Name: Class:

WAVES
of matter

Visual Quantum Mechanics

ACTIVITY 1

Exploring Light from Gases

Goal
We will view the colors of light which are emitted by different gases. From these patterns of light we gain information about energies in atoms.

The importance of light as a form of energy is apparent in our everyday lives. In addition to enabling us to see and plants to grow the energy of light has provided important clues in understanding the structure of matter. By looking carefully at light scientists have made surprising (at the time) discoveries about atoms and molecules. The explanations of these observations have led to a new level of understanding about all types of matter. This understanding has provided an entirely different view of atoms, molecules and, even, what we can know.

In this unit we will explore and learn about some of the important discoveries in the 20th Century. These observations and theories have helped scientists reach their present level of knowledge about very small objects such as electrons, atoms and molecules. Our investigations will begin with observations of light coming from atoms.

We begin by considering objects that emit their own light. Think about how you could get an object to emit light. What would you do to get light from objects?

If you look at your answer and all of your classmates, you will probably have several ways that light is produced. All involve providing some type of energy to the object. In everyday life providing electricity or heat is the most common way to create light. Sometimes light from electricity produces a large amount of heat. For example, a light bulb or a toaster produces both light and heat. In other cases, such as a fluorescent tube, the amount of heat is rather small. The relatively large and small amounts of heat indicate different processes for creating light. We will concentrate on processes similar to those occurring *inside* a fluorescent tube.

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Gas tubes contain atoms of one element. When supplied with electrical energy, the atoms emit light. You will use a spectroscope to break this light into its component colors. The display of colors is called a spectrum.

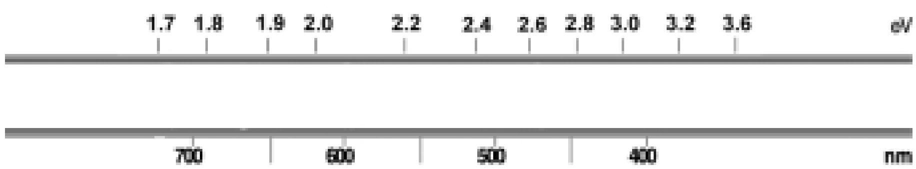
Caution:	(1) Some power supplies for gas tubes have exposed metal contacts. Because the gas lamp is a high voltage light source, do not touch the metal contacts that connect the gas tube to the power supply. (2) Never look at the sun or a tanning lamp with a spectroscope. Eye damage may occur from brightness and from high energy ultraviolet photons.

On the following scales, draw the pattern of emitted light observed with the spectroscope for three gas lamps.[Hint] Use colored pencils or markers to indicate the position of color(s). Add a written description to record which colors seem bright or dim.

Light Patterns Emitted by Gas Lamps

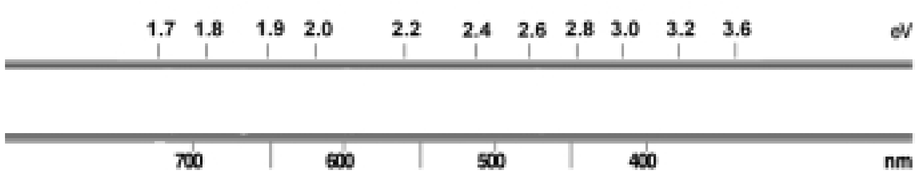
Hydrogen or ________________:

Color of the light without spectroscope__________



Helium or __________________:

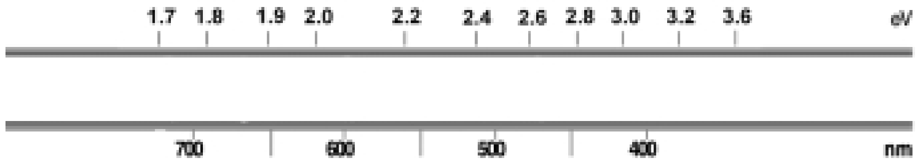
Color of the light without spectroscope__________



Hint To ensure that the light patterns are clearly visible, position the vertical slit of the spectrometer (found on the end with a screen) so that it is directly facing the light source and, if possible, hold the spectrometer less than a foot away from the light source. Dim the lights of the room so that the light patterns may be seen. The room, however, should be lighted enough for the energy scale to be seen.

Mercury or _________________:

Color of the light without spectroscope_________



As you can see, different elements emit different colors. These colors can be described quantitatively in terms of wavelength which is the nanometer (nm) scale above. A nanometer is .000000001 meters, so the wavelength of light is very small. Alternately we can describe the colors in terms of energy. The electron-volt (eV) scale provides an energy associated with the light. An electron volt is also very small — 1.6×10^{-19} Joules.

In our investigations we will be particularly interested in the energy of the light emitted by the gas. Two factors — brightness and color — contribute in very different ways to the energy of a light.

When we think about the definition of energy, the brightness makes sense. A bright light has more energy in it than a dim light.

The color connection is not quite so obvious. Atoms emit light in small packets of energy. These packets are called photons. Each individual photon contains an amount of energy that is related to its color. So, if we wish to discuss the energy of one of these photons, we need to know its color.

For light that we can see the energy ranges from red at the low energy to violet at the high-energy end. Not visible but still a form of light are infrared photons with an energy lower than red and ultraviolet photons which have energies higher than violet. The order of energies for the various colors of photons is shown below.

	Infrared
Low energy visible photons:	Red
	Orange
	Yellow
	Green
	Blue
High energy visible photons:	Violet
	Ultraviolet

Each time an atom produces light, it emits a photon. In our investigations we will be primarily interested in the energy of individual photons. As we will see, this energy will tell us something about the atoms of a material. Thus, the color of a light will be an important variable.

Each photon of visible light carries a very small amount of energy. This energy ranges from about 2.56×10^{-19} Joules for red light to 4.97×10^{-19} Joules for violet. Using these very small numbers is inconvenient, so we will use different units – the electron volt (eV). In these units, visible light energies range from about 1.6 eV (red) to 3.1 eV (violet) – much easier numbers to deal with.

The brightness of the light is related to the number of photons emitted. A dim light will emit fewer photons than a bright light. Thus, we have two measures of energy — brightness and color. Because color is related to the light from each individual atom, we will concentrate on it.

In the table below record the color of light emitted by each gas lamp that is related to the greatest and least energy per photon.

Gas	Greatest Energy	Least Energy
Hydrogen		
Helium		
Mercury		

? How can you tell which particular color of light emitted by each gas lamp results in the greatest number of photons emitted?

In the table below record the color(s) of light for which the greatest numbers of photons are emitted by each gas lamp.

Gas	Greatest Number of Photons
Hydrogen	
Helium	
Mercury	

? What are the similarities among the light patterns observed for the various gases?

? What are the differences?

Atoms have a nucleus and electrons. These components are attracted to each other. 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.

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 attached 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. The questions below will help you check your understanding of these ideas.

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

-1 eV   0 eV   18 eV   -8.6 eV

B. 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

C. 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?

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

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

F. Will it be moving away from the atom? 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 1-4 represents an energy of -3.4 eV.

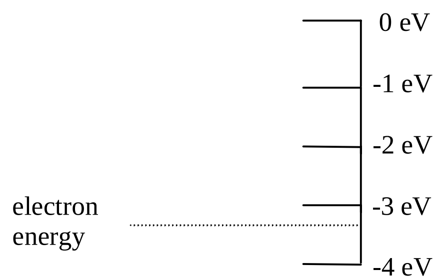


Figure 1-4: An energy diagram for an electron with -3.4 eV of energy.

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.

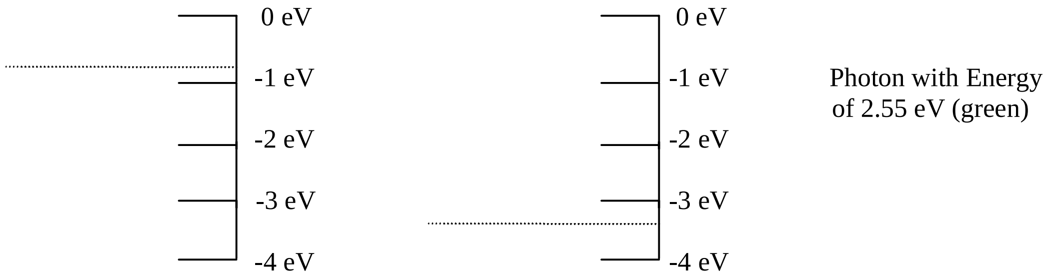
Changing Energies — Transitions

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 1.5

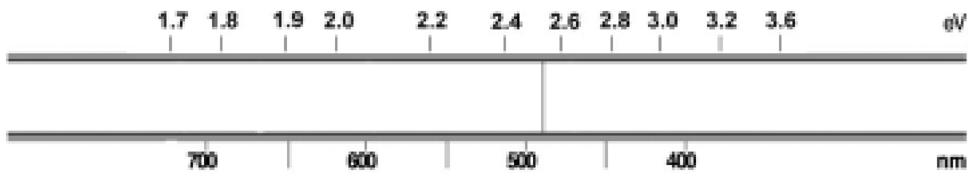


(a) (b)

Figure 1-5 (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 1-6.



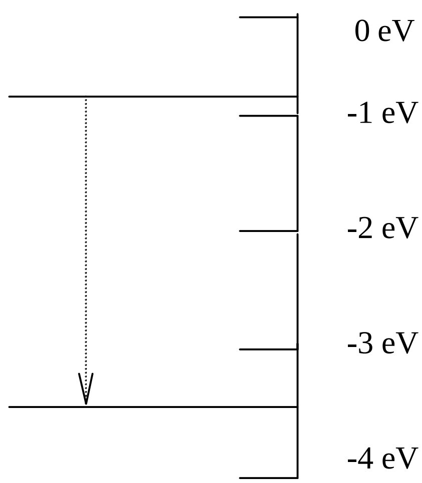
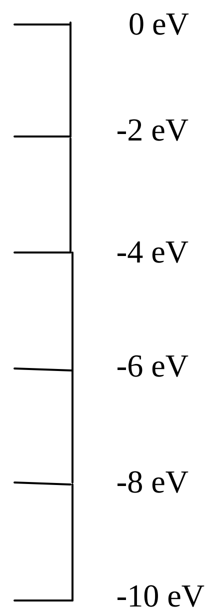


Figure 1-6 The interaction that was shown in the previous figure but combined onto one graph.

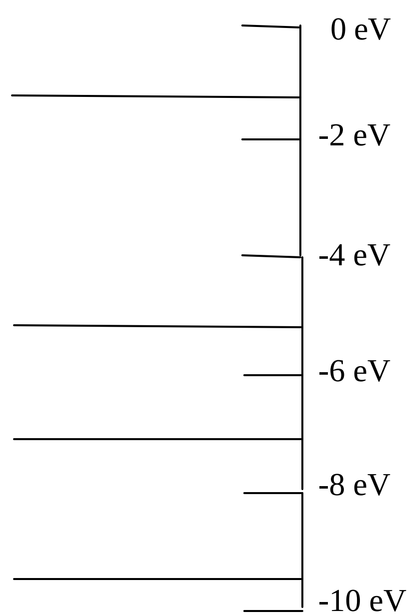
The arrow in Figure 1-6 indicates that electron changed from an energy of -0.85 eV to an energy of -3.40 eV. The sketch above the energy diagram represents what we would see in a spectroscope when the photon is emitted. (One photon is too few to see but it is representative of the energy.)

The process during which an electron changes energy is called a *transition*. Thus, Figure 1-6 represents a transition from -.85 eV to -3.40 eV.

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

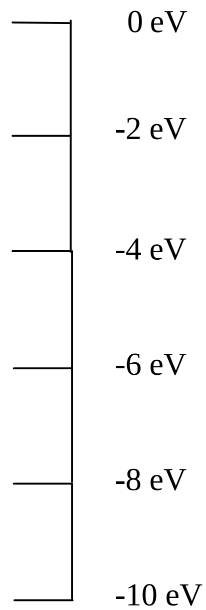


The energy diagram below has four possible energies for the electron. Indicate all transitions that could occur.



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. One of these processes is the emission of light. As we apply energy diagrams to light emission you will learn why 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 not covered with colored glass. The next step is to build an energy model of an individual atom. That model is the subject of Activity 2.