

Periodic Properties and Light Emitting Diodes

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Purpose:

The object of this module is to relate observed properties such as color, wavelength and energy of light, and excitation voltage for a series of compound semiconductors to composition and periodic trends. The changes in electrical resistance of a metal and a semiconductor, in regards to temperature and illumination respectively, will be observed.

Learning Objectives:

- Through an understanding of semiconductors students will be able to recognize and explain forward and reverse bias.
- Through an understanding of Fermi energy students will be able to analyze the effects of temperature on LED's.

Introduction:

A light emitting diode (LED) is a semiconductor device that emits visible light when an electric current passes through it. Light is emitted when this current is strong enough to excite the chemically bonded electrons within the diode.

Just as with all other diodes, LED's are composed of a p-type semiconductor and an n-type semiconductor. This simply means that the semiconductor material is intentionally introduced to a positive or negative material, respectively, in order to change its electrical properties.

P-type semiconductors are created by positive doping, which is used to create a loss of electrons and creates holes in the material. N-type semiconductors are created by negative doping that increases the amount of "free" electrons in the material.

If enough voltage is applied to an LED the electrons in the n-type region and the holes in the p-type region move toward the junction, thus allowing current to flow, and the electrons and holes can then combine and give off energy in the form of light when they cross the junction. This is known as forward bias.

The fundamental property of a diode is its tendency to conduct electrical current in only one direction. If the direction on voltage is reversed, holes and electrons move away from each other, so very little electric current can pass and no light is emitted. This is known as reverse bias.

However, if enough voltage is applied to the system in this reverse direction then electric current will once again be able to pass through. This is known as the breakdown voltage in reverse bias. Eventually enough energy will be produced for the electrons to move from the valence shell and over the band gap thereby allowing conduction to occur.

The size of this band gap is affected by the Fermi energy, or the energy of the highest filled energy level. An increase in Fermi energy moves the electrons further out of the valence shell and closer to the conduction band, thereby shrinking the band gap. Since Fermi energy increases with temperature, a higher temperature is equated with a smaller band gap.

Materials:

- 5 Kobiconn Test Clips, 10PC 5 Color Set
Mouser Electronics, #13AC012
- Eagle Premium Battery Snaps, white molded, 2PC, I-6”
Mouser Electronics, #123-7016
- 1-k Ω 1/4W Carbon Film Resistor
Mouser Electronics, #291-1K, \$0.009 ea in lots of 200.
- White Water Clear T-1 3/4 LED
Mouser Electronics, #606-CMD333UWC, \$3.02 ea.
- Battery, 9 Volt
- 1-M Ω 1/4W Carbon Film Resistor
Mouser Electronics, #291-1M, \$0.009 ea in lots of 200.
- Multimeter
- Thermometer
- Liquid nitrogen
- Polystyrene coffee cups
- Replica Diffraction Grating with 530 Grooves/MM
The Welch Scientific Co., # 3813
- LED reference strip box (See attached *Building the LED Reference Box*)
- Red Super Bright Water Clear T-1 3/4 LED
Mouser Electronics, #512-MV8112, \$0.20 ea in lots of 100.
- Orange Super Bright Water Clear T-1 3/4 LED
Mouser Electronics, #512-MV8713, \$0.38 ea in lots of 100.
- Yellow Super Bright Water Clear T-1 3/4 LED
Mouser Electronics, #512-MV8313, \$0.38 ea in lots of 100.
- Green Super Bright Water Clear T-1 3/4 LED
Mouser Electronics, #512-MV8412, \$0.29 ea in lots of 100.
- Blue Water Clear T-1 3/4 LED
Mouser Electronics, #606-CMD383UBC/H2, \$2.52 ea. Digital voltmeter
- Economy Encapsulated RF Choke
Mouser Electronics, #43LJ415, \$1.18 ea.
- CdS Photocell
Jameco Electronics, #202403, \$1.49 ea.

Procedure:

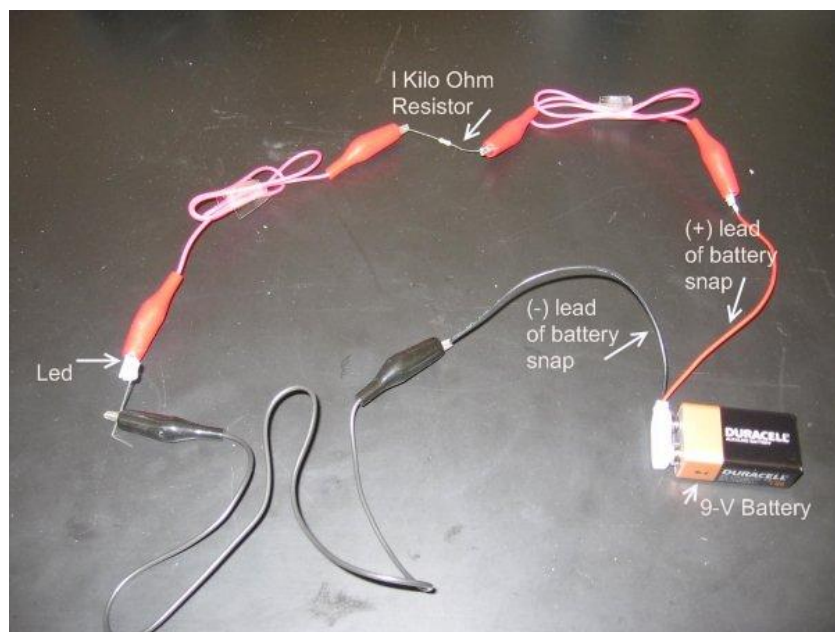
Creating a Circuit:

- 1) Create a circuit containing a 1-k Ω resistor. You will need 3 alligator clips, a battery snap, a 1-k Ω resistor, and a white LED.

Note: Recommended to use 2 alligator clips of one color and 1 of another to distinguish between positive and negative sides of the circuit (i.e. red for positive)

and black for negative). The single alligator clip will be used for the negative side and the 2 clips of the same color will be used for the positive side.

- 2) Connect the “negative” clip to the corresponding negative wire of the battery snap.
- 3) Connect one of the “positive” clips to one side of the 1-k Ω resistor and connect the remaining end of this clip to the corresponding positive wire of the battery snap.
- 4) Now connect the remaining “positive” clip to the other end of the resistor.
- 5) Connect a 9-V battery to the battery snap.



- 6) To complete or “turn on” the circuit connect the LED. Do this by connecting the remaining end of the “positive” clip to one prong of the LED and the remaining end of the “negative” clip to the other prong.
Note: Make sure the two clips aren’t touching.

Does the LED light up?

- 7) Try inserting the LED in the alternate direction by reversing the negative and positive clips.

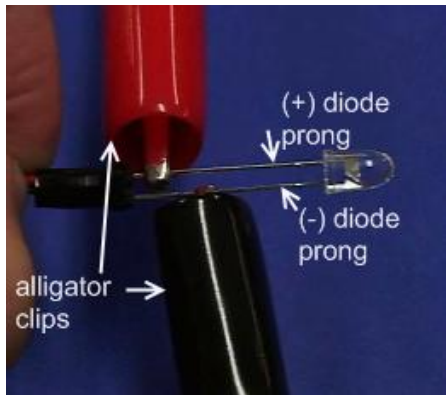
Does the LED light up this time?

Does it matter which way the LED is inserted?

Measuring Voltage:

- 8) Leave the LED inserted in the correct direction (so that it's lit up).
- 9) Now replace the 1-k Ω resistor with a 1-M Ω resistor.
- 10) Obtain 2 more alligator clips. Attach a multimeter to the set-up. Do this by attaching a new alligator clip to the red probe of the multimeter and the remaining end to the LED prong that is connected to the "positive" clip. Similarly, attach another alligator clip to the black probe of the multimeter and the other end of the clip to the remaining LED prong, or the prong that is connected to the "negative" clip.

Note: The meter must be set to measure in 20 Volts DC setting.



- 11) Record the measured voltage along with the room temperature.

Room Temperature: _____

Measured Voltage: _____

- 12) Obtain liquid nitrogen in a foam cup.

13) Plunge the LED into liquid nitrogen in a foam cup and record the measured voltage.

Caution: liquid nitrogen is extremely cold. Do NOT allow it to come into contact with skin or clothing, as severe frostbit may occur.

Measured Voltage: _____

14) Remove the LED from the liquid nitrogen. Allow it to return to room temperature.

Analysis of the Light Output:

15) Replace the 1-M Ω resistor with the 1-k Ω resistor.

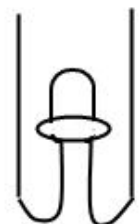
16) Obtain a diffraction grating and an LED reference strip box.



17) View the white LED in the circuit through the diffraction grating.



18) Bend the two prongs on the LED so it is almost allowed to “swing” from the alligator clips and the top surface of the LED can be seen when looking straight down on the LED.



19) Plunge the LED into the liquid nitrogen and view the diffraction grating again.

Does this change anything? (i.e. Is any band of color shorter than it was before?)

20) Repeat step 16 with each colored LED, using the LED reference strip to observe changes in the emitted colors at low temperatures. Record all observations in the chart provided.

Observed Effects of Liquid Nitrogen on LEDs

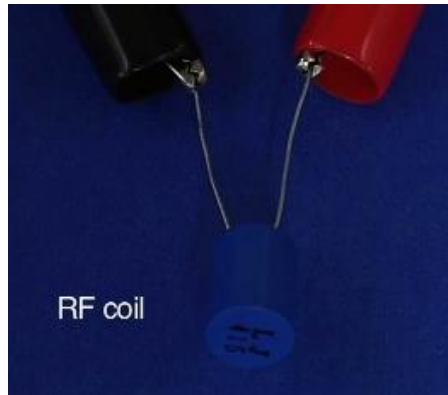
LED Color	Observations
White	
Blue	
Green	
Yellow	
Orange	
Red	

Measuring Resistance:

21) Obtain a digital ohmmeter and a copper RF coil.

22) Attach the ohmmeter to the coil. Do this by clipping an alligator clip to each probe of the ohmmeter and then attaching each of the remaining ends to the two wires of the coil.

Note: The meter must be set to measure in 200Ω setting.



23) Record the measured resistance.

Measured resistance: _____

24) Dip the copper RF coil into liquid nitrogen. Record the measured resistance.

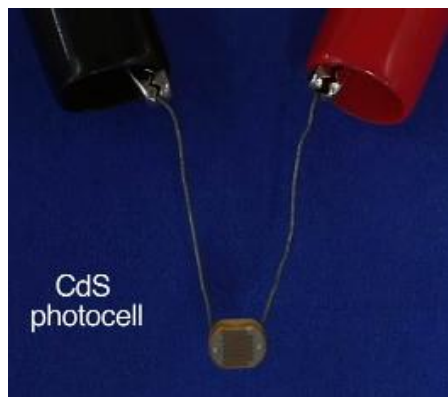
Measured resistance: _____

25) Obtain a CdS semiconductor photocell.

Note: Do not immerse the photocell in liquid nitrogen, this can damage it.

26) Remove the copper RF coil from the ohmmeter clips and replace it with the photocell.

Note: The meter must be set to measure in 2000 Ω setting.



27) Record the measured resistance.

Measured resistance: _____

28) Cover the photocell with your hand to block out most of the light. Record the measured resistance.

Measured resistance: _____

29) Try blocking out all of the light.

What does this do to the resistance of the cell? Explain why this occurs.

Discussion Questions:

1) Explain why the LED lights up when it is inserted into the circuit in one direction, but not in the other.

2) Explain the change in voltage produced by the LED as it goes from room temperature to being plunged into the liquid nitrogen.

3) Using the table provided, explain the various changes observed in the diffraction gratings as the different LEDs were plunged into the liquid nitrogen.

Color of Light	Approximated Wavelength (nm)
Red	700
Orange	620
Yellow	580
Green	530
Blue	470
Violet	420

References:

- Fishbane, P. M., S. G. Gasiorowicz, & S. T. Thornton (2005). *Physics for scientists and engineers with modern physics*. Upper Saddle River, New Jersey: Pearson Education Inc.
- Voss, E. (2006, July 22). Periodic properties of light emitting diodes. *Interdisciplinary Education Group*, Retrieved June 4, 2008, from <http://www.mrsec.wisc.edu/Edetc/nanolab/LED/text.html>

Teacher Key:**Discussion Questions:**

- 1) An LED is a semiconductor device and therefore composed of p-type and n-type semiconductors. The n-type is negatively doped and therefore contains extra “free” electrons. The p-type is positively doped and therefore is missing electrons, creating holes. In forward bias, voltage is applied to an LED and the electrons in the n-type region and the holes in the p-type region move toward the junction, thus allowing current to flow, and the electrons and holes can then combine and give off energy in the form of light as they cross the junction. However, the fundamental property of a diode is its tendency to conduct electrical current in only one direction. In reverse bias, the direction on voltage is reversed holes and electrons move away from each other, so very little electric current can pass and no light is emitted.
- 2) An LED is a semi-conductor and therefore contains a band gap between its valence shell and its conduction band. In order for conduction to occur, electrons in the valence shell must have enough energy to pass over the band gap and into the conduction band. The size of this band gap is affected by the Fermi energy, or the energy of the highest filled energy level. An increase in Fermi energy moves the electrons further out of the valence shell and closer to the conduction band, thereby shrinking the band gap. Since Fermi energy increases with temperature, a higher temperature is equated with a smaller band gap. Therefore, when the LED was plunged into the liquid nitrogen it experienced a large decrease in temperature causing an increase in band gap, which consequently caused an increase in resistance showing up here as an increase in voltage.
- 3) As previously stated, a decrease in temperature causes an increase in band size. This increase in band size causes a decrease in wavelength. As the wavelength shortens it loses the higher wavelength end of the spectrum or the red end of the spectrum causing a loss of the red color in the LEDs as they are plunged into the liquid nitrogen.
- 4) Resistance measures the difficulty with which an electron moves through a material. Copper is a conductor and therefore has no band-gap. This means that all of the electrons can get to the conduction band and the real determining factor is how easy their “path” is there. Therefore a decrease in temperature will decrease resistance because the atoms are vibrating a slower speed and lower amplitude, thereby freeing the “path” for the electrons.
- 5) As the intensity of light reaching the CdS semiconductor photocell is decreased, the resistance gradually increases, eventually reaching infinity when there is no light reaching the cell. This is expected because a photocell is a variable resistor and light hitting the cell provides more available electrons, so a decrease in light increases resistance.

Suggestions for lab placement:

This could be used in the Physics 101/102 lab because it covers a variety of the topics discussed in the class: circuits, diodes, resistance, current, voltage, semi-conductors, band gaps, light spectrum, etc. Also, it would be great if the students could somehow be involved in helping create the box. Maybe certain parts came pre-made by the instructor (Steps 1 – 30 and 52 – 56 of Building the LED Reference Box) and the students could put the box together (Steps 31 – 51 of Building the LED Reference Box).

Note: Soldering could be left out.

Supplies List (For 10 Students):

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Mouser Electronics, #291-1K, \$0.009 ea in lots of 200.
- 10 White Water Clear T-1 3/4 LEDs
Mouser Electronics, #606-CMD333UWC, \$3.02 ea.
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- 1-M Ω 1/4W Carbon Film Resistors
Mouser Electronics, #291-1M, \$0.009 ea in lots of 200.
- 10 Multimeter
- Thermometer
- Liquid nitrogen
- Polystyrene coffee cups
- 10 Replica Diffraction Grating with 530 Grooves/MM
The Welch Scientific Co., # 3813
- 5-10 LED reference strip boxes (See attached *Building the LED Reference Box*)
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- 5 Economy Encapsulated RF Chokes (1 per every 2 students)
Mouser Electronics, #43LJ415, \$1.18 ea.
- 5 CdS Photocell (1 per every 2 students)
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