

Name:

Class:

LUMINESCENCE
It's Cool Light!

Visual Quantum Mechanics

ACTIVITY 6

Introducing the Potential Energy Diagram as a Model of the Atom

Goal

Now we will introduce an atomic model that we will use to explain luminescent processes. This model will describe an atom in terms of potential energies.

Atoms are extremely small objects that we cannot see directly. So, to understand atoms we complete experiments such as those in the previous activities and use the observation to build our understanding and make predictions. The ideas that we create to help us understand and make predictions are called models. These models give us a representation of the behavior of the object we are studying. This representation does not need to look like the actual object. It is not a model in the way that a Hot Wheels car is a miniature version of the real thing. Instead, it may be quite different from "the real thing" in form but similar in behavior.

We do not have a good "picture" of an atom because we do not see them directly. Instead we build models to help us explain the observations. The model that will be introduced in this activity can provide an understanding of how light is produced by atoms and why different objects emit different types of light.

Our model is based on the knowledge that electrons have a negative electrical charge while the nucleus of an atom has a positive charge. Opposites charges attract, so the atom is held together by electrical forces.

All of our observations have involved light – a form of energy – coming from the materials. We have assumed that atoms in the material emit this light. The process of emitting the light involves changing energy from some other form into light. Thus our model needs to include energy and its conservation.

We begin by looking at the electrical potential energy versus distance for

- one dimension in space,
- a positive electrical charge at 0,
- a small negative electrical charge elsewhere,

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- the positive charge cannot move, and
- negative energies indicate an attraction between two objects.

The graph of the potential energy vs. distance is shown in Figure 6-1. If atoms were one-dimensional, this graph would represent the potential energy of an electron in an atom. The atom is not one-dimensional, but we want the simplest possible model. So, we begin with a one-dimensional model and see what we can learn.

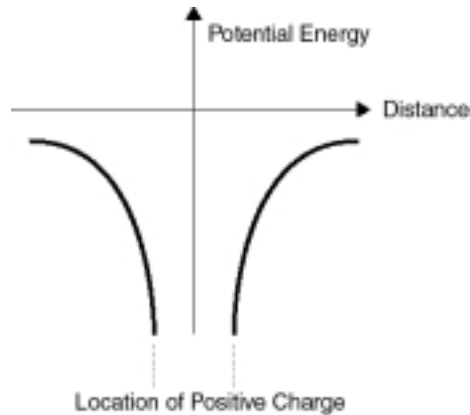


Figure 6-1: Example of the Potential Energy Diagram that Represents a Single Atom. (The dots indicate that the potential energy continues with more negative numbers.)

The graph in Figure 6-1 is an example of a potential energy diagram.

Although the potential energy diagram illustrated in Figure 6-1 does not look like an atom, it does effectively describe the interaction that occurs between an electron and a nucleus. As we shall see, the diagram also allows us to predict some of the atom's behaviors. Thus, Figure 6-1 could be used to represent a single atom.

To get Figure 6-1 as the potential energy representation we made several assumptions to simplify our model. Now, we will make one more – that Figure 6-2 is a good approximation to Figure 6-1.

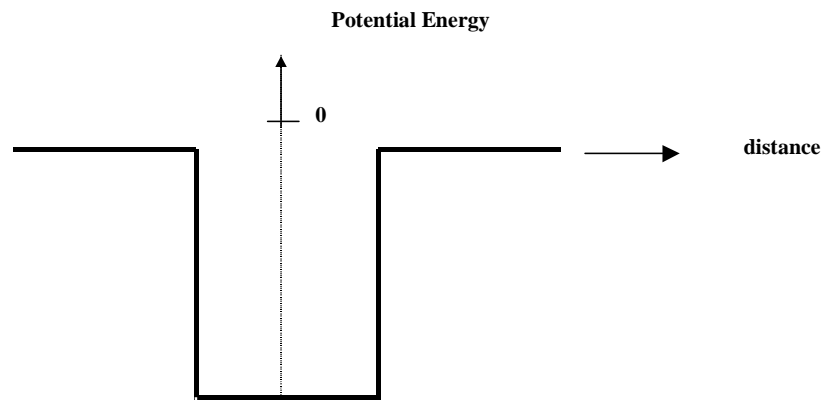


Figure 6-2: Simplified potential energy diagram that we will use to represent a single atom.

This statement is an *assumption*. If we are able to use this model to explain our observations of luminescence, then we conclude that the assumption was good. If the model gives results different from our observations, then the assumption is not so good.

(The change from the curves to the straight line is primarily to allow the computer to calculate faster. As we shall see, it works for most of what we need but it has some limitations.)

In the patterns of light observed through the spectroscope for the gas lamps, we observed distinct lines of different colors. Recall that for this discrete spectrum each line of a different color corresponds to light of a different energy. For each gas lamp, we saw a different number of lines with distinct colors. From this observation, we concluded that atoms of a gas, like hydrogen and mercury atoms, emit only a few distinct energies that can be used to identify these gases. In this and the next activity, we will use computer programs to see how these energies of light are related to the allowed energies for an electron in the atom.

The computer program *Energy Band Creator* does the mathematics to determine the value of the energy for each of the discrete energies in our simple model of the atom. We do not need to know how the math works; we will just look at potential energy diagrams of the results.

To see how it works we will begin with a situation similar to gas atoms. In a gas the atoms interact very little with each other.

Start the *Energy Band Creator* computer program. Click on the Default button. A single potential energy diagram similar to Figure 6-2 will appear on the screen.

The program can determine the allowed energies for the atom represented by this potential energy diagram. Click the Find Energies button. You can enlarge the diagram by clicking inside the potential energy diagram. Click on the magnifying glass with a negative sign to return to the original size.

In the space below, sketch the allowed energies for this situation.

-27 eV ———

-81 eV ———

To see the effect on the energy values, change the lowest value of the potential energy diagram from -100 eV to -200 eV by either using the mouse to drag the green triangle found below the eV scale or by typing 200 in the box to the right of Depth (eV). If you type in the new value, click on the Update Graph button. The potential energy diagram that would represent a different single atom appears on the screen.

Find the allowed energies for this potential energy diagram and sketch them in the space below.

? What is the effect of changing only the depth of the potential energy diagram from -100 eV to -200 eV on the number and values for the allowed energies?

Now investigate changes in the region. Keep the lowest energy at -200 eV and change the width from 0.1 nm to 0.2 nm.

In the space below sketch the allowed energies for the "atom" represented by this diagram.

Describe the effect on the values of allowed energies of changing the width of the potential energy diagram from 0.1 nm to 0.2 nm when the lowest energy is held constant.

The lowest energy and width of this diagram depends on the electrical charge of the nucleus and the number of electrons in the atom. We will not look at details for different elements here. However, we see that changing the lowest energy and width of the potential energy diagram changes the number and location of the possible energies. These changes are similar to ones that we see for energy levels in real atoms.

The horizontal lines on the potential energy diagram represent the allowed *total* energies that an electron in that potential energy can possess. The vertical position represents the electron's total energy. Figure 6-3 (without the axes) is an example of what is called an energy level diagram, and it shows the electron's allowed total energies (dashed lines). Once the diagram contains the allowed energies of the an electron, the diagram becomes an *energy level diagram*.

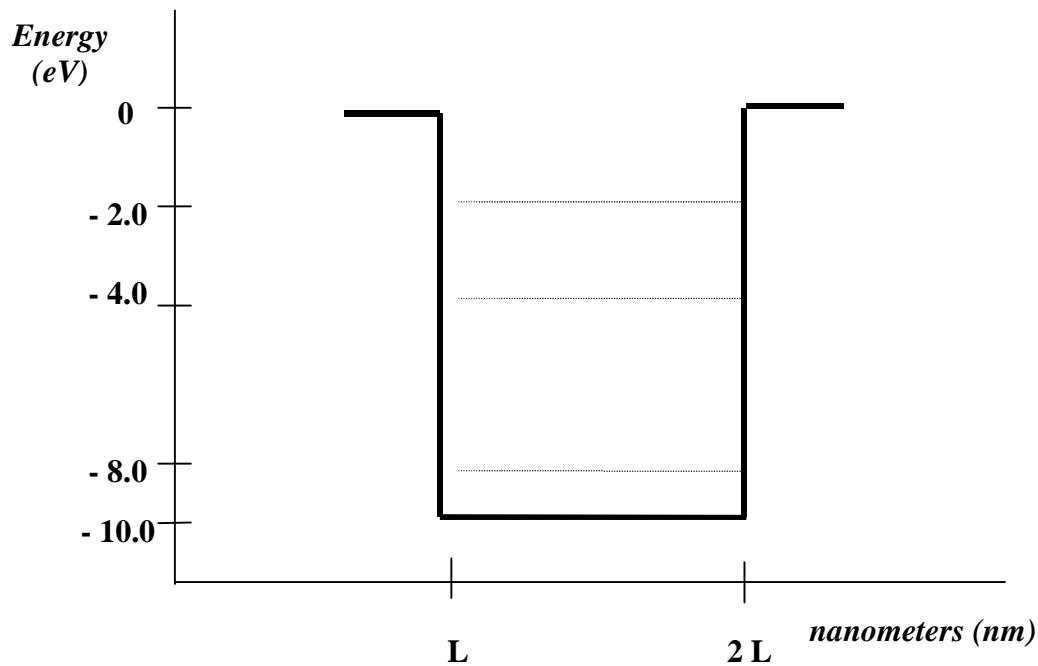


Figure 6-3: Energy Level Diagram

Notice that the total allowed energies have negative values. We use negative values to represent that the electron is attached (bound) to the atom. In Figure 6-3 the value -8.0 eV represents a situation in which an electron has the lowest energy and is attached. The value -2.0 eV represents a situation in which an electron has the greatest energy and is more loosely bound. For the electron to be free and no longer be attached to the atom, the electron must have at least a total energy of 0.0 eV.

The idea of a negative energy may seem rather strange at first. However, the zero for a potential energy can be set at any place that we choose. Then we make all measurements relative to that value. We have chosen the zero of potential energy to be that energy which determines if the electron is attached to the "atom". Positive total energies indicate that it is not attached; negatives that it is. This choice is a matter of convenience.

So far, we have looked at a representation of a single atom and seen how the energy levels change when the parameters (lowest energy and width) are changed. You can see how this representation is similar to the diagrams that you created to describe energy changes that gave us spectra. Both the energies for spectra and the energies in the potential energy diagram exist at only certain allowed values. Different elements have different allowed energies and, thus, different spectra. The potential energy diagram seems to fit our observation of gas atoms. We will now see how it is applied to explain the observations of solid light sources.