ACTIVITY 10

Applying Energy Level Models to LEDs

Goal
The energy levels of two joined materials showed some additional properties that we had not seen previously. By looking at the response of these levels to an applied voltage we will see how light is emitted. As a bonus we will learn why an LED only emits light when the battery is connected in one way.

We will begin where we ended in Activity 9. Start the *LED Constructor*. Then, add acceptors and donors, and merge the materials to create an LED.

Now, we wish to apply a voltage to the LED and see what happens to

- the energy levels in both materials, and
- the light emitted.

Use the slider control (upper left) to vary the voltage (input energy) applied the LED. The energy diagrams show how the energy level responds to the voltage.

? What is the effect on the energy bands as the applied voltage changes from 0.0 Volts to +1.0 Volts?

To apply a negative voltage we need to flip the LED and place it in the circuit with the wires reversed (long lead on the right). Use the flip button to reverse the LED.

? What is the effect on the energy bands as the applied voltage changes from +1.0 Volts to -1.0 Volts by flipping the LED?

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? For which of the two applied voltages (-1.0 Volts or +1.0 Volts) would it be more likely for the electrons to move from the conduction band of the right block to the conduction band of the left block? Explain.

Reverse the LED again by flipping it so that the long lead is on the left.

Move the slider to the minimum voltage necessary for the LED to begin emitting light. Recall we defined this voltage as the *threshold voltage*.

? What happens to the energy bands of the two semiconductor blocks when the threshold voltage is applied to the LED?

Record the threshold voltage displayed on the voltmeter. Indicate the LED that you were assigned.

Record the range of color(s) and energies (in eV) of the output spectrum of your LED.

Compare your results with others in the class.

? How are all results similar?

LED	Threshold Voltage (V)	Energy Gap (eV)	Output Spectral of Range of Energies (eV)

How are they different?

Since the energy bands on the material with acceptor atoms are higher than the bands of the material with donor atoms, the excess, free electrons found in the conduction band of the right block must be supplied additional energy to move to the conduction band of the left block which has a deficiency of electrons. Electrons cannot flow from the left block to the right block because there are not many free electrons on the left block.

When a battery is properly connected across an LED and when the electrical energy (voltage) supplied by the battery is increased, the difference in energy between the right and left energy bands decreases. As the difference in energy decreases, the likelihood of the free electrons moving from the right block to the junction between the blocks increases. When the appropriate voltage (threshold voltage) is applied, the right and left energy bands reach the same energy level, and the free, energetic electrons of the conduction band of the donor material move toward the acceptor material which has fewer electrons. Once there, the energetic free electrons combine with atoms and lose their energy in the form of light emitted by the LED while making the transition to the valence band as shown in Figure 10-1.

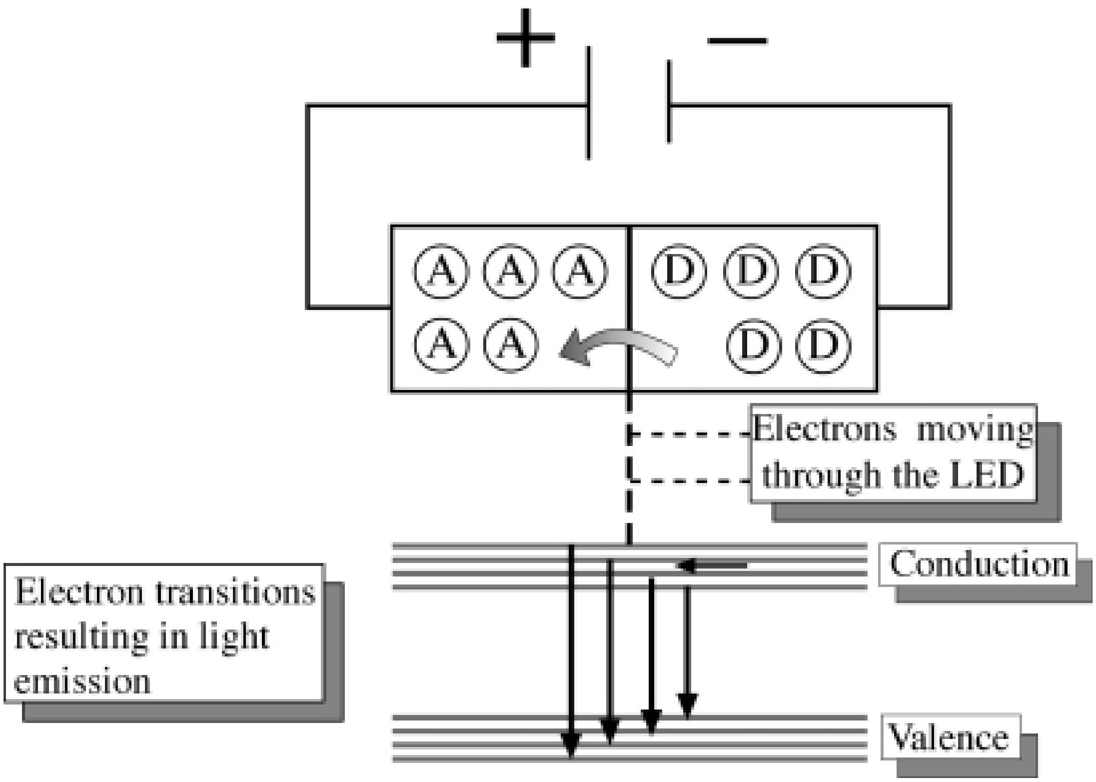

Figure 10-1: Energy Band Diagram of an LED Emitting Light at the Threshold Voltage

The free and excess electrons (which are negatively charged) of the material with donor atoms must be pushed toward the material with acceptor atoms. When a battery is properly connected to an LED, it supplies these excess electrons with sufficient electrical energy to go toward the acceptor side of the chip. Because the negative terminal of the battery repels electrons, the donor side must be connected to the negative terminal of the battery so that the excess electrons are pushed toward the acceptor side.

The short lead of the LEDs is connected to the side of the LED chip that contains the semiconductor with the donor atoms. The long lead connects to the side of the LED chip that contains the semiconductor with acceptor atoms.

When the positive terminal of the battery is connected to the donor side atoms, the free electrons are attracted to the positive terminal of the battery instead of being pushed into the acceptor side. This situation is shown in Figure 10-2. They have insufficient energy to reach the acceptor side. They can only emit light in the junction between the acceptor and donor sides, so no light is emitted.

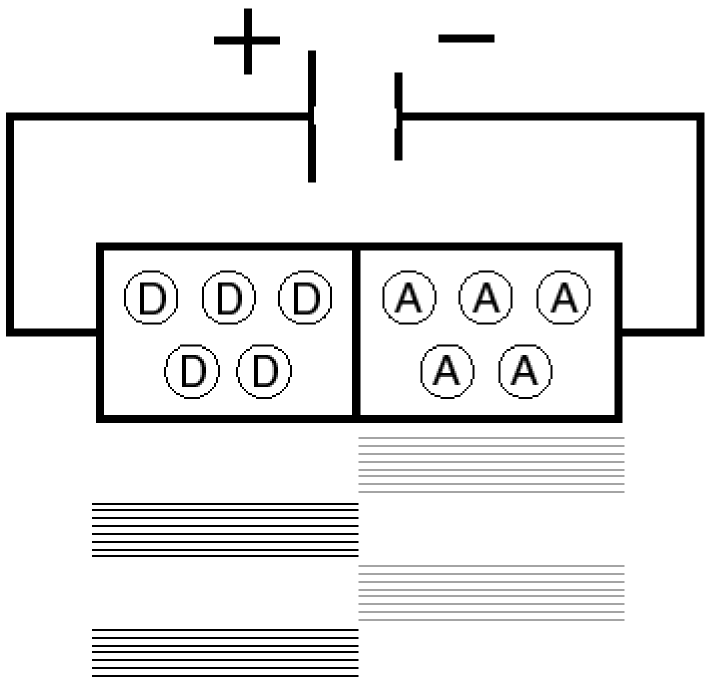

Figure 10-2: Placing the LED in backwards results in the available electrons on the donor side having insufficient energy to move to the acceptor side. No light is emitted.

In our energy level model we have assumed that electrons in a solid acquire and lose energy. Our energy level model of how an LED works, like all models, has limitations. Our energy level model is not perfect and should not be considered a description of all processes that occur in an LED. The model, however, does enable us to explain the general nature of the phenomena that we observed and gives us a general idea of how an LED works at the atomic scale.

We now have gone full circle from exploring the properties of LEDs to constructing an energy level model that explains these properties. The development of this comprehensive model began with atoms of gases to explain the spectral properties of gas lamps and ended with atoms of solids to explain the physical properties of incandescent lamps and LEDs. Along the way we have also learned about gas lamps and the limited number of energies available to an electron in an atom. Knowledge of the energies has been important in almost every area of modern science and technology. One example, the LED and its applications, are important to our daily lives and will play a bigger role as alternate light sources in our future. We could say that the LED and the quantum model that explains how this tiny device works provide us with an “illuminating” experience that allow us to see everyday phenomena in a new “light”.

Homework:

One active research area involves using LEDs for plant growth, especially for space applications where low weight and low power consumption are critical. LEDs are a promising light source for plant-growth experiments in space due to their high intensities and electrical efficiencies, small size and mass, long life, and excellent record of safety and reliability. Several crops – lettuce, spinach, wheat, and potatoes have been successfully grown when illuminated by an array of LEDs supplemented with fluorescent light.

Assume we are members of a group of NASA scientists working on a project that focuses on using LEDs to grow plants in a space station currently orbiting Earth. We must make a decision on what types of LEDs should be used and what the electrical requirements for the batteries to power these LEDs should be. A NASA botanist on our team has collected the following information on the light spectra that would be most conducive for photosynthesis (the process by which plants use light energy to manufacture food). Plants reflect green light but absorb energy in the blue and red regions.

1. What would be the energy gap(s) of the material(s) you would choose to make the two LEDs that would produce the required spectrum? Explain.

2. NASA has to provide batteries to supply the minimal electrical power to these LEDs. If the batteries are too large they will weigh more than necessary and waste valuable fuel. NASA, like any government agency, must be very specific in their request so that bids could be taken on the contract to provide these batteries. What would be the minimum voltage the battery must supply in order to make both LEDs emit light simultaneously? Assume that the LEDs will be connected in such a way that the battery would have to provide a voltage equal to the sum of the threshold voltages for each LED. Explain.

3. Based on our observations using these LEDs, what types of problems can occur when using this set-up?