Headings

Experiment Title: Determining Planck's Constant
Experiment Start Date: 14th October 2021
Experiment Start Time: circa. 0930

Aims

Briefly outline the aims of the experiment.

An experiment was carried out to ascertain the value of Planck's constant through the measurement of current-voltage characteristics across LEDs that emitted various characteristic wavelengths, and back-extrapolating from this data to find a threshold voltage (V_t). Then, by relating information of the wavelength of the photons emitted through data obtained by a spectroscope, we can determine an experimental value of Planck's constant through some algebraic manipulation of equations.

Background

Briefly outline the theoretical background of the experiment, but do not just repeat what is in the lab manual. Include all important equations that will be used for data analysis. Include any key references

Planck's constant is often regarded as one of the most significant, recognisable constants in Physics. It ranges in appearances in areas as strikingly different as the Photoelectric Effect, in which Max Planck, whom the constant is eponymously named after, came to the surprisingly elegant conclusion that the energy of a photon is directly proportional to its frequency *(as related by his constant)*; to areas such as nuclear magnetic resonance, in the determination of the uncertainty of an electron's position around an atom, and even the current definition of a kilogram, one of the Seven Fundamental SI Units. This experiment acts as a demonstration of how the use of simple lab equipment, with the help of some basic mathematics, can lead to the obtaining of an experimental value of this most fundamental of constants.

In order to obtain such a value, we must begin with Planck's equation:

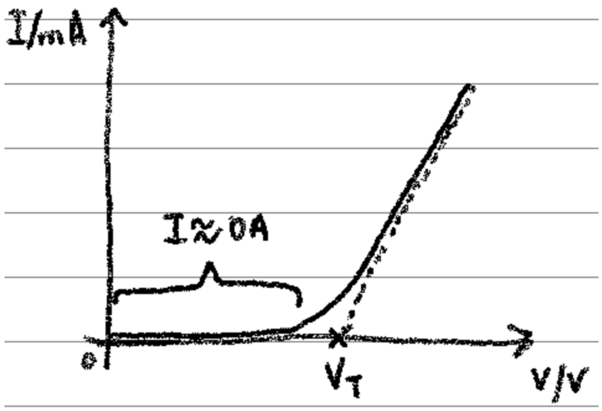
$$E = h \cdot v \quad (1)$$

This equation relates the frequency (v / Hz) of a photon to its energy.
We also know that the energy of charged particle E_q accelerated through voltage V is:

$$E_q = q \cdot V \ (2)$$

Thus, we obtain that for an electron of charge e, that $E_e = e \cdot V$ (3), and therefore if by setting the power supply to our LED so $E_e = e \cdot V > E_g$ (4), which means that electrons are driven from the valence band to the conduction band, and can then recombine, emitting photons, energy E_g

Figure 1: A graph displaying the I-V Characteristics of an LED.



The threshold voltage, or *"turn-on"* voltage, denoted V_T is calculated through a back-extrapolation from the portion of the graph at voltages beyond V_T that approximate linear behaviour. By continuing this linear trend backwards until the x-intercept, we obtain V_T.

It follows that $E_e = e \cdot V_T = E_g = h \cdot v$ (5) after we substitute (1). Consequently, $V_T = \frac{h}{e} \cdot v$ (6) and as $v = \frac{c}{\lambda}$, it follows that we can form an equation for the threshold voltage in terms of the LED photon wavelength, so that $V_T = \frac{hc}{e\lambda}$ (7). Consequently, by plotting graphs of voltage (V_T) against the reciprocal of wavelengths ($\frac{1}{\lambda}$), we have that the gradient is given by $\frac{hc}{e}$ and the graph should be a straight line passing through the origin. Therefore, we have that $h = \frac{e \cdot gradient}{c}$.

Description of Set Up

Using diagrams and sketches, describe the setup of the experiment. Draw the schematic of the circuit used to determine the threshold voltage.

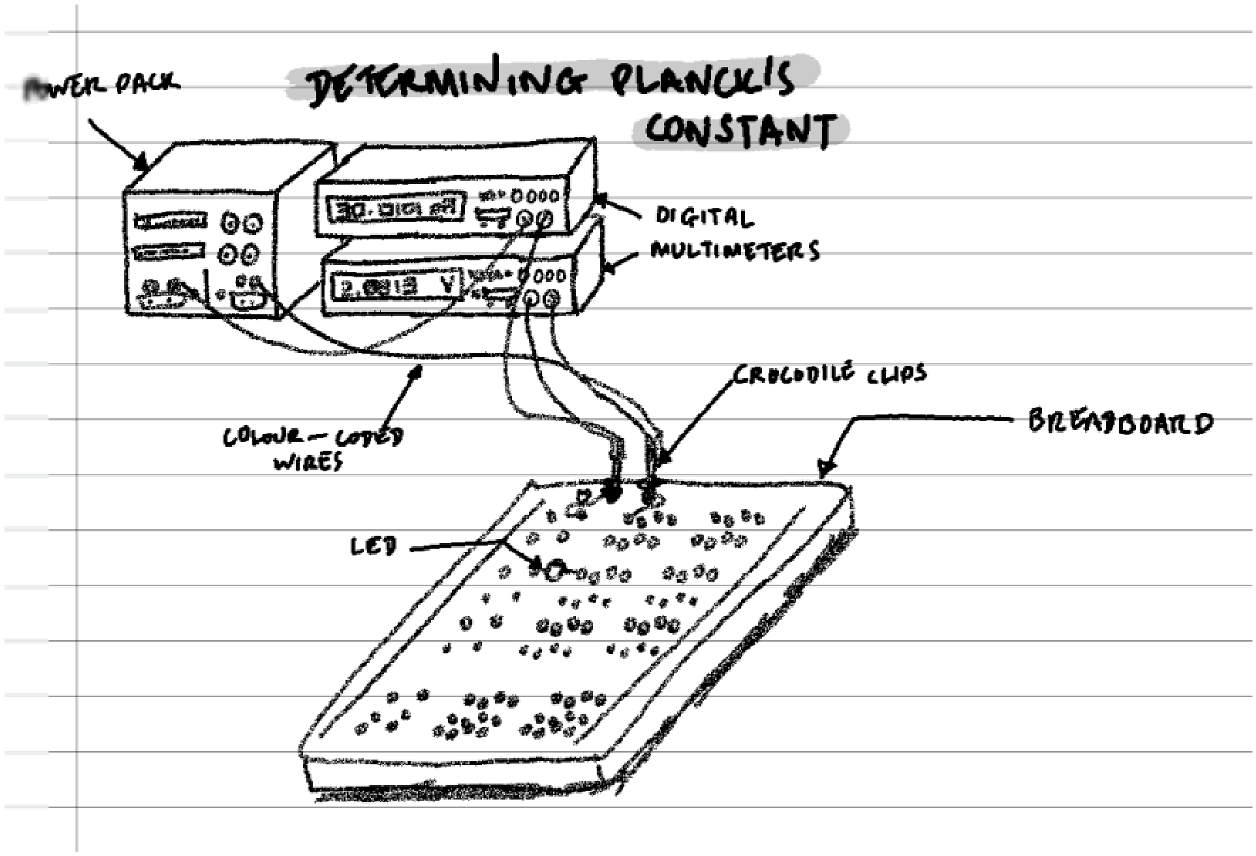
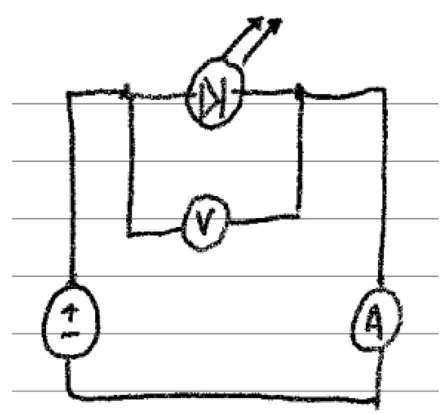


Figure 2: Diagram of apparatus as set up for the determination of Planck's Constant experiment.



A circuit was constructed as crudely shown above to determine the I-V characteristics across various LEDs. A power pack was set up with two wires leading out connecting to both a multimeter on ammeter setting in series, as well as a multimeter on voltmeter setting in parallel across the breadboard inputs. A breadboard was placed with wires linking it to the input terminals, and various LEDs were placed across the breadboard to complete the circuit. It was ensured that the diodes were placed the right way around so as not to compromise the circuit (as current would not pass through). The wires were colour-coded for convenience *(i.e. black for negative terminal, red for positive terminal, blue for voltmeter, white for ammeter)*. Prior to supplying power to the board, the upper limit of the power-pack was set to 30mA in order to prevent the LED from burning. The voltage and current were then adjusted respectively so that the I-V characteristics (and therefore, the threshold voltage) for each LED could be determined.

Above, side: *Figure 3:* a simplified schematic of the circuit used.

Preliminary Current-Voltage Data

Make rough measurements of the threshold voltage by visual observation. Measure the voltage at 30mA.

Preliminary data was obtained prior to accurate data collection to roughly measure the value of V_T as well as to gauge the voltage at the pre-assigned upper limit; it was previously decided to be 30mA. Additionally, the wavelengths of light emitted by the various diodes were obtained through the use of a spectroscope linked through to analytical computer software *(see, LED Emission Wavelength Data).*

LED	Visual Threshold / V	Voltage at 30mA / V
1	2.88	3.40
2	2.40	2.97
3	1.80	2.43
4	1.69	2.02
5	1.66	2.30
6	1.98	2.30

Review

Comment on your findings. Explain what step size and voltage ranges you will be using for each diode.

Due to the relatively straightforward nature of the practical, it was decided that step sizes of roughly 0.05V increments would be used to obtain more data and reduce uncertainties, especially focusing on the linear portion of the graph since this would be from where the back-extrapolation would draw upon. For each diode, a voltage range above or around the visual threshold was used, up until roughly where the current was observed to be 30mA. Due to the shorter range of LED 4, smaller increments were used to obtain the equivalent amount of data.

IV Curve Data

We recommend you enter your data into Excel to allow plotting and analysis.
You should copy and paste the data into here.

The data below has been rounded to 2 decimal places. The original data was recorded to a precision of 4 decimal places for the voltage / V, and 2 decimal places for the current readings to neglect the effect of fluctuations (see *Sources of Uncertainty)* in current / mA.

LED	Observed Voltage / V	Observed Current / mA	LED	Observed Voltage / V	Observed Current / mA
1	2.89	0.75	4	1.70	0.15
	2.91	1.08		1.75	0.44

	2.96	2.34		1.80	1.25
	3.04	5.83		1.85	3.50
	3.10	8.73		1.90	8.10
	3.15	11.91		1.95	14.36
	3.20	14.96		1.98	18.75
	3.25	18.19		2.00	22.51
	3.30	22.11		2.03	27.54
2	2.40	0.15		2.04	30.87
	2.45	0.41	5	1.65	0.06
	2.50	1.08		1.79	1.34
	2.55	2.29		1.86	3.20
	2.60	4.28		1.90	5.11
	2.65	6.29		1.95	7.26
	2.71	9.70		2.00	10.29
	2.75	12.66		2.06	13.36
	2.83	18.52		2.08	14.94
3	1.89	1.43		2.15	19.42
	1.96	3.39		2.20	22.61
	1.99	4.89		2.25	26.50
	2.05	7.49	6	1.90	1.88
	2.10	10.24		1.94	3.73
	2.15	13.00		1.97	5.23
	2.20	16.07		2.02	7.89
	2.25	18.98		2.06	7.81
	2.31	22.66		2.11	14.28
	2.35	25.50		2.16	18.42
	2.40	28.71		2.20	21.83
				2.25	25.89
				2.30	29.89

IV Curve: Sources of Uncertainty

Note down the various sources of uncertainty and their values in this section.

It was observed that readings obtained from the multimeters gradually decreased following changes to the configuration of voltage and current of the power pack. Consequently, it was ensured that readings were obtained in a swift manner to minimise this effect.

Voltmeter		Ammeter	
Systematic	0.05V	Systematic	0.0002mA
Fluctuations	0.0001V	Fluctuations	0.005mA
Total Uncertainty	0.05V	Total Uncertainty	0.0052mA

LED Emission Wavelength Data

We recommend you enter your data into Excel to allow plotting and analysis.
You should copy and paste the data here.

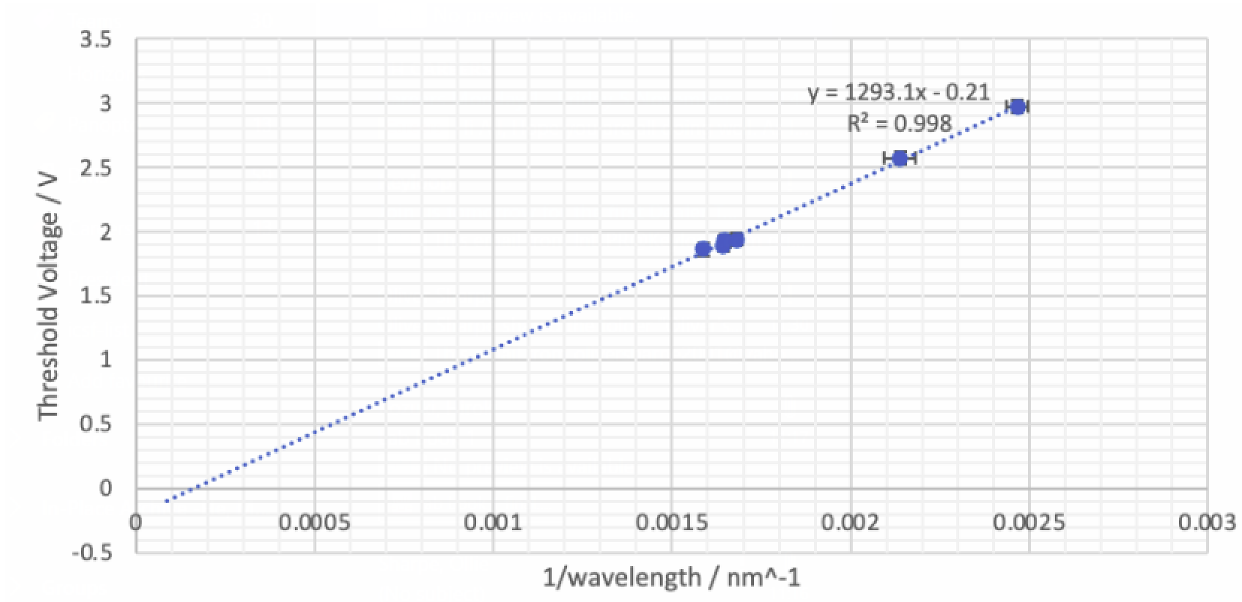
Centroid Wavelength / nm	Peak /nm	FWHM /nm	Colour	Uncertainty
405.35	404.29	11.97	purple	5.08
467.86	466.00	22.12	blue	9.39
594.97	595.81	15.56	yellow	6.61
608.53	609.59	12.91	orange	5.48
630.22	631.19	11.99	red	5.09
607.29	608.53	13.71	green	5.82

Diode	Colour	Threshold Voltage / V	Wavelength / nm	1/Wavelength / nm^-1	Threshold Voltage / V2
1	purple	2.971782768	405.35	0.002467004	2.971783
2	blue	2.572119806	467.86	0.002137392	2.57212
3	yellow	1.938565669	594.97	0.001680757	1.938566
4	orange	1.89396365	608.53	0.001643304	1.893964
5	red	1.863550774	630.22	0.001586747	1.863551
6	green	1.933707728	607.29	0.00164666	1.933708

Data Analysis

Use this section to record the process and outcome of your data analysis.

Graph of Threshold Voltage (V_T) against the Reciprocal of the Wavelength (λ)



From the above data, we obtained this graph. Since the gradient of the resultant graph is given by $gradient = \frac{hc}{e}$, you can rearrange the equation in order to obtain h.

Summary

Briefly summarise the main outcomes of the experiment

As a result, our final calculated value of g was 6.90×10^{-34} J.s, which was relatively close to the accepted value of 6.63×10^{-34} J.s. As a result, Planck's constant experiment was somewhat successful, though the true value lied outside the uncertainty range.