Rainbow Analysis

Summary

Students are introduced to the scientific tool of spectroscopy. They each build a simple spectroscope with which 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). Students compare the continuous spectrum of incandescent lights and the solar spectrum (which appears continuous at the resolution typical of plastic diffraction gratings) with the clear spectral lines of the fluorescent or sodium room lights and discharge lamps show. They learn how the spectral "fingerprints" of each particular element help astronomers recognize the presence of specific elements in distant astronomical objects. Students are also introduced to the broader electromagnetic spectrum beyond what is visible with our eyes. They discuss how scientists observe distant objects using multiple wavelength bands to gather different types of information about those objects.

Objectives

- ★ To understand that light is composed of different wavelengths of energy, including many we cannot see with our eyes
- ★ To recognize that light can be separated by wavelength, which, in visible light, is equivalent to color
- ★ To build an astronomical tool, specifically a spectroscope, to study light
- ★ To learn that the spectra of elements and molecules each have a unique "fingerprint" of lines at different wavelengths

Materials

- ★ Paper towel tubes (1 per student) *
- ★ Aluminum foil (2 pieces at 4 x 4 inches and 2 strips at 1 x 3 inches per student; measurements are approximate and do not need to be exact)
- ★ Diffraction grating (approximately 1 inch square of material per student) **
- ★ Masking tape
- ★ Poster or handout about the electromagnetic spectrum (an example can be found following the activity)
- ★ Example spectra (a handout can be found following the activity)
- ★ Light sources
  - ★ Incandescent light bulb as a source of a continuous spectrum ***
  - ★ Discharge lamps (recommended; examples: H, He, O, N, Ne, H_2O, and CO_2) ****

** Any tube of a similar dimension, such as PVC piping, shipping tubes, etc., can work just as well for this, so the primary factors are expense and ease of acquisition. Make sure you test any tubes you are using ahead of time. If it is too short (like a toilet paper tube) or too narrow (like the tube from an aluminum foil roll), the activity won't work.*

*** Information about where to purchase this can be found in Appendix B.*

**** Common household bulbs are incandescent or flourescent light sources. If you don't know what kind of lamp you have, build a spectroscope and look at it. Descriptions of the spectra of common types of lights are at: http://isaac.exploratorium.edu/~pauld/summer_institute/summer_day9spectra/spectra_exploration.html*

***** Distinct lines are produced by light sources from only one element or compound. Discharge lamps are the best for this, but most institutional buildings have mercury fluorescent lamps that will work if discharge lamps are not practical for your purposes. You will want to have as many different sources of this type as possible, for increased student interest and understanding, but even one helps. Information about where to purchase discharge lamps can be found in Appendix B.*

Other Requirements

- ★ A room that can be darkened (preferably completely darkened)

Background

Element: A material consisting of all the same atoms

Examples:
- Pure gold
- Silver
- Copper
- Aluminum
- Oxygen

Compound: A material consisting of atoms of two or more different elements that are chemically bound together

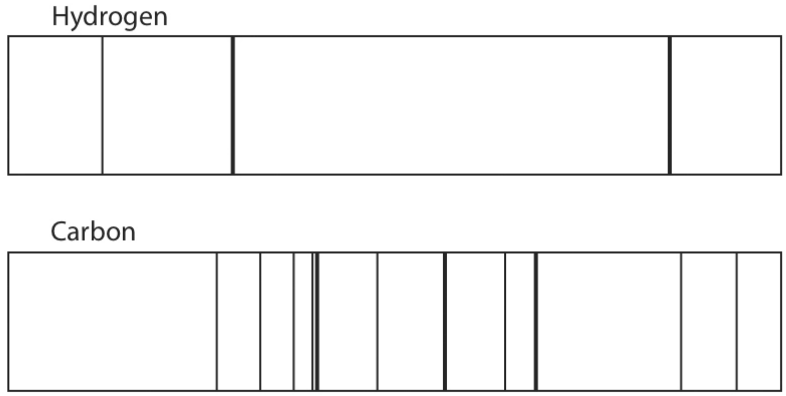
Examples:
- Water (hydrogen + oxygen)
- Table salt (sodium + chlorine)
- Ammonia (nitrogen + hydrogen)
- Sugar (carbon + hydrogen + oxygen)

"**Spectra**" is the plural of "**spectrum**."

A **diffraction grating** separates the light from a source into the full range of visible light, similar to what a prism does, making it possible to see individual lines in the source's spectrum.

The light from each element or compound produces a unique pattern of lines within the spectrum (a "fingerprint" – not a technical term, by the way) that identifies its presence. The lines are always in the same place for that particular element or compound.

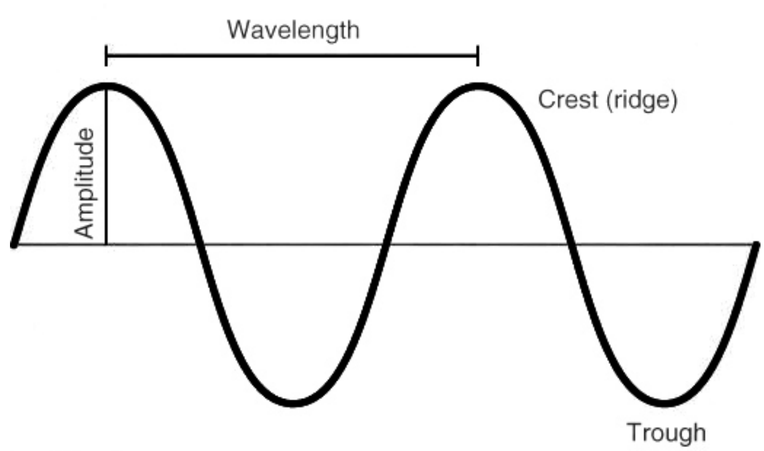
If the fingerprint of a specific element or compound is in the spectrum of a distant astronomical object, it is evidence that that element or compound is present in that object.



The spectra of hydrogen and carbon, illustrating how different two different elemental spectra can be.

Using instruments such as the ones in this session, the Sun's spectrum (seen throughout the sky) appears essentially continuous, rather than having distinct lines. We call this white light, meaning it is a combination of all the colors of visible light. Rainbows are the result of Sunlight being diffracted (spread out) by water droplets in the air.

When we talk about light, **wavelength** refers to the distance between the two peaks (or crests) of the light wave.



A diagram of terms with regard to a wave.

Longer wavelengths correspond to shorter frequencies. So, the wavelength or frequency of light is a characteristic that defines what type of light it is (radio, microwave, infrared, visible, ultraviolet, X-ray, or gamma-ray). Note that scientists use the word "light" to refer to energy in any wavelength – not just the visible range.

Element discharge lamps are the best way to show students the fingerprints for specific elements. These very specific lamps send an electrical charge through the gas of a certain type of element. The resulting light will show the signature spectrum, or fingerprint, of that element. Viewing them is best done in a completely darkened room. Covering bulbs with colored paper or using colored bulbs **will not change** the spectral lines of a clear bulb, because the source of the light is the filament, not the glass of the bulb.

We use a narrow slit to select what we want to look at and adjust the size and shape of its spectrum. The diffraction grating at the other end of the device spreads the incoming light in a specific direction. During the calibration, we line the slit up so that it is perpendicular to this direction in the diffraction grating. In this way we limit the data that contributes to our spectrum. If we did not do this, the spectrum for any extended object, such as a galaxy, would be hopelessly jumbled and impossible to interpret.

Preparation

1. Prepare parts of the spectroscopes: approximately 30 minutes

   Cut pieces of foil (2 pieces of 4 x 4 inches and 2 pieces of 1 x 3 inches per student) and diffraction grating (a 1-inch square of diffraction grating per student). Exact measurements are not at all necessary. Collect one paper towel tube for each student. You can put each kit in a Ziploc bag.

   Handle the diffraction grating carefully with clean hands (or gloves), touching only the edges. Avoid smudges and fingerprints, which will negatively affect the function of the spectroscope.

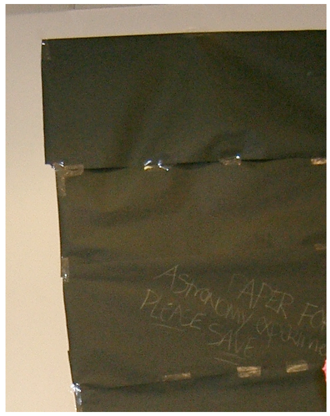
This room has been set up with full spectroscope kits at each desk.

2. Build example spectroscope(s): approximately 15 minutes

   This accomplishes two things. First, it makes the activity much easier for when you go through it with students. Second, it can help the students to see an example of a spectroscope that is already assembled. Instructions can be found in the Activity section below.

3. Darken the room: 10-30 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 proven useful for this.



This window has been fully covered to stop any light coming into the room.

Activity

Talking Point: How do we know what we know?

Discuss the following questions with the students:

What do astronomers study?

How do astronomers learn anything about the things they study?

Do we take pieces of stars and planets and put them under a microscope in our lab?

What do you think is the most distant astronomical object from which we have a physical sample?

- ★ Right now it's a comet tail
- ★ We also have collected samples from the moon
- ★ Soon we will add Mars to this list

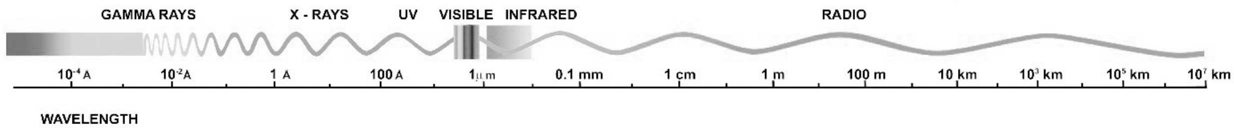
So since we can't collect pieces of more distant objects, how do we learn about them? The only thing we get from distant objects – the only thing that can traverse such vast distances – is light.

Talking Point: Spectroscopes

Ask if students know what a "spectroscope" is:

spectro – from spectrum, or rainbow (show an example)
scope – a viewing instrument, as in telescope or microscope
spectroscope – an instrument for viewing spectra

Ask them if they know what the electromagnetic spectrum is - the range of all the wavelengths of energy possible, from the shortest wavelengths (highest energies/frequencies) to the longest wavelengths (lowest energies/frequencies). Visible light is just a small part of the entire electromagnetic spectrum.



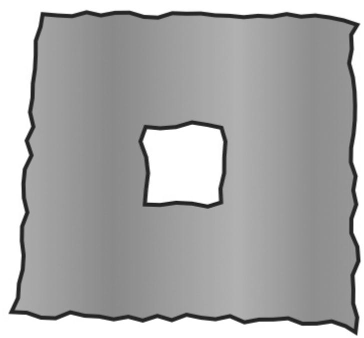
Note that scientists often use the word "light" to refer to energy in any wavelength – not just the light that we can see with our eyes (visible light).

Pass out the handouts of the electromagnetic spectrum or put up the poster. Point out the full spectrum and have a student find the small portion that is visible light. Discuss what **wavelength** means, and how wavelength corresponds to energy/frequency range.

Activity: Construction of the Spectroscope (~20 minutes)

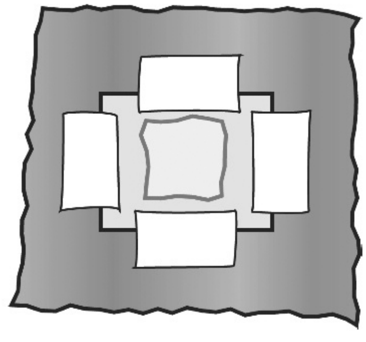
1. The spectroscope has two ends, one for the diffraction grating (which is the end you look through) and one for a slit, which controls the entry of light into your instrument so you can select which object to look at and improve the dispersion of light into a longer spectrum. We will assemble the grating end first.

2. Students should take one piece of aluminum foil about 4x4 inches and tear or cut a small hole in the center of the foil. The hole should be smaller than the square of diffraction grating material. A hole in between a nickel and a dime in size is usually good. The easiest way to do this is to fold the foil square in half, and then in half again the other direction. Cut or tear off the corner that is at the center of the foil and then unfold the foil – voila!



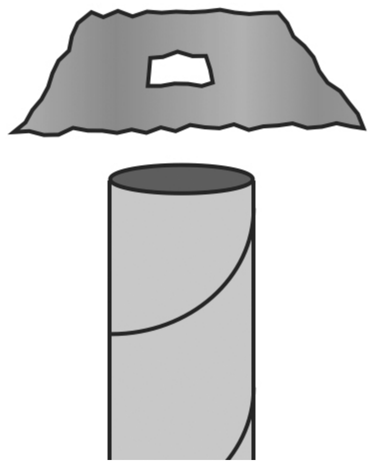
A foil square with a hole in the center.

3. Again, being careful to handle the diffraction grating only by its edges, tape it over the hole. Tape only the edges of the grating, not across the middle. It doesn't matter which side of the grating or the foil is up/out.



Diffraction grating taped over the
hole in the foil square.

4. Students should then center this foil-mounted grating over one end of the tube, taped side in, and tape it to the outside of the tube at its edges.

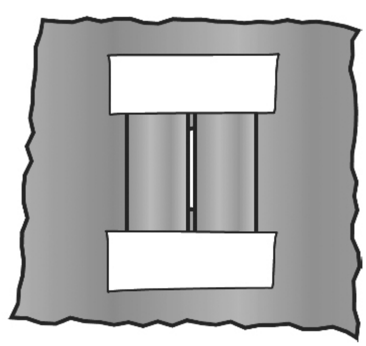


Placing the diffraction grating over the end of the tube.

5. Next we will assemble the slit end of the scope. Students should take the other large piece of aluminum foil 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, as long as the hole is smaller than the end of the tube).

6. Students should take the two 3x1-in strips of aluminum foil and carefully fold each of them in half along the length. Make a sharp crease at the fold of each.

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 face each other without 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).



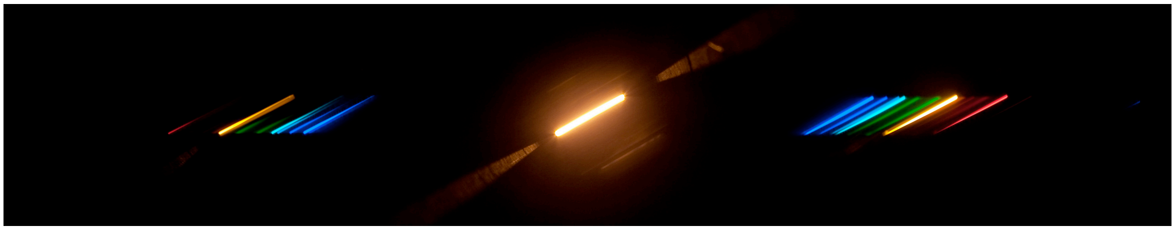
Construction of the slit end of the spectroscope.

8. Place the slit over the open end of the paper towel tube, taped side in (for structural stability) and wrap the aluminum foil around the tube - BUT DO NOT TAPE THE SLIT TO THE PAPER

TOWEL TUBE YET! The slit allows you to select what you want to look at and adjust the size and shape of its spectrum.

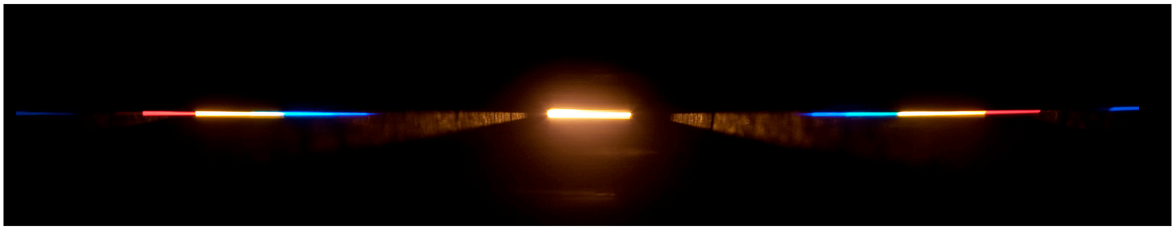
9. Now we need to **align** (or precisely adjust) our spectroscope. We want to align our slit with the diffraction grating so that we get a wide spectrum, which will be easy to see.

   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).

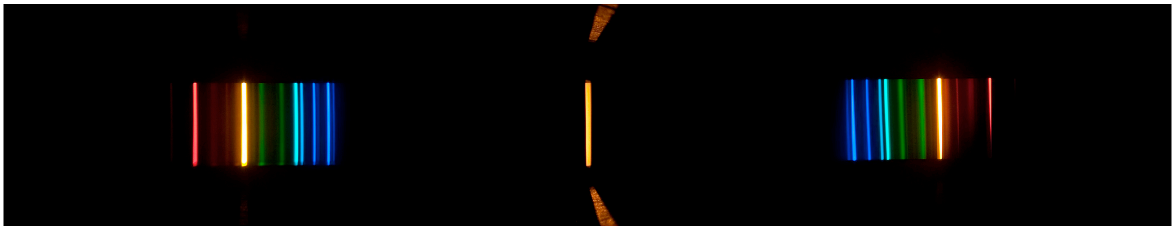


This is an example of what you might see through your spectroscope.

   While still pointing your spectroscope at the same light source and holding the tube steady, twist the slit around until the rainbow is as "fat" or "tall" as you can make it. (Conversely, you can twist the tube while holding the slit end steady – either is equally effective.) Once you are satisfied, tape the foil of the slit end into position.

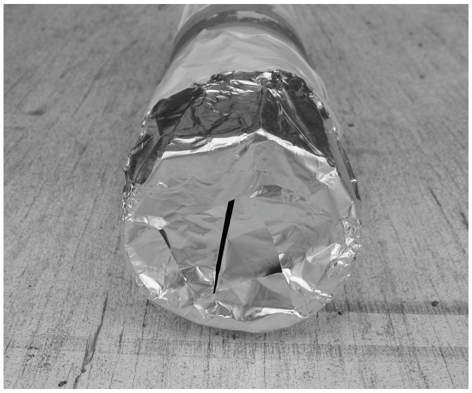


This smear of color is NOT the final state you are looking for in your spectroscope.



These nice orderly lines represent a fully aligned spectroscope. If this is what you are seeing through yours, you can tape the slit end in place.

10. 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!

This is what each end of your spectroscope should look like when it is finished.

Remind them NEVER to look at the Sun!

A girl looks through her spectroscope at the lights on the ceiling.

Activity: Using the Spectroscope (~15 minutes)

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

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

   Instead of looking directly at the Sun, 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. For added safety, you can also see a solar spectrum by looking through the spectroscope at a white piece of paper that is reflecting bright Sunlight. However, neither of these methods may be feasible if it is actually raining, in which case an incandescent bulb can be substituted. At this resolution, both the solar spectrum and the spectrum from an incandescent bulb are fairly uniform rainbows, showing all the usual colors (the students will usually remember and recognize ROY G BIV – Red Orange Yellow Green Blue Indigo Violet).

A group of Girl Scouts looks at the sky (but NOT the Sun!) with the spectroscopes they have built.

Now is also a good time to point out (in conjunction with a spectrum poster or handout) 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, but it is only audible with the proper kind of ears (like dogs' ears!). Similarly, radio, IR, UV, X-ray, and other wavelength 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 only corresponds to 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 from many meters in the radio to less than a picometer (trillionth of a meter) for gamma rays.

2. Next, students should examine a light source with obvious discrete spectral lines – most schools and other institutional buildings have bright mercury (or other) 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

   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 in the spectrum and some appear as very strong, 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. Hydrogen and helium are good elements to start with, because their spectra are very simple. 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!