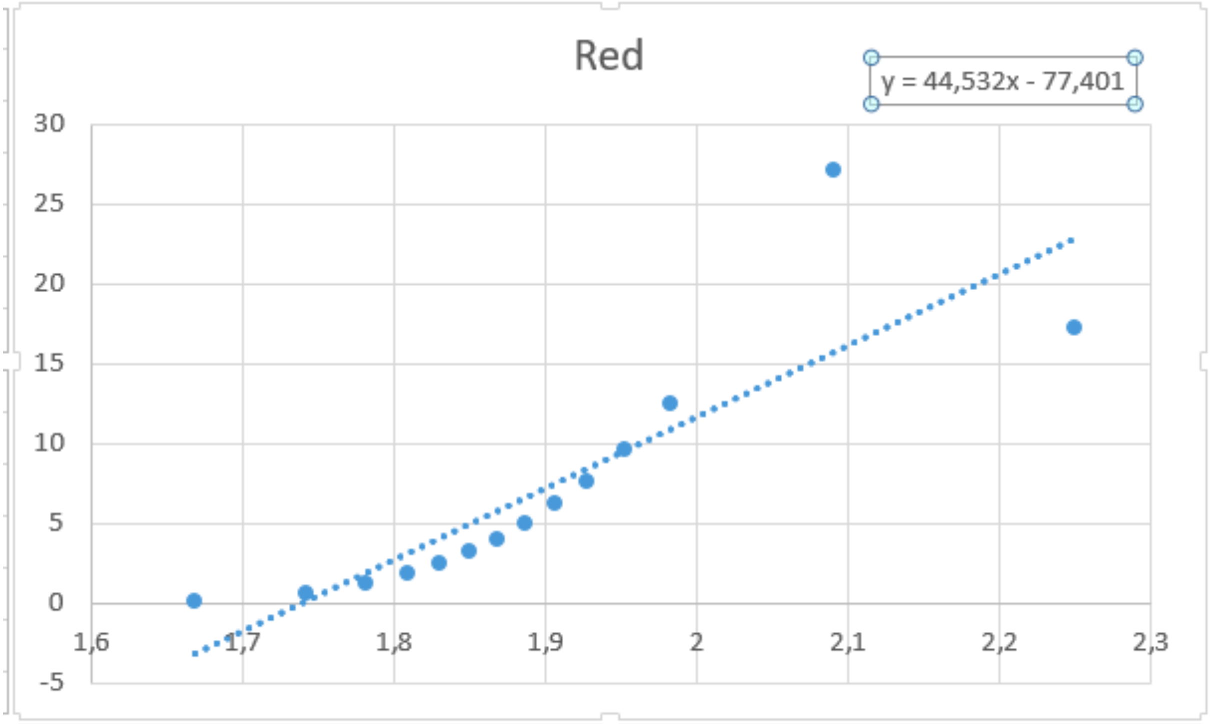
Measurements

Twenty potential-current instances are measured for 4 different colors of LEDs. For each color, wavelengths are measured. Resulting data sets are plotted and analyzed.



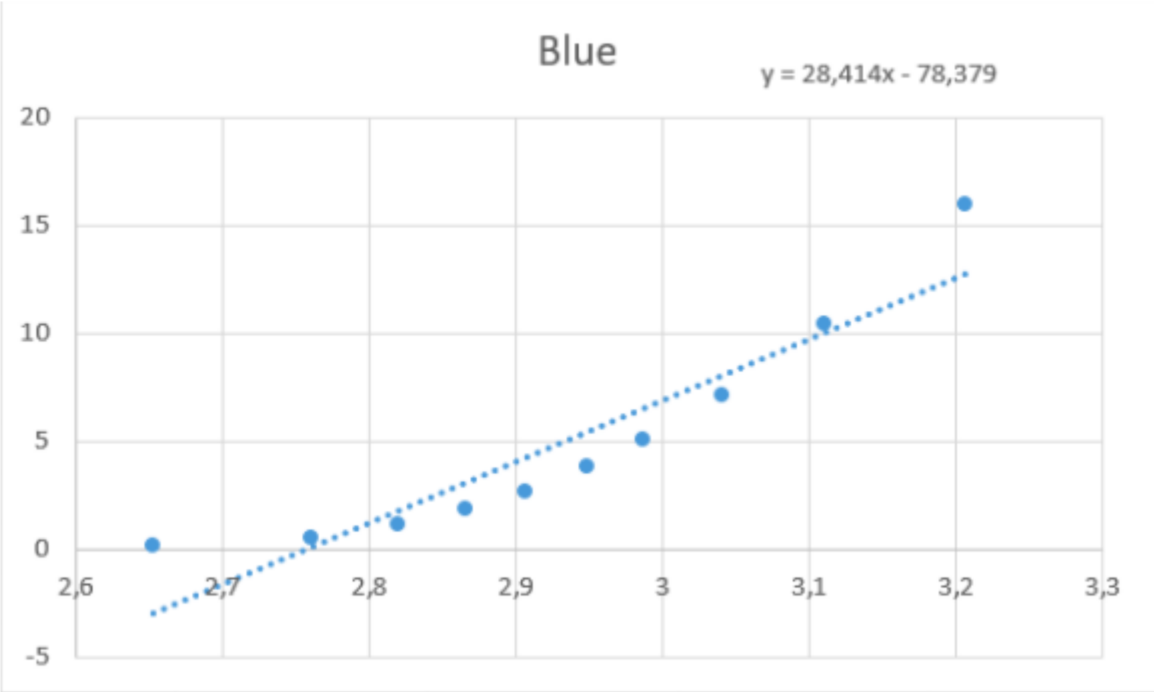
Green	U[V]	I[mA]	λ[nm]	U_b	$\mu_c(U_b)$	h	μ_c(h)
Resolution	0,001	0,1	1	1,91	0,55	4.31e-34	1.05e-24
1	0.022	0	560				
2	0.48	0					
3	0.727	0					
4	0.976	0					
5	1.224	0					
6	1.475	0					
7	1.695	0.04					
8	1.794	0.48					
9	1.835	1.07					
10	1.859	1.66					
11	1.879	2.37					
12	1.897	3.07					
13	1.912	3.84					
14	1.927	4.88					
15	1.937	5.97					
16	1.951	7.63					
17	1.967	9.59					

18	1.98	12.43	
19	1.998	17.67	
20	2.023	28.09	



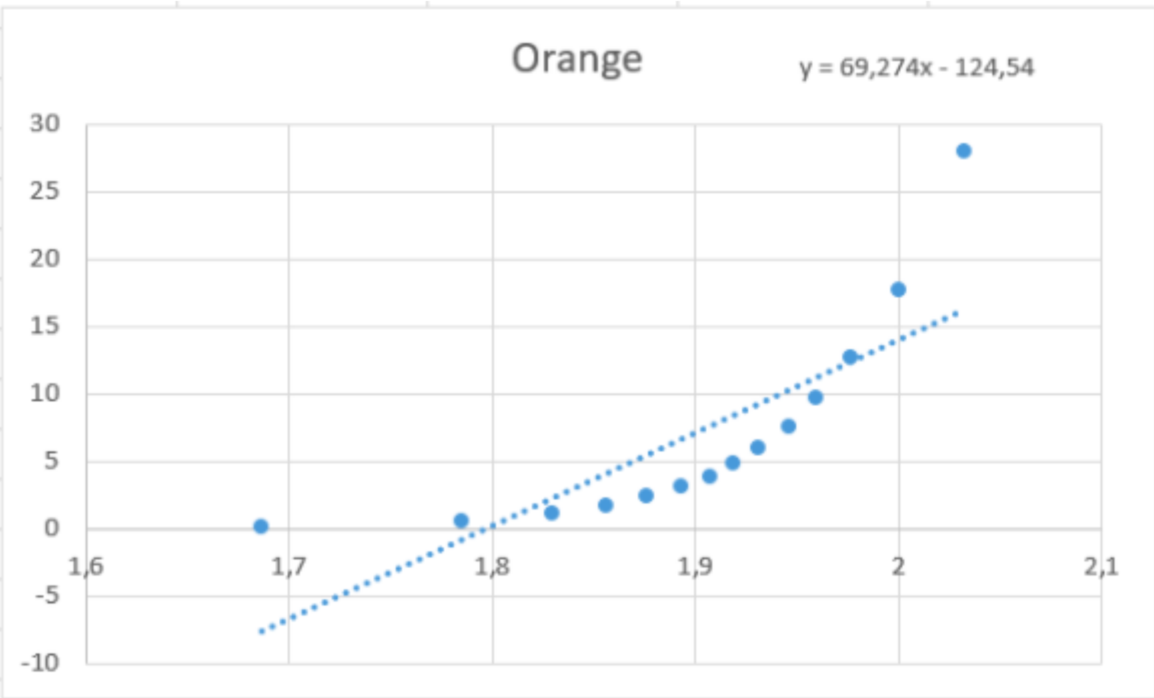
Red	U[V]	I[mA]	λ [nm]	U_b	$\mu_c(U_b)$	h	μ_c(h)
Resolution	0,001	0,1	1	3,56	0,37	3.45e-34	5.85e-35
1	0.021	0	616				
2	0.483	0					
3	0.726	0					
4	0.97	0					
5	1.22	0					
6	1.467	0					
7	1.668	0.12					
8	1.742	0.58					
9	1.782	1.2					
10	1.809	1.82					
11	1.83	2.47					
12	1.85	3.21					
13	1.868	3.99					
14	1.887	4.96					
15	1.906	6.16					
16	1.927	7.61					

17	1.953	9.61	
18	1.983	12.46	
19	2.25	17.26	
20	2.09	27.04	



Blue	U[V]	I[mA]	λ [nm]	U_b	$\mu_c(U_b)$	h	μ_c(h)
Resolution	0,001	0,1	1	1,61	0,40	4,03e-34	2.03e-35
1	0.0234	0	447				
2	0.491	0					
3	0.729	0					
4	0.971	0					
5	1.226	0					
6	1.489	0					
7	1.724	0					
8	1.972	0					
9	2.207	0					
10	2.46	0					
11	2.653	0.12					
12	2.761	0.54					
13	2.82	1.14					
14	2.866	1.85					
15	2.906	2.67					

16	2.949	3.83	
17	2.987	5.04	
18	3.041	7.12	
19	3.111	10.46	
20	3.206	15.96	



Orange	U[V]	I[mA]	λ [nm]	U_b	$\mu_c(U_b)$	h	μ_c(h)
Resolution	0,001	0,1	1	1,92	0,21	4.34e-34	3.36e-35
1	0.023	0	574				
2	0.476	0					
3	0.733	0					
4	0.996	0					
5	1.224	0					
6	1.472	0					
7	1.687	0.07					
8	1.785	0.51					
9	1.83	1.1					
10	1.856	1.68					
11	1.876	2.35					
12	1.893	3.11					
13	1.907	3.88					
14	1.919	4.87					
15	1.931	5.95					

16	1.946	7.6	
17	1.96	9.67	
18	1.977	12.65	
19	2	17.73	
20	2.033	27.95	

Calculations:

Deriving Planck's Constant

Planck's Constant is calculated for each data set by the equation:

$$h = \frac{e}{c} \cdot \lambda \cdot U_b$$

where potential barrier is calculated by: $U_b = \frac{-b}{a}$

Variables from *y=ax+b* line fit. (U vs I)

	Green	Red	Blue	Orange
a	69.83622174	44.53210712	20.32014952	69.27397902
b	-125.901761	-77.40105596	-54.23981351	-124.5405601
μ_a	16.21	7.53	4.056	14.95
μ_b	30.90	14.3	11.74	28.43

Uncertanities

Uncertanity of potential barrier calculated by:

$$\mu_{Ub} = \sqrt{\left(\frac{\partial U_b}{\partial a}\,\mu_a\right)^2 + \left(\frac{\partial U_b}{\partial b}\,\mu_b\right)^2} = \sqrt{\left(\frac{-b}{a^2}\,\mu_a\right)^2 + \left(\frac{-\mu_b}{a}\right)^2}$$

Uncertanity of Planck's Constant calculated by:

$$\mu_h = \sqrt{\left(\frac{\partial h(\lambda, U_b)}{\partial \lambda}\,\mu_\lambda\right)^2 + \left(\frac{\partial h(\lambda, U_b)}{\partial U_b}\,\mu_{U_b}\right)^2}$$

CONCLUSION

Planck's constant was determined by measuring the energy emitted by a selected number of light emitting diodes. A spectrometer was used to measure the wavelength of the light emitted by each LED. A measure of voltage drop across each light emitting diode was used to Planck's constant by relating it to the energy absorbed/emitted by the diodes through calculating it from the wavelength and voltage. It was found to be approximately similar to the theoretical value whereby it was concluded that the proposed method can be used to determine the wavelength of light emitted by unknown LED.

RESULTS AND DISCUSSION

The purpose of this study was to determine Planck's constant using the energy needed to excite free electrons in a light emitting diode. In this work, an electric current was used to excite electrons and the corresponding energy was measured using a voltmeter as it was emitted.