Name: Class:

ACTIVITY 7

Using Gas Lamps to Understand LEDs

Goal

With the help of computer programs, we have been able to use the energy level diagram to explain the spectra emitted by gas lamps. We will now apply what we have learned to explain the spectra emitted by LEDs.

Our study of gas spectra has led us to the conclusion that only certain energy levels can exist in a gas atom. Now, we wish to extend our investigation to solids so that we understand how LEDs emit light. As a first step we will explore how we might create a spectrum similar to that of an LED.

Open the *Emission* version of the *Gas Lamp Spectroscopy* computer program and place the unknown gas tube in the gas lamp socket.

When the unknown is in the socket, you can create your own spectrum by dragging the lines near the top of the screen. Edit the energy values for the computer-generated spectral lines so that the spectrum is similar to the spectrum of one LED that you observed in Activity 2.

Create an energy level diagram for an atom that could produce this spectrum.

In the space below sketch this energy level diagram.

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Compare your results with other students who observed different LEDs in Activity 2. The resulting discussion should focus on answering the following questions.

? How are the allowed energies in your diagram similar to the others?

? How are they different?

? How are the energy level diagrams for the LED similar to ones for a gas lamp?

? How are they different?

This exploration shows us that we could get a spectrum similar to that of an LED by having several closely spaced energy levels. When we look at the spectrum of an LED, we see a broad spectrum with no dark regions in it. So, atoms in an LED must have many energy states that are extremely close together. No real gas has the energy levels to create this type of spectrum. We can create it only on a computer with our "un-known" gas. So, we must look beyond gas atoms to explain the spectra of LEDs. This conclusion is not surprising because LEDs are made of small bits of solids.

Solids have many atoms that are close together and interact with each other. These interactions create very closely spaced energy levels. In addition to having energy levels which are very close together, a solid has an extremely large number of levels – literally billions and billions. Because of the large number and the close spacing we treat each group as a band of energy level. When you tried to match an LED spectrum with the *Emission Spectroscopy* program, you created something similar to an energy band with just a few levels. A solid may have several bands of energy. However, only two of the bands are involved in light emissions. (So, it works just like the model you created with closely spaced spectral lines.) The band with the highest energy contains electrons that cannot leave the solid but are not firmly attached to any atom. They can move throughout the solid. This freedom of motion allows these electrons to carry (or conduct) energy through the solid. So, we call this band the *conduction band*.

Electrons that have energies in the next lower band are bound to their respective atoms more strongly and are unable to break free from the atoms. This lower energy band is called the *valence band.* Electrons with these low energies have large negative values because they require more energy to escape their respective atoms.

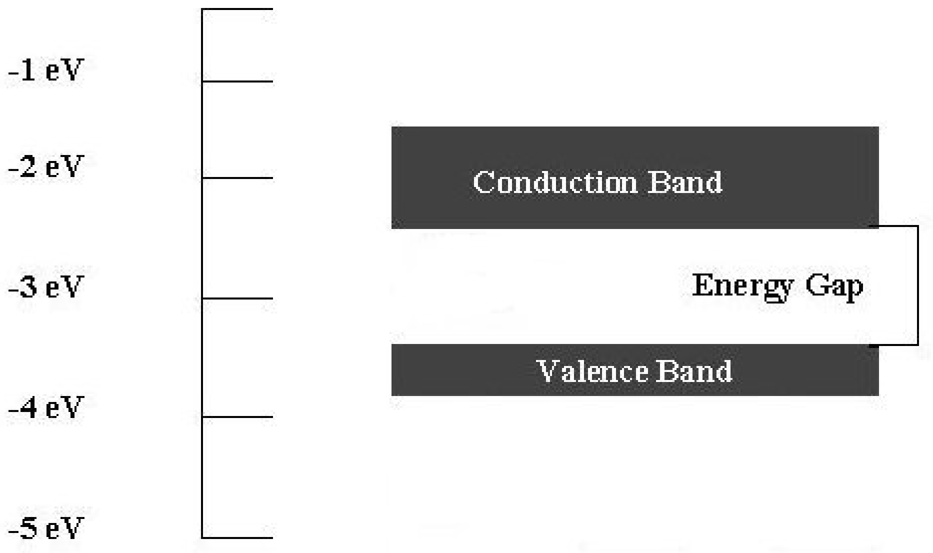

Figure 7-1: Energy diagram with a Very Large Number of Solid Atoms

The space between the conduction band and valence band has no allowed electron energies. This region is called the *energy gap*.

Now let's look at how energy bands are related to the spectra of LEDs.

At the beginning of this activity, we used *Gas Lamp Spectroscopy* to get an idea about how the energy level diagram must look to explain the spectrum emitted by an LED. At that time we created a pseudo-band by putting several energy levels close together. Now, we will look specifically at the energy bands in LEDs.

In the *Spectroscopy Lab Suite* software package, select LEDs from the main menu. Figure 7-2 illustrates how the screen should appear and provides basic instruction for using the program.

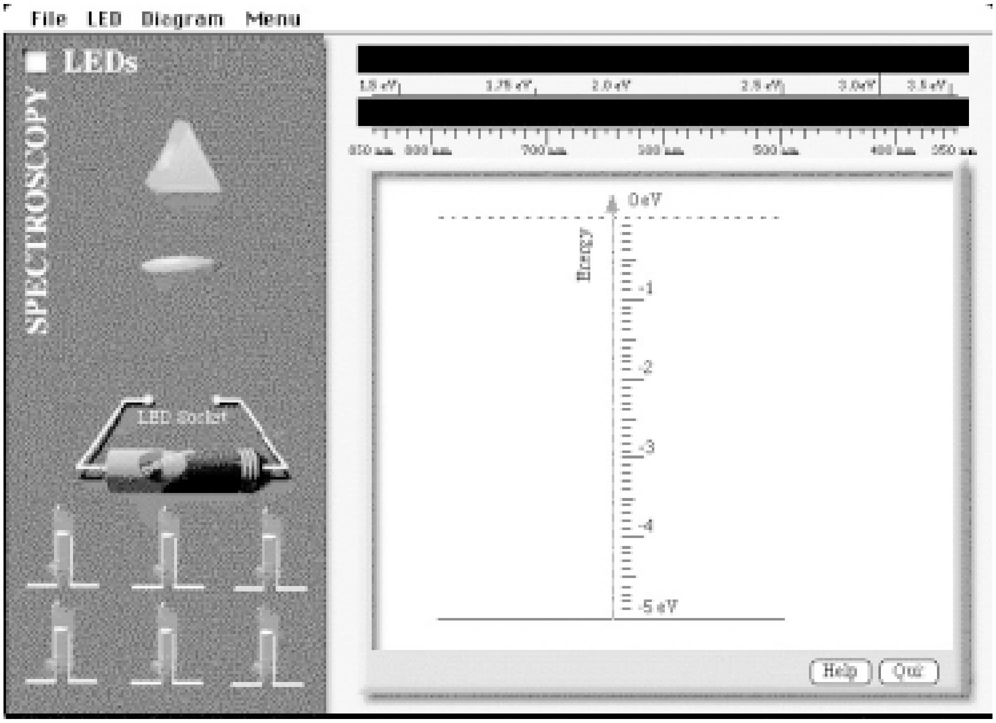

Figure 7-2: *LED Spectroscopy* Computer Program

Drag the LED assigned to you to the LED socket found on the left of the screen. The computer-generated spectrum emitted by the LED will appear on the top screen.

Click the Add Conduction Band button. A red rectangle that represents the conduction band for the LED should appear near the top of the energy scale.

Click on the Add Valence Band button. A faded-red rectangle that represents the valence band for the LED should now appear near the bottom of the energy scale.

The broad, orange vertical arrow represents the allowed transitions for electrons as they move from any energy in the conduction band to any energy level in the valence band. As these electrons make transitions, they emit energy in the form of light.

Place the cursor in the center of one of the bands.The band turns green and a hand symbol appears. You can now change the energy of the band by dragging it up and down.

Place the cursor on the top or bottom edges of one of the bands.The band turns green and up-down arrows appear. You can change the range of energies allowed in the band.

As you change the location of or range in a band, you will see the spectrum. Now manipulate the location and range of both energy bands until the spectra described by the energy level matches.

In the space below sketch the resulting energy band diagram and indicate the range of energy values (in eV) for each band and the resulting energy gap.

After all groups have sketched the energy band diagram for his/her LED, they should share their results with the class. The resulting discussion should focus on answering the following questions.

? How is the size of the energy gap related to the color of light emitted by the LED?

? How are the ranges of energies for the conduction and valence bands important?

We are now able to apply energy diagrams to explain the spectra of LEDs. However, to be successful we needed to extend the concept of individual allowed energies to allowed energy bands. The spectra emitted by LEDs is the result of electrons making transitions from a number of energy levels in the conduction band to a number of energy levels in the valence band. The electron transitions that are allowed can range from the highest energy level of the conduction band to anywhere between the lowest and highest energy levels of the valence band (See A on the left side of Figure 7-3.). Other electronic transitions that are allowed can range from the lowest energy level of the conduction band to anywhere between the highest and lowest energy levels of the valence band (See B of Figure 7-3.). These electronic transitions result in the emission of a broad continuous spectrum that is concentrated on a particular color (and thus energy) of light. The size of the energy gap in solids inside an LED determines the color of light emitted by the LED. Thus, if we know the spectra of light emitted by an LED we can predict its energy gap.

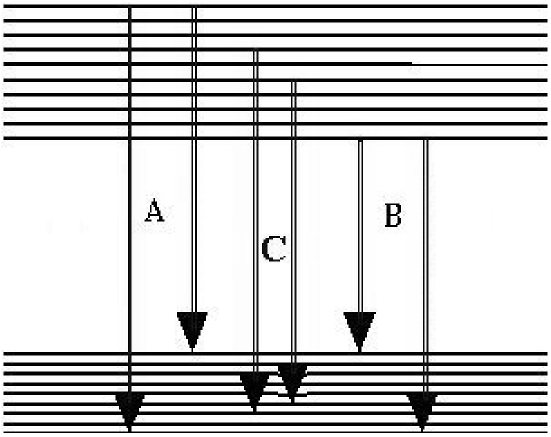

Figure 7-3: Ranges of Allowed Transitions for a Solid that Makes Up an LED

Homework Problem:

An LED is created with a semiconductor that has the energy bands and gaps

a) What is the energy gap of the semiconductor?

b) Determine, using the diagram above, the range of energies emitted by electrons in this solid.

c) Describe the spectrum of visible light emitted by this LED.[Hint]

d) Use the *LED Spectroscopy* computer program to check your answers.

Hint The range of visible light ranges from 1.6 eV (red) to 3.1 eV (violet).

Appendix: Conductors and Insulators

If you have studied the movement of either thermal or electrical energy through solids, you may be interested in how the energy bands are related to conduction and insulation.

The electric current that flows through a solid consists of electrons with energies associated with the conduction band. Solids that conduct heat or electric current (called *conductors*) will have many electrons with energies in the conduction band. Solids that do not readily conduct heat or electric current (called *insulators*) will have few electrons in the conduction band. Thus, the electrons in insulators are found mostly in the valence band. Solids that are good conductors will have many electrons in the valence band because these materials have enough electrons to fill all available energies in the valence band and many left over in the conduction band. Further, these two bands overlap in conductors.

In addition to the difference in the number of electrons found in their respective conduction bands, conductors and insulators also differ in the size of their respective energy gaps. For conductors, the two bands either overlap or are so close together that electrons with energies in the valence band can easily acquire enough energy to have energies associated with the conduction band. Insulators, on the other hand, have energy gaps that are so large that thermal or light energy is not sufficient for electrons to move to the conduction band from the valence band.

The solids that make up LEDs are called *semiconductors*. As the name implies, a semiconductor is a solid whose physical properties place it somewhere between conductors and insulators. In semiconductors the energy gap is small enough that when sufficient energy (i.e. thermal, electrical, or light) is supplied, electrons gain enough energy to become the conduction band electrons.

The electrons in the conduction band carry the energy. Materials that have electrons in this band can transmit easily both thermal and electrical energy. The good electrical conductors are also good thermal conductors.