Spectrometers

Overview: Spectrometers (spectroscopes) are used in chemistry and astronomy to measure light. In astronomy, we can find out about distant stars without ever traveling to them, because we can split the incoming light from the stars into their colors (or energies) and "read" what they are made up of (what gases they are burning) and thus determine their what they are made of.

What to Learn: In this experiment, you'll make a simple cardboard spectrometer that will be able to detect all kinds of interesting things!

SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun. But you can point the tube at a sheet of paper that has the Sun's reflected light on it.

Materials:

Easy Spectrometer

- Old CD
- Razor
- Index card
- Cardboard tube at least 10 inches long

Advanced Spectrometer (Calibrated)

- Cardboard box (ours is 10″ x 5″ x 5″, but anything close to this will work fine)
- Diffraction grating
- 2 razor blades (with adult help)
- Masking tape
- Ruler
- Photocopy of a ruler (or sketch a line with 1 through 10 cm markings on it, about 4cm wide)

Easy Spectrometer:

1. A CD has a diffraction grating built into it. We're going to use a CD instead of a diffraction grating for this experiment.
2. Cut a clean slit less than 1 mm wide in an index card or spare piece of cardboard.
3. Tape it to one end of the tube.
4. Align your tube with the slit horizontally, and on the top of the tube at the far end cut a viewing slot about one inch long and ½ inch wide.
5. Cut a second slot into the tube at a 45-degree angle from the vertical away from the viewing slot.
6. Insert the CD into this slot so that it reflects light coming through the slit into your eye (viewing slot).
7. Aim the 1 mm slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find EXCEPT THE SUN.
8. Look through the open hole at the light reflected off the compact disk (look for a rainbow in most cases) inside the cardboard tube.
9. Complete the data table.

Advanced Spectrometer (Calibrated)

1. Using a small box, measure 4.5 cm from the edge of the box. Starting here, cut a hole for the double-razor slit that is 1.5 cm wide 3 cm long.
2. From the other edge (on the same side), cut a hole to hold your scale that is 11 cm wide and 4 cm tall.
3. Print out the scale and attach it to the edge of the box.
4. Very carefully line up the two razors, edge-to-edge, to make a slit and secure into place with tape.
5. On the opposite side of the box, measure over 3 cm and cut a hole for the diffraction grating that is 4 cm wide and 3 cm tall.
6. Tape your diffraction grating over the hole.
7. Aim the razor slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find. Put the diffraction grating up to your eye and look at the inner scale. Move the spectrometer around until you can get the rainbow to be on the scale inside the box.

How to Calibrate the Spectrometer with the Scale

8. Inside your box is a scale in centimeters. Point your slit to a fluorescent bulb, and you'll see three lines appear (a blue, a green, and a yellow-orange line). The lines you see in the fluorescent bulb are due to mercury superimposed on a rainbow continuous spectrum due to the coating. Each of the lines you see is due to a particular electron transition in the visible region of Hg (mercury).
    1. **blue line (435 nm)**
    2. **green line (546 nm)**,
    3. **yellow orange line (579 nm)**

    If you look at a sodium vapor street light you'll see a yellow line (actually 2 closely spaced) at 589 nm.

9. Line the razor slits along the length of the fluorescent tube to get the most intense lines. Move the box laterally (the lines will move due to parallax shift).
10. Take scale readings at the extreme of these movements and take the average for the scale reading. For instance, if the blue line averages to the 8.8 cm value, this corresponds to the 435 nm wavelength. Do this for the other 2 lines.
11. On graph paper, plot the cm (the ruler scale values) on the vertical axis and the wavelength (run this from 400-700 nm) on the horizontal axis.
12. Draw the best straight lines through the 3 points (4 lines if you use the Na (sodium) street lamp). You've just calibrated the spectrometer!
13. Line the razor slits up with another light source. Notice which lines appear and where they are on your scale. Find the value on your graph paper. For example, if you see a line appear at 5.5 cm, use your finger to follow along to the 5.5 cm until you hit the best-fit line, and then read the corresponding value on the wavelength axis. You now have the wavelength for the line you've just seen!

Notes on Calibration and Construction: If you swap out different diffraction gratings, you will have to re-calibrate. If you make a new spectrometer, you will have to re-calibrate to the Hg (mercury) lines for each new spectrometer. If you do remake the box, use a scale that is translucent so you can see the numbers. If you use a clear plastic ruler, it may let in too much light from the outside making it difficult to read the emission line.

Spectrometer Data Table

Light Source	**Draw what you see:**	**Wavelength** *For Advanced Spectrometers Only!*

Reading

Diffraction gratings are found in insect (including butterfly) wings, bird feathers, and plant leaves. While I don't recommend using living things for this experiment, I do suggest using an old CD. That's how we're going to build the *Easy Spectrometer.*

CDs are like a mirror with circular tracks that are very close together. The light is spread into a spectrum when it hits the tracks, and each color bends a little more than the last. To see the rainbow spectrum, you've got to adjust the CD and the position of your eye so the angles line up correctly (actually, the angles are perpendicular).

You're looking for a spectrum (think of a rainbow). –Depending on what you look at (neon signs, chandeliers, incandescent bulbs, fluorescent bulbs, halogen lights, etc.), you'll see different colors of the rainbow.

For the *Advanced Spectrometer,* we're actually going to calibrate it by plotting information on a graph and using a diffraction grating to make it more precise. It's much more like the instrument that scientists use in their labs.

Scientist use spectroscopes (spectrometers) to collect a small sample of light and test it to see what made the light. As the light passes through the diffraction grating, it gets split into different bands of light, and you'll see these as different wavelengths, or colors of light.

Scientists can figure out what fuel a star is burning, the age of the star, the composition of the star, how fast it's moving, and whether it's moving toward or away from Earth. For example, when hydrogen burns, it gives off light, but not in all the colors of the rainbow, only very specific colors in red and blue. It's like hydrogen's own personal fingerprint, or light signature.

While the spectrometers we're about to make aren't powerful enough to split starlight, they're perfect for using with the lights in your house, and even with an outdoor campfire. Next time you're out on the town after dark, bring this with you to peek different types of lights – you'll be amazed how different they really are.

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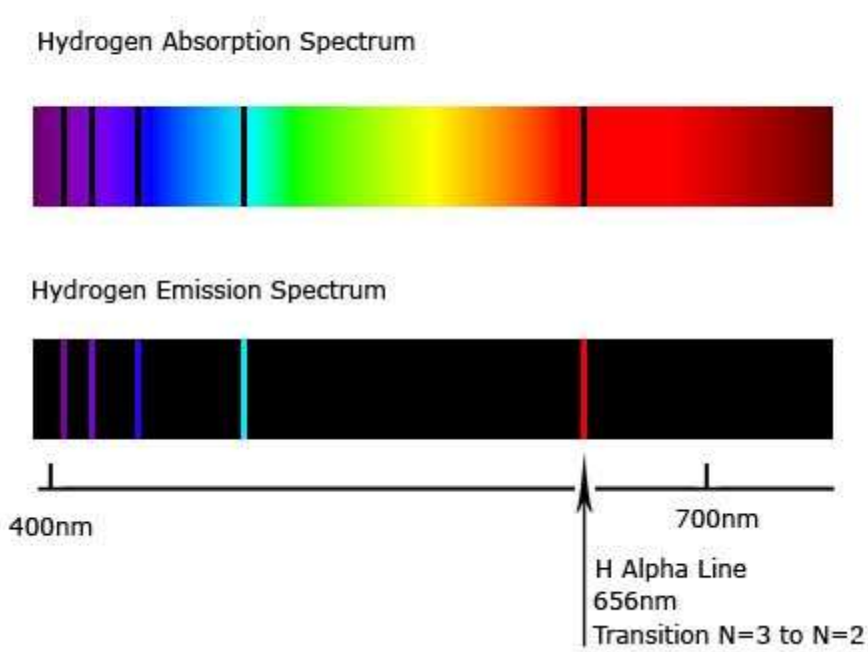
How to Tell Which Elements are Burning



For example, if you were to view hydrogen burning with your spectroscope, you'd see the bottom appear in your spectrometer:

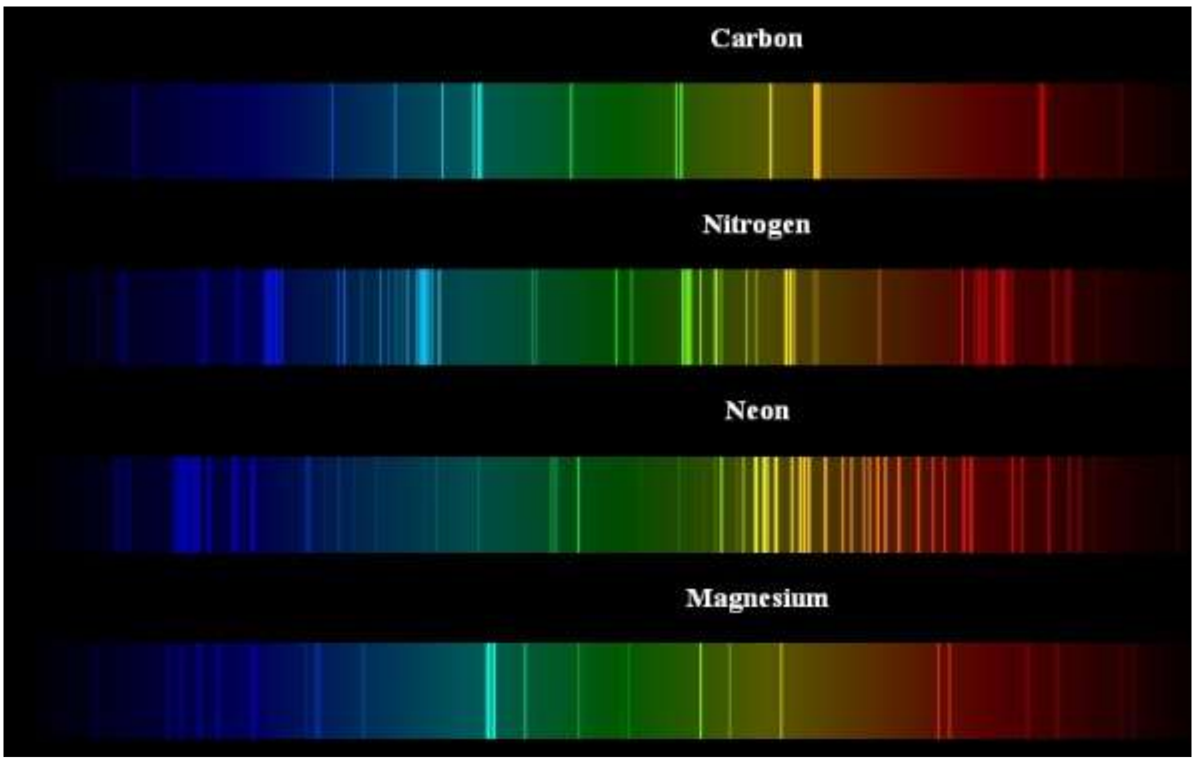
Notice how one fits into the other, like a puzzle. When you put the two together, you've got the entire spectrum.

What's the difference between the two? The upper picture (absorption spectrum of hydrogen) is what astronomers see when they use their spectrometers on distant stars when looking through the earth's atmosphere (a cloud of gas particles). The lower picture (emission spectrum of hydrogen) is what you'd see if you were looking directly at the source itself.

Note - Do NOT use your spectrometer to look at the Sun! When astronomers look at stars, they have computers look for them - they aren't putting their eye on the end of a tube.

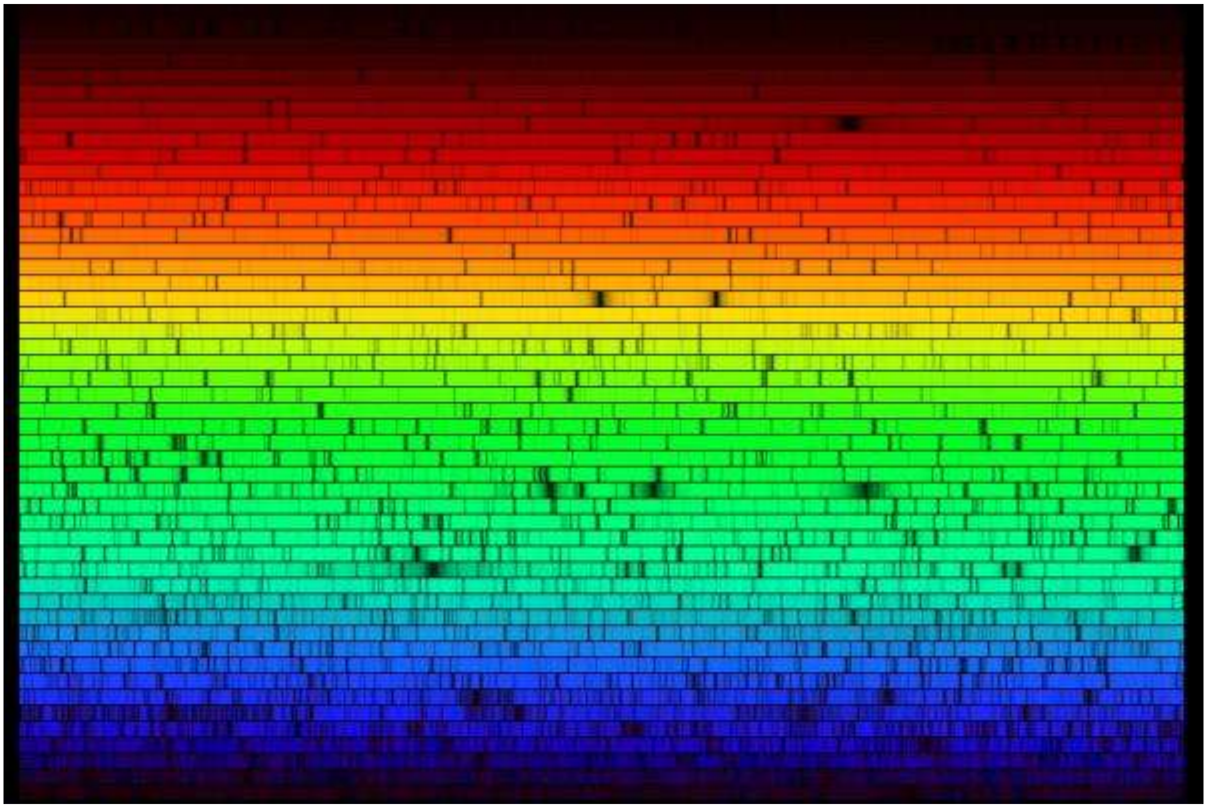
Each element has its own special 'signature', unique as a fingerprint, that it leaves behind when it burns. This is how we can tell what's on fire ***in*** a campfire.

For example, here's what you'd see for the following elements:



Just get the feel for how the signature changes depending on what you're looking at. For example, a green campfire is going to look a lot different from a regular campfire, as you're burning several elements in addition to just carbon. When you look at your campfire with your spectroscope, you're going to see ***all*** the signatures at the same time. Imagine superimposing all four sets of spectral lines above (carbon, neon, magnesium, and nitrogen) into one ***single*** spectrum... it's going to look like a mess! It takes a lot of hard work to untangle it and figure out which lines belong to which element. Thankfully, these days, computers are more than happy to chug away and figure most of it out for us.

Here's the giant rainbow of absorption lines astronomers see when they point their instruments at the Sun:



Do you see all the black lines? Those are called emission lines, and since astronomers have to look through a lot of atmosphere to view the Sun, there's a lot of the spectrum missing (shown by the black lines), especially corresponding to water vapor. The water absorbs certain wavelengths of light, which corresponds to the black lines.

Exercises

1. Name three more light sources that you think might work with your spectroscope.

2. Why is there a slit at the end of the tube instead of leaving it open?

Answers to Exercises: Spectrometers

1. Name three more light sources that you think might work with your spectroscope. (answers will vary)
2. Why is there a slit at the end of the tube instead of leaving it open? (The light that strikes the end of the tube gets mostly reflected away, and only a tiny amount of light gets inside the tube to the diffraction grating. If you had too much light, you wouldn't be able to see the spectrum.)