Physics 197 Lab 10: Planck's Constant from LED Spectra

Equipment:

Item	Part #	Qty per Team	# of Teams	Total Qty Needed	Storage Location	Qty Set Out	Qty Put Back
Red Tide Spectrometer	Vernier V-Spec	1	8	8			
Computer with Logger Pro		1	8	8			
Optical Fiber Assembly	For Red Tide	1	8	8			
Ring Stand and Clamp		1	8	8			
USB Cable – Red Tide to Computer		1	8	8			
Planck's constant LED apparatus	Esco	1	8	8			
DMM and probes for voltage		1	8	8			
DMM and probes for current		1	8	8			

Layouts:

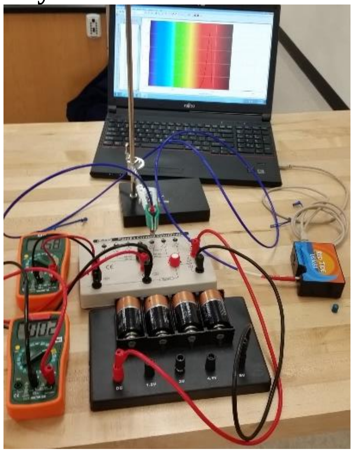


Figure 1, LED Planck's Constant Setup

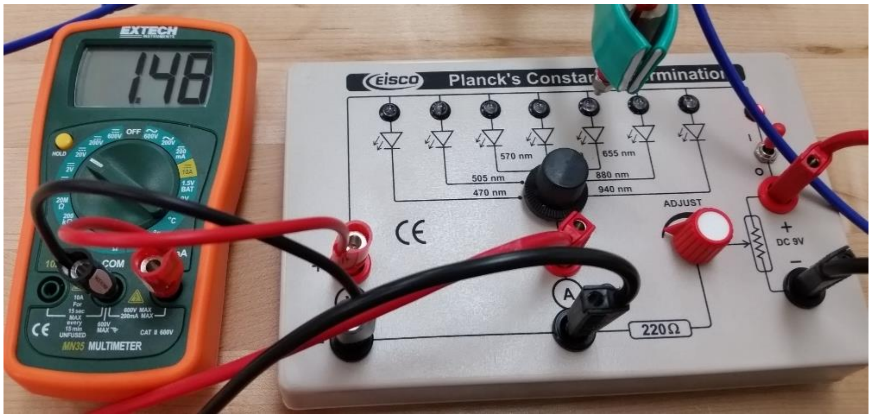


Figure 2, Measurement of LED Voltage at Emission Threshold

Summary:

In this lab, students will determine a value for Planck's constant by measuring the emission wavelength of 7 LED's along with the threshold voltage at which they first turn on. The LED's range in wavelength from 470nm to 940 nm. The emission spectra will be observed with a Red Tide Spectrometer coupled to the LED's with a fiber optic cable which can be positioned right above the LED. The peak wavelength of the emission curve will be measured using the spectrometer. The voltage to the LED can be varied, and a voltmeter will be used to measure the voltage at which the LED just starts emitting, which should be close to the bandgap. The energy of the emitted photons should be close to the bandgap voltage multiplied by the electron charge, and should also be equal to Planck's constant multiplied by the photon frequency, allowing for a calculation of Planck's constant. The apparatus will also be used to measure a Current vs. Voltage curve for one of the LED's around threshold, showing the sudden way in which the LED starts conducting above its bandgap voltage.

The write-up for this experiment is copied from the manual which came with the ESCO LED Planck’s constant determination apparatus.

PreLab:

Read the experiment and answer the following questions in your notebook. (Include the questions in your answers).

1. According to the Particle Theory of Light, how is the energy of a single photon related to its frequency?

2. Recalling that the speed of light equals the product of its frequency and wavelength, how is the energy of a single photon related to its wavelength?

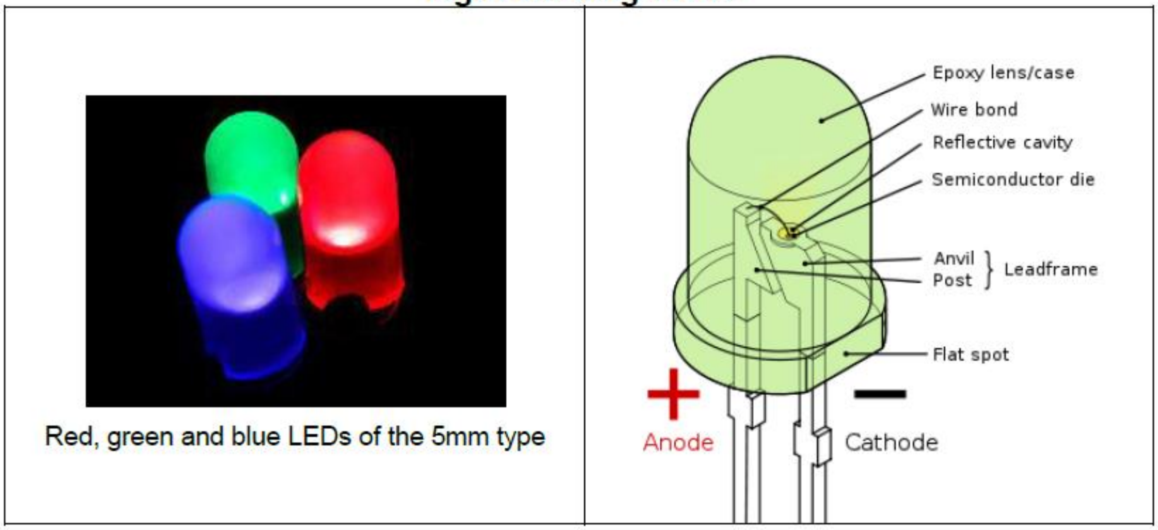
3. If you make a plot of the LED On-Voltage, *Vd* versus the reciprocal of the LED wavelength, $1/\lambda$, what combination of Physical Constants represents the Slope?

4. Two of the LEDs on the Planck’s Constant Determination Apparatus emit no visible light. What type of electromagnetic radiation do they emit?

5. For a LED, the wavelength of the light emitted, and therefore its color, depends on the ________________ of the materials forming the *p-n junction*.

Experiment A: Planck’s constant from LED spectra and turn-on voltage.

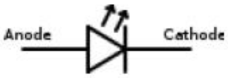
Light-emitting diode



Red, green and blue LEDs of the 5mm type

Invented	Nick Holonyak Jr. (1962)

Electronic symbol

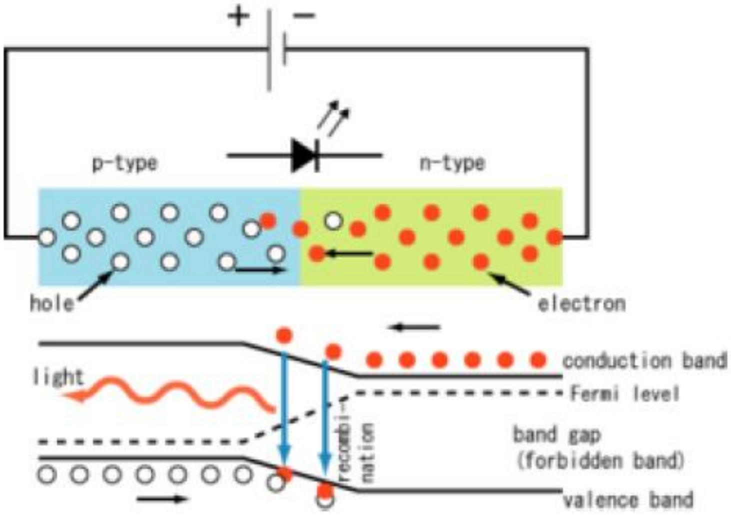


A **light-emitting diode** (**LED**) is a semiconductor light source. LEDs are used as indicator lamps in many devices, and are increasingly used for lighting. Introduced as a practical electronic component in 1962, early LEDs emitted low-intensity red light, but modern versions are available across the visible, ultraviolet and `infrared wavelengths, with very high brightness.

The LED is based on the semiconductor diode. When a diode is forward biased (switched on), electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor.

After performing this experiment and analyzing the data, you should be able to:

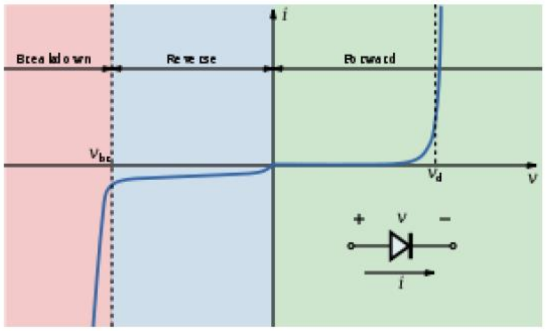
1. Read the wavelength from LED spectra.
2. Determine the voltage at which the LED stops emitting light.
3. Determine Planck's constant from a graph of Voltage vs 1/wavelength.



Like a normal diode, the LED consists of a chip of semiconducting material doped with impurities to create a *p-n junction*. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers—electrons and holes—flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon.

The wavelength of the light emitted, and therefore its color, depends on the band gap energy of the 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, because these are indirect band gap materials. The materials used for the LED have a direct band gap with energies corresponding to near-infrared, visible or near-ultraviolet light. Conventional LEDs are made from a variety of inorganic semiconductor materials, the following table shows some of the available colors with wavelength range, voltage drop and material:

I-V diagram for a diode:



An LED will begin to emit light when the on-voltage, ***Vd*** is exceeded. Typical on-voltages are 2-3 Volt.

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Infrared	λ > 760	ΔV < 1.9	Gallium arsenide (GaAs) Aluminium gallium arsenide (AlGaAs)
Red	610 < λ < 760	1.63 < ΔV < 2.03	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	590 < λ < 610	2.03 < ΔV < 2.10	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	570 < λ < 590	2.10 < ΔV < 2.18	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	500 < λ < 570	1.9 < ΔV < 4.0	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Blue	450 < λ < 500	2.48 < ΔV < 3.7	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	400 < λ < 450	2.76 < ΔV < 4.0	Indium gallium nitride (InGaN)
Purple	multiple types	2.48 < ΔV < 3.7	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic

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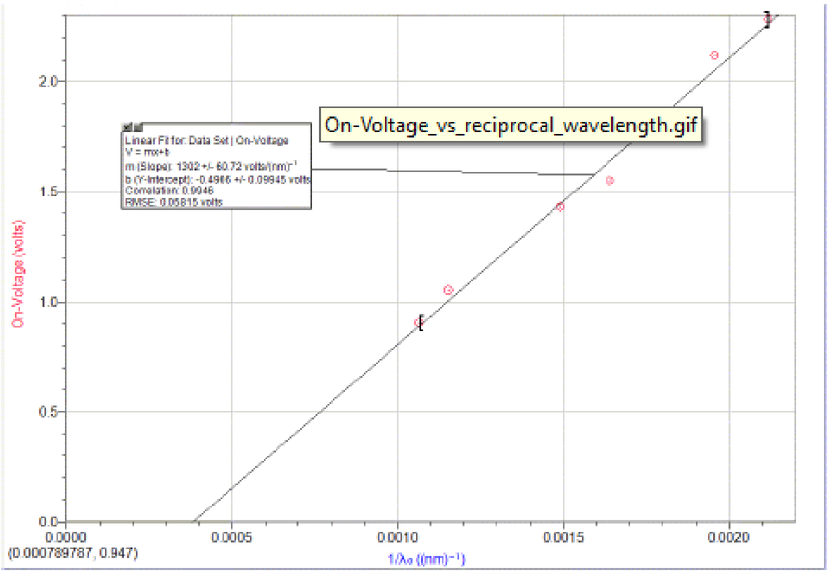
From Conservation energy, one can write,

$$eV_d = hf$$

where e is the charge on an electron charge, h is Planck's Constant and f is the frequency of the emitted photon. Using the wave relationship, $c = f\lambda$, we may rewrite this as:

Equation 1:
$$V_d = \left(\frac{hc}{e}\right)\frac{1}{\lambda}$$

This implies that if one graphs the on-voltage of the LED vs the reciprocal of the wavelength of the emitted light, the slope of the graph may be used to calculate Planck's Constant. A sample of such a graph is shown below:



EXPERIMENTAL PROCEDURE

(Note: turn off room lights to avoid mercury lines in spectrum. Solar lights are fine).

1. A red tide emission spectrometer will be used to display the LED spectra in this experiment. Connect the Fiber-Optic Cable to the SMA connector on the Red Tide Spectrometer. Connect the USB cable from the Spectrometer to the Computer. Mount the other end of the Fiber-Optic Cable in the clamp as shown in Figure 1. Point the fiber at the 1st LED in the array. Hook up the 6V battery pack and the digital meters as shown (The Voltage Range should be 20 V and Ammeter Range 200 mA). Prepare the spectrometer to measure light emission. (It needs to be in Intensity mode rather than the Absorbance default. Under the experiment menu select Change Units, Spectrometer 1, Intensity.). Click "Collect". An emission spectrum will be graphed. Turn the selection dial to the 470 nm LED. Turn on the Power Switch on the "Planck's Constant Determination" box and adjust the red dial until a sizable peak appears in the Logger Pro Program Window. Typical LED spectra are shown at the end of the experimental procedure. These can be combined onto one graph for a printout.

Use the Examine Tool to display the wavelength that corresponds to the maximum intensity. Record this in the data table. Turn the red knob counterclockwise until the LED peak in the spectrum disappears. Record the On Voltage, *Vd* where this happens in the data table. Repeat the above procedure for the other LEDs on the Apparatus after Turning the Selection Dial to the LED you want to display and moving the fiber optic cable over that LED. Record the results in the data table.

λ (nm) (maximum intensity)	V_d *(volts)*	Color	Printed LED λ (nm)
		Blue	470
		Green	505
		Green/Yellow	570
		Yellow/Red	605
		Red	655
		Infra-Red 1	880
		Infra-Red 2	940

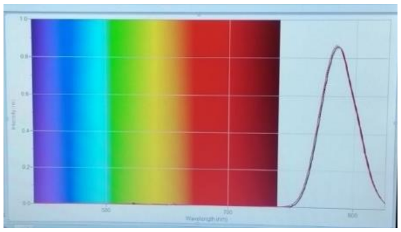
2. Either in Logger Pro, Excel, or by Hand (Professor Korevaar LOVES large graphs done by hand directly in the notebook) plot the On-Voltage V_d versus the reciprocal of the wavelength ($1/\lambda$). Have both the y-axis (V) and the x-axis (nm^{-1}) start at 0, and make sure the x-axis scale is linear in nm^{-1} (for instance, extending from 0 to 0.0025 nm^{-1} in even increments across the page).

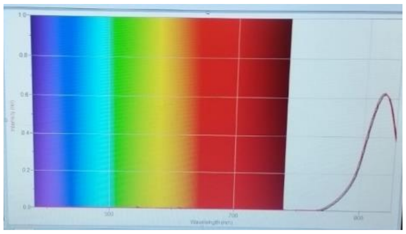
Plot a line through the data, and compute the slope. Since according to Equation 1: $V_d = (hc/e)(1/\lambda)$, the slope of your best fit line should be equal to hc/e. Using known values of e and c, calculate a value for Planck's constant h from your measured slope. (Remember to convert 1 nm to 10^{-9} m as part of your calculation).

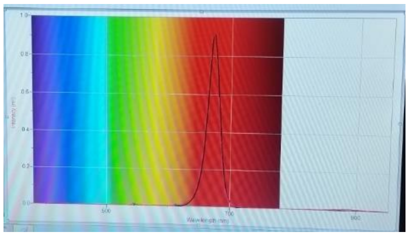
The known value of Planck's constant is $h=6.626 \times 10^{-34}$ Js. Calculate the percent difference between your measured value of h and the known value.

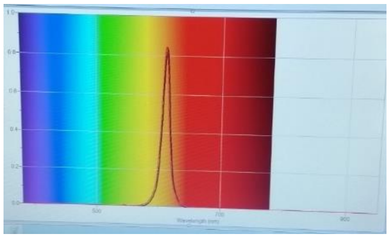
After group discussion, write a one-paragraph conclusion that summarizes the results of this experiment.

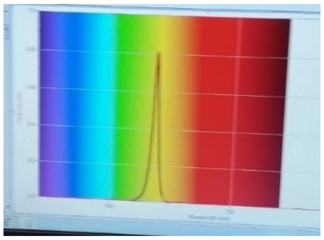
Sample LED spectra are given below:

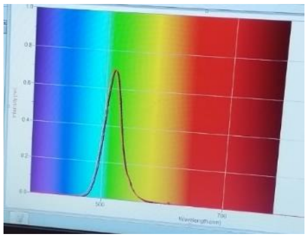


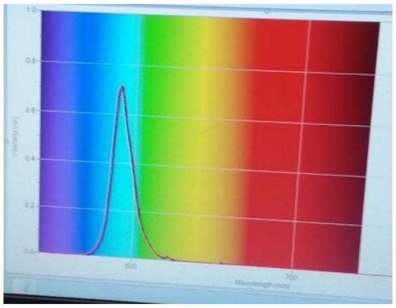


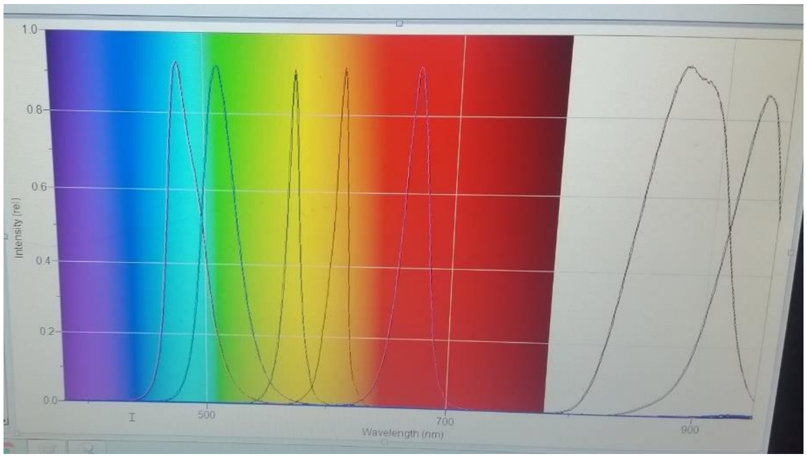












Experiment B: Diode Current-Voltage Curve (I-V Curve).

Using the 605 nm diode, observe the characteristics of current versus voltage just around where the diode turns on (starts emitting light). Measure the current for a voltage of 0.5 V, 1, V, 1.5V, and then carefully increase the voltage, recording the voltage where the current becomes 0.1 mA, 0.2 mA, 0.3 mA, 0.4 mA, 0.5 mA. Continue and find the voltage corresponding to 1 mA, 2 mA, 4 mA, 8 mA and 12 mA. Carefully Plot current versus voltage on a linear plot carefully scaled so the voltage range goes across the width of the graph paper in your notebook. Compare to the right half of the I-V curve in the figure on page 3 of this write-up.