# Light-Emitting Diodes (LEDs)
## *Student Materials*


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# LED Review Questions

1. Consider two samples in the form of powders: sample A is a physical mixture comprising equal moles of pure Ge and pure Si; sample B is a solid solution of composition $Si_{0.5}Ge_{0.5}$. For which of the following measurements will the two samples appear identical?

   A. X-ray diffraction
   B. elemental analysis
   C. band gap energy measurement based on absorption of light
   D. none of the above

2. Both of the semiconductors GaAs and GaP have the zinc blende structure. From X-ray diffraction, one sample has a cubic unit cell size of 5.45 Angstroms and the other has a cubic unit cell size of 5.65 Angstroms.
   a) Which is which based on position in the periodic table?

   b) From the relationship between atomic spacing and the resulting diffraction spots, which sample, GaAs or GaP, would have given the larger diffraction pattern and why?

3. Is Ga or Al more electronegative? Considering only the electronegativity difference, would GaAs or AlAs have a larger band gap energy? Explain.

4. Considering only atomic radii, rank the following in order of increasing band gap energy: $GaP_{0.40}As_{0.60}$, $GaP_{0.65}As_{0.35}$, $GaP_{0.85}As_{0.15}$, $GaP_{1.00}As_{0.00}$

5. Considering only electronegativity, rank the following in order of increasing band gap energy: $Al_{0.35}Ga_{0.65}As$, $Al_{0.25}Ga_{0.75}As$, $Al_{0.15}Ga_{0.85}As$, $Al_{0.05}Ga_{0.95}As$

6. What usually happens to the bond distances of a material when it is cooled? Considering only bond distance, would a material's band gap be larger when warm or cold? Explain.

7. Some LED materials can be prepared by combining Ga, In, As, and P in the zinc blende structure. If the formula of the solid is $Ga_{0.45}In_xAs_{0.75}P_y$, what are x and y equal to, and how would you interpret this formula based on the zinc blende structure?

8. Give a brief explanation for the following:

   Why does squeezing some LED's (applying pressure to them) make their spectrum move to shorter wavelengths?

9. In a recent news clipping from *Science* magazine, a breakthrough in making blue LEDs was described. Samples of gallium nitride, GaN, can give blue emission. In our lab, the green LED was GaP. If both GaP and GaN are emitting at about their band gap energies, discuss why it is reasonable that GaN would emit in the blue part of the spectrum.

10. Predict what would happen to the emission spectrum of the GaN LED if it were run at low temperatures (e.g., a cold Madison day) and why.

11. GaN is described as being harder (more resistant to mechanical damage) than ZnSe, which is also being used to construct blue LEDs. Suggest a reason why GaN is harder.

12. Explain with a sketch why the emission of an LED can give an estimate of the band gap energy of the solid.

13. Two LEDs are excited with the same amount of electrical energy from a battery and emit the same number of photons. One of these LEDs is emitting green photons at around 500 nm; and the other is emitting red photons at around 700 nm. Which is doing a better job of converting the electrical energy into light energy and why (i.e., which is more energy efficient?)?

14. An InP LED is connected between electrodes. Does it matter which side of the p-n junction is connected to which electrode and, if so, how do you connect it to make it glow?

15. Suggest dopants that will substitute for In to make the p-type region of the LED and for P to make the n-type region. Explain your choices.

16. If a material has a band gap in the infrared portion of the spectrum, it will appear
   A. black.
   B. red.
   C. green.
   D. colorless.

## INVESTIGATION 1

### PURPOSE

To become familiar with the structure of graphite. To understand on the basis of this structure why graphite is a good electrical conductor.

### METHOD

If a model of the graphite structure has been made available to you, look at it carefully as you answer the following questions. If you are to build the model yourself, follow the instructions on page 67 of the manual that accompanies the Solid State Model Kit..

### ANSWERS TO THE FOLLOW-UP QUESTIONS

1. How many nearest neighbors does each carbon atom have in this structure?

2. How are the nearest neighbors arranged about any given central atom? What is the name of the shape these neighbors assume?

3. How many atoms are in the unit cell? (**HINT:** Recall from your earlier investigations that a unit cell is defined as a three dimensional, six sided figure having parallel faces. When a face is reproduced and moved along its entire edges a distance equal to the length of the edge, it generates the entire structure.)

4. Draw the $z$ layer sequence showing the position of the atoms at $z$ = 0, 1/2, and 1.

5. Consider your answer to (2) above and the following information. Carbon typically forms four bonds by sharing the four electrons in its outermost energy level (valence level). This bond formation “localizes” these valence electrons about the atom and restricts their movement throughout the remainder of the structure. In addition the formation of four bonds with other carbon atoms (such as the diamond structure) results in a completely filled band. Why then is graphite a conductor?

## INVESTIGATION 2

## PURPOSE

To compare the similarities and differences between the diamond and zinc blende (ZnS) structures. To understand why zinc blende is said to demonstrate AZ stoichiometry.

## PROCEDURE

If models of diamond and zinc blende have been made available to you, look at them carefully as you answer the following questions. If you are assigned to build one or both of the models yourself, follow the instructions on pages 23 and 51 of the manual that accompanies the ICE Solid State Model Kit.

## FOLLOW-UP QUESTIONS

1. How many nearest neighbors does each carbon atom in the diamond structure have? How many nearest S neighbors does each Zn in the ZnS structure have? How many nearest Zn neighbors does each S in the ZnS structure have?

2. What is the name of the shape defined by the nearest neighbors to each C in the diamond structure? To each Zn by S atoms in the ZnS structure? To each S by Zn atoms in the ZnS structure?

3. How many atoms of C are in the diamond unit cell? How many atoms of Zn are in the ZnS unit cell? How many atoms of S are in the ZnS unit cell?

4. How are these structures similar? How are they different?

5. How does the zinc blende structure demonstrate AZ stoichiometry? (Stoichiometry refers to the quantitative relationship between the atoms in the structure, and AZ indicates two different atoms in a 1:1 ratio.)

6. Draw the z-layer sequence showing the position of the atoms at z = 0, 1/4, 1/2, and 3/4 for both diamond and zinc blende.

## EXPERIMENT 1

### PURPOSE

To find the relationship between band gap energy and composition using LEDs that utilize the $GaP_xAs_{1-x}$ $(0 \leq x \leq 1)$ series of solid solutions.

### PROCEDURE

1. Set up the apparatus as shown in Figure 1 below.

LED

Diffraction slide

90°

a

Meter stick

Brightest spot

b

Meter stick

**Figure 1**.



2. One lab partner will position the LED directly behind the intersection of the two perpendicular meter sticks so that it is clearly visible to the other partner positioned at the end of the meter stick, directly opposite the LED. Once the team is ready, connect the LED to the battery and wait for the room lights to be turned off.

3. The partner with the diffraction grating will view the emission spectrum. The other partner will move a pencil slowly along the meter stick at the LED end of the apparatus away from the LED. The student viewing the spectrum should indicate when the pencil is at the brightest point of the spectrum on either side of the LED. At that point, measure the distance in cm from the LED to the brightest point and record as distance (X) in Data Table 1.

4. Repeat Step 3 for the other LEDs.

5. Disconnect all LEDs when you are finished.

**Data Table 1**

| LED | COLOR | a (cm) | b (cm) | (x) |
|---|---|---|---|---|
| 1 | RED | | 100 | 0.40 |
| 2 | ORANGE | | 100 | 0.65 |
| 3 | YELLOW | | 100 | 0.85 |
| 4 | GREEN | | 100 | 1.00 |

## CALCULATIONS

Calculate the following and record in Data Table 2.

1. Find the distance (z) from the diffraction grating to the bright image in the spectrum for each LED. $\mathbf{c = \sqrt{(a^2 + b^2)}}$

2. Find the sine of angle θ for each LED. $\mathbf{\sin\ \theta = a/c}$.

3. Find the wavelength (λ) in cm: $\lambda = \mathbf{d}\ \mathbf{\sin}\ \theta$ where d is the distance between the lines on the diffraction grating. (Ask your instructor for this value).

4. Using the relationship between wavelength and energy, find the energy $E_g$ that corresponds to the wavelength for each LED.



**Data Table 2**

| COLOR | c(cm) | SIN θ | λ (cm) | $E_g$ (eV) |
|---|---|---|---|---|
| RED | | | | |
| ORANGE | | | | |
| YELLOW | | | | |
| GREEN | | | | |

## ANALYSIS

From the data in Tables 1 and 2 make a graph of $E_g$ vs. x.

**FOLLOW-UP QUESTIONS**

1. What is the relationship between the band-gap energy and x in this $GaP_xAs_{1-x}$ ($0 \leq x \leq 1$) series of LEDs?

2. The distance between the nuclei is one factor that determines how strongly an electron is held between covalently bonded atoms. As the size of the nuclei increase, the band gap energies decrease. Considering only size, would the LED made of GaP or GaAs be redder in color?

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A. black.
B. red.
C. green.
D. colorless.

# LED Assessment

Name ________________
Date _______ Hour ____

## Matching

**Match the word with the best definition.**

____ 1. LED
____ 2. doping
____ 3. solid solution
____ 4. semiconductor
____ 5. band gap
____ 6. conduction band
____ 7. insulator
____ 8. metal
____ 9. valence band
____ 10. energy band
____ 11. orbital
____ 12. isoelectronic
____ 13. electronegativity
____ 14. biasing

a. the attraction of an atom for electrons
b. the highest energy filled band that lies at the bottom of the band gap
c. a type of material that is a poor conductor of electricity
d. applying a voltage, often done to alter electrical and optical output of a device
e. a material with a partially filled energy band
f. a semiconductor p-n junction that is optimized to release light of about the band gap energy when electrons fall from the conduction band to the valence band under forward bias
g. containing the same number of electrons
h. a homogeneous solid in which one type of atom (or ion) has been substituted for a similar atom (or ion) in a structure
i. the energy separation between the top of the valence band and the bottom of the conduction band
j. a region of the atom where electrons are most likely to be found when they have a particular energy
k. a collection of orbitals closely spaced in energy
l. a band that when partially occupied by mobile electrons, permits their net movement in a particular direction
m. process by which atoms in a semiconductor are replaced with other atoms having more or less valence electrons, which leads to an excess of mobile electrons or holes, respectively
n. a substance conducting only a slight electrical current at room temperature

## Multiple Choice

**Choose the best answer.**

____ 15. An example of a solid that possesses the zinc blende structure is

a. NaCl
b. CsCl
c. GaAs
d. Zn

____ 16. Energies of the electrons *within any one isolated atom* exhibit all these characteristics **EXCEPT**

a. At most, only two electrons may occupy any one orbital.
b. Electrons within the same orbital must "spin" in opposite directions.
c. Electrons fill the lowest energy levels first.
d. Electrons occupy spaces in between energy levels.

____ 17. Although the alkaline earth metals have their s orbitals filled and the p orbitals empty, overlapping occurs because

a. a "bridge" exists between the two types of orbitals.
b. the lowest levels of the p band are lower in energy than the upper levels of the s band.
c. the highest levels of the p band are lower in energy than the upper levels of the s band.
d. the lowest levels of the p band are higher in energy then the upper levels of the s band.

____ 18. If a material has a band gap in the ultraviolet portion of the spectrum, it will appear

a. black
b. red
c. violet
d. colorless

____ 19. A semiconducting solid solution used in manufacturing an LED has the zinc blend structure and the chemical formula $Al_xGa_{0.35}As_yP_{0.80}$, where

a. x = 0.80 y = 0.35
b. x = 0.65 y = 0.20
c. x = 1.00 y = 0.00
d. x = 0.20 y = 0.65

____ 20. For electrical conductivity two conditions are necessary, namely

a. the presence of charged particles and their ability to move.
b. the presence of charged particles and their stability.
c. the presence of neutral atoms and their ability to move.
d. the presence of neutral atoms and their stability.

____ 21. As the size of atoms increase in a solid, the accompanying orbital overlaps

a. are increased, and the resulting energy gaps get larger.
b. are increased, and the resulting energy gaps get smaller.
c. are reduced, and the resulting energy gaps get larger.
d. are reduced, and the resulting energy gaps get smaller.

## True/False

**If the statement is true, write true on the line. If the statement is false, correct the underlined word and place that on the line.**

_____________ 22. Only electrons near the <u>bottom</u> of the filled orbitals of a band contribute to electrical conductivity.

_____________ 23. LEDs last longer, are brighter, and are more efficient than <u>incandescent lights</u>.

_____________ 24. Solids having atoms of <u>comparable</u> sizes and forming the zinc blende structure can be combined to form solid solutions.

_____________ 25. Solid solutions can be formed in a <u>few</u> stoichiometries, which allows the "tuning" of band gap energies.

_____________ 26. Elements having the zinc blende structure contain <u>different numbers</u> of valence electrons.

## Problems

27. Suppose you want to create a red cutoff filter (of all the colors in the visible region of the spectrum, the filter will transmit only red light). What should the band gap be to make such a filter out of a semiconductor?

28. Sketch the band-structure diagrams for an insulator, a semiconductor, and a metal.

29. Name two solids with the zinc blende structure that are isoelectronic with α-Sn, and predict how their band gaps will compare to that of α-Sn.

30. Suggest a two-element (binary) compound that is isoelectronic with diamond; such a material might be expected to rival diamond in hardness.

31. Explain why $CdSnP_2$ has the same valence electron count as GaAs.

32. Which contain partially filled bands and why: Mg, Si, and NaCl?

33. Some LED materials can be prepared by combining Ga, In, As, and P in the zinc blende structure. If the formula of one such solid is $Ga_{0.4}In_xAs_yP_{0.7}$, what are x and y equal to, and how would you interpret this formula based on the zinc blende structure?