

Name:

Class:

# WAVES of matter

Visual Quantum Mechanics

## ACTIVITY 2

# Understanding the Spectra Emitted by Gas Lamps

### *Goal*

You will use your observations of gas spectra to build a model of energies in an atom.

In the last activity, we learned that light is emitted when atoms change energies. An electron in an atom loses energy. The energy lost by the electron appears in the form of light. The energy difference determines the energy and, thus, the color of light emitted by the atom.

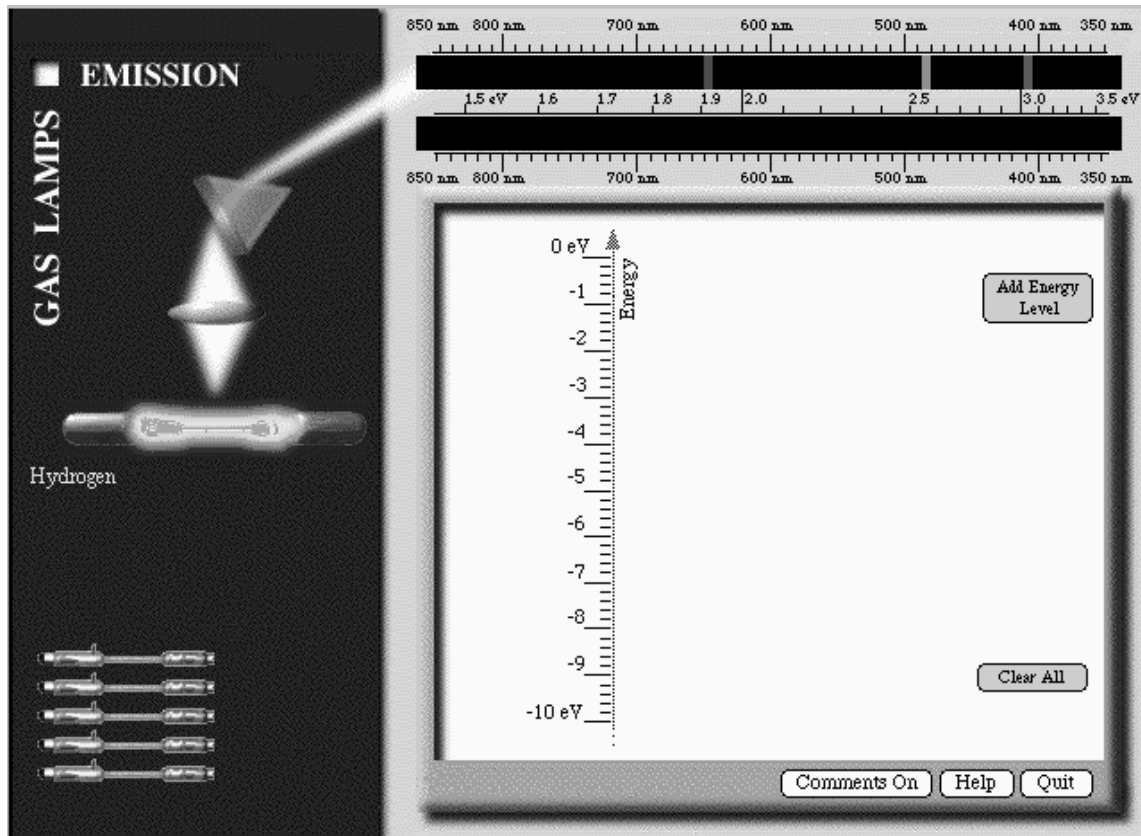
We will now use *Spectroscopy Lab Suite* to see how the spectra of light emitted by gases can help us understand more about the energies in an atom.

In *Spectroscopy Lab Suite*, select *Emission* under *Gas Lamps*. Figure 2-1 shows the screen that appears. In this program, we can

- Select a gas tube and drag it to the socket that is just above the lamps. Some of the light in the spectra for that gas will appear at the top of the screen.
- Add energy levels for an electron in a potential energy diagram by using the Add Energy Level button.
- Move the energy levels by selecting them at the left of the vertical energy scale and dragging them to the desired position.
- Create transitions (represented by vertical arrows) by selecting the electron's initial energy on the right of the energy scale. (It turns green.) Drag the transition arrow to the electron's final energy. When you reach the final energy, it will turn green.
- This process will enable you to create an energy level model of the light emitting process in an atom. From the results you will be able to learn about energy levels in atoms. A colored spectral line on the screen above the potential energy diagram will indicate the light emitted by the transition. If the light is not in the visible region of the spectrum, it will not appear on the screen.

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- Move any of the energy levels after you have created a transition.

Figure 2-1: *Gas Lamp Spectroscopy Computer Program*

Begin with hydrogen. Follow the procedure on the previous page to place the hydrogen gas tube in the socket. Some of the spectral lines for hydrogen will appear in the top spectrum.

Create energy levels and a transition that will match one of the spectral lines of hydrogen. The spectrum that you create appears on the lower spectrum.

- ? How many energy levels are needed to create one spectral line?
- ? What is the energy of the spectral line as indicated by the eV scale?

? List the energies of the levels that you created.

? What is the difference in energy between the electron's initial total energy and its final total energy?

? How is this energy difference related to the energy of the light emitted by the atom?

Move both of the energy levels but keep the difference in energy between them unchanged.

? Why does the spectral line end up at the same energy?

Now create and move energy levels until the bottom spectrum matches the spectrum of hydrogen as shown in the top spectrum.

Sketch the resulting energy level diagram for hydrogen in the space below.

? How many energy levels are needed to create these three spectral lines?

? How many electron transitions are needed to create these three spectral lines?

- ? What other, if any, possible electron transitions can take place with the energy levels illustrated on your screen?

Compare your energy diagram with the diagrams created by other students.

- ? How are they similar?

- ? How are they different?

At this time none of the energy diagrams is more right or wrong than the others. We do not have enough information to distinguish exactly what transitions or initial and final energies occur in nature. Our model is limited by the knowledge that we have. Thus, all sets of energies and transitions that reproduce the spectrum are equally correct. (Scientists have more information to help distinguish the various possibilities, but that is not needed for our purposes.)

We can create energy diagrams that provide all of the spectral lines rather easily. We need only a few energies to have sufficient transitions for all of the visible light. From this construction we conclude that an electron in an atom can have only a few energies. Otherwise we would see light of many more colors. This conclusion is somewhat surprising. When an electron moves in an atom, *it might seem* that the electron could have any one of many energies. But, nature does not behave that way. Instead electrons in atoms are limited to a very few discrete energies. We call them the allowable energies.

Repeat the steps to determine the energy levels and transitions necessary to produce the spectral lines emitted by another gas that is assigned by your instructor.

Sketch the resulting energy level diagram for the helium gas in the space below.

? How is the energy level diagram for the helium gas similar to the diagram for hydrogen?

? How are they different?

Up to this point, we have learned that light is produced when electrons make transitions in atoms. If they have high energy, they naturally lose it in the form of light as they move to a lower energy level. In a normal situation the electrons will be in a low energy level. They must first be given energy to attain high energies so that it can naturally lose that energy. An external energy source, such as electricity must supply that energy. This process is illustrated in Figure 2-2.

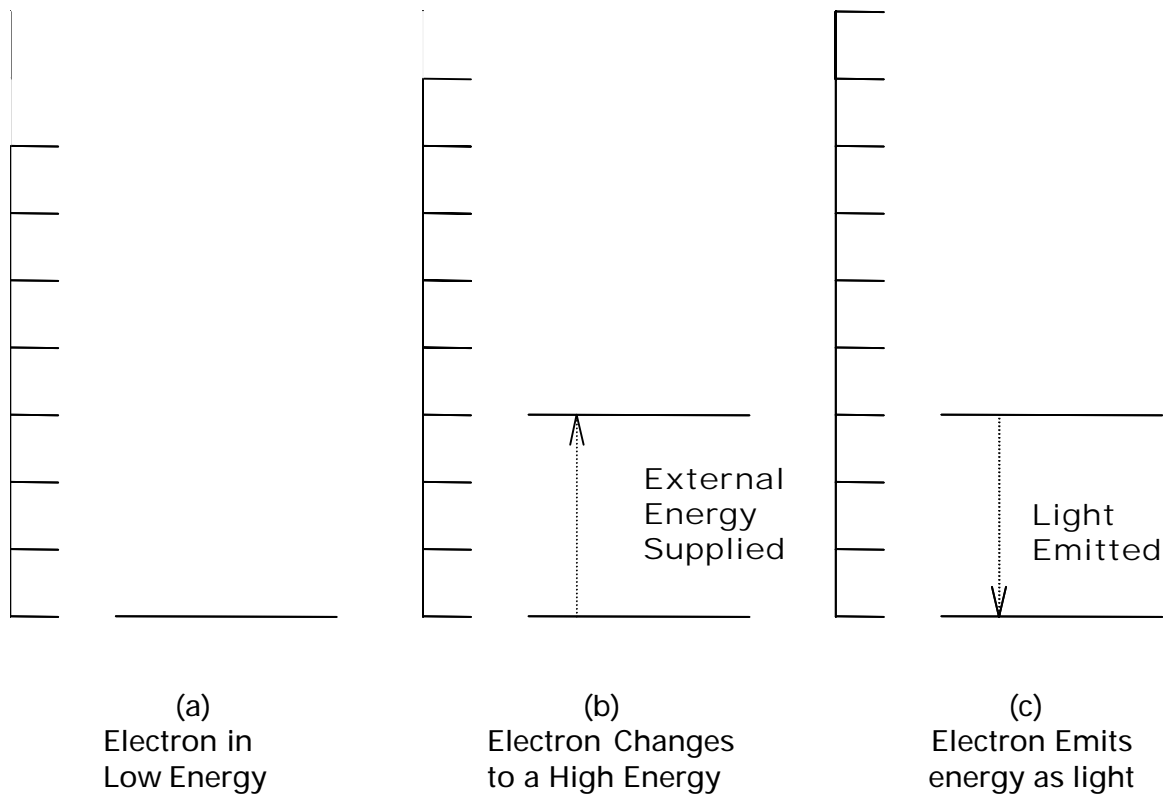


Figure 2-2: Gain and Loss of Energy by Electrons in an Atom

? What external energy source was necessary for the hydrogen and helium gas lamps to emit light?

The larger the external energy provided, the greater the number of electrons that will obtain higher energies. For example, suppose the energy difference between two allowed energies is 2.55 eV. See Figure 2-3.

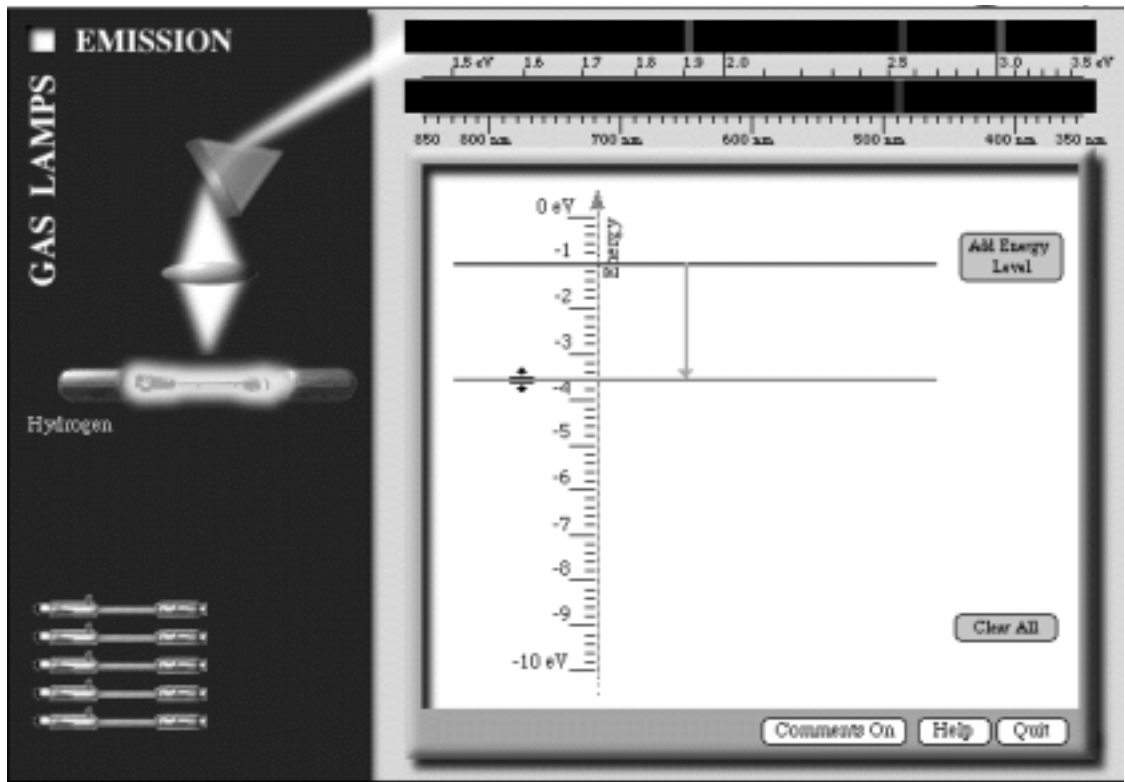


Figure 2-3: Screen capture from the Gas Lamps program.

In other words, 2.55 eV must be supplied by the external source for a *single* electron to change from a low energy to a higher one. If 5.10 eV of energy is supplied by an external source, *two* electrons can have the highest energy. Supplying a larger amount of external energy does not change the allowed energies, but it can change the number of electrons with the higher energy. Recall that the allowed energies for an electron bound to an atom depend on the type of gas atoms found in the lamp. Supplying a larger amount of external energy causes a larger number of electrons to possess the highest allowed energies. Thus, more electrons will make transitions from higher allowed energies to lower allowed energies that result in the greater emission of photons and brighter light.

A different situation occurs if the energy supplied to the atom is not equal to the difference between energy levels. For the example illustrated in Figure 2-3 no transition will occur if we supply less than 2.55 eV. If we provide the electron with 2.40 eV of energy, it cannot use it. No energy level exists for that transition to occur. If we provide more than 2.55 eV but less than 5.10 eV of energy, only one electron can make the transition. When 3.20 eV is available, the electron can use 2.55 eV and the remaining 0.65 eV will end up as some other form of energy.

In hydrogen and helium atoms, unlike the *Gas Lamp Spectroscopy* computer program, the allowed energies for an electron cannot be changed because the type of atom uniquely defines them. The values for the energies are determined by electrical interactions between the nucleus and the electrons.

- ? What differences are there between hydrogen and helium atoms that might account for their electrons having different energies?

The electrical properties of an atom uniquely determine what energies its electrons are allowed to have. So, even though the *Gas Lamp Spectroscopy* computer program allows you to adjust the energies available to the electrons, these energies are fixed at very specific values by the electrical properties of the atom.

Because the atoms of each of the elements have a unique set of energies, the light given off by a material can be used to determine the type of elements present. This property is used to learn about the composition of distant stars as well as substances on earth.

#### Homework Problem

1. Art historians are frequently faced with determining whether paintings are originals or forgeries. Suppose an art dealer who seems a little suspicious has a painting that she claims was painted in 1704. Because of its age she says that it is very expensive. However, one of the colors looks remarkably like pigments from cobalt blue. As an art expert you know that blue paint that used the element cobalt was not used by artists until 1804. How might you use the ideas presented in this activity to determine whether the painting contains cobalt blue?<sup>1</sup>

<sup>1</sup> Adapted from Jacqueline D. Spears and Dean Zollman, *The Fascination of Physics*, (The Benjamin /Cummings Publishing Company, Inc., Menlo Park, CA 1985). Permission granted by the Authors.