Experiment
22

Planck's Constant

INTRODUCTION

The energy of a photon is related to its frequency by the equation $E = hf$, where h is Planck's constant. By determining the potential required to excite an LED to emit light, you can estimate the energy of the photons emitted. Using a spectrometer, you can measure the peak wavelength of the emitted light; from this, the frequency can be calculated. Performing this analysis for a number of LEDs will enable you to obtain a reasonable approximation of the value of Planck's constant.

OBJECTIVES

In this experiment, you will

- Collect and analyze current *vs*. potential data to estimate the energy required to excite a number of LEDs.
- Use a spectrometer to determine the wavelength of the peak output of each LED.
- Determine a value for Planck's constant from an analysis of the energy and frequency of the light emitted by a number of LEDs.

MATERIALS

Vernier data-collection interface
Logger *Pro* **or** LabQuest App **or** a computer
with the Vernier Power Amplifier computer program
Red Tide Spectrometer and VIS-NIR Optical Fiber
or Vernier SpectroVis Plus and Optical Fiber
Vernier Differential Voltage Probe
Vernier Power Amplifier
Vernier Current Probe
10–15 Ω resistor
4–5 LEDs

PRE-LAB INVESTIGATION

1. Connect the Vernier Power Amplifier in series with a power resistor and a red LED as shown in Figure 1. Connect the longer pin on the LED to the wire lead from the red terminal.

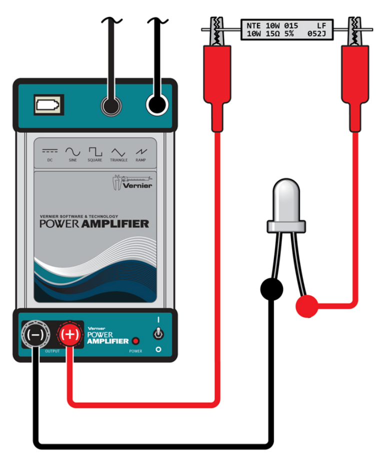

Figure 1

2. Choose one of the following options to investigate the effect of the forward biasing voltage on the LED.

   LabQuest with Logger *Pro*

   a. Use the mini stereo cable that came with the power amplifier to connect the Speaker Out port on LabQuest and the Audio In port on the amplifier.
   b. In Logger *Pro* choose Set Up Sensors ► Show All Interfaces from the Experiment menu.
   c. From the Sensor Setup dialog box, click Power Amplifier. Close the Sensor Setup dialog box and move the Power Amplifier dialog box to a convenient place on your screen. In the Waveform list, click DC Mode.
   d. Click Start, then adjust the voltage until the LED begins to glow.

   LabQuest as a standalone device

   a. Use the mini stereo cable that came with the power amplifier to connect the Speaker Out port on LabQuest and the Audio In port on the amplifier.
   b. Launch Power Amplifier from the Home screen. In the mode list, select DC.
   c. Tap Start. Use the up arrow next to the V field to gradually increase the voltage until the LED begins to glow.

   Vernier Power Amplifier computer program and the computer's audio output

   a. Use the mini stereo cable that came with the power amplifier to connect the speaker out port on your computer and the Audio In port on the amplifier.
   b. Set the computer's sound output on and at maximum volume.
   c. Start the Vernier Power Amplifier computer program.
   d. Set the mode to DC, .
   e. Click Start, then adjust the voltage until the LED begins to glow.

3. Observe what happens if you reverse the connections to the pins on the LED once it is lit.

In your classroom discussion you will learn about the design and operation of an LED. You can use the LED Constructor simulation[1] at the Visual Quantum Mechanics web site or another web resource to understand what you have observed thus far.

PROCEDURE

Part 1 Turn-on voltage

Rather than manually increasing the voltage to determine the point at which charge begins to flow through the LED as you did in the Pre-Lab Investigation, in this part of the lab you will monitor the voltage and current for one cycle of a saw-ramp AC waveform. Doing so affords much greater precision in determining the turn-on voltage.

1. If you were using a LabQuest to drive the power amplifier in the Pre-lab Investigation, connect a Differential Voltage Probe and a Current Probe to LabQuest. If you were using the Vernier Power Amplifier computer program, connect an interface (LabQuest Mini or LabPro) to your computer and connect these sensors to the interface and start Logger *Pro*.

[1] http://phys.educ.ksu.edu/vqm/html/ledcons.html

2. Connect the current probe in series in your circuit between the resistor and the red LED. Connect the leads of the voltage probe to the clip ends of the wire leads attached to the LED (see Figure 2).

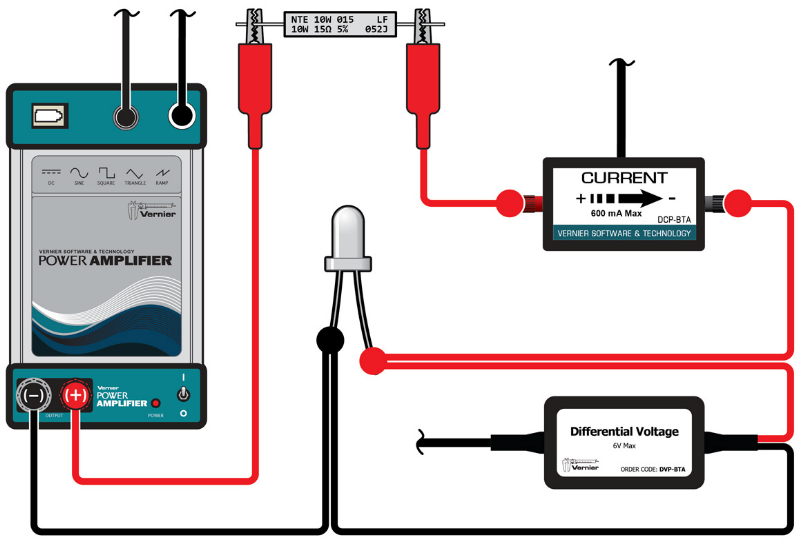

Figure 2

3. If you are using LabQuest as a standalone device, launch Power Amplifier from the Home screen. In the mode list, select the saw-ramp AC current output, .

   If you are using Logger *Pro* with any of the interfaces, choose Set Up Sensors ► Show All Interfaces from the Experiment menu. From the Sensor Setup dialog box, click Power Amplifier. In the waveform list, click Ramp Up.

   In either case, set the frequency to 100 Hz and the AC voltage to 3.0 V. For blue and UV LEDs, increase the forward voltage to 4.0 V.

4. Set the data-collection rate to 10,000 Hz and the duration to 0.010 s. Enable Triggering and set data collection to begin when the voltage is increasing across 0.2 V.

5. Zero the current probe. Touch the leads of the voltage probe together and zero this sensor.

6. Start the current as you did earlier. If the LED does not light, check your connections. Start data collection. The graph of voltage *vs.* time should show a steady increase before a sharp drop; the current *vs.* time graph should fluctuate at about zero before showing a rapid increase. If this occurs, store the run. If not, check your connections and try again.

7. Stop the current and replace the red LED with another of the LEDs that you are testing. Be sure to note its color. Repeat Step 6. Continue in this way until you have tested all of the LEDs. Save your experiment file.

Part 2 Spectral Analysis

1. Disconnect the voltage and current probes from your interface. If you are using LabQuest as a standalone device, connect the spectrometer to the USB port on LabQuest and choose New from the File menu. If you are using Logger *Pro*, connect the spectrometer to a USB port on the computer and choose New from the File menu. Connect the appropriate optical fiber to your spectrometer.

2. Choose from one of the following options to illuminate the LED and collect spectral data.

   Logger *Pro* and a LabQuest

   a. Make sure that the mini stereo cable still connects the Speaker Out port on LabQuest to the Audio In port on the amplifier.
   b. In Logger *Pro*, choose Set Up Sensors ► Show All Interfaces from the Experiment menu.
   c. Click the icon for the Power Amplifier. Select DC Mode as the Waveform, set the DC voltage to 3.0 V (use 4.0 V for blue or shorter wavelengths), and click Start.
   d. Move this window to a more convenient spot on your screen and close the LabQuest window.
   e. Choose Change Units ► Spectrometer ►Intensity from the Experiment menu.

   LabQuest as a standalone device

   a. Make sure that the mini stereo cable still connects the Speaker Out port on LabQuest to the Audio In port on the amplifier.
   b. Choose Power Amplifier from LabQuest Home menu. Select the icon for direct current output shown at right, set the DC voltage to 3.0 V (use 4.0 V for blue or shorter wavelengths) and tap Start.

   

   c. Use the down arrow in the upper-left corner of the screen to return to the LabQuest data collection window.
   d. Tap in the meter window (USB: Abs) and choose Change Units ►Intensity.

   Power Amp computer program and the computer's audio output

   a. Make sure that the mini stereo cable still connects the speaker out port on your computer to the Audio In port on the amplifier and that the computer's sound output is turned on.
   b. Start the Vernier Power Amplifier computer program.
   c. Set the DC voltage to 3.0 V (use 4.0 V for blue or shorter wavelengths) then click Start.
   d. Return to the Logger *Pro* window. From the Experiment menu choose Change Units ► Spectrometer ►Intensity.

3. Start data collection. Aim the end of the optical fiber at the top of the illuminated LED. If the peak of the graph maxes out (flat, wide peak at an intensity of 1.0), move the tip of the optical fiber slightly farther away. If the peak is too small, shift the position of the tip so that light from the LED enters it. When you see a suitable peak on the graph of the spectrum, stop data collection. Record the color of the LED and store the run.

4. Replace the LED with one of the others that you tested in Part 1. If the LED does not light, check to make sure you have correctly connected the leads to the pins. Adjust the voltage if necessary, then repeat Step 3.

5. When you have finished, stop the current, turn off the power amplifier, and save your file.

EVALUATION OF DATA

1. Disconnect the spectrometer from the computer or LabQuest. Open the experiment file in which you measured the current through and the potential across the various LEDs you tested. Choose to view just one graph: current *vs.* potential.

2. For each LED, determine the value of the turn-on voltage.

   Logger *Pro*

   a. Choose Examine from the Analyze menu. Position the cursor on the graph where the current begins to climb. Note that the values of the potential and current corresponding to this location are highlighted in the data table. Scroll up and down until you find the value of the potential where the current appears to increase without fluctuating. Record this as the turn-on voltage in your lab notebook.

   LabQuest App

   a. Tap the portion of the graph where the current begins to climb, then tap the Table tab. Note that the values of current and potential corresponding to this location are highlighted. Scroll up and down until you find the value of the potential where the current appears to increase without fluctuating. Record this as the turn-on voltage in your lab notebook.

3. Next, open the file in which you recorded the spectrum for each of the LEDs that you tested.

4. For each LED, find the wavelength at which the output of the LED reached a maximum. Record this value in your lab notebook.

You are now ready to examine the relationship between photon energy and frequency, and then to determine the value of Planck's constant, h.

5. Choose New from the File menu. Manually enter the values of the turn-on voltage and the wavelength of the maximum output for each LED.

6. Create a new calculated column to determine the energy (in joules) of the photons of light emitted by the LED at the wavelength corresponding to the maximum output. This value is approximately equal to energy required to move an electron from the conducting band in the n-type material to that in the p-type. This is the product of the charge of an electron and the turn-on voltage, $E = qV$.

7. Create a new calculated column in which you determine the frequency (in 1/s) of the light corresponding to the wavelength at the maximum output. Recall that you recorded the wavelengths in nm.

8. Change what is plotted on the graph to produce a graph of energy *vs.* frequency. To ensure that the best-fit line passes through the origin, choose Curve Fit from the Analyze menu and select Proportional from the list of options. Record the value and units of the constant of proportionality.

9. How does the value you obtained for the constant of proportionality compare to Planck's constant? Considering the difference between your experimental value of Planck's constant and its accepted value, would you say that your values of turn-on potential were too low or too high? Explain.

EXTENSIONS

1. How likely is it that the disagreement between your experimental and accepted value for Planck's constant is due to uncertainty in the measurement of the potential or the wavelength? You can obtain specifications for resolution of the sensors at the Vernier web site.

2. The manufacturer of one infrared LED states that its maximum output wavelength is 840 nm. What would you expect its turn-on potential to be? (Use the accepted value for h.)

Vernier Lab Safety Instructions Disclaimer

THIS IS AN EVALUATION COPY OF THE VERNIER STUDENT LAB.

This copy does not include:

- **Essential instructor information including discussions on how to lead students to a successful activity**
- **Sample data**
- **Important tips for successfully doing these labs**
- **Answers to questions and extensions**

The complete *Advanced Physics with Vernier – Beyond Mechanics* lab manual includes 22 experiments, as well as essential teacher information. The full lab book is available for purchase at: www.vernier.com/phys-abm

Vernier Software & Technology

Vernier Software & Technology
13979 S.W. Millikan Way • Beaverton, OR 97005-2886
Toll Free (888) 837-6437 • (503) 277-2299 • FAX (503) 277-2440
info@vernier.com • www.vernier.com