Plasma Globe and Spectra

Part of a Series of Activities related to Plasmas for Middle Schools

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Preface

This activity, produced by the Contemporary Physics Education Project (CPEP), is intended for use in middle schools. CPEP is a non-profit organization of teachers, educators, and physicists which develops materials related to the current understanding of the nature of matter and energy, incorporating the major findings of the past three decades. CPEP also sponsors many workshops for teachers. See the homepage **www.cpepphysics.org** for more information on CPEP, its projects and the teaching materials available.

This activity packet consists of the student activity followed by notes for the teacher. The Teacher's Notes include background information, equipment information, expected results, and answers to the questions that are asked in the student activity. The student activity is self-contained so that it can be copied and distributed to students. Page and figure numbers in the Teacher's Notes are labeled with a T prefix, while there are no prefixes in the student activity.

The Student Section of this Activity is structured on the BSCS 5E model for Inquiry instruction.

The following description of the 5E model is excerpted from the Introduction to the BSCS text: *BSCS Science: An Inquiry Approach*

- ***ENGAGE***
- ***EXPLORE***
- ***EXPLAIN***
- ***ELABORATE***
- ***EVALUATE***

According to the BSCS 5E model, each "E" represents an important part of the sequence through which students progress to develop their understanding. First, students are *engaged* by an event or a question related to a concept, and they have opportunities to express their current understanding. Then they participate in one or more activities to *explore* the concept and share ideas with others before beginning to construct an explanation. Following the initial development of an explanation, students have the opportunity to *elaborate* and deepen their understanding of the concept in a new situation. Finally, students *evaluate* their growing understanding of the concept before encountering a new one. The combination of the 5E model with a strong assessment-oriented design provides opportunities for learning and conceptual change in students, which leads to an improved understanding of science (Bransford, Brown, & Cocking, 2000).

National Standards addressed by this activity are included at the end of the Teacher's Notes as Appendix 1.

Plasma Globe and Spectra

ENGAGE: Light and Rainbows

Your teacher will provide you with the following materials:

light sources:
flashlight (“white” light)
red light
green light
blue light
incandescent bulb
fluorescent bulb
room lights
sun light
plasma globe
discharge gas tube(s)

other supplies:
colored pencils
white paper to use as screen
Prism
Diffraction gratings/glasses
(have your teacher show you how to use these)

Note: A darkened room may allow for better observations.

Using the first four light sources listed above, shine them at the screen, overlapping colors when two or more are indicated in the table (i.e. red and blue). In the table below, draw what you see.

Light(s) on screen	***resulting color(s)***
Flashlight	
Red	
Green	
Blue	
Red and green	
Red and blue	
Blue and green	
Red, green and blue	

What combinations of colors created white light?

If we can combine different colors to get white light, we can also try to split white light up into different colors. We will try this using two different tools: a prism and a diffraction grating.

Shine the flashlight through the prism and try to make a rainbow on the white paper. Draw what you see. Try this with the other colors of lights.

Light(s) through prism	***resulting color(s)***
Flashlight	
Red	
Green	
Blue	
Red and green	
Red and blue	
Blue and green	
Red, green and blue	

When light goes through a prism, it is split up into the colors that are in it. From the experiments that you have done so far, can you determine what colors are in white light?

Ask your teacher for a diffraction grating. Like a prism, a grating can break light up into different colors. Using each light source, look through the diffraction grating. Draw what you see in the table below.

Light(s) through diffraction grating	***resulting color(s)***
Flashlight	
Red	
Green	
Blue	
Red and green	
Red and blue	
Blue and green	
Red, green and blue	
Incandescent bulb	
Fluorescent bulb	
Room lights	
Sun light	
Plasma globe	
Discharge tube 1	
Discharge tube 2	
Discharge tube 3	

Do most of the rainbows created by the grating have anything in common? Explain.

Do any of the rainbows created by the grating look different from the others? Explain.

Earlier you saw that a prism split light up into the colors that are in it. Looking at your results, does a diffraction grating do the same thing?

For which types of light(s) do the diffraction grating and the prism give the same results?

For which types of light(s) do the diffraction grating and the prism give different results?

How do the results using the diffraction grating compare to the results using the prism?

How would you describe the differences between what you saw with the flashlight and a discharge tube while using the diffraction grating?

Remembering what you have learned about white light, do you think the light coming from the discharge tube is white light? Explain your answer.

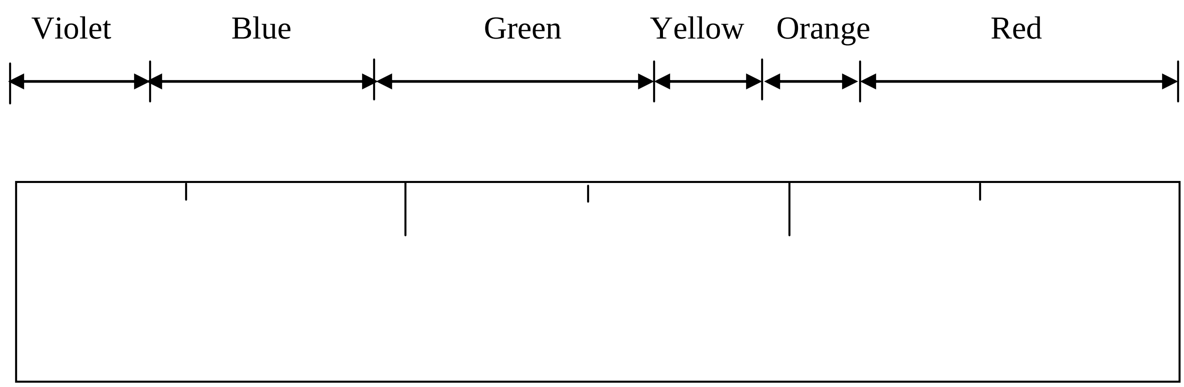
EXPLORE:

Your teacher will show you several glowing spectrum tubes which may include:

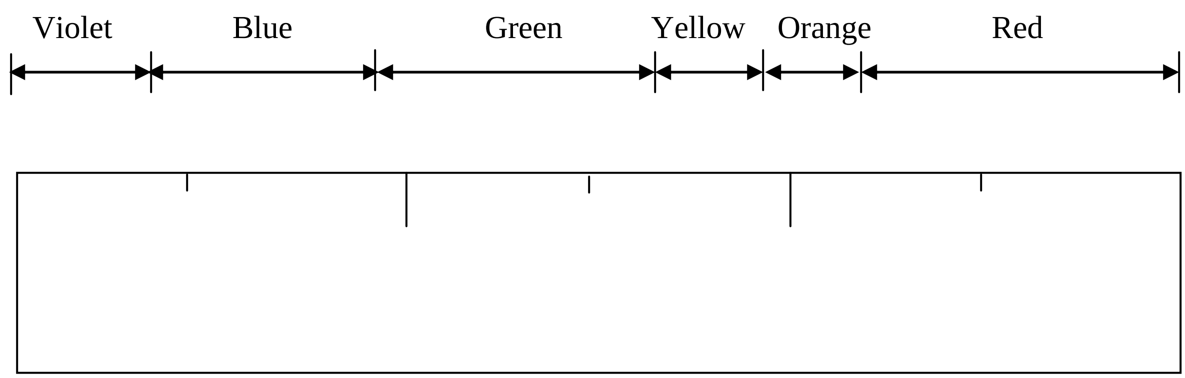
- Helium
- Mercury
- Argon
- Krypton
- Xenon

On the charts below, record the color and brightness (dim, medium, bright) along with the name of the material in the tube. Then, look at the tube through the grating. Use your colored pencils to draw the vertical lines that you see (at least the brightest ones). Be as accurate as possible with color and line location.

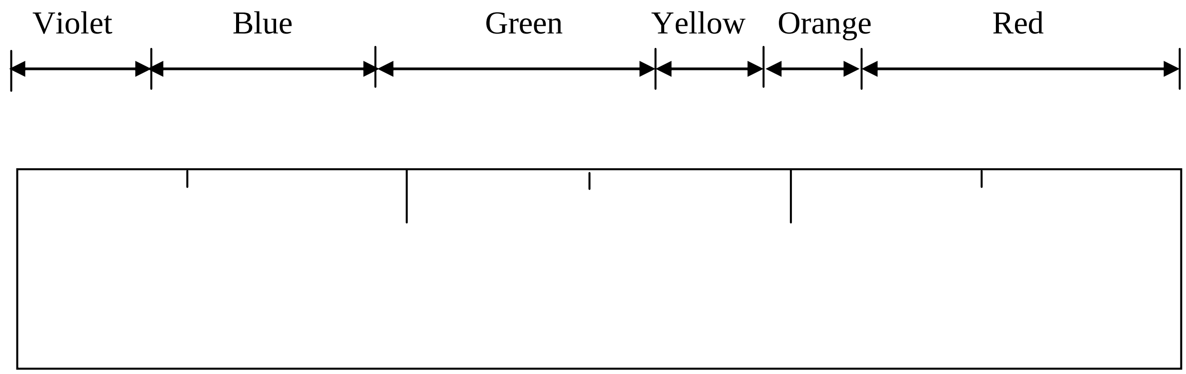
Gas Name ________________ Color_____________ Relative Brightness ______________



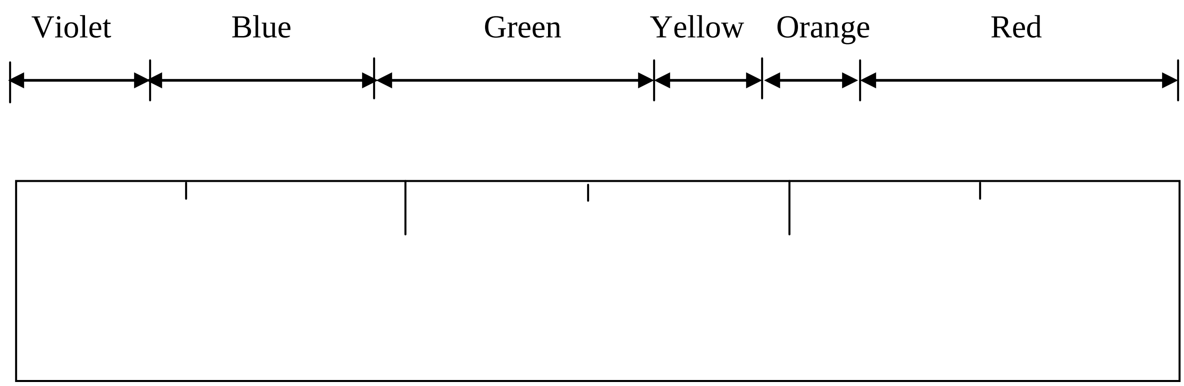
Gas Name ________________ Color_____________ Relative Brightness ______________



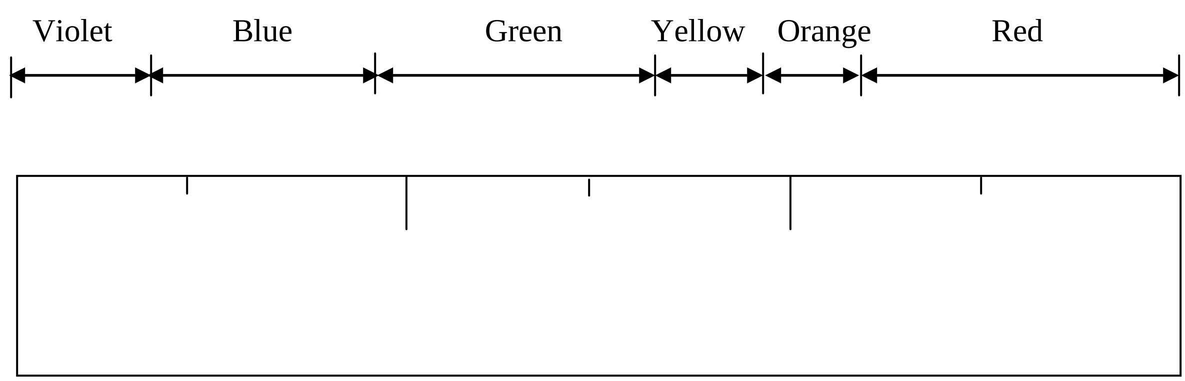
Gas Name ________________ **Color**_____________ **Relative Brightness** ______________



Gas Name ________________ **Color**_____________ **Relative Brightness** ______________



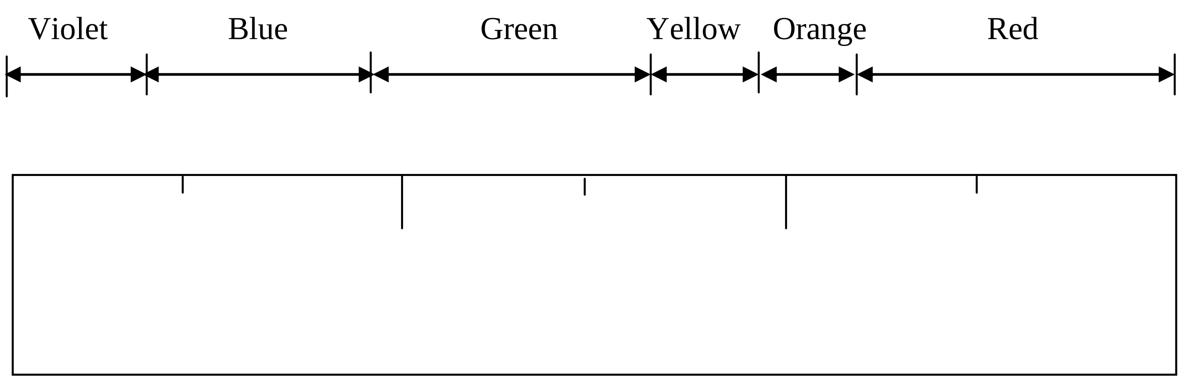
Gas Name ________________ **Color**_____________ **Relative Brightness** ______________



The sets of lines that you drew for each gas are called “line spectra”.   Each type of gas has its own line spectrum. Much like a fingerprint can identify a person, a line spectrum can be used to identify a gas. A line spectrum can be seen through a grating when the gas is very hot

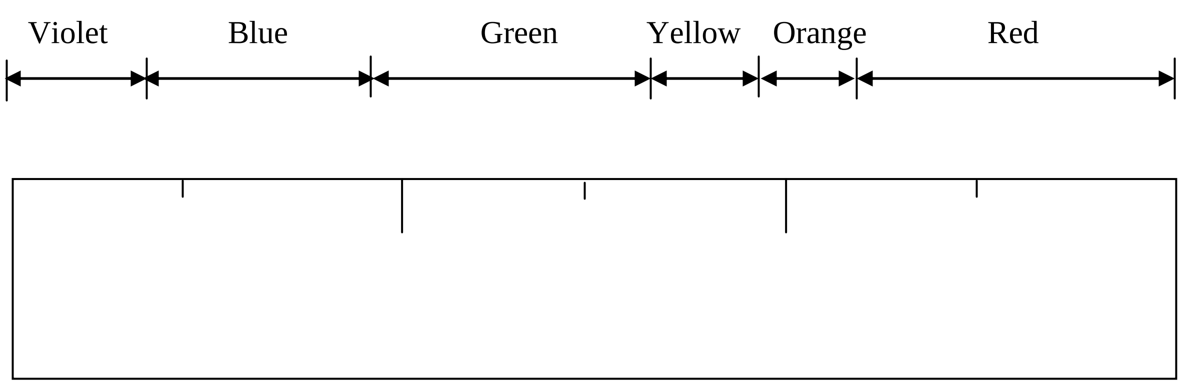
Make a prediction: What do you think it would look like if two of the gases were mixed together?

Gas Names _______________ and _______________ **Color____________**



Observe a plasma globe. What color(s) are the streamers? ______________________

While your teacher touches the plasma globe and makes one strong streamer, now look at the streamer through the diffraction grating and draw the line pattern that you see.



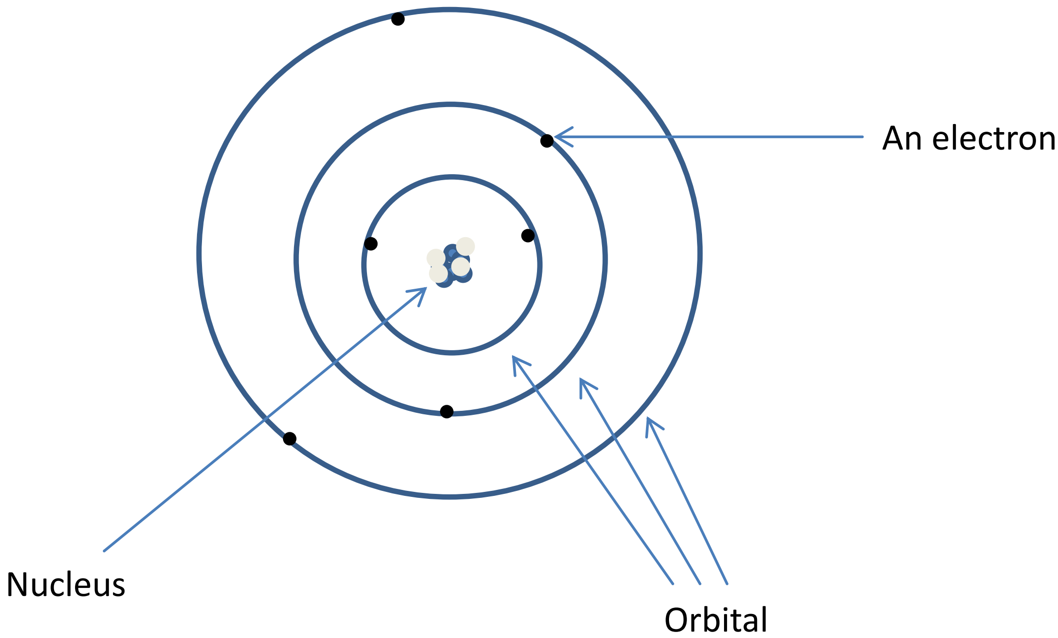
EXPLAIN:

When looking at the plasma globe through the diffraction grating, do you see a rainbow like you would see if the light were white, or do you see line spectra?

Examine the lines that you drew after looking at the plasma globe. Can you use these lines to guess what gasses might be in the globe?

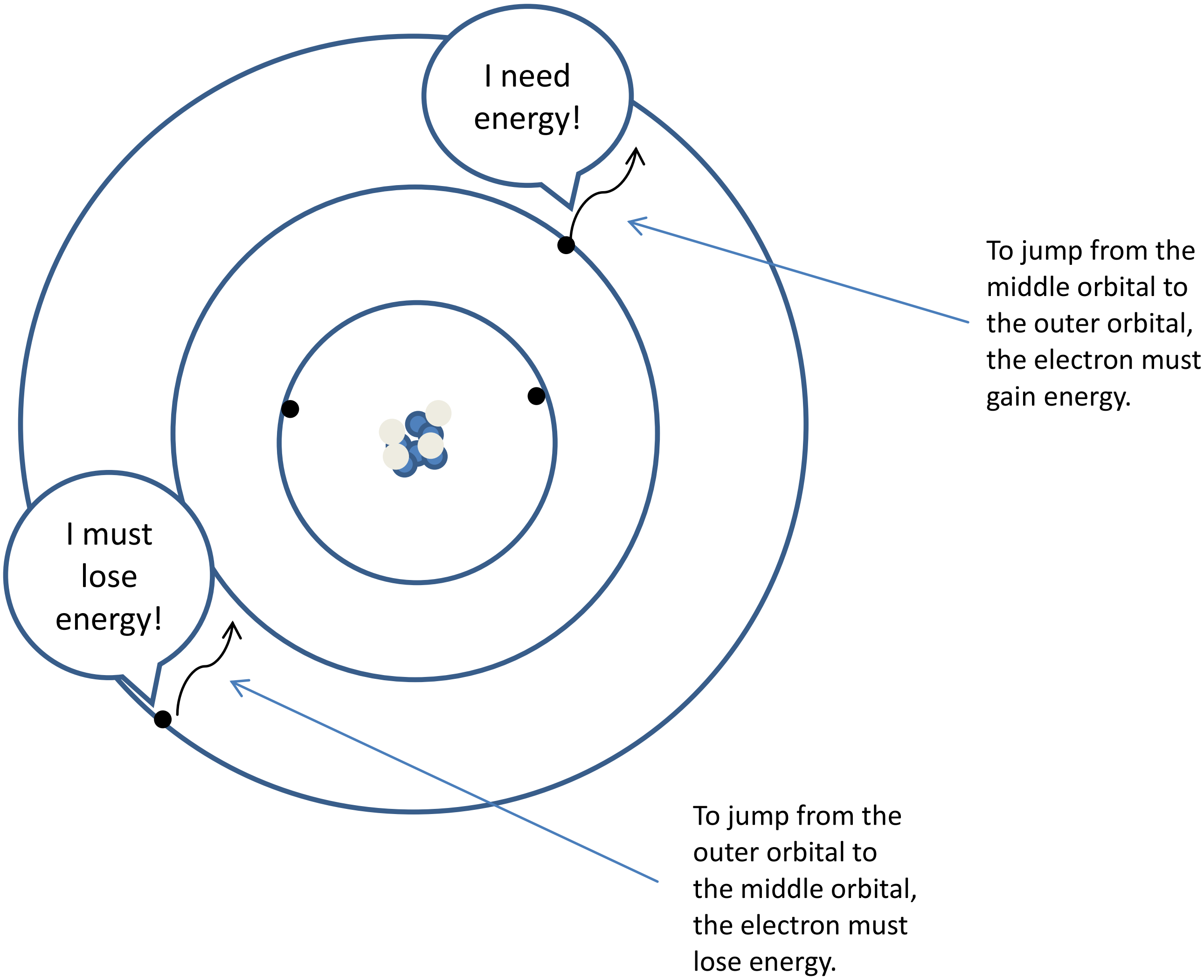
Your teacher will show you some line spectra for some other gasses. Do these help you to identify the gasses in the plasma globe?

Everything in the world, including gasses, is made up of tiny atoms. The atoms have even smaller parts inside of them called electrons, protons and neutrons, as shown in the drawing below. The protons and neutrons are in the center, which is called the nucleus. The electrons move around the center of the atom, much like the way the planets go around our sun. We say that planets move around the sun in orbits, but we say electrons move around the nucleus in orbitals. Orbitals are not just simple circles around the nucleus (they are actually complicated three-dimensional shapes around the nucleus) but we draw them as circles because this makes it easier for us to describe them.



The electrons can't be just anywhere. They have to stay in one of the orbitals where they are allowed to be. This is similar to a person going up and down the stairs. The person would have to be on one step or the next but they could not stand in between steps. The person could, however, hop from step to step. To go up the steps a person would need energy. In a similar way, electrons can also hop from orbital to orbital. For some of these hops they have to be given extra energy just as you would need extra energy to go up a stairwell. For other hops, the electrons would have to lose energy. The amount of energy that an electron has is related to its orbital: electrons in some orbitals will have a lot of energy, and electrons in other orbitals will have less energy. Let's label the orbitals in our picture above. Write an 'A' somewhere on the inside orbital, a 'B' somewhere on the middle orbital and a 'C' somewhere on the outer orbital. Also label these orbitals in the picture below.

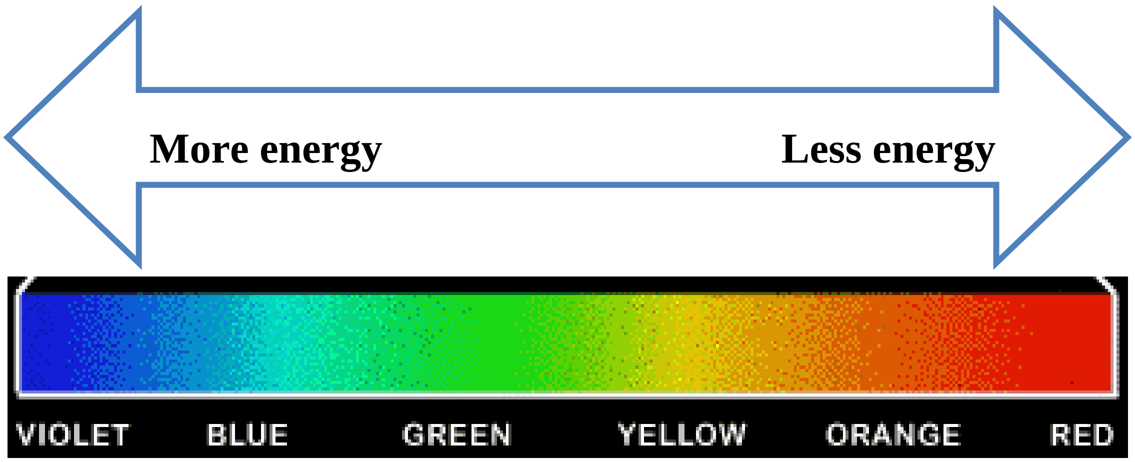
In our simple model, an electron in orbital B would have less energy than an electron in orbital C. So, for instance, an electron that wanted to go from orbital B to orbital C would have to gain energy, but an electron that wanted to go from orbital C to orbital B would have to lose energy. The next picture of our atom shows this.



When a gas is heated to a very high temperature, the electrons get extra energy and can move to different orbitals where they have more energy (like from A to B, or B to C, or A to C). The electron doesn't like all of the extra energy so it can lose the energy and go to a lower energy orbital (like from B to A or C to B, or C to A).

We say that the electrons have energy. Energy can be stored in different ways, and we give the different ways of storing energy different names. What are some of the names for different ways of storing energy that you can think of?

When we talk about energy, we say that it is ‘conserved’. This means that energy cannot be created and it cannot be destroyed. However, energy can change the way it is stored. For instance, let’s imagine that we have a battery connected to a light bulb by some wires. The battery has chemicals in it that allow it to store energy. When it is hooked up to the bulb, this energy is transferred through the wires as electrical energy to the bulb. The bulb then lights up and also warms up. If the bulb is kept hooked up to the battery for a long time, the battery will eventually ‘die’ and not be able to light the bulb. This does not mean, however, that the energy in the battery was destroyed. Instead, that energy which was stored in the battery was transferred to the bulb and stored in a different way in the bulb. The bulb, to which the energy was transferred, then transferred that energy to its surroundings. One of the transfers of energy is to the light it gives off. Light also has energy and the amount of energy it has determines its color. For example, blue light has more energy than red light, as shown in the picture below.



When an electron hops from orbital C to orbital B it loses energy. That energy cannot be destroyed – instead it comes out of the atom as light. This is how the line spectrum is created. Each of the possible hops that the electron can make when losing energy, gives off a different color of light. So, in our simple model, an electron that hops from B to A would release its energy as red light, while an electron that hops from C to A (it’s making a bigger hop) loses more energy and it would release its energy as blue light. Thus each of the colored lines that we see when we look at the discharge tube through a diffraction grating, are created by electrons that are making certain hops between orbitals.

Why do you think that the line spectrum looks different for each type of gas?

If an atom is heated even more, the electrons can get enough energy that they completely jump off of the atom.

ELABORATE:

Earlier in this activity you learned that colors can be combined to form other colors and that in some cases prisms and diffraction gratings can be used to break a beam of light into component colors. Then you found that atoms can form line spectra, and this has something to do with the fact that atoms can have different amounts of energy. These different amounts of energy depend on the electrons in an atom. An atomic electron can start at a high energy and drop to a particular lower energy. When this happens the energy apparently lost by the electron becomes the energy of emitted light.

Light color indicates the energy of the light. If we think of the visible spectrum as made of colors named as red, orange, yellow, green, blue, indigo and violet, the lowest energy is red and the highest is violet. In other words when an electron loses relatively little energy in an atom, the light emitted is at or near the red end of the spectrum. When it loses much more energy, the light emitted is near or at the violet end of the spectrum.

Now it's time to build physical models to get a better sense of how energies in atoms relate to colors of light.

You will be using a set of blocks provided by your teacher (it is also possible to make your own blocks for this activity. Your teacher can provide instruction). Your teacher has a simplified block model of an atom for you to examine. It is really too simple to be a good model for an atom and its energy levels, but it can be used as a guide, as your group puts together better models.

Your teacher's model indicates energy levels in an atom as different heights of the tops of blocks. The base on which the blocks rest is the lowest energy level of the atom. The blocks make two steps above this base for a total of three energy levels.

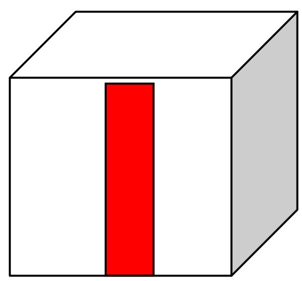
A marble is used to represent the electron that will be changing energy levels. If the marble is gently pushed so that it falls from on level to another, it loses energy as it falls, and it makes a sound when it hits the lower level. This sound represents the light that would be emitted when an electron in a real atom drops to a lower energy level. Louder sounds indicate more energy.

In the model provided by your teacher, the two step-sizes are the same. This means that if red light would be emitted when the marble drops from the first step to the base, red light would also be emitted when the marble drops from the second step to the first. This doesn't happen in real atoms. No two energy differences are the same, and this is one of the reasons that there can be many different colors in the spectrum of an atom.

The given model does have a realistic feature. The marble could drop from the second step to the first, but it could also drop from the second step to the base. In the later case it would lose more energy and produce light with more energy. If you say that red light would be emitted in the one step drop, you might then say that blue, indigo or violet light would be emitted in the two-step drop. In real atoms electrons can at times drop through more than one step, as in this model.

Now it is time to build one or more of your own models from the blocks that you have. The model should be similar to your teacher's, but the drop from the first step to the base should be larger than the drop from the second step to the first. If you have time and enough blocks, you could even build a three-step model. The number of different energy levels in real atoms is in fact very large, but the use of a two to three level model is sufficient to represent the ways in which electron energies change to produce light of particular colors.

To indicate what color of light might be emitted when an electron (marble in your model) drops from one energy level to another, you should have a colored vertical line or column in your model. The colored line or column should go from the top of the starting step down to the end step. If you are using Lego blocks, you could use blocks in the steps to show the color. In other cases tape white paper on the vertical parts of the steps, and use a colored pencil to draw in a vertical line or column of the color you've chosen, as indicated below.



Now you are ready to use your physical model of an atom.

Slowly push a marble so that it drops from one level of your model to a lower level. Do this for every different drop that is possible with your model. Notice how loud the impact sound is when you do this. When is the sound loudest, and when is it less loud?

Questions:

1. If you had a model with 3 steps above the base level, how many different energy changes could your marble go through?

2. We can only see light from red to violet or light made of mixtures of some of the colors from red to violet. But atoms can radiate something like light with less energy than red. This is known as “infrared” radiation. Some atoms can also radiate something like light with more energy than violet. This is known as “ultraviolet” radiation. How could you modify one of your step heights to have an energy difference that would model the production of infrared radiation? How could you make a step drop in your model that would model the production of ultraviolet radiation?

3. Your answer to number 1 suggests that the number of spectral lines for any atom that has many energy levels should be very large. Why don’t we see more than a few spectral lines for many atoms?

It can take a long time to represent many energy levels in an atom with a physical model like the one(s) you built, but now that you have seen how such a model works, you can also represent many energy levels on a sheet of paper. Graph paper may be best for this.

On a piece of lined paper or graph paper draw a set of 5 or more horizontal lines to represent energy levels in an atom. The lowest line is like the base level in your physical model. The next line should be well above the base line. The third line should be a little closer to the second than the first was to the base line. Each additional gap should be a little less than the one below it.

Draw downward pointing arrows from each line, except for the lowest one, to all of the lines below it. The lengths of these lines show how much energy will be radiated in light, infrared or ultraviolet when an electron drops from one level to the lower one.

Questions:

1. So far your models don't say anything about the actual range of energies in visible light. In fact to make the physical models that you built work, we have to pretend that the energy range of visible light is a little bigger than it really is. The ratio of energy of the most energetic violet light to the least energetic red light is just under a factor of 2. Pick one of the shorter arrows in your drawing to represent the lowest energy red line. How many of the arrows that you drew are less than twice the length of this arrow? These would be the arrows for visible light.

2. How many of the arrows you drew are too short or too long to be for visible spectrum lines? How many would be in the infrared part of the spectrum? How many would be in the ultraviolet spectrum?

3. In real atoms the radiation emitted when an electron drops from the first step above the base step to the base is often not visible, Use your model to explain this.

4. What features of real atoms do your models get right?

5. What features of real atoms do your models get wrong or not explain?

EVALUATE:

In this part students compare their models to the ideas that atoms can undergo only definite changes in energy and that this results in line spectra of stimulated gases.

They will also compare their models to the understanding of how low energy light is emitted by phosphors that have absorbed higher energy light.

Students should then discuss how the results of this activity could be applied to determining the compositions of systems such as stars (including our sun) and nebulae, even though we can't get instruments to these objects.