ACTIVITY 12

Constructing a Model to Explain the IR Detector Card

Goal
We use *IR Detector Card Spectroscopy* to construct a model that explains the properties of the IR detector card.

In the previous activity you completed several experiments using infrared detection material. Each of the experiments were directed toward understanding how the material can absorb infrared light and then emit higher energy visible light. In this activity you will work with a computer program that uses energy bands to create a model of the IR detecting material. By changing variables in the program you will be able to see how the model explains each of the observations in the previous activity.

Open the *Spectroscopy Lab Suite* and select IR Detector under *Luminescence*. A figure of the IR detector card will appear on the left part of the screen and an energy scale will appear on the right part of the screen.

Notice that the energy scale contains a black set of horizontal lines located at -5 eV. These lines represent the valence band of the IR detection material.

Create an Excited State Band (conduction band). A set of gray horizontal lines representing the excited state band appears next to the energy scale.

Click on the Create Impurity State Band button. A set of gray horizontal lines appears in the energy gap.

The material that makes up the IR detector card consists of many solid atoms, including some impurities. Interactions occur among solid atoms that are relatively close together. Electrons bound to these atoms have allowable energies that are in both excited and ground state bands. The impurities create additional allowable energies in the impurity state band.

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The program begins with a simulated IR detection material that is similar to material that has been exposed to an intense IR source. So, it must be exposed to some visible light before it will function. The Input Spectrum represents the source of this visible light.

Figures of the IR detector card and the first energy source appear on the bottom left of the screen along with an energy scale labeled Input Spectrum. The Input Spectrum indicates the energy of light emitted by the visible source and absorbed by the computer-simulated IR detector card.

As you have for models of other types of luminescence, complete investigations by varying the energies of the source, the conduction band, and the valence band.

? What relation must you have for the electrons to make a transition from the valence band to the conduction band?

If the light emitted by the first source provides enough energy for the electrons in the card to change energies from the ground state band to the excited state band, a transition (represented by solid black arrow) is possible. Recall that you performed this experiment in the previous activity by placing colored transparencies over the IR detector card.

As with other computer models of solids the gray and black illustrate that the electrons have changed energy.

? Set up a situation in which transitions occur and electrons change energies. How much energy did the electrons in the detecting material lose as they made the transition from the excited state band to the impurity band? Explain how you determined this value.

The general scheme here is similar to that of phosphorescence. However, the change in energy when electrons move from the conduction band to impurity band is much greater here. Similar to phosphorescence the IR detector requires a second source of energy. In this case, of course, the second source is visible light. We will now look at the energy band model for this process.

On the left of the computer screen is a diagram of an LED and an energy scale labeled Input Spectrum for the Second Source. As with the Input Spectrum for the first source, select the energy (color) of the LED.

Choose several energies for the light emitted by the LED. Describe the energy required for electrons to change energy to the conduction band.

Some electrons with energies in the conduction band will lose all their energy and make a transition to the valence band. These atoms emit the light that we see coming from the detecting material.

? How much energy did electrons in the card lose as they made the transition from the excited state band to the ground state band? Explain how you determined this energy.

? What is the energy and color of light emitted by the IR detector card?

? How is the energy band model that is used to explain the IR detection process, consistent with the law of conservation of energy?

We will now use the computer program to create a model that is consistent with your observations. In the previous activity we saw that the IR detector card

a) was able to detect IR only after exposure to visible light
b) was not effective if exposed only to red light but is effective when exposed to other colors
c) decreased its effectiveness over time when not exposed to visible light, and
d) emits only a reddish orange light.

Use the computer program to create an energy band model that can explain as many of these observations as possible. In the space below, sketch your model and label the energies.

Describe how your model is consistent with each of the observations listed above. If your model does not explain an observation, explain why.

In the previous activities, we used energy band models to explain fluorescent and phosphorescent materials. How is the energy band model used to explain the IR detector card similar to the energy band model used to explain fluorescence?

? How are these models different?

? How is the energy band model used to explain the IR detector material similar to the model used to explain phosphorescence?

? How are these models different?

The process by which the IR detector card works is summarized in Figures 12-1 to 12-4.

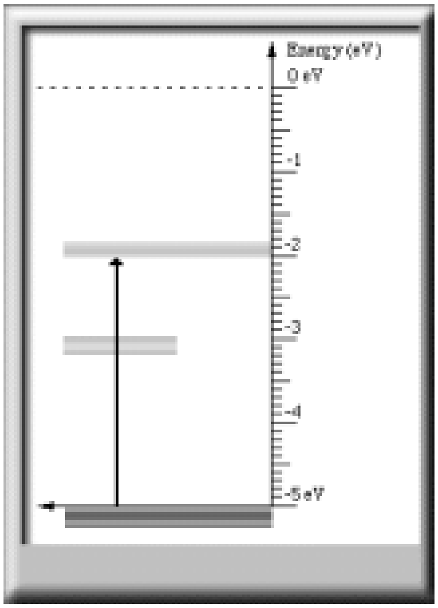

Figure 12-1: Electrons absorb energy from visible light and make a transition to the conduction band.

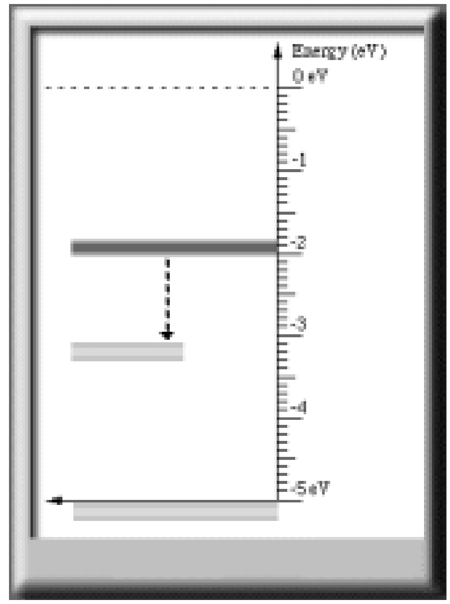

Figure 12-2: Electrons losing energy to neighboring atoms and making a transition to the impurity state band.

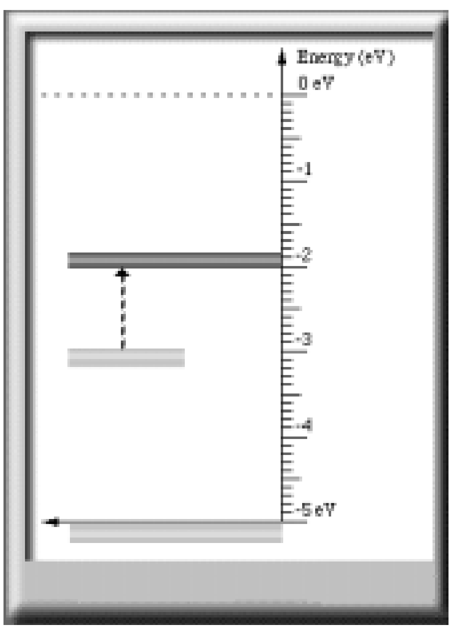

Figure 12-3: Electrons absorb energy from infrared photons and make a transition back to the excited state band.

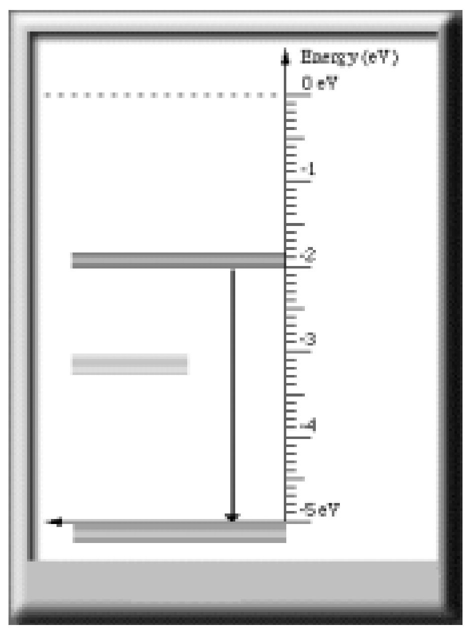

Figure 12-4: Electrons lose energy by emitting visible photons and make a transition to the ground state band.

In terms of energy in and energy out, infrared detection is described in Figure 12-5.

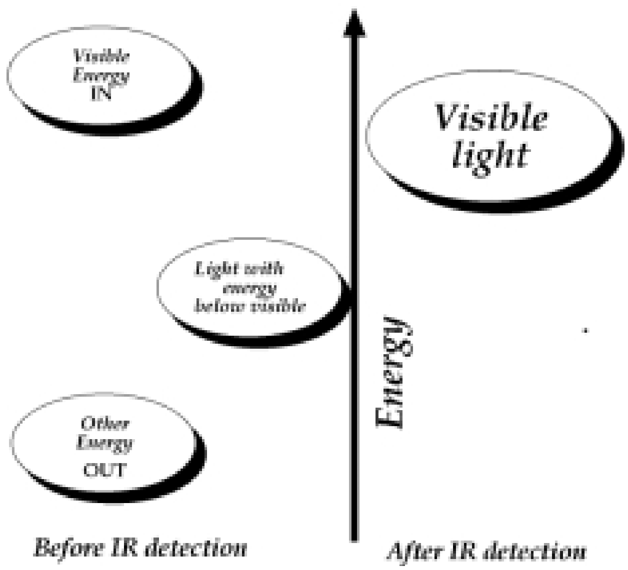

Figure 12-5: A summary of the energies needed to cause the infrared detector material to work.

In this unit, we have explored the physical properties of various luminescent materials and devices including "glow-in-the-dark" toothbrushes; fireflies; light sticks; Lifesavers®; and fluorescent markers & minerals; fluorescent lamps; and IR detector cards. The quantum mechanics model that involves energy bands explains how these materials and devices emit light. The development of this comprehensive model started with atoms of gases to explain the properties of gas lamps and ended with the atoms of solids with impurities to explain luminescent materials such as the fluorescent lamp and the IR detector card. We could say that the quantum mechanics model is very "cool" because it allows us to see everyday phenomena in a new "light" and gives us a deeper understanding and appreciation for the various processes in which matter emits light.

Homework

1. Researchers who investigate the properties of light use materials similar to the IR detector card. However, they sometimes need to detect only a small range of the energies in the infrared. Suppose such a card is created and it detects only photons with energies between 1.1 eV and 1.2 eV. Describe the energies of the bands of this material. Explain your conclusions. (Such materials exist but are much more expensive than the IR detector that you used.)

2. A rock music group has decided to use IR detector cards as part of its light show during concerts. Each ticket for the concert will have some infrared detecting material on it. During the concert big infrared lamps will flash; ticket holders will see nothing but light coming from the tickets. However, the leader of the group would like some tickets to emit red, some to emit green and some to emit blue light. As the scientific consultant to the group your job is to determine whether this process is possible. Your first step will be to see if you can arrange energy bands and gaps so that the IR detection material can emit only green photons or only blue photons. (We already know about red because we saw it happen.) What advice would you give the group?