Building your own Spectroscope

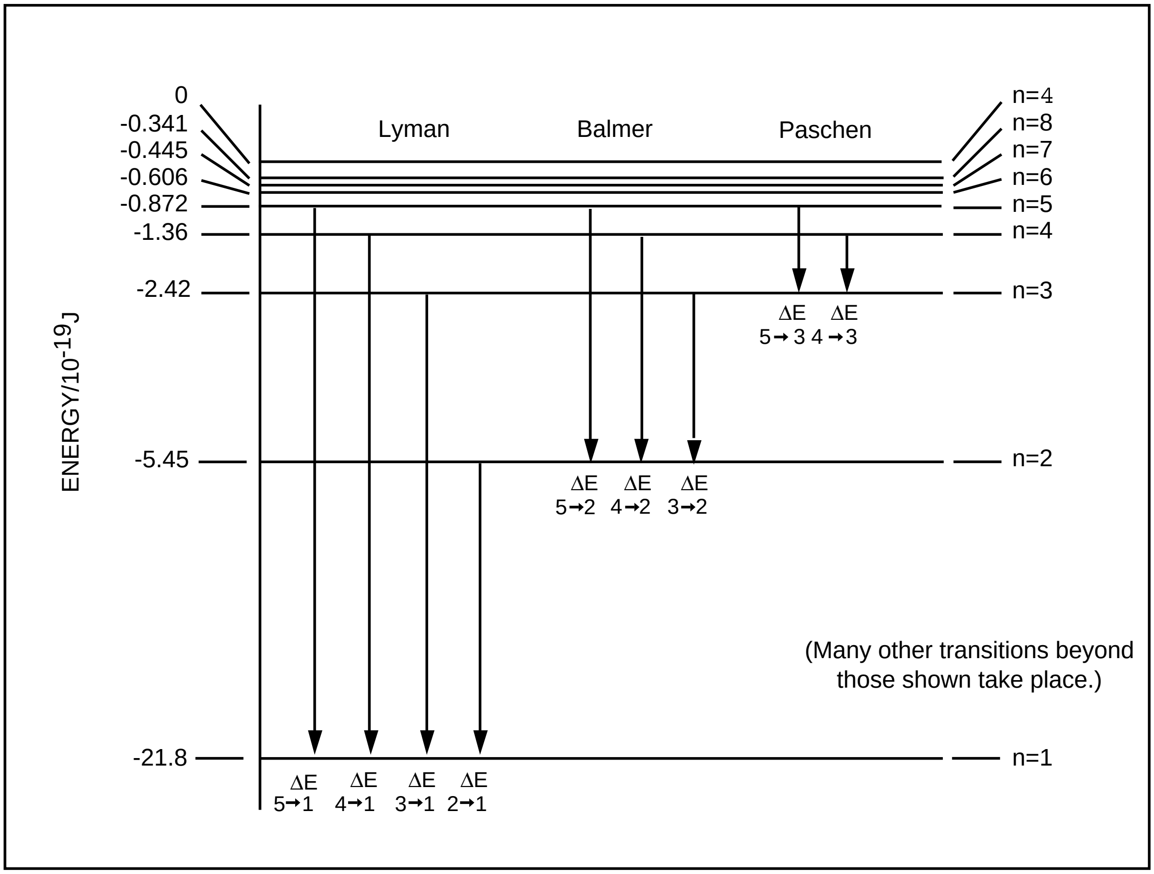


Figure 1. Energy Levels and Transitions for Atomic Hydrogen

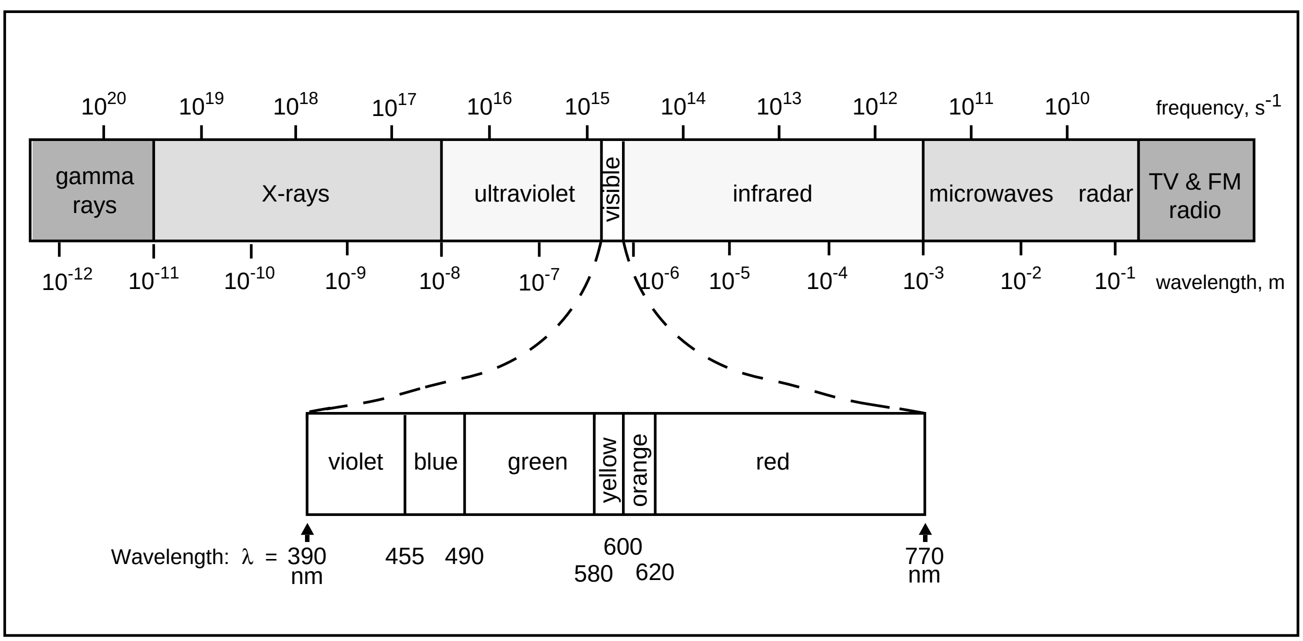
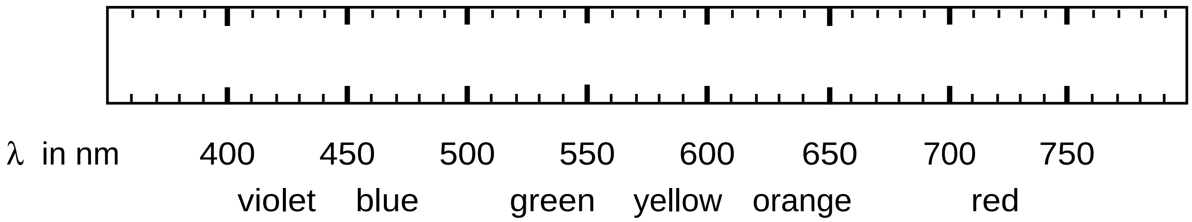
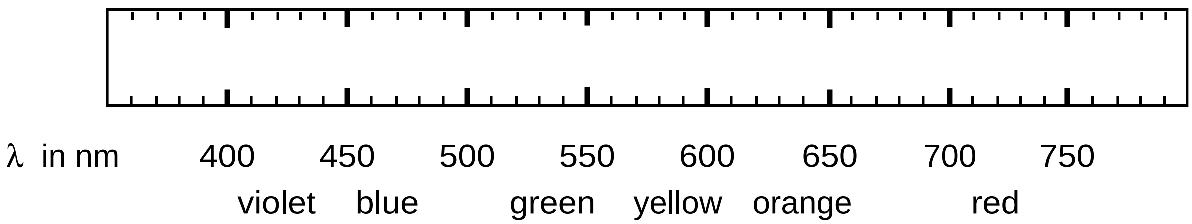


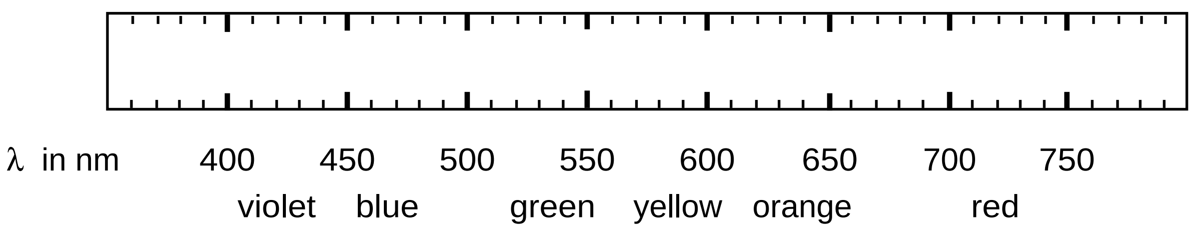
Figure 2. The Electromagnetic Spectrum

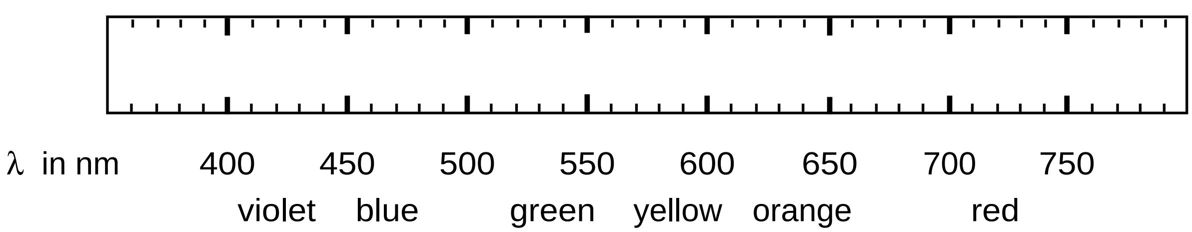
Blank Visible Spectra

This page has been included for your convenience. You may photocopy or duplicate this page for use in recording observations and answering questions in this experiment.









Experimental Notes

Color, Light, and Atomic Spectroscopy

"***Why are my socks red?***" was the title of a popular science education poster that appeared in the Paris underground in recent years. The question "***Why is the sky blue?***" has puzzled both parents and many an inquisitive youth.

In this lab we will explore what gives rise to color, and how the interaction between light and molecules can be used for a variety of tasks from determining chemical concentration and composition, to understanding what elements are present in the stars, or what materials give rise to the colors we see in everything from clothing to fireworks. In this experiment you will build and calibrate a "box spectrometer" and use it to exploring the chemistry of color.

Write-up

For this experiment you will work in your teams. The write-up to this experiment consists of handing in a <u>signed copy</u> of your lab notebook data along with the answers to the questions posed at the end of the experiment. This is due next lab period. The box spectrometer you construct is yours to keep! Only one report and copy of your data with all your team members names is required next week, but each team member should keep all the data and notes in their own notebook for future reference (or in case one team member mysteriously vanishes… it can happen!).

Don't forget to get your notebook signed before leaving the lab! Only data taken in an approved laboratory notebook will be signed by your instructor.

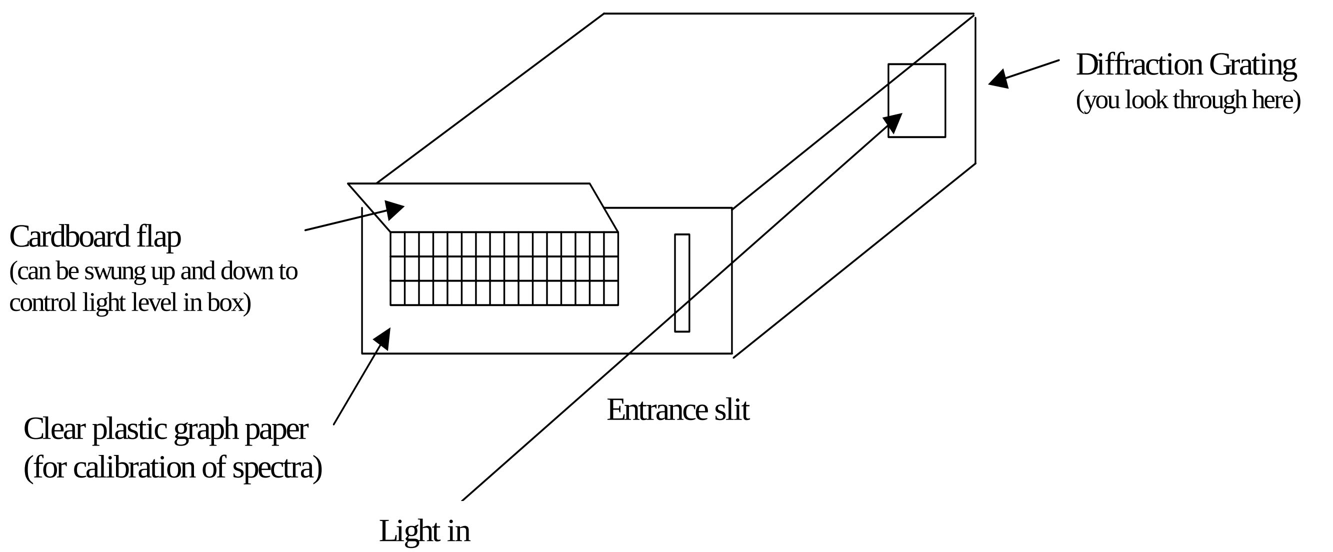
Building the Box Spectroscope

<u>For this project you will need a cardboard box from home</u> measuring at least 1.5" x 7" x 7" (4cm x 18cm x 18 cm). This is the size of a small "personal pizza box." However a *slightly* larger box such as a shoe box, medium pizza box, or other cardboard container of similar size will do.

Black electrical tape, clear plastic graph paper, a diffraction grating, safety knives, scissors, rules, and black magic markers will be provided.

Your instructor will show you how to construct and test the spectroscope. The basic design is shown on the next page.

Basic Box Spectroscope Design



Assembly notes

Cut a hole for the grating and slit. If you are using a shoe box or non-square box it is suggested that you use the wide sides for your slit and grating; not the narrow sides. Mount the grating loosely and hold the box up to the light. Aim your spectroscope at a fluorescent lamp and look through the grating. You should see a spectrum (or rainbow) on the side (not top) of the box. If you do not see a spectrum on the side of the box try rotating the grating 90 degrees. Note the position of the spectrum you observe and mark it on the box so that you can cut out a cardboard flap accordingly (the position will vary depending on the box size). Mark where the spectrum starts and ends and then cut a flap on three sides slightly wider than this area to allow for mounting of the transparent graph paper scale later (see diagram). **Do NOT mount the transparent graph paper at this time.** Finally, place a strip of black tape on either side of the hole where the light enters your box, narrowing it to a slit with a width of approximately 1 mm.

Show your assembled spectroscope to the lab instructor before continuing.

Exploring your Spectroscope

Now that you have built a working spectroscope it is time to explore the workings of your new instrument. In this way you can both determine the working limits of your spectroscope as well as potentially improve on its design! Record all data neatly in your laboratory notebook.

1. How do you think the grating works? Explain in several sentences.

2. If you were to use your spectroscope to view a source that only emitted two wavelengths of light – one red and one blue, what would the spectrum you saw look like? Make a sketch of the top view of your spectroscope and draw colored arrows to indicate the rays of red and blue light and where they would appear in the box and to your eye. Use solid lines to indicate real light rays and dashed or dotted lines to indicate virtual (or imaginary) rays.

3. Look up at the fluorescent lights in the room. Do you see a rainbow? What are the colors? Do you see any prominent lines? Does the spectrum appear different depending on whether you open the flap or not? Write all observations in your notebook.

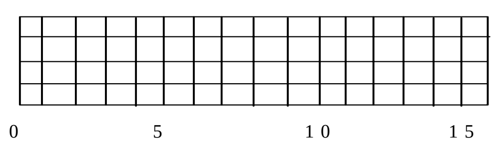
4. Now look at the spectrum from the mercury lamp, how does that appear? Is there a rainbow or just bright lines? Why do you think the mercury lamp has a different spectra from the fluorescent lights? Write all observations in your notebook.

5. Try moving the spectroscope closer and further from the mercury lamp. What happens to your spectra? Do the lines get brighter or sharper? Do the lines move? Is the position of the lines the same? What changes occur? Record all observations.

6. Now let's change some things. Vary the slit width by unpeeling one of the pieces of electrical tape and repositioning it on the box. How does making the slit larger and smaller affect the spectrum you observe? What is the best width for your spectroscope? What did you base this determination on? Record all observations.

Calibrating your Spectroscope

All scientific instruments must be calibrated before any quantitative measurements are made. Commercial instruments are almost always calibrated by the manufacturer before they are actually used in the factory or laboratory. The transparent sheet of graph paper will be used to calibrate your spectroscope.



Use a permanent marker to label some of the lines on your transparent graph paper 1, 2, 3, etc. Write these numbers below the graph so that you can read them when the graph paper is mounted to the box. It does not matter weather you label each line 0,1, 2, 3… or every 5th line, or every 10th line. As long as the spacing in your numbering scale is consistent, you will be able to use it to calibrate your spectroscope!

Tape the transparent graph paper to your box so that you can see the spectrum on the scale and with the flap slightly open you can read the numbers that you wrote from <u>inside</u> the spectrometer.

Now aim the tube at the mercury emission lamp set up in the room (if you are unsure where this is ask your lab instructor). You should see four bright lines in your spectroscope. You may see some other lines as well.

7. In the mercury spectrum you should see a deep violet or purple line (this may be hard to see), a bright blue line, a bright green line, and a bright yellow line in that order. You may also see a faint "split" green line between the bright blue and green lines, and a faint red line at the far end of the spectrum.

   Write the exact position and color of each these lines on your scale in your notebook. (Remember you should always estimate one decimal place beyond the markings on the scale of any instrument, for example, record "8.2" rather than just "8"). You may want to adjust your slit width again at this point to get the sharpest lines possible while still maintaining a reasonably bright spectrum. Make notes about any changes you make to the spectrometer in your notebook.

   The exact wavelengths of the four bright lines are given below:

Color	**Wavelength**
dark violet	404.7 nm
bright blue	435.8 nm
bright green	546.1 nm
bright yellow	579.0 nm

8. Using full sheet of blank graph paper (in your notebook), plot a graph of the exact wavelength of the four mercury emission lines given above as a function of the numbers on your scale. Note: the variable you measure (or control) should always go on the x-axis. Use a wavelength axis from 350nm to 750nm. Using a ruler, draw a best fit straight line through all the points (or as close to all the points as possible). This graph is the calibration curve that will allow you to find the exact wavelength of unknown spectral lines.

   Does your line fill the page? Is it straight? If not you should fix it and sketch it again! If the points you measured do not fall on or very close to a straight line you should check that you plotted them correctly. If they still do not form a straight line, re-measure the position of the lines using your spectrometer since this graph will determine the accuracy of your spectroscope!

9. Determine the equation for the calibration line you drew. Be sure to use the whole line for this and not just two of your data points. The best way is to pick two points near the ends of your best-fit line for determining slope and then extend your line out to the y-axis to find the intercept.

   Write the equation on your spectroscope for easy reference! Add your names and the date to the equation on the box so that someone else using the instrument will know who calibrated it and when. By using this equation you can easily convert a spectroscopic measurement into a wavelength in nm without having to look at your graph.

   Have your instructor initial your graph and check your equation before continuing.

Measuring Spectra

Now that you have built and calibrated your spectroscope it is time to measure some spectra and see how good your spectroscope is at measuring wavelengths.

10. Your instructor should have several emission lamps set up in the room. Use your spectroscope to view the lines from any two pure single-atom (monatomic) elements other than mercury and hydrogen (such as Ne, Xe, Kr, Li, etc.). Do you see lines or bands? Record the wavelengths of

the brightest lines in your notebook and sketch a picture of the spectrum your observe (you may want to use the blank spectra diagrams at the beginning of this experiment for this part). If you see too many lines to measure each individually (or bright colored bands), you may simply record, “about 20-30 bright red lines between 9.8 and 10.2”, or a similar notation. Repeat this for the second element. Be sure to label each spectrum with the names of the two elements you observed.

11. Repeat the above steps using a compound such as CO_2. Record the spectrum in the same way.

12. Now lets look at hydrogen. You already know the wavelengths predicted for the hydrogen spectrum by the Bohr equation (calculating this was part of your pre-lab assignment). Use the spectroscope to observe and record the visible lines from the hydrogen emission lamp set up in the room. You should see three lines. Record the data for hydrogen in your notebook.

13. Now lets look at the flame spectrum of some metal salts. Some of these elements are used to produce the spectacular colors observed in fireworks. Observation of spectral lines in this way is also the method used by astronomers to determine the composition of distant stars. Somewhere in the room there should be a series of test tubes with metal wires in them and a Bunsen burner. Using just your eyes (no spectroscope) record just the color of the flame made by each salt when it is placed in the flame using the nichrome wire loops. Be careful not to cross contaminate the wires record the contents of each tube.

14. Now repeat the experiment using your spectroscope for <u>two</u> of the salts: sodium and any one salt of your choice. Record the wavelength(s) of the brightest line(s) for sodium and for the other element of your choice. You will need a friend to help hold the wires in the flame while you record the spectrum. It may take several trials to record each spectrum.

15. A CRC handbook has been placed in the front of the room. You may want to use this handbook to begin lab report question 7 by looking up the brightest lines in the spectrum of the two elements you just observed in the flame. Using the CRC to find spectral data can be tricky and it may be helpful to do this while your instructor is still present.

16. Have your instructor initial your notebook before you leave.

17. As a homework assignment you are to compare the spectrum of five different sources of light and record the spectra in your notebook. Some suggestions are: TV’s, street lamps, candles, moon light, neon signs, regular light bulbs, etc… Explore!! The spectroscope is yours to keep!

Lab Report Questions:

Your team needs to answer these questions and hand them in along with your signed data sheets by next week. Only one report is needed per team. Be sure to include the full name of all team members in your report.

1. Suppose you made your spectroscope from a giant pizza box several times bigger than the one you actually used. How would the brightness of the lines in the spectrum you observed change for the giant pizza box? How would the resolution (ability to distinguish and measure two close lines) of your spectroscope change if you? What else would change? Explain why each of these changes would occur.

2. Your instructor will show you how to use the computer program Excel in class. Use Excel to re-plot the calibration graph you made by entering the four data points into the spread-sheet in two columns:

Sample Data	Wavelength
4.1	404.7
6.2	435.8
12.0	546.1
15.9	579.0

   Now highlight the four data points and click on the chart wizard button (a picture of a bar graph).

   Select "XY (scatter)" as the plot type and click "next."

   You should see a "preview" of your plot, if it looks OK hit "next," if not you may have made a mistake in highlighting or selecting your data.

   Enter "Calibration Plot" as the title, "Spectroscope Readings" as the x-axis label, and "Wavelength in nm" as the y-axis label. Then click on "finish" (not next).

   Voila! Your graph appears on the spread-sheet!

   Now insert a best-fit line by clicking on one of the points on your graph to highlight them. Then select the "Chart" feature from the pull-down menus at the top and click on "Add Trendline…"

   The trendline menu will pop-up. The menu should already have "linear" highlighted (linear will add a line to your graph). Click on the "Options" tab at the top of menu. Near the bottom of the new menu, check the box labeled "Display equation on chart," and then click "OK."

   Wow! Now you have a graph with a best-fit line and the equation all done for you!

   Print your Excel plot out and staple it to the back of your report.

   How close was your hand-drawn graph to the one from Excel? Obviously knowing how to use Excel to make graphs will be useful for future assignments and other classes as well – not to mention a great resume skill when searching for a job!

3. Now consider the equation of your line. Would this same equation work for another group's spectroscope? Why or why not?

4. Suppose that you were to go into production and sell spectroscopes. How could you ensure that all the spectroscopes used the same calibration line and equation? What would you need to be sure was always the same? What could be changed without affecting the calibration?

5. How did the spectrum of the polyatomic element you recorded differ from that of the two mono-atomic elements you observed? What do you think causes these differences? Explain. Based on this what would you predict the spectrum of a very complicated molecule like the hemoglobin found in our blood to look like? Why?

6. Now compare your hydrogen data you recorded to the wavelengths you predicted. Do the wavelengths of the three lines you measured match closely to three that you predicted in the pre-

lab assignment? (They should). Using the three wavelengths you predicted as your theoretical values, calculate the percent error in each of your three measured wavelengths. How good is your spectrometer? What was the largest percent error? Was it under 3%? If it's close to this, you have built an excellent instrument capable of measuring the spectrum that earned Niels Bohr the Nobel prize in 1922!

7. A CRC handbook is available at the reference desk in the campus library. Use this handbook to look up the brightest lines in the spectrum of sodium and the second element you observed in the flame. Record the exact page number you found this data on in your notebook and the edition of the CRC handbook that you used. Do these lines match the ones you recorded? If so calculate the percent error for each wavelength you measured. How good were your results?

   Notes on using the CRC to look up spectral data:

   Spectral data for the elements can be found in section E (pages vary with edition number) under "Line spectra of the elements" (use the index).

   You should know the wavelengths of the lines you observed before you begin (convert your measurements to wavelengths using the calibration equation you determined for your spectroscope).

   Start by finding the element you examined in the table, for example, suppose you picked Beryllium (Be) (this is just an example and was not one of the elements in the salts we had in class) and found a bright line at 528nm. Wavelength data in the CRC handbook is given in units of Angstroms (Å). 1Å = $1x10^{-10}$m. Converting 528nm to Angstroms we get 5280 Å. Looking in the table at around that wavelength for Be we find the following data:

Intensity	Wavelength (Å)
80	5087.75
8	5218.12
20	5218.33
3	5255.86
64	5270.28
→ 500	5270.81
20	5403.04
20	5410.21
	5558.
10	6229.11

Search for the line with the largest intensity (brightest) close to our wavelength. In this case we find the line at 5270.81 Å with an intensity of 500. In general lines with an intensity below 500 will be too dim to see with the naked eye; whereas lines with an intensity in the thousands and above will appear quite bright. Since this is the brightest line in this region of the spectrum it is probably the line we observed. Now we can convert 5270.81 Å into nanometers and use this as our theoretical value to find the percent error in our measured wavelength.