
Session 5 – The Astronomer’s Toolbox: Spectroscopes

General Description

Students each build and calibrate a simple spectroscope and use it to examine light from different sources. This allows them to work the way astronomers do to learn about the composition of objects in the distant Universe.

Objectives

- To ensure that students understand that light is composed of different wavelengths of energy, including many we cannot see with our eyes.
- To show that light provides information about the composition of objects.
- To introduce the spectroscope as an instrument used to study light.

Concepts Addressed

- Electromagnetic spectrum
- The correspondence of different elements and compounds to unique patterns of spectroscopic lines at different wavelengths

Materials

- The *Electromagnetic Spectrum* handout (black and white version included in Appendix E and color version included in Appendix F)
- Paper towel tubes, 1 per student (any tube of a similar dimension, such as PVC piping, shipping tubes, etc, will work just as well for this, so the primary factor is ease of acquisition)
- Aluminum foil: two 4" × 4" pieces AND two 1" × 3" strips per student (these dimensions are estimates only)
- Masking tape
- Diffraction grating (single axis; approximately 1 inch square of material per student) *
- Light sources
 - Incandescent light bulb as a source of a continuous spectrum **
 - Additional sources of light that produce spectra with distinct lines *** (Optional, if you have access to such lights)
- Full page diagram of paper tube spectroscope, one per student (included)

* *Information about where to purchase this, along with the part number can be found in Appendix C.*

*** Common household bulbs are incandescent or fluorescent 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. You will want to have as many different sources of this type as possible, for increased student interest and understanding, but even one helps.*

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, and 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)

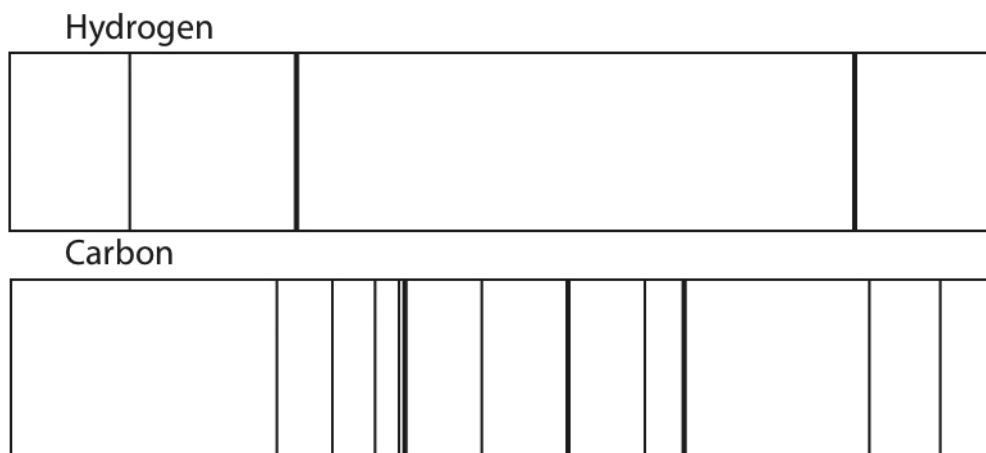
(More on the above in Session 8.)

“**Spectra**” is the plural of “**spectrum**.”

A **diffraction grating** separates the light from a source into the full range of visible light, 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 (a “fingerprint” — not a technical term, by the way) that identifies its presence. The lines are always in the same place for that element or compound.

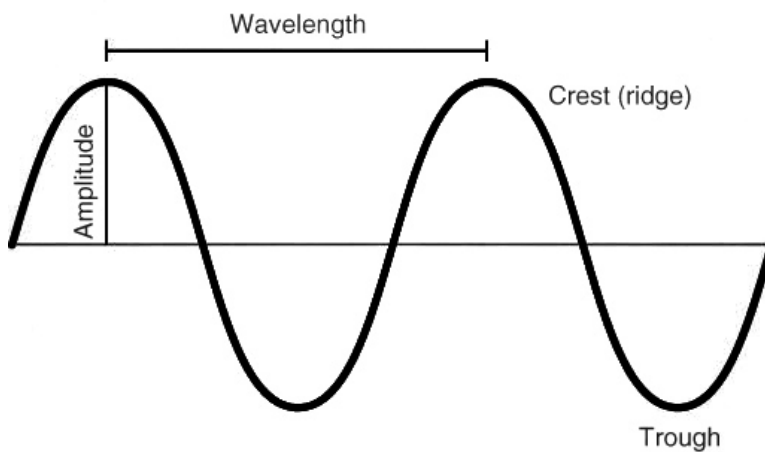
If a fingerprint of a specific element or compound is in the spectrum of a distant astronomical object, it is evidence that the element or compound is in that object.



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.



Basic terminology for talking about waves.

Longer wavelengths correspond to shorter frequencies. So, 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 often 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 lamps send an electrical charge through the gas of a certain type of element. The resultant light will show the signature spectrum 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 from that of a clear bulb, since 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 in some way, the spectrum for any extended object, such as a galaxy, would be hopelessly jumbled and impossible to interpret.

Session Overview

After a short discussion with the leader on what a spectroscope does, students build and calibrate a simple one. They use it to examine light from different sources — the sky and one or more artificial lights - while discussing with the leader and other students what they are seeing.

Preparation

- Put together a spectroscope of your own in advance and try it out, to make the activity much easier when you go through it with students.
- Become familiar with the handout to help with explanations.
- Set up all of your light sources.
- Cut the foil and diffraction gratings to the correct sizes. Exact measurements are not at all necessary. If time is an issue with the students you can also cut the necessary holes in the foil.
- 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.

Activity

I. Discussion (5-10 minutes)

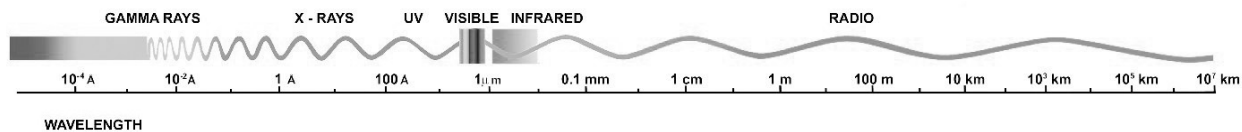
1. Ask students if they know what the word “spectroscope” means.

spectro — from spectra or rainbow

scope — a viewing instrument, as in telescope or microscope

Ask them if they know what a 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 visible range.



2. Pass out the handouts of the electromagnetic spectrum. 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.

II. Making the spectroscopes (20-25 minutes)



Check our online resources for a video about building this spectroscope.

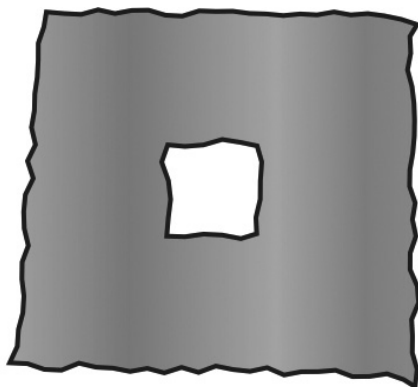
Discussion among students is encouraged for the rest of this session.

1. Distribute construction materials to the class: paper towel tubes, aluminum foil, masking tape, diffraction grating, and rubber bands. Tell the students to be very careful about touching the diffraction gratings only by the edge to avoid leaving fingerprints.

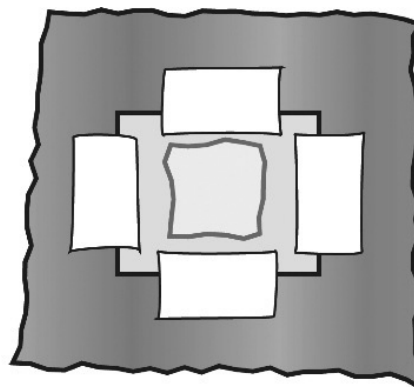
Distribute copies of the spectroscope diagram, and go through it with the students.

Like the telescope, the spectroscope has an eyepiece end for the diffraction grating (the end you look through) and an objective for a slit that controls the entry of light and points at the object you are observing.

2. Assemble the **grating end** first. Take one of the 4" × 4" pieces of foil and tear or cut a small hole in the center of it — a hole that is *smaller* than the square piece of diffraction grating. A hole in between a nickel and a dime in size is usually good. (An easy way is to fold the foil square in half, then half again the other direction. Tear off the corner that is at the center of the foil, and unfold it.)



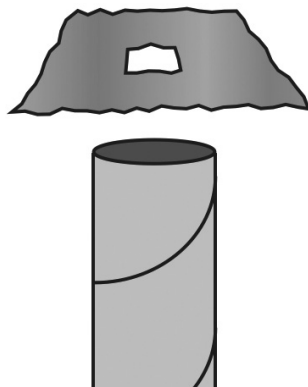
A foil square with a hole in the center.



Diffraction grating taped over the hole in the foil square.

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.

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.

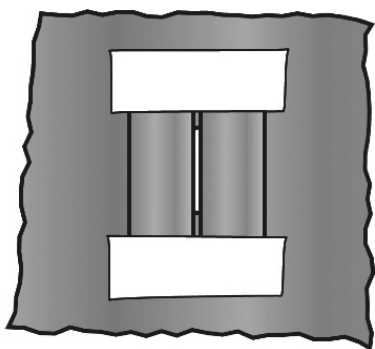


Placing the diffraction grating over the end of the tube.

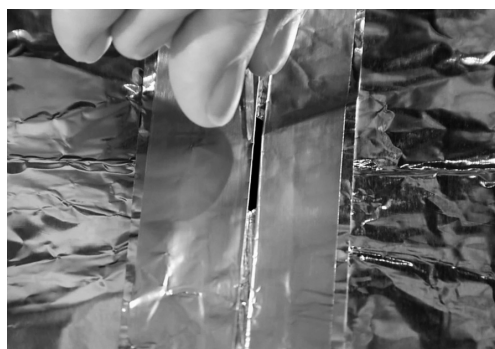
Look at the room lights with the grating installed, to see the effects of the grating before the spectroscope is finished.

3. Assemble the **slit end** on the table. Take the other 4" × 4" piece of foil and make a hole in the center as before. The diameter of the hole should be smaller than the diameter of the tube, to avoid gaps and tears.

Carefully fold each of the two smaller strips of foil (the 1" × 3" pieces) in half along the length. Make a sharp crease at the fold of each. Lay them over the hole in the larger piece of foil so that their creased edges face each other with a very small gap between them (no more than the width of a toothpick, or the thickness of a coin). Tape the two creased pieces of foil in place over the hole, and make sure not to cover the slit with tape.

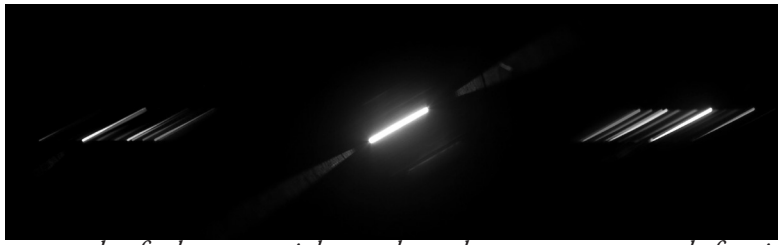


Construction of the slit end of the spectroscope.



Placement of the pieces for the slit end of the spectroscope, with the gap about as wide as the thickness of a coin.

Place the foil-mounted slit over the open end of the tube, taped side in, and wrap the foil around the end of the tube to hold it in place. Don't tape the slit end to the tube, but you may secure it with a rubber band if you wish. The slit allows you to select what you want to look at and adjust the size and shape of its spectrum. (The rubber band is not strictly necessary. You can also hold the slit end in place with your hand, and it is almost as easy.)



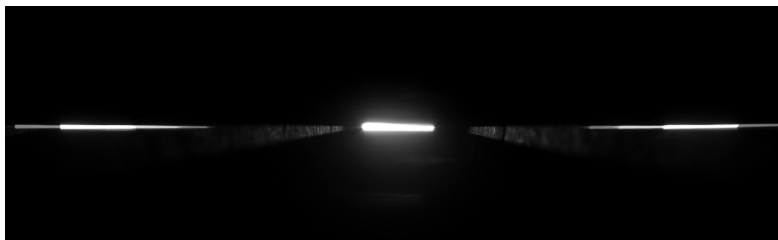
This is an example of what you might see through your spectroscope before it is aligned.

4. **Align** (precisely adjust) the spectroscope. We want to align our slit with the diffraction grating so that we get a wide spectrum, which will be easy to see. You’ll need some patience for this.

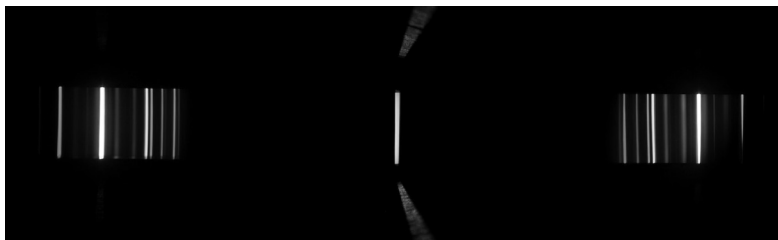
Hold the spectroscope so that you can look through the diffraction grating end (the plastic square should be about as close to your eye as your glasses’ lens or as close as you would put a microscope). Point the slit end of the spectroscope towards a light source – this can be a light in the room or 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).

Never look directly at the Sun with the spectroscope or your naked eye!
It can result in permanent eye injury!

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. That’s it!



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.



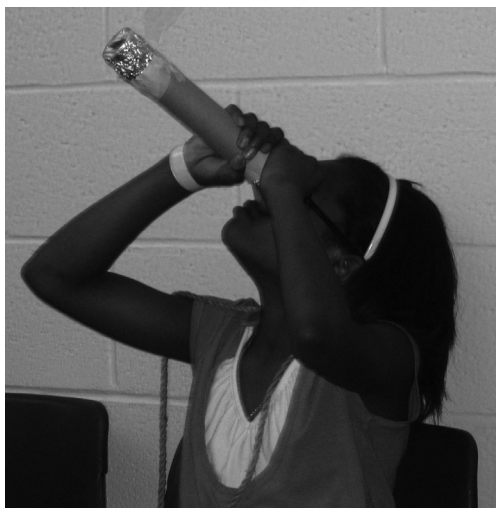
The slit end of a spectroscope. This end points at your light source.



The diffraction grating end of a spectroscope. This end goes up to your eye

Make the point that since they’ve built the spectroscopes themselves, they know how to fix them if they break.

III. Using the spectroscopes (15 minutes)



A girl looks at a light in the ceiling with her spectroscope.

1. Have students look through their spectroscopes at the sky, which is bright from sunlight, or, for added safety, at a piece of paper that is reflecting the sunlight.

Remind students not to look directly at the Sun, only at other parts of the sky!

This should work even if it’s cloudy, but it may not work if it’s raining. In that case, an incandescent (common household) bulb can be used.

Ask what kind of spectrum they see.

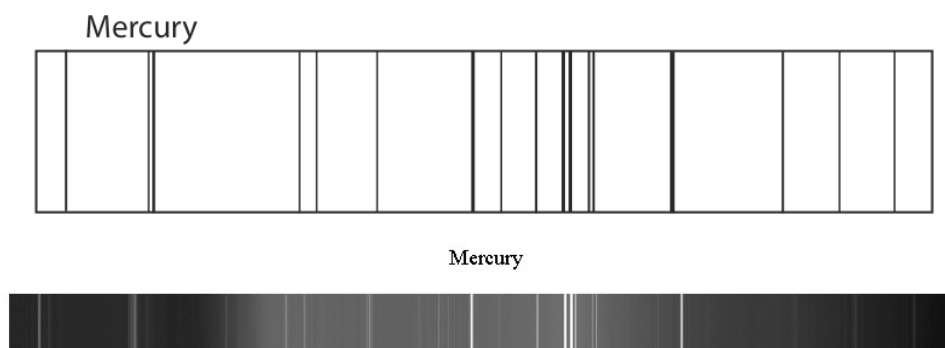
Do they have an idea of what the diffraction grating in the spectroscope is doing to the light entering it? It separates light into the different wavelengths (colors) that the light is made of. The Sun’s (or the incandescent bulb’s) spectrum shows all the usual colors of the rainbow. Sunlight is white light, meaning it includes all wavelengths of visible light.

If you’re interested, here’s a phrase to help remember the order of the colors in the visible spectrum: **ROY G BIV** — (red, orange, yellow, green, blue, indigo, violet)

2. The different colors seen inside the tube represent different wavelengths of light, but all are in the visible range. Going back to the handout, remind students of the last session, and the fact that the spectrum really extends beyond what they can see in their spectroscopes — to “invisible light,” like infrared, ultraviolet, X-ray, radio, etc.
3. If you have light sources that produce distinct bright lines, have the students look at them but don’t tell them what they are looking at. What differences do they notice between the Sun’s spectrum and the spectra of these artificial lights?

Are all of the ROY G BIV colors present in this new spectrum?

Mercury fluorescent lights produce a faint continuous spectrum (like the Sun, but much dimmer) with four or five bright lines. Depending on how much your personal eyes can see, one or two lines will be red, one will be green, and two will be blue/violet. These bright lines are the spectral “fingerprint” of mercury. Whenever you see these lines at the same wavelengths, mercury is in the light source. If you don’t see them, there is little or no mercury in that bulb.



Two versions of the spectrum of Mercury. The first is a simplified line drawing, and the second is a black and white version of what would actually be seen in a spectroscope.

Each element and compound has a unique fingerprint — a unique pattern of spectral lines at specific wavelengths. The word spectrum is also used to refer to the fingerprint for a particular element or compound, so mercury’s fingerprint is also called mercury’s spectrum. Remind students that:

Elements contain all the same kind of atom.

Examples:

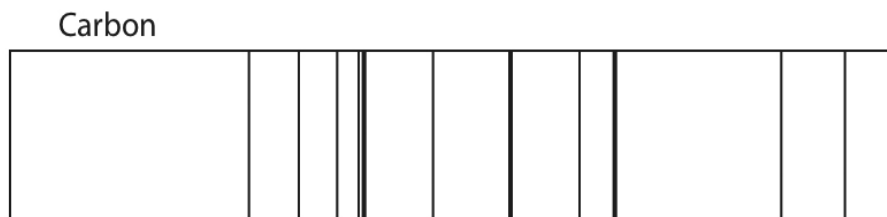
- pure gold
- silver
- copper
- aluminum
- oxygen

Compounds contain 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)

Astronomers use spectral fingerprints to figure out what objects, like stars and galaxies, are made of. With very powerful instruments, they can even tell how much of an element or compound is present: bright lines mean a lot; faint lines mean very little.



The spectral fingerprint of carbon.

4. It can be fun to provide colored pencils, markers, or crayons for them to draw the different spectra that they observe. In Appendix F, there is a picture of several of the different spectra that they might see, depending on what light sources are available.
5. Send students home with their spectroscopes and encourage them to look at lights near their homes. Most street lamps are either mercury or sodium lamps, but “neon” signs often contain many different elements besides neon. Sodium street lamps have a distinct dark line that is easily visible.

Remind students not to look at the Sun!

Have them talk about what they found the next time the group convenes.

Suggestions for Running this Session

- For this session, you’ll need enough paper towel tubes for each student to build a spectroscope, so you should begin collecting these well in advance of the session! Ask friends, colleagues, students, etc. to save their paper towel tubes for you. You may even be able to have the cleaning staff at your location save you some (though make sure that those tubes are still a good size/shape for building a spectroscope). In a pinch, you can buy mailing tubes that have the same size/shape as a paper towel tube.
- People often ask about using toilet paper tubes or other tubes for the spectroscopes, and these generally don’t work well. A paper towel tube has the right diameter and length to project the spectra from the diffraction grating onto the inner walls of the tube. There may

be some other viable options out there, but we haven’t found any, so we’re sticking with paper towel tubes.

- When purchasing the diffraction grating for the spectroscopes, make sure you choose single axis diffraction grating and avoid double axis or holographic options. While these will create interesting effects, they will not accomplish the desired goals of this session.
- When building spectroscopes with a group of people, it is common for individuals to either get ahead or fall behind. Whoever is guiding the activity should be careful to do each step one at a time, and then pause so that everybody has a chance to catch up. Everybody following along should be encouraged to wait, and not get ahead of the group.
- If the students cut too large of a hole in the foil piece intended for the diffraction grating, they may be able to set it aside for the other end, as long as the hole they have cut is smaller than the opening in the tube.
- If you have access to them, there are special elemental spectrum light bulbs that can be purchased in a variety of different elements. These bulbs allow you to see the spectrum of specific elements, and are an excellent extension to this activity if you have access to them. However, they are expensive, so we do not include them as a default part of this session. Sometimes science departments have these lamps and are willing to lend them out for educational programs, so you might consider checking with your local high school or university.

Useful websites for background or activity extension

- ***Imagine the Universe!***
Basics on the electromagnetic spectrum, with a link to more advanced information
http://imagine.gsfc.nasa.gov/docs/science/know_11/emspectrum.html
- **Steward Observatory, University of Arizona**
Higher level information on spectroscopy and its tools, and astronomical spectroscopy
<http://loke.as.arizona.edu/~ckulesa/camp/>
- **NASA’s Infrared Processing and Analysis Center (IPAC)**
Good explanations of absorption and emission spectra and spectroscopy
<http://www.ipac.caltech.edu/Outreach/Edu/Spectra/spec.html>
- **University of Ottawa**
Beautiful displays of spectra from the first 36 elements on the periodic table in the top half of the page (no need to look at the bottom half)
<http://laserstars.org/data/elements/index.html>