Name: Class:

SOLIDS & LIGHT

Visual Quantum Mechanics

ACTIVITY 3

Introducing Energy Diagrams for Atoms

Goal

Now that we have explored spectral properties of LEDs, incandescent lamps, and gas lamps, we will build a model that can be used to explain these observations. This model will be applied first to explain the spectral properties of gas lamps.

Observations of Light

In the previous activities we observed somewhat different patterns of light emitted by the different types of light sources. We see one difference by just looking at the various light sources. The gas lamps and LEDs are made of clear material yet they emit light of different colors. For the gas lamps the color depends on the type of gas in the tube. For LEDs, the color comes from a process that we will study later. The incandescent lamps, such as Christmas tree lights, are different; the color is contained in the glass surrounding the filament. Understanding these differences is one of our goals.

Another difference appears when we view the spectra. Both the LEDs and incandescent lamps display parts of a continuous spectrum. Their color determines which part of the spectrum is emitted. Gas lamps are different. Each of them emits only certain colors resulting in a spectrum that we call discrete.

In all cases matter inside the lamp emits the light. This material is made of atoms. So we must learn something about atoms to understand the emission of light.

The attraction between the electrons and nucleus means that energy in the form of electrical potential energy is stored in the atom. In addition the electron's motion contributes kinetic energy. So, each electron has a total energy that is equal to its kinetic energy plus its electrical potential energy.

Electrical potential energy occurs for attraction (opposite charges) and repulsion (same charges). To distinguish these two situations we use positive and negative numbers. The positive numbers indicate potential energy associated with repulsion, while negative numbers go with attraction. Because we will work with attraction, we will be using negative potential energies.

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To get the total energy we add kinetic energy (a positive number) and potential energy (a negative number). For an electron in an atom the result for the total energy will always be negative. The idea of a negative energy may seem strange at first. To get an idea of its meaning consider an electron which is *not* attached to an atom, not near any other electrical charges, and is not moving. It is interacting with nothing and not moving, so it has zero potential energy, zero kinetic energy and zero total energy.

If this electron is attached to an atom, its energy becomes negative. The *magnitude* of the energy must be added to the electron to get it back to zero energy — to get it to be no longer attach to an atom and not moving.

For example, suppose we know that an electron has an energy of -13.6 eV. From this information we know that

- the electron is attached to an atom, and
- to get the electron completely free from that atom we must give it 13.6 eV of energy.

Thus, the negative total energy can convey some valuable information about the electrons.

? Which energies below indicate that the electron is attached to an atom?

-1 eV   0 eV   18 eV   -8.6 eV

? For each of the energies below indicate how much energy you must add to get the electron free from the atom.

-3.4 eV   -54.4 eV   -11.5 eV

? An electron has an energy of -4.6 eV. An interaction occurs and it *loses* 5.1 eV of energy. What is its new energy?

? Is it still attached to the atom? Explain your answer.

? An electron is attached to an atom and has a total energy of -8.9 eV. Kevin adds 12.0 eV to this atom. What will be the electron's new energy?

? Will it be moving? Explain your answer.

A useful way to describe the energy of electrons in an atom is to use an energy diagram. The diagram plots the electron's energy on the vertical axis of a graph. We simply draw a line at the energy of the electron. As an example the diagram in Figure 3.1 represents an energy of -3.4 eV.

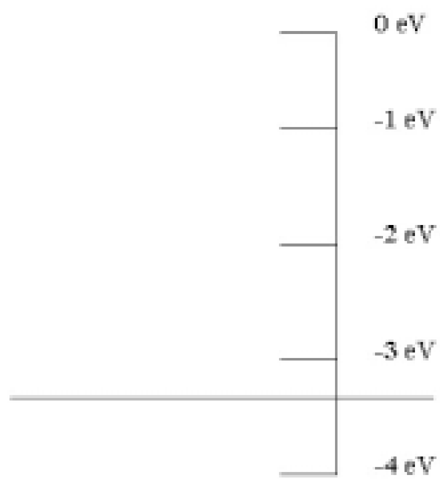


Figure 3.1: An energy diagram for an electron with -3.4 eV of energy.

In this scheme the horizontal axis has no particular meaning. We are only dealing with one variable — the electron's energy. We could just draw dots on the energy axis, but lines are easier to see.

In our studies we will always be interested in electrons that are attached to atoms. So, we place zero energy at the top of the diagram and do not include positive energies.

Changing Energies — Transitions

To emit light an electron must change its energy. This statement reflects conservation of energy.

Electron energy before = Electron energy after + Light (photon) energy

Each time an electron decreases its energy it emits one photon. Thus, by looking at the energy of photons we can learn about what is happening in an atom. From what we can see (light) we infer about what we cannot see (the atom). This process allows us to build models of the atom.

We will use energy diagrams to indicate the changes in the electron's energy. The process is shown in Figure 3.2

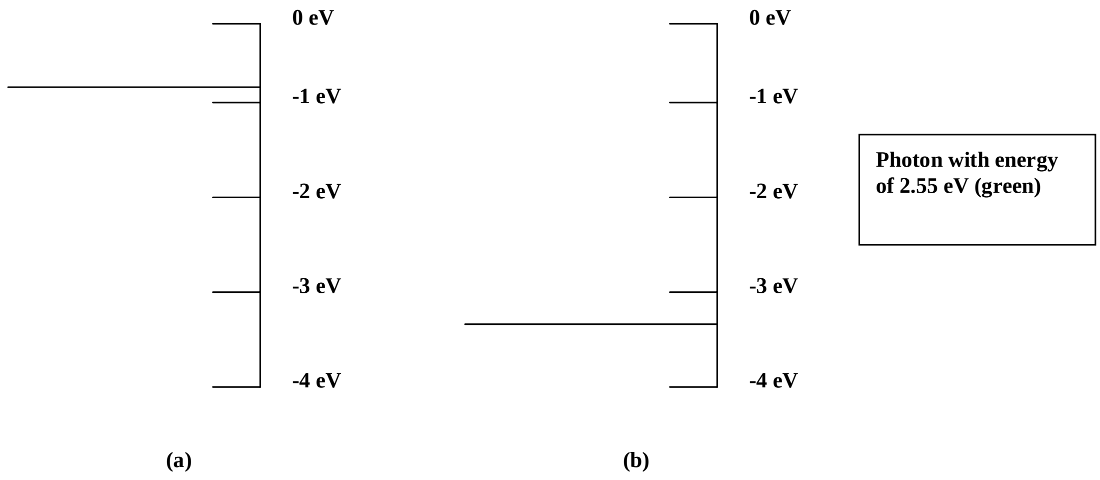


Figure 3.2 (a) Before the emission of light the electron has an energy of -0.85 eV. (b) After the emission of light the electron has an energy of -3.40 eV and a photon of 2.55 eV has been emitted.

The diagrams show the before and after pictures for the electron's energy and indicate that a photon was emitted. To simplify our drawings we generally combine all of the information onto one graph as in Figure 3-3.

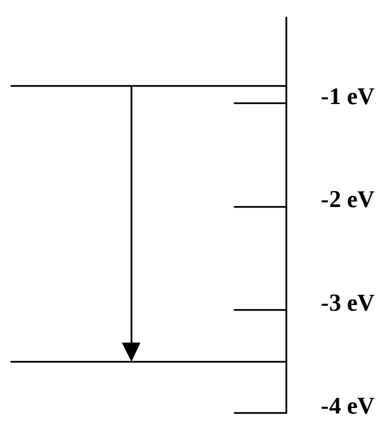
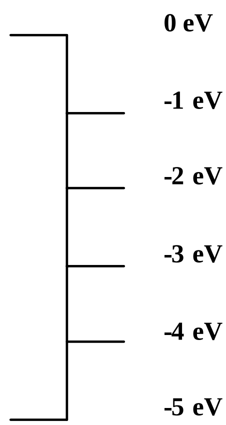


Figure 3-3 The interaction that was shown in the previous figure but combined onto one graph.

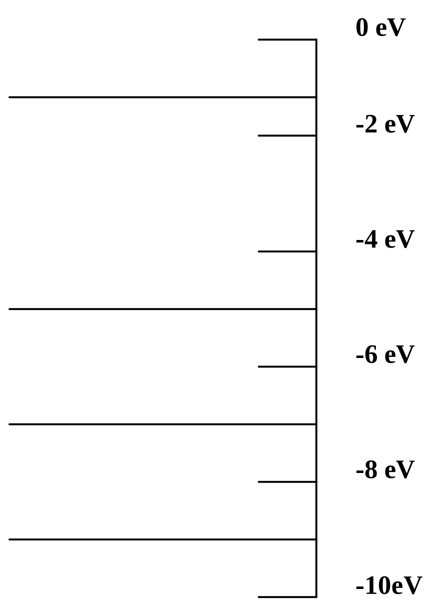
The arrow in Figure 3-3 indicates that electron changed from an energy of -0.85 eV to an energy of -3.40 eV. The sketch above the energy diagram represents what we would see in a spectroscope when the photon is emitted. (One photon is too few to see but it is representative of the energy.)

The process during which an electron changes energy is called *transition*. Thus, Figure 3-3 represents a transition from -0.85 eV to -3.40 eV.

Draw an energy diagram which represents a transition from -2.3 eV to -4.6 eV.

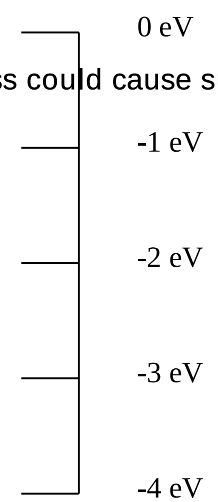


The energy diagram below has four possible energies for the electron. Indicate all transitions that could occur.



? Determine the energies of the photons for each transition.

Another type of transition involves the electron gaining energy rather than losing it. Sketch a diagram which indicates that an electron changed from -3.47 eV to -1.1 eV.



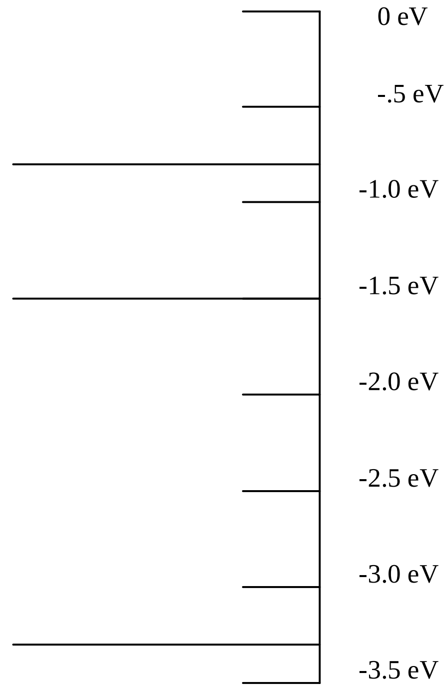
? Speculate about what type of process could cause such a transition. Explain your answer.

An Energy Model for the Atom

The energy diagram provides us with a way to understand some of the processes in the atom. You will use it to understand the various spectra that you have observed. In the process you will learn why, in terms of energy, the spectra of incandescent lamps, LEDs, and gas lamps are different from each other. You will also learn how gas lamps and LEDs can emit certain colors even though they are clear. The first step is to build an energy model of an individual atom. That is the topic of the next activity.

Application Question

The energy diagram below represents a set of energies for an atom.



? What electron transition(s) can exist?

? For the electron transition(s), what are the resulting energies of the emitted light?

? What are the colors of light associated with these electron transitions?