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# Rainbow Analysis

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## Summary

Students are introduced to the scientific tool of spectroscopy. They will each build a simple spectroscope so that they can examine the light from different light sources, particularly the Sun (if logistically feasible) and artificial lights (fluorescent or sodium lamps, discharge lamps, or whatever is available locally). The solar spectrum will appear continuous at the resolution typical of plastic diffraction gratings; however the fluorescent or sodium room lights and discharge lamps will show clear lines (students often describe the spectra as "broken up"). These lines represent the "fingerprint" of the element contained in the lights and are always the same, no matter where the element appears or how much of the element is present. Appearance of a fingerprint in the spectrum of a distant astronomical object demonstrates the existence of that substance in the object. The discharge lamps provide the opportunity to show students a variety of spectral fingerprints.

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## Purpose

To teach students how astronomers determine the composition of distant objects.

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## Audience

Approximately 20 students (grade range 6<sup>th</sup>-9<sup>th</sup>) in a group works well

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## Objectives

- ♣ To understand that light is composed of different wavelengths
- ♣ To recognize that light can be separated by wavelength, which is equivalent to color
- ♣ To build an astronomical tool, specifically a spectroscope, to study light
- ♣ To learn that elements and molecules each have a unique "fingerprint" of lines at different wavelengths

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## Badge Requirements



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## Materials

- ♣ empty paper towel tubes (1 per student)
- ♣ aluminum foil (2 squares about 4 x 4 inches and 2 strips about 1 x 3 inches per student; measurements are approximate and do not need to be exact)
- ♣ masking tape
- ♣ diffraction grating (approximately 1 inch square of material per student)
- ♣ example spectrum (e.g. poster from Spitzer Science Center at <http://www.spitzer.caltech.edu/>)
- ♣ discharge lamps (optional, H, He, Ar, O, and CO<sub>2</sub>)
- ♣ completely blacked-out room (optional)

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## Preparation

1. Prepare parts of spectroscope: approximately 30 minutes

Cut pieces of foil and diffraction grating. Collect a paper towel tube, 2 larger pieces of foil, 2 foil strips, and a 1 inch square of diffraction grating for each student. You can put each kit in a Ziploc bag.



2. Darken the room: approximately 10 minutes (depending on room)

The room should be capable of going from brightly lit to dark so that both the overhead fluorescent lamps and the narrow discharge lamps can be seen effectively. Sometimes this means lights or light leaks must be covered. Dark black plastic trash bags and duct tape have proved useful for this.



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## Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

### *I. Discussion*

Ask if students know what a "spectroscope" is:

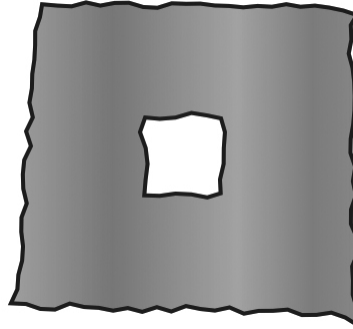
**spectro** - from spectrum, or rainbow (show example from e.g. a NASA poster)

**scope** - a viewing instrument, as in telescope or microscope

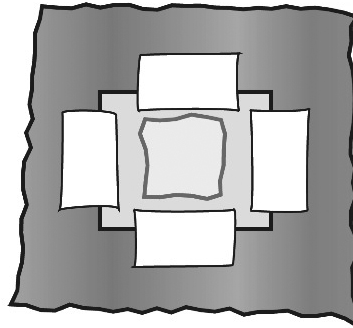
**spectroscope** - an instrument for viewing spectra

### *II. Construction of the spectroscope (~ 20 minutes)*

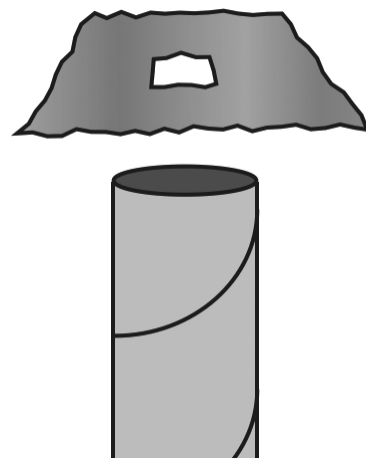
1. The spectroscope has two ends, one for the diffraction grating (which is the end you look through) and one for a slit, which controls the entry of light into your instrument, so you can select which object to look at, and to improve the dispersion of light into a longer spectrum. We will assemble the grating end first.
2. First we will assemble the **grating end** of the spectroscope. Students should take a piece of aluminum foil about 4x4 inches and tear or cut a small hole in the center of the foil, about the size of a nickel or a dime. The hole should be *smaller* than the square of diffraction grating material. If it's not, set the foil aside for step 5 and try again. The easiest way to do this is to fold the foil square in half (more or less), then half again the other direction. Tear off the corner that is at the center of the foil, and unfold it. Then unfold the foil - voila!



3. Next the students should tape the diffraction grating over the hole, being careful not to handle the diffraction grating too much, and to tape only the edges of the grating, not across the middle. It does not matter which side of the grating or foil is up/out.



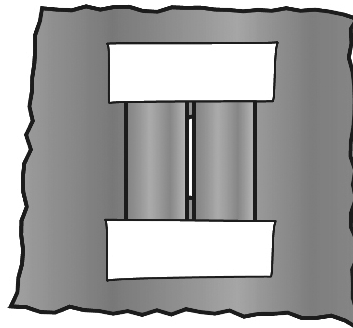
4. Students should then take the foil mounted grating, and put it over one end of the paper towel tube (with the grating over the hole) and tape the foil to the tube with masking tape. It is better for the tape side to be towards the tube at this stage, for both stability and aesthetics.



5. Next we will assemble the **slit end** of the scope. Students should take the other piece of aluminum foil (about 4x4 inches) and put a hole in the center of the foil as before (if the

hole they made the first time was a little too large for the diffraction grating, the piece of foil can probably be recycled for the slit end).

6. Students should take the two strips of aluminum foil and carefully fold each of them lengthwise (so the strips are now about .5x3 inches) making a sharp crease at the fold (the crease is the important part, so don't worry too much about the dimensions).
7. Take the two creased pieces of foil and lay them over the hole in the large piece of foil - the two creased edges should be next to each other but not overlapping - a gap of a few millimeters (or perhaps the width of a toothpick) is perfect. Tape the two creased pieces of foil in place over the hole (but make sure that the tape isn't covering the gap) and place the slit over the open end of the paper towel tube and wrap the aluminum foil around the tube - BUT DO NOT TAPE THE SLIT TO THE PAPER TOWEL TUBE YET!



8. Now we need to "calibrate" (or precisely adjust) our spectroscope - we want to align our slit with the diffraction grating so that we get a wide spectrum which will be easy to see. Hold the spectroscope so that you can look through the diffraction grating end (the plastic square should be about as close to your eye as your glasses lens or as close as you would put a microscope). Point the slit end of the spectroscope towards a light source - this can be a light in the room or if you are outside, at the SKY, but **NOT the SUN!** Look for a rainbow in the spectroscope, probably a little bit off to the side or up or down (you should be able to see regular light from your source coming through the slit, but the rainbow will be off-center). While still pointing your spectroscope at the same light source, twist the slit around until the rainbow is as "fat" or "tall" as you can make it. Then, tape the foil for the slit end into position.
9. That's it! Make the point to the students that since they've built this spectroscope themselves, they know how to fix it if it breaks - if the aluminum foil tears, or they accidentally sit on their paper towel tube, or some of the tape comes off, they can fix it themselves!



**Remind them NEVER to look at the sun!**



***III: Using the spectroscope (~ 20 minutes)***

1. Now that the spectroscopes are built, it's time to put them to some use - the first object students should look at (if at all possible) is a spectrum of the sun.

**IMPORTANT WARNING: NEVER LOOK DIRECTLY AT THE SUN WITH THIS INSTRUMENT OR YOUR NAKED EYE.**

There are a couple ways we can see a solar spectrum without looking directly at the sun. First, we can look at the sky, which is bright from sunlight scattered off of little bits of dust in the air. This should be possible even if it is fairly cloudy; however it may not be feasible if it is actually raining. If you are worried that even this will give students the idea that it is safe to look at the sun, you can also put a white piece of paper on the ground on a sunny day, and they can look at the paper, which will reflect the solar spectrum.

If it is raining, or viewing the solar spectrum is otherwise impractical, an incandescent bulb can be substituted. You should point out that the solar spectrum (at this resolution) is

a fairly uniform rainbow, showing all the usual colors (the students will usually remember and recognize ROY G BIV).

Now is also a good time to point out (in conjunction with a spectrum poster) that the spectrum really extends beyond what the students can see in their spectroscopes, to "invisible light", like radio, infrared, ultraviolet, X-ray, etc. This is similar to sound of a dog whistle - the sound a dog whistle makes is real, and with the proper kind of ears we could hear it. Radio, IR, UV, X-ray, and other wavelength ranges of light are real, and with the proper kind of "eyes" or cameras, we can see these other wavelengths of light. If you think of light in terms of keys on a piano, the light we can see is only the keys from middle-C up to E—less than a full octave. Everything else is invisible light.

Different colors that the students see represent different wavelengths of light, but visible light wavelengths have a very narrow range - only about 300-700 nanometers (a nanometer is a billionth of a meter) - while wavelengths of light can range longer than meters in the radio to shorter than a picometer (trillionth of a meter) for gamma rays.

2. Next, students should examine a light source with obvious discrete lines - most schools and other institutional buildings have bright mercury fluorescent lamps, which are ideal. If you are unsure of what kind of lamps you have, build yourself a spectroscope in advance and have a look around - descriptions of the spectra of common types of lights can be found at:

[http://isaac.exploratorium.edu/~pauld/summer\\_institute/summer\\_day9spectra/spectra\\_exploration.html](http://isaac.exploratorium.edu/~pauld/summer_institute/summer_day9spectra/spectra_exploration.html)

Ask students what differences they notice between the solar spectrum and the spectrum of the artificial light. Prompt them, if necessary, with the question "Are all of the ROY G BIV colors present in this new spectrum?"

For mercury fluorescent lights, there will only be a faint continuum, but there will be four or five bright lines (depending on how far red your eyes can see): 1 or 2 will be red, 1 will be green, and 2 will be blue/violet. Some colors are missing, and there are very clear lines - these lines are the fingerprint of mercury. If you see these lines, there is mercury in your light source. If you don't see them, there is little or no mercury. This is how astronomers figure out what distant objects are made of - every atom and molecule has its own unique fingerprint, and based on the brightness of the "fingerprint", we can even tell how much of an atom or molecule is present (lots of "stuff" means bright lines, very little "stuff" means faint lines).

3. If time and resources permit, you can show students other light sources containing other molecules and elements (e.g. with discharge tubes) to show them what some of the other fingerprints look like. If you have a good selection, H and He lamps are good to start with since they have less complicated spectra. Regardless, you should send students home with

their spectroscopes and encourage them to check out the lights in their local neighborhoods - most street lamps are either mercury or sodium lamps, and "neon" signs often contain many different elements which produce different colors (only the orangey-red ones are actually neon). The website mentioned above would be a useful guide for their own explorations.

**Remind them again NEVER to look at the sun!**