2.7: Determining the Composition of an Unknown Gas

Learning Objectives

- You will know that chemical elements leave distinct "fingerprints" on the light from astronomical sources.

WHAT DO YOU THINK: FINGERPRINTS

Three students are talking about today's lecture on spectroscopy.

- **LaTasia:** "What did our professor mean when she said that stars have spectral fingerprints? Is every star unique, like people's fingerprints are?"
- **Malia:** "I don't think the stars have spectra that are absolutely unique, but you can use the spectra to identify certain stars—at least the ones that are close enough to get a spectrum ."
- **Noelle:** "Each kind of element and molecule does have a unique spectrum, and that's what is the "fingerprint". You can identify what elements or molecules are in the object by looking at what lines are present in the spectrum."

Do you agree with any of these students, and if so, whom?

LaTasia

Malia

Noelle

None

Explain

So far, we have looked at how light can be emitted and absorbed by atoms. We have looked specifically at hydrogen because it is simple. However, other atoms can also absorb and emit light when their electrons change energy levels. These atoms have more complicated energy configurations though. Unlike hydrogen, where the energies are determined solely by the interaction between the electron and the nucleus, other atoms always have more than one electron. Since the electrons are charged particles, they interact with each other, as well as with the nucleus. As a result, most atoms have a much richer set of possible energies than hydrogen. Even helium, with two electrons instead of one, has a much more complicated spectrum than hydrogen. In an atom with many electrons, the energy levels are usually extremely complicated. Consider neon, which has ten electrons. It has a spectrum that is much more complex than either hydrogen or helium. In the next interactive activity you will explore a few examples for several common elements.

CREATION OF ABSORPTION AND EMISSION SPECTRA FROM A MIXTURE OF GASES

We are now ready to return to our simulated *Spectrum Explorer* tool. This time we will not study only hydrogen. We will look at more complicated atoms as well. One caveat to keep in mind is that not all the lines in an atom are the same strength. Some lines appear strong, while others are quite faint. We have chosen to display only the strongest lines for this activity. This keeps things simpler. Some atoms have many hundreds or thousands of lines (or more!). We don't need to look at every single line to understand how spectroscopy is used in astronomy.

Answer the following questions using the *Spectrum Explorer* where appropriate. Again, keep track of your answers to questions. Note your predictions and observations, and be sure to resolve any discrepancies between the two.

Play Activity

A. Light source head on.

As before, the glass tube starts out devoid of gas, and both light sources are off.

1. What will you see when source B is turned on without any gas in the tube?

A series of bright lines

A series of bright lines on top of a continuous rainbow

A series of dark lines in an otherwise continuous rainbow

A continuous rainbow with no lines

Nothing will change. We will still see darkness.

2. Now select hydrogen from the drop-down menu for the tube. With light source B on, verify that you see the same spectrum that you saw before with hydrogen. Is this an absorption spectrum or an emission spectrum?

Absorption

Emission

B. Other gases, light source head on.

Now we have several other gases available to choose from to fill the tube instead of hydrogen.

1. Now select helium to fill the tube instead of hydrogen. Recall that helium has 2 electrons rather than a single electron like hydrogen. How does the helium spectrum compare to that of hydrogen? Do you have an explanation for the differences?

2. If we replace helium with neon, which has 10 electrons rather than 2, what do you think will happen? Record your predictions.

3. Now replace the helium with neon. Record your observations. Was your prediction confirmed or not?

4. Now try some of the other gases and note the spectra produced. Do you see any relationships between the number of lines and the number of electrons? (Note that we are showing you only the strongest lines, while ignoring faint ones. Also, we are only showing lines in the visible part of the spectrum. Atoms also have energy levels in other wavelength regions, so your conclusion here might not be generally true).

5. Are any of the lines common to one or more different gases? If so, note these lines below. (The wavelength is given along the bottom of the spectroscope display.)

C. Other gases, light source to the side.

In the previous examples, the light passed through the gas tube on its way to the spectroscope. We thus observed an absorption spectrum for each type of gas. We will now explore what will happen if we turn off light source B and turn on source A.

1. Select the tube to be filled with helium, and turn on light source A. What type of spectrum does the spectroscope show?

2. Switch between light source A and light source B, leaving the helium inside the tube. What do you notice about the spectra produced? Are they at all related to each other?

3. Repeat the procedure for the other gases by switching from light source A to light source B and back again. Do they behave the same as hydrogen or helium, or do you note differences for different gases?

4. You have had an opportunity to study both absorption and emission spectra from various gases. Write down any general patterns you see for the gases emission and absorption spectra. Give a general rule for when you will see an absorption spectrum for an object and when you will see an emission spectrum. Give a brief explanation of what is happening to the atoms in the gas to produce these spectra.

5. Explain how using spectral techniques might be useful in determining the composition of distant stars, galaxies, and other celestial objects. (Hint: What would the spectrum look like if we could put a mixture of gases into the tube, rather than just one gas at a time?)

Fortunately, no matter how complicated the spectrum of an atom is, it will always be different from the spectrum of any other atom, just as with a set of fingerprints. Each element exhibits a unique pattern of spectral lines. Whenever we see that particular pattern in the light from a source, we know that element is present. The patterns of spectral lines allow us to measure the composition of stars and other objects at very great distances, even all the way across the visible Universe. Not only can we tell what the objects are made of, but the relative strengths of the lines can tell us about physical conditions in the emitting or absorbing gas. Quantities like temperature, density, magnetic field strength, and the relative abundance of elements can all be determined by careful examination of electromagnetic spectra. Complete the next activity to get some experience matching an unknown spectrum to the known lines from the previous activities.

DETERMINING THE COMPOSITION OF AN UNKNOWN GAS

In the preceding *Spectrum Explorer* activities, you learned how absorption and emission spectra are created from gases and light sources. You also learned that gases made of different kinds of atoms have unique patterns of spectral lines. These patterns of lines can be used to determine the composition of a gas.

In this activity, you will use what you have learned previously to identify the composition of an unknown mixture of gases.

Play Activity

To begin, click on the "generate" button in the *Spectrum Explorer*. You will see a pattern of lines appear on the lower strip; this is your unknown gas spectrum. The unknown contains two types of atoms, so you will not be able to match all the lines with just a single type of gas.

To match this unknown, you will compare the line pattern to lines from known gases. Use the gas tube pull-down to check the patterns of different gases against your unknown. Check each gas in succession, keeping track of which gases match or do not match.

When you have matched all of the lines in the unknown, click in the "identify" button, and select the gases you think are in the unknown. You will be given feedback about whether you are correct.

Describe a method for using spectral techniques to determine the composition of distant stars, galaxies, and other celestial objects.

In 1842, the French philosopher Auguste Comte (1798–1857) declared that the "chemical and mineralogical structure" of the stars would never be known. He was referring to what we call planets, but he thought the same was true for stars. Given the immense distances to even the closest stars, which were known even to Comte, it is hardly surprising that he held this opinion. Yet, within just a couple of decades of his death, advances in atomic physics allowed scientists to begin studying the spectral lines from the Sun and other stars, much as you have done using the *Spectrum Explorer*. The composition and inner structure of the stars began to be revealed. And of course, we now have physical samples returned from the Moon, and robots regularly visit the surfaces and atmospheres of the planets to carry out experiments. Perhaps there is a cautionary tale here about holding too fast to our ideas of what might be possible in the distant, or even not too distant, future.
