A Determination of Planck's Constant with LED's

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The purpose of this experiment is to measure Planck's constant, a fundamental physical constant in nature, by studying the energy needed to excite the free electrons in a light emitting diode, or LED. Planck's constant is named after Max Planck, a nineteenth century physicist who first described it in the relationship, $E = h\upsilon$. His work is important in this experiment as it compares the quanta of energy absorbed and with that emitted during electron transitions.

When a light-emitting diode is 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 band gap of the semiconductor. An LED is often small in area (less than 1 mm2), and integrated optical components may be used to shape its radiation pattern.[6] LEDs present many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching.

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 thus 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.

While the exact mechanism of an energy level transition in solid state devices such as an LED is slightly different than that learned while studying atomic structure, both the concepts and mathematics are the same. That is, electrons within the LED crystal will be excited to a higher energy state emitting photons as they return to a lower energy state. In our experiment, we will follow this process using an electric current to excite the electrons measuring this energy with a voltmeter. The unit of a volt, a Joule per coulomb, is equivalent to the energy unit, an electron-volt, eV. The wavelength of the resulting light will be determined with a spectrometer. Since we know the relationship $c = \lambda\upsilon$, or the speed of light (3.00×10^8 m/s) = wavelength of the light times its frequency, we can find the frequency of the light emitted by the diode. Planck's constant can then be calculated by substituting this frequency and energy from the voltmeter in the relationship, $E = h\nu$.

Objectives:
1. In this experiment, you will determine Planck's constant by measuring the energy emitted by a selection of light emitting diodes (LED's).
2. Use a spectrometer to measure the wavelength of the light emitted by each LED.
3. Measure voltage drop across each light emitting diode, a number related to the energy absorbed by the diodes and calculate Planck's constant from the wavelength and voltage.
4. Design Experiment to determine the wavelength of light emitted by un known LED.
5. Determine wavelength of unknown LED

Materials:
computer, or LabQuest
Vernier interface
Vernier spectrometer w/USB cable
fiber optic cable for the spectrometer
voltage sensor
LED exciter box (pwista.com)
collection of LED's
labels or masking tape

Procedure:
1. Insert an LED into the exciter box completing the circuit with the longer leg connected to the red wire connected ti internal resistor. If the LED doesn't immediately light, reverse the polarity of the device.

2. Attach a fiber optic cable to your spectrometer and connect it to your computer or LabQuest by means of a USB cable. If using a computer, start the Logger Pro software. Once the software identifies the spectrometer, click on the "Experiment" drop down menu and scroll down to "Change Units," then "Spectrometer 1," and select "Intensity." You should now be ready to generate a spectrum for your LED.
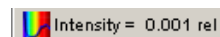
   If using a LabQuest, connect the USB cable from the spectrometer to the USB port in the back. Tap the 0.000 abs reading in the Meter screen select "Units," then "Intensity." Next, tap the "Mode: Full Spectrum" in the same screen changing the Sample Time to 10 ms and Sample to Average to 1. The sample time can also be adjusted later, if necessary.

3. Click or tap "Collect" and aim the fiber optical cable at the LED. You should observe a spectrum. If the intensity is too low or high, first adjust the distance from the tip of the cable to the LED. If that doesn't work, adjust the sample time. On a computer, click on the Intensity icon in the upper left hand corner of your screen just above the data table. Note the adjacent capture. When using a LabQuest, stop data collection and return to the meter screen as described above.

   The spectrometer setup menu on a computer will appear as in the adjacent capture. Increase or decrease the sample time until a
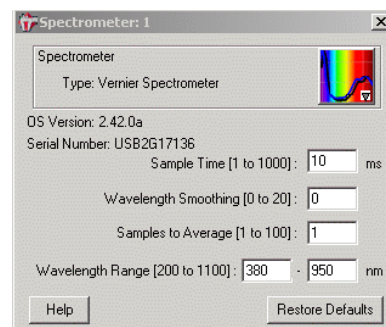
usable spectrum is produced. Changing the Wavelength Smoothing to "0" and Samples to Average to "1" will speed up the data collection.

5. Once you have a suitable spectrum, find the peak wavelength of the LED light at its maximum intensity. One method to identify the peak wavelength is to highlight the spectrum and zoom in magnifying the peak as many times as is necessary to resolve the maximum. Record both the peak or maximum wavelength of the LED and the color of the LED's light in Data Table #1. In addition, write the wavelength on a small piece of tape and attach it to one of the leads of the LED to later identify its wavelength.

6. Repeat steps #4 and #5 for each of the available LED's.

Part II

7. Unplug the spectrometer from your computer or LabQuest. Select "New" in the File drop down menu or icon. Plug a voltage sensor into a Vernier interface. Both Logger Pro and a LabQuest will automatically identify the voltage sensor.

8. The next step is to change the mode of data collection from "Time Based" to "Events with Entry." If using a computer, click on the data collection icon, 🕓, changing the "Time Base" mode to "Events with Entry." Type the column name to Wavelength, the short name to the Greek letter, λ, the symbol for wavelength, and the units, nm, for nanometer. Then click on "Done."

   If using a LabQuest, change the Mode by tapping the Mode box in the Meter screen and changing it as in Logger Pro to "Events with Entry" naming the column "wavelength" and units to nanometer, nm. Then tap "OK."

9. Next, disable the "Connect Points" option on the Graph Options menu. When using a computer, this can be accomplished by clicking anywhere in the open space of the graph. The Graph Options menu will appear. Deselect "Connect Points" and select "Point Protectors." Click "Done" to return to Logger Pro.

   When collecting data with a LabQuest, tap the "Graph" drop down menu in the Graph screen, then "Graph Options," then deselect "Connect Points" and select "Point Protectors." Tap "OK" to return to the Graph screen.

10. Start data collection by clicking or tapping "Collect." Observe the "Keep" icon adjacent to the "Collect" icon.

11. Insert a LED into your circuit as when measuring the wavelength. Again, if the LED doesn't light, reverse the leads. When the voltage stabilizes, click or tap on "Keep," enter the wavelength for the LED, then "Done" or "OK." Repeat this process until data has been collected for all your assigned LEDs. Finally, click or tap "Stop."

12. Remove the labels from all LED's and return all materials to their designated areas.

Part III

13. Determine procedure to determine the wavelength of unknown LED. Perform experiment and determine wavelenth of light emmited from unknown LED.

Guided Conclusion Questions and Calculations:

Q1. If the voltage data was collected on a LabQuest, first transfer the data to a computer with a SD card, USB thumb drive, or a USB cable connecting the two units.

Sort the data on the computer by wavelength after selecting "Sort Data" in the Data drop down menu, and following the instructions. Transfer the wavelength and LED color from Data Table #1 to Data Table #2 in wavelength order.

Q2. In the Data drop down menu, prepare each of the calculated columns utilizing the New Calculated Column option. Copy the results of these calculations to Data Table #2.
  (a) Convert the wavelengths from units of nanometers to meters by multiplying the wavelength by the conversion, 1×10^{-9} m/nm.

  (b) Calculate the frequency, ν, of the light emitted for each LED.

  (c) Calculate the energy required to excite each LED in Joules by multiplying the voltage measured by 1.6×10^{-19} J/eV.

  (d) Calculate experimental Planck's constant, h, from the relationship, $E = h\nu$.

  (e) Find the average value for Planck's constant from your data.

Q3. Plot the energy needed to excite the LED's vs the frequency of the LED light. Determine the slope of the best straight line. What is the significance of the slope?

Q4. According to your data, what is the relationship between the voltage required to excite the electrons in the LED and the wavelength of resulting light produced? How do you explain this trend?

Q5. Describe briefly how this experiment verifies the quantum mechanical model of the atom.

Q6. How would you describe the pattern of the various colors of the light produced by the LED's when sorted by wavelength?

Data:

Table #1:

Wavelength nanometers	Color	Wavelength nanometers	Color	Wavelength nanometers	Color

Table #2:

Wavelength (meters)	Color	Voltage Drop (volts)	Frequency (hertz, sec^{-1})	Energy (Joules)	Experimental Planck's Constant (Joule·seconds)

Notes for Teachers

1. This experiment is an adaption of one described by Patrick O'Connor and Leah O'Conner in the October 1974 issue of The Physics Teacher, p 435. The major differences being the size of the current limiting resistor and the use of a spectrometer to measure the wavelength of the light emitted.

2. LED Exciter Box Purchased at http://www.pwista.com/Mini_Scale_Concepts.htm

3. This lab addresses the presentation of Essential Knowledge 1.B.1.d and 1.D.3.a of College Board Recent Curriculum.

Sample Experimental Planck's Constant Data

Wavelength (nm)	Potential (volts)	Planck's Constant (J·s)
401	3.06	6.54×10^{-34}
463	2.92	7.20×10^{-34}
506	2.89	7.80×10^{-34}
518	2.81	7.77×10^{-34}
564	2.00	6.02×10^{-34}
591	1.92	6.07×10^{-34}
594	1.96	6.20×10^{-34}
610	1.87	6.08×10^{-34}
618	1.88	6.19×10^{-34}
625	1.84	6.12×10^{-34}
627	1.83	6.12×10^{-34}
635	1.83	6.20×10^{-34}
646	1.66	5.73×10^{-34}