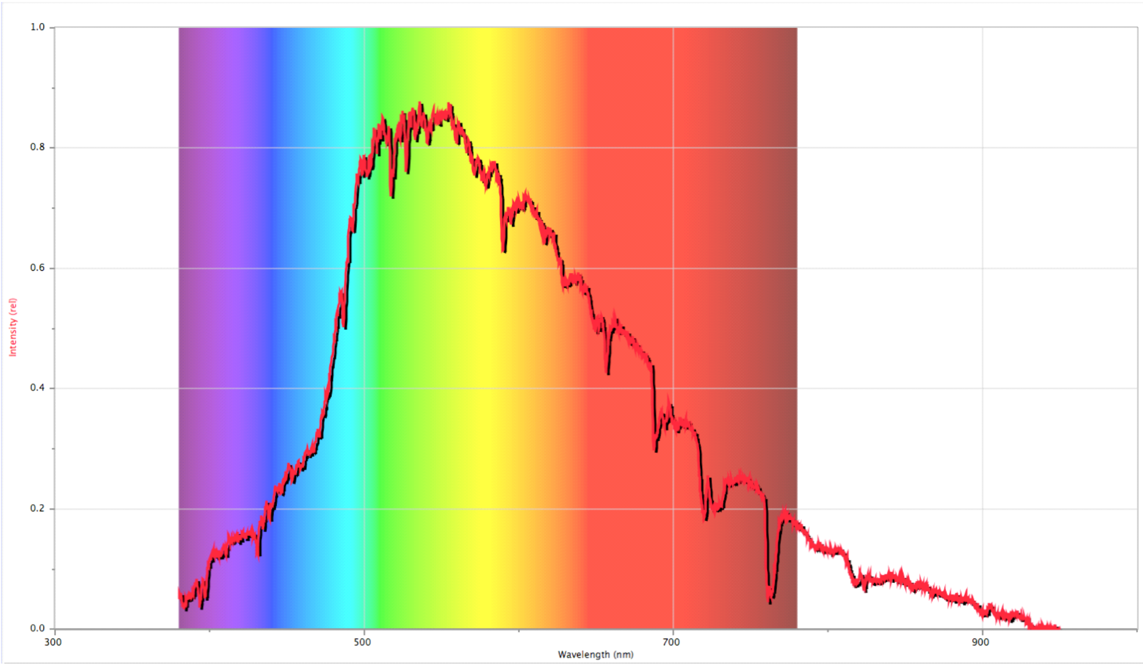
AS 102
Spectroscopy



Introduction

Spectra allow us to determine properties of distant objects, including the properties of temperature and composition. In this lab, we will make observations of the three different types of spectra: continuous, emission, and absorption spectra. We will observe the spectrum of the Sun and identify the absorption lines that result from sunlight passing through the Sun's atmosphere and our atmosphere.

Every object or collection of atoms and molecules with a temperature gives off light in the form of a **continuous spectrum**. The light spectrum comes from the complex interactions that take place in high-density objects. These objects, often referred to as "blackbodies," absorb and re-emit all of the light that reaches them. The re-emitted light is continuous over a large range of wavelength. The spectrum depends on the object's temperature, with cooler objects emitting lower frequency (redder) light and warmer objects emitting more light on the high frequency (blue) end of the spectrum.

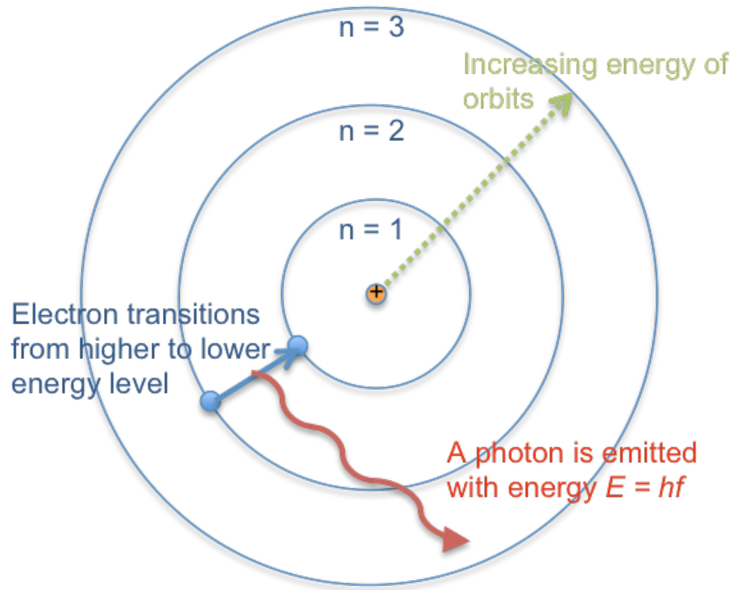


Figure 1: A photon is emitted when an electron drops from a higher to a lower energy level

Atoms and molecules emit light when there is a transfer from a high to low energy state or absorb light when the electrons go from a low to high energy state. In the simple case of a single atom in a low-density gas, the electrons surrounding the atom are confined to specific energy levels. As the diagram in Figure 1 shows, a photon is emitted when an electron drops from a higher to a lower energy level. The difference in energy is equal to the energy of the emitted photon, which determines the frequency (and wavelength) of the resulting light. The energy of light is proportional to its frequency. A photon of frequency f has energy E = hf, where h is a constant known as Planck's constant.

Emission spectra are emitted from low-density gases. When light from another object or, in the case of the emission spectra we will observe in this lab, electrical current passing through the gas excites the electrons into higher energy levels, it is absorbed. When the electrons lose energy, the light is then re-emitted at the frequency E/h, where E is the difference in energy levels, as described above.

Absorption spectra occur when light from a high temperature object emitting a continuous spectrum passes through a cooler, low-density material before reaching the observer. The cooler material absorbs some of the light at wavelengths that depend on the elements and molecules within it. The same characteristic energies of an element's emission spectrum, determined by the differences in energy levels of that element, are the energies of its absorption spectrum.

Equipment

Handheld diffraction grating spectroscope

Computer-based grating spectroscope

Incandescent light bulb with variac

Gas discharge tubes

Bottles of liquid chemicals

Sunlight

Procedure

We will observe the three different types of spectra using a handheld spectroscope, shown in figure 2 below and a computer-based spectroscope.

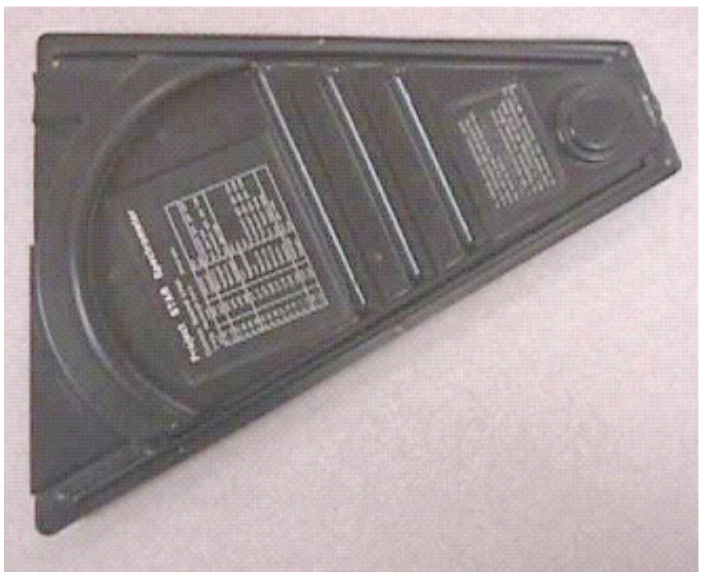


Figure 2: Handheld spectroscope
To use the spectroscope, you will look through the eyepiece, shown on the right of this picture. The light source should be aimed at the top left, and the projection of the spectrum will be on the bottom left.

Our diffraction grating spectroscopes use gratings with thousands of closely spaced, parallel lines etched on a transparent medium. The light that comes into the spectroscope is diffracted, or spread, by the grating at different angles depending on wavelength. As the diagram in figure 3 shows, the diffraction grating spectroscope bends the spectrum of light on either side of the incoming light. When using your **handheld spectroscope**, point the slit directly at the light source, then look to the side where you will see a scale marked in units of nanometers. The spectrum is visible projected against the scale.

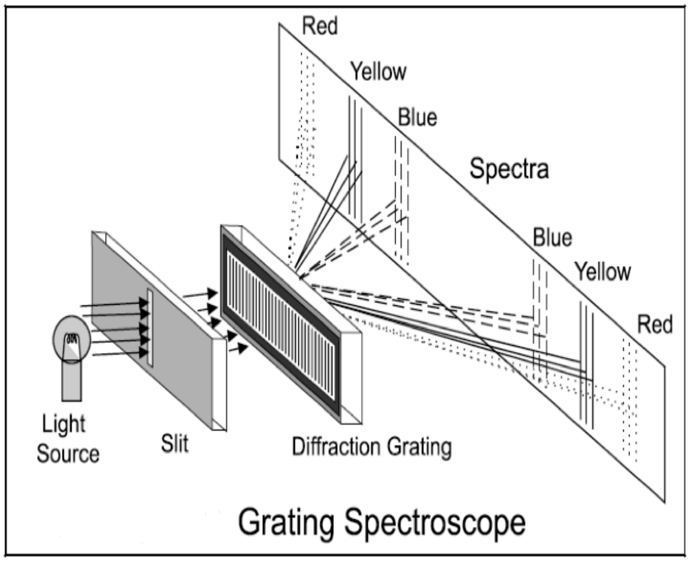


Figure 3

The **computer-based spectroscope** takes its light input through an optical fiber instead of a slit. The light is again passed through a diffraction grating, then projected onto a detector, which sends a signal to the computer.

To collect and view the spectrum, we will use the *Logger Pro* program whose icon is on the desktop. Once the program is open, check the units on the left side of the graph. They should say *Intensity*. If they do not, then go to *Experiment* → *Change Units* → *Spectrometer: I* and select *Intensity*.

To observe the spectrum, you need to point the fiber optic directly at the source. Click the *Collect* button (the green button with a white arrow), and after a few seconds, hit the button again to stop the collection. You may need to experiment a bit to figure out the best distance from the source and the best time over which to collect light for the spectrum - if the time is too short or the optical fiber is too far away, then the lines will not stand out enough for you to be able to pick them out easily. If the time is too long or the optical fiber is too close, the lines will saturate (the emission lines will start flattening out as they reach the top of the graph).

To clear an experiment, select: *Experiment* → *Clear Latest Run*.

You will need to print out a few of your spectra from the computer. If you are in the basement lab, you may need to print to a pdf file by choosing *Print…* → *Print to PDF*. Then you can either email the file to yourself or use a usb drive to transfer the file to your own computer.

Continuous spectrum:

We will use the computer-based spectrograph to observe how continuous spectra depend on temperature. The variac will be connected to an incandescent light bulb. As you turn the knob, you are increasing or decreasing the voltage across the light bulb, which proportionately increases or decreases the current flowing through the bulb. Increasing the current through the bulb increases the temperature of the filament.

Using *Logger Pro*, observe the spectrum at 3 different variac settings. Record your observations of brightness (intensity) and color, making sure to describe how these change with the temperature of the glowing light bulb filament. How hot do you think the filament in the bulb is?

Emission spectrum:
Observe the spectra of the gas tubes in your lab. In words, record descriptions of each of the spectra, paying attention to which spectra have fewer lines and which have more. Make detailed sketches of 4 of the tubes, including the sodium, hydrogen, and the unknown gas. Your detailed sketches should note wavelength and brightness of several lines. Try to identify the unknown gas using one or more of the known spectra. Include your best guess in your report, and explain how you reached your conclusion.

Use the computer to record 3 different emission spectra, including sodium and hydrogen. Detailed instructions for using *Logger Pro* are given above. The wavelength is shown along the x-axis and is measured in nanometers (nm). Note that when you use your mouse to run the cursor over the graph, the cursor's location is shown to the lower left. You can use this to determine the exact wavelength of the features you observe. Print out the 3 spectra for your lab report.

The sodium D lines are at wavelengths of 589.0 and 589.6 nm: Locate the sodium D lines in your sketch of the sodium spectrum and in your computer-based spectrum. Were you able to separate out these lines? What does that tell you about the resolution of your spectroscope? Calibrate your spectrum using the sodium D lines: Did you observe these lines at exactly the same location using the computer and the hand-held spectroscopes? Is one of your spectroscopes off? If you assume that all of the wavelengths were shifted by the same amount, then you now have the information you need to correct your previous spectra. Re-calculate one of your other emission spectra with your new calibration.

Absorption spectrum:
Hold the bottles of liquid in front of the incandescent bulb. Using your handheld spectroscope, observe how the spectrum is no longer continuous but has dark bands blocked out. Compare the spectra, describing them in words, and make detailed sketches of 2, including the unknown substance. Try to identify the unknown substance using one or more of the known spectra. Include your best guess in your report, and explain how you reached your conclusion.

Solar spectrum:
Use the computer to find the spectrum of the Sun. Compare the absorption lines you observe with the spectrum of the Sun found on the wall of the lab. Can you identify any of these lines in your spectrum? In your lab report, you should mark the lines you identified on a printout of your solar spectrum. Compare your solar spectra with

the emission spectra you observed. Can you identify substances that way? Absorption spectra indicate that a bright, dense object is glowing with a continuous spectrum, and a cooler object between you and the continuous spectrum is absorbing certain wavelengths. What is creating the absorption lines in the solar spectrum? Where are the elements and molecules you observe located?

Questions to consider:

What did you learn about how continuous spectra depend on temperature? Comparing the spectra of the incandescent light bulb to the Sun's spectrum and temperature, what can you conclude about the temperature of a light bulb?

What did you learn about the emission spectra of different elements and molecules? How are the spectra of molecules different from the spectra of elements? What were you able to discover about the resolution and calibration of your spectroscopes? What was the unknown gas, and how did you figure that out?

Can you figure out why the absorption spectra you observed have thick bands instead of thin lines of absorption? What was the unknown liquid, and how did you figure that out?

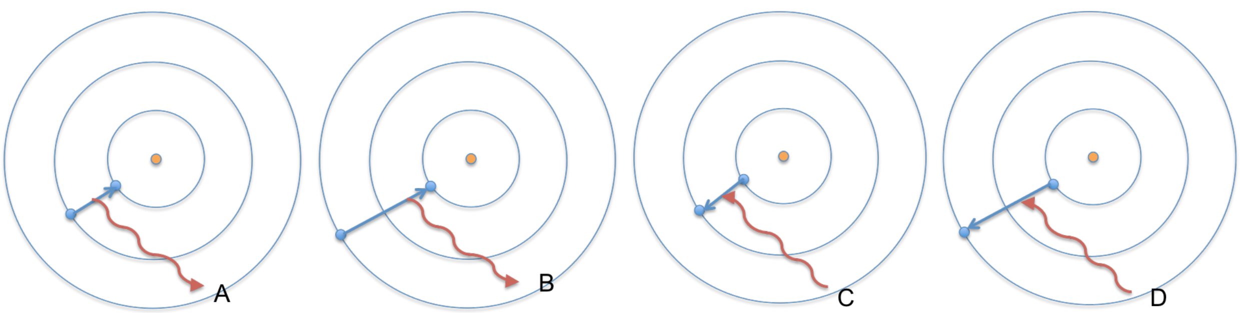
Can you identify the lines of your solar spectrum using the known solar spectrum as found on the wall of the lab? Can you identify them by comparing with the emission spectra you observed? What is creating the absorption lines in the solar spectrum, and where those elements and molecules located?

Spectroscopy Pre-lab

1. For the 4 interactions shown below, which photons are redder?

2. Which ones are higher frequency?

3. What kind of spectrum would each of these interactions produce?



4. What kind of spectrum is displayed on the first page of this lab?

5. What are some of the things that you do not understand about this exercise?

Spectral Line Diagrams - Page 1

Emission Spectrum 1

750 700 650 600 550 500 450 400 350
Wavelength (nanometers)

Description of Source____

Emission Spectrum 2

750 700 650 600 550 500 450 400 350
Wavelength (nanometers)

Description of Source____

Emission Spectrum 3

750 700 650 600 550 500 450 400 350
Wavelength (nanometers)

Description of Source____

Spectral Line Diagrams – Page 2

Emission Spectrum 4

| |

750 700 650 600 550 500 450 400 350

Wavelength (nanometers)

Description of Source____

Absorption Spectrum 1

| |

750 700 650 600 550 500 450 400 350

Wavelength (nanometers)

Description of Source____

Absorption Spectrum 2

| |

750 700 650 600 550 500 450 400 350

Wavelength (nanometers)

Description of Source____