LUMINESCENCE
It's Cool Light!

Visual Quantum Mechanics

ACTIVITY 4

Applying Energy Levels to Luminescence

> ***Goal***
> With the help of energy levels diagrams, we have been able to use the spectra to learn about energy in atoms. We will now apply a similar technique to learn how energy levels in luminescent materials are similar to and different from atoms.

Just by viewing various objects we see that some luminescent devices emit light that *looks* similar to gas lamps. Others however seem to emit light that is quite different. In this activity we will look closely (through a spectroscope) at light emitted by some objects. Then we will apply energy levels to understand more about energy in atoms of solids and liquids.

Your instructor will assign your group a device such as an LED, light stick or glow-in-the-dark object. Observe the spectrum of the object and record the results below.

Object: _____

| 1.7 | 1.8 | | 1.9 | 2.0 | | 2.2 | | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.6 | | eV |

| 700 | | 600 | | 500 | | 400 | | nm |

Describe the spectrum in words.

Compare your observations with those of other groups.

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? How are the spectra similar?

? How are they different?

? Do you see any similarities between these spectra and those of gases?

? Do you see a difference?

Now, we will see what these observations can tell us about energies in solids and lights. To begin we will pretend that these objects have gas atoms. So, we will try to use the gas model to build a set of energy levels and explain these spectra.

Open *Emission* under *Gas Lamps* in the *Spectroscopy Lab Suite* and place the unknown gas tube in the gas lamp socket.

Click on the **Edit** button and type in the energy values for the computer-generated spectral pattern that will appear on the top black screen which illustrates the spectrum that you have just observed.

Use the program to produce an energy level diagram that would result in the following spectrum.
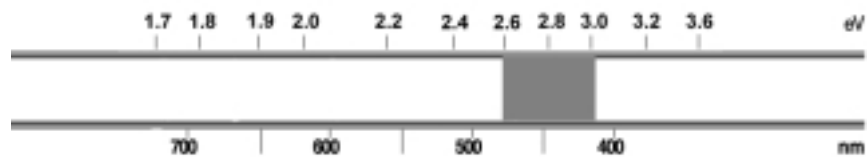
? In the space below sketch your energy level diagram.

Compare your results and those of your fellow students' with previous energy level diagrams that were drawn in the previous activity. The resulting discussion should focus on answering the following questions.

? How are the allowed energies in your above diagram similar to ones drawn in the previous activity?

? How are they different?

Placing the energy levels close together gives us a spectrum that approximates the spectrum of the luminescent objects. To create energy diagrams that come closer we would need to use more energy levels. Putting in all of the transitions would be tedious. So we will just note an important conclusion: A spectrum which is continuous and covers part of the visible spectrum leads us to conclude that initial energies of the electrons are very close together. The final energies are also close together. The light energy is related to the energy levels as shown in Figure 4-1.
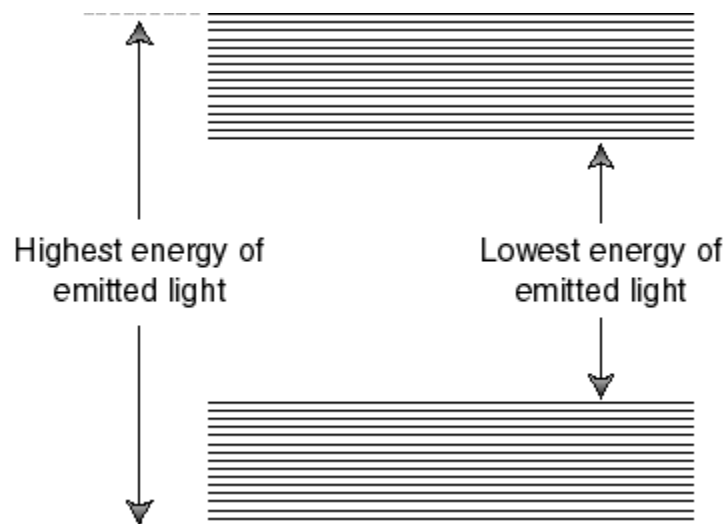

Figure 4-1: An approximation to the energy level diagram for an LED or lightstick.

To improve the approximation we add more energies. As we add the energies the diagram will look as Figure 4-2.

Highest energy of
emitted light
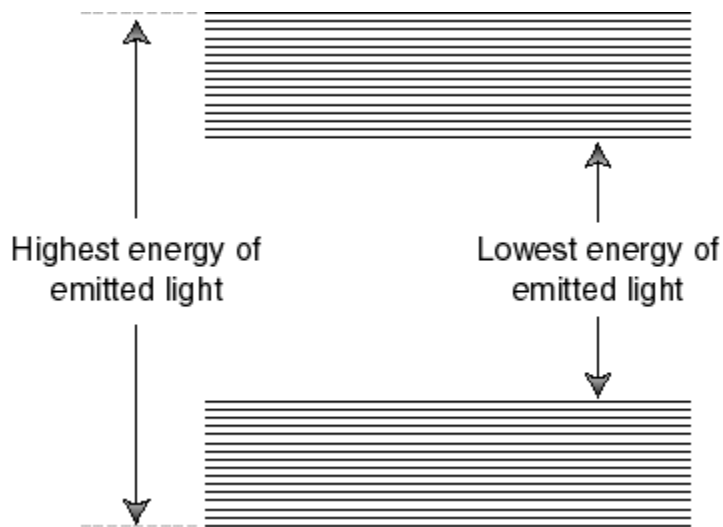
Lowest energy of
emitted light

Figure 4-2: Energy bands for a solid.

When the energies become so close together that we cannot distinguish individual levels we say that we have *energy bands*. These bands are separated by an *energy gap*. The bands are given names as shown in Figure 4-3.
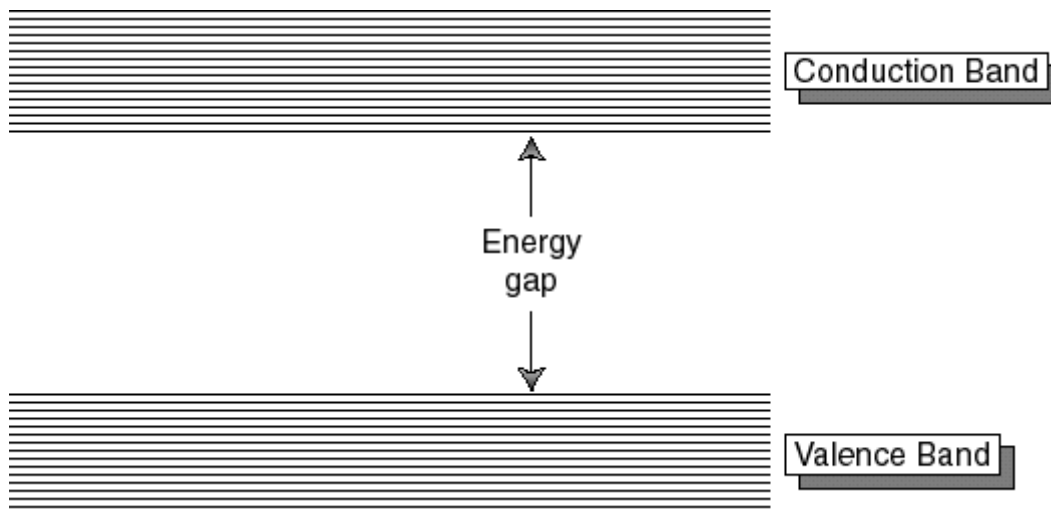
Conduction Band

Energy
gap

Valence Band

Figure 4-3: The names of the bands and gap.

Now we will use another program in the *Spectroscopy Lab Suite* to understand LEDs and how the bands and gap are related to spectra. Begin by selecting LEDs in the program.

Drag the figure of the LED that is closest in color to the object you observed to the socket. The computer-generated spectrum emitted by the LED should appear at the top of the screen.

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

Click on the **Add Valence Band** button. A faded-red rectangle that represents this band will appear near the bottom of the energy scale. The spectrum that results from these energy bands is displayed on the lower spectrum.

The broad, orange vertical arrow represents the allowed transitions for electrons in the LED as they move from energy levels in the conduction band to energy levels in the valence band. As these electrons make transitions, they lose 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 may change the energy of the selected band by dragging it.

Place the cursor on the top or bottom edges of one of the bands. The band turns green and arrows that point up and down appear. You may now change the energy of the selected edge of the band.

Now adjust the energy bands and their edges until the bottom LED spectrum matches the spectrum illustrated on the top.

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

After everyone has sketched the energy band diagram for their LED, each group should share its results with the class. The resulting discussion should focus on answering the following question.

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

We are now able to apply energy level diagrams to the spectra of the electroluminescent device—an LED. The spectra emitted by LEDs is the result of electrons making transitions from a large number of energy levels in the conduction band to a large number of energy levels in the valence band (See Figure 4-4.). The maximum energy for electron transitions is from the highest energy level of the conduction band to the lowest energy level of the valence band (See A of Figure 4-4.). The lowest energy transitions are from the lowest energy level of the conduction band to the highest energy levels of the valence band (See B of Figure 4-4.). Transitions between these extremes result in the emission of a continuous spectrum that is concentrated on a

few colors (and thus energies) of light. The size of the energy gap of the solid determines the lowest energy of light emitted by the LED. Thus, if we know the spectra of light emitted by an LED or any other luminescent device we can predict its energy gap.
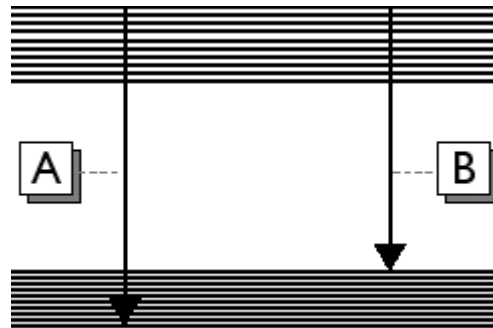

Figure 4-4: Ranges of Allowed Transitions for a Solid that Makes Up an LED

As stated earlier, the interactions among atoms in solids and liquids are more complex than in gases. In terms of allowed energies, gases have individual energy levels whereas solids have a number of energy levels grouped in bands. Although this model can be used to understand the properties of luminescent materials made up of solids, the energy band model is not sufficient to describe the properties and operation of a light stick. The light stick consists of liquids that involve more complex types of interactions than the ones we have discussed for atoms of solids. Thus, our model cannot and should not be used to describe the mechanism in which the light stick operates. However, since the light stick emits a spectrum similar to that of a solid luminescent object, the light stick is a very appropriate source to study in this unit. We will return to it later.

Homework

4-1)   A phosphorescent toy is created with a solid which has the energy bands and gaps shown below:
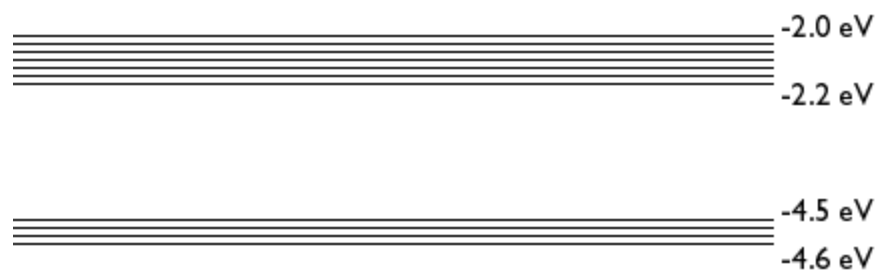
a)   What is the energy gap of the solid?

b)   Explain, using the diagram, the possible transitions for electrons in this solid.

c)   Describe the spectrum of visible light emitted by this glow-in-the-dark toy in terms of energy and color.