

Name:

Class:

ACTIVITY 9

Creating an Energy Level for Model LEDs

*Goal*

The model we developed with energy bands and gaps explained why we see a partial continuous spectrum for LEDs. They even allowed us to understand why we needed some minimal energy (voltage) to turn on each LED and why that energy depended on color. The model does not, however, explain how electrons get into the conduction band so they can emit light. To understand this process we must expand our model of the LED energy levels.

We have used energy bands and gaps to explain the spectral properties of an incandescent lamp and LEDs. Recall that the conduction and valence energy bands and the resulting energy gap result from interactions of numerous atoms that are very close together - a situation that occurs in solids. As we have seen, the energy gap of the solid materials (called semiconductors) that make up the LED determine the energies (and thus, colors) of light emitted by the LEDs.

A solid can be a pure material in which all atoms are the same element. As a result, each nucleus of the atom contained in this solid has the same electrical charge. Thus, each atom in this solid has identical properties. The interactions among these atoms create the energy bands and gaps that we have studied. Modern technology can create materials that are very close to being all identical atoms. These pure materials have light emitting properties much like we have studied in previous activities.

For today's technology pure materials are not the most valuable. Instead, a wide range of devices — from LEDs to computer chips — use almost pure materials into which a small quantity of a different element — an *impurity* has been introduced. Then materials with different impurities are joined.

Suppose we start with a pure material and add atoms of a different element. These different elements will have a different number of electrons than the atoms of the original material. We place the impurities into two groups:

- *Donors* have more electrons than the material's pure elements. They donate electrons to the solid.
- *Acceptors* have fewer electrons than the material's pure element. They accept electrons from the solid.

Both the donors and acceptors have zero electrical charge. They have more or less charge in the nucleus to balance the more or fewer electrons.

The LED chip consists of two solids – a material that has been supplied with donor atoms and the same material that has been supplied acceptor atoms. We will now use the *LED Constructor* computer program to understand how these two materials are combined to construct a simulation of an LED. Begin the process by opening the *LED Constructor* computer program.

Notice that on the left of the screen is an illustration of 6 different LEDs and a version of the circuit apparatus that we used in the first activity when we explored the properties of LEDs. On the right of the screen are the two blocks of material that make up the LED chip with an energy scale and output spectrum illustrated below the blocks.

In this program, we can:

- Select an LED and drag it to the power supply (LED socket).
- Create an energy band diagram for each of the two semiconductor blocks that make up each LED.
- Add donors or acceptors to each semiconductor block with a click of the mouse inside each block and thus create the LED chip.
- Control the voltage applied across the LED by moving the slider.

When the voltage is appropriate, transitions (represented by a vertical arrow) will occur and light will be emitted. A spectrum will appear below the energy scale.

Drag the LED assigned to you by the instructor to the LED socket. The energy bands that appear on both sides of the energy scale represent the bands and gap for materials associated with these LEDs.

Notice that the valence bands of both semiconductor materials are shaded darker than the conduction band. This shading indicates that the majority of electrons have energies associated with the valence bands. Electrons are naturally found in these bands because they seek the lowest possible energies. Also notice that energy of the energy gaps of both blocks are the same to represent that the LED is constructed of two blocks of the same semiconductor.

? Record the color of the LED you were assigned and the energy (in eV) of the energy gap.

Now, click on the Add Impurities button. This places acceptors in the left block and donors in the right block.

? How does adding acceptors — atoms with fewer electrons — affect the energy bands of the left block?

? What is the effect on the energy bands of adding donor atoms to the right block?

? Do the sizes of the energy gaps for either semiconductor block change as donor or acceptor atoms are added?

? A material that has donor atoms has more electrons than one with acceptors. When these two materials are joined together, the electrons can move from one material to the other. Which way would you expect the electrons to move? Why?

To see the effect of this process on the energy bands, click the Merge button to bring the two semiconductor blocks together and, thus, create a “chip” that makes up the LED. Figure 9-1 illustrates the screen that should appear.

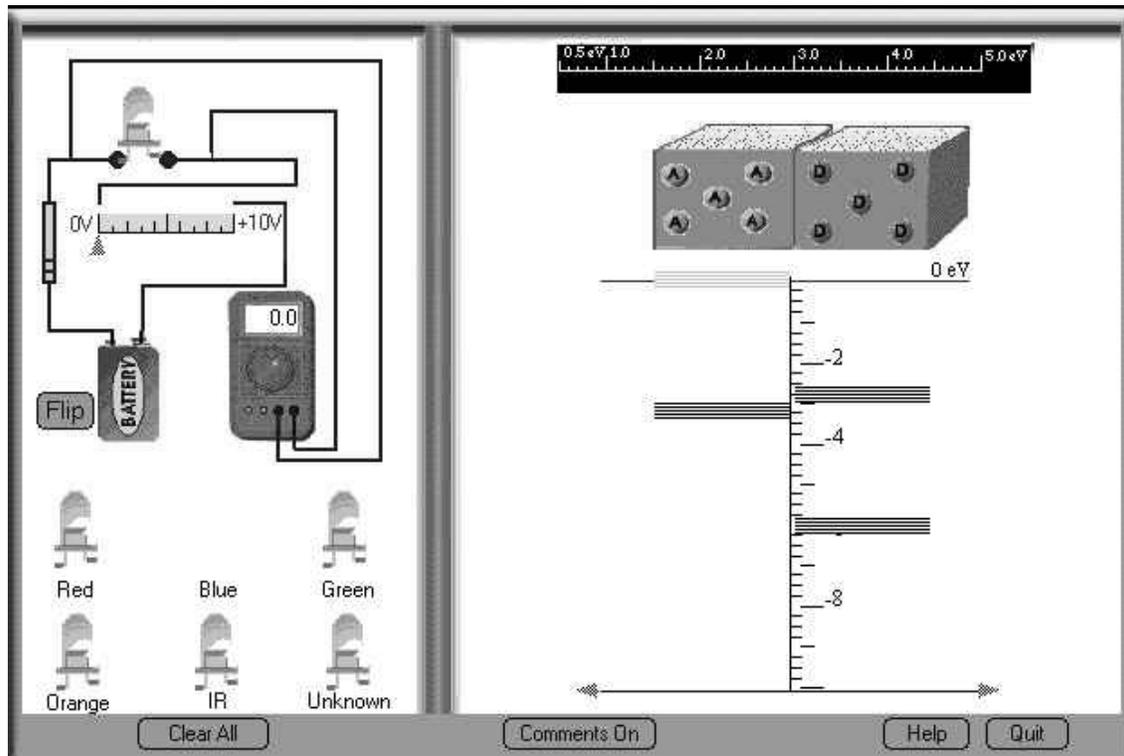


Figure 9-1: The screen of the *LED Constructor* after merging two semiconductor blocks.

As you see, the bands and gaps shift from their usual energies. This shift is a result of the movement of electrons from one material to the other.

Compare the energy diagram for your LED with the diagrams of other students who used different LEDs.

? How are they similar?

? How are they different?

The situation that is now represented on the screen is equivalent to an LED that is not connected to an energy source. The energy diagram for the merged material is similar to Figure 9-2.

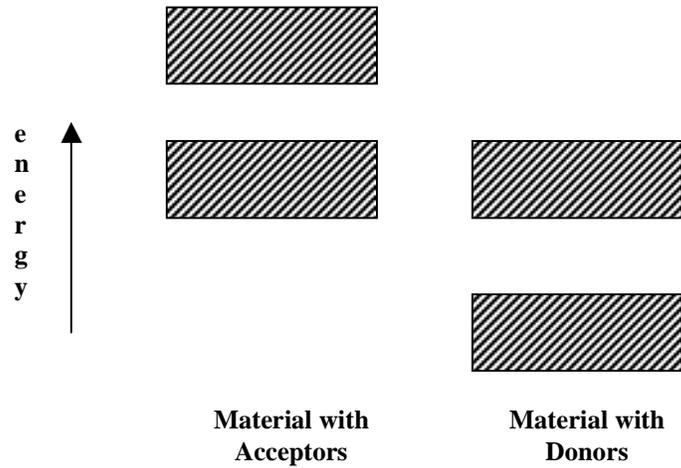


Figure 9-2: Energy level diagram for a chip made of a material with acceptors and a material with donors.

In this situation extra electrons are still available on the right (donor) side. However, they cannot change energies from the conduction band to valence band in the donor side. All of the valence energies are already filled with electrons. We must move the electrons to the other material where the change in energy is easy. In the next activity we will use a battery for this purpose.