Lab 11 - Atomic Spectra

Atomic line spectra are characteristic for every element. These are emission spectra (without color)

OBJECTIVES

• Review the quantum nature of light and how light photons are produced in atoms.
• Learn to use an optical spectrometer to measure light wavelengths.
• Examine carefully the visible spectrum of hydrogen, the simplest of all atoms, and compare with the Rydberg result.
• Identify various elements by examining their optical spectra.
• Examine carefully the spectrum of sodium to study the well-known yellow doublet.
• Compare the spectra of incandescent and fluorescent lamps.
• Determine the element responsible for producing light in a fluorescent lamp.
OVERVIEW

Light is an electromagnetic wave, its color is determined by its wavelength. The red light from a He-Ne laser has a wavelength of 632.8 nm. The bright yellow light from a sodium lamp has a wavelength of about 589 nm. White light, such as sunlight, is a mixture of light waves with many different wavelengths. Light is emitted whenever electrons are accelerated rapidly. Such rapid acceleration can be due to random thermal motion, as in the hot filament of an incandescent light bulb, or it can be due to the transition of an electron from one quantum state in an atom to another. In the latter case the light wave will have a well-defined frequency

\[ f = \frac{\Delta E}{h}, \tag{11.1} \]

where \( \Delta E \) is the energy difference between the two quantum states, \( f \) is the frequency of the light, and \( h = 6.6261 \times 10^{-34} \text{ J} \cdot \text{s} \) is a universal constant called Planck’s constant. Because

\[ c = \lambda f \quad \text{or} \quad f = \frac{c}{\lambda} \tag{11.2} \]

we can solve Equation \((11.1)\) for the wavelength and obtain

\[ \lambda = \frac{hc}{\Delta E} \tag{11.3} \]

for the wavelength of the light emitted during such quantum jumps. The atoms of different elements have different energy levels (quantum states) and emit light of different wavelengths. These wavelengths can be measured with extraordinary precision and are characteristic of the atom that has emitted the light. It is thus possible to determine the elemental composition of any substance by measuring the wavelengths of the light emitted by it. This technique is known as spectroscopic analysis.

The electrons in an atom are normally in the state with the lowest possible energy, called the ground state. In order to make them emit their characteristic light they must be excited to states of higher energy from which they can go to states of lower energy by emitting light. This excitation can be achieved in various ways:

- If you place a crystal of sodium chloride, table salt, in the flame of a Bunsen burner you will notice that the flame will emit the intense yellow light characteristic of sodium. In this case the sodium atoms are stimulated to emission by thermal excitation.

- If you draw a small electrical spark from a copper wire you will see the green light characteristic of copper. Here the excitation is both thermal and electrical.

- In this experiment, you will study the light that is emitted when gas atoms are subjected to an electric discharge. You will find that these atoms emit light of several different wavelengths (colors) that are, together, characteristic of the atoms that have emitted them. These colors are often called “spectral lines” from their appearance in spectrometers such as the ones that you will be using. By measuring many of the different spectral lines emitted by a particular element one can obtain detailed information about the energy levels of its atoms. A thorough study of the spectrum of the simplest element, hydrogen, led physicists to the development of quantum mechanics, the theory that takes the place
of Newtonian mechanics in the submicroscopic realm and which led in turn to a complete understanding of the atomic structure of all elements.

Even with your simple spectrometer you will be able to measure the wavelengths of spectral lines with an accuracy of 3 significant figures or ± 1 nm. With modern research equipment wavelengths can be measured to six or more significant figures. Quantum mechanics can account for these experimental results down to the last decimal place. It is this kind of agreement between theory and experiment that makes us confident that quantum mechanics provides an accurate description of nature at the most fundamental level.

**Diffraction Grating**

An excellent instrument to measure the wavelength of light is the **diffraction grating**. Diffraction gratings can utilize both reflection (light reflects off the surface) or transmission (light passes through). In either case the grating is equivalent to a large number of narrow parallel slits. The transmission grating you will be using is a film placed on a glass backing. In order to understand how a grating works, we recall the double slit experiment of Thomas Young: If one shines monochromatic light with a wavelength \( \lambda \) on two very narrow slits that are a distance \( d \) apart (see Figure 11.1), constructive interference will result at an angle \( \theta \) at which

\[
\sin \theta = \frac{\lambda}{d} = \frac{y}{D}.
\]

\( D \) is the distance from the slit to an image on a screen, and \( y \) is the distance along the screen from the center position.

Now consider a grating consisting of very many narrow equidistant slits. For each adjacent pair of slits, constructive interference will result when Eq. (11.4) is satisfied. In other words a grating in which the individual “slits” are a distance \( d' \) apart will act like a double slit with the same slit to slit distance \( d \). Well, almost like a double slit: While the “spectral lines”, i.e. the

\[\text{Figure 11.1:}\]

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1For a more detailed description of the double slit experiment you might want to have another look at a previous lab on the Microwave and Light Interference in this manual.
regions of highest intensity, will appear at the same angles in either case, the lines produced by
the grating will be the brighter and narrower the more slits it has. This can easily be explained
quantitatively, but we will just give a handwaving argument.

The constructive interference from all the “slits” in the grating will occur at the same angle
and make the lines that much brighter. However, the destructive interference will also be more
effective. Assume that we observe a double slit from an angle at which the path length difference
is not 1.000\lambda but 1.01\lambda. Clearly that will mean almost complete constructive interference. If we
view a grating from the same angle, there will be another “slit” 50 d away whose light will be
half a wavelength out of step and will lead to complete destructive interference with the light
from the first “slit”, etc., etc.

Just as the double slit produces lines of higher order when the path length difference is an
integer multiple of one wavelength, so will the grating. In the case of the grating, however, it is
possible by cutting the grooves to a certain shape, a process called blazing, to concentrate most
of the light intensity in the first order spectrum.

We have already used diffraction gratings in the previous lab on light interference. The condi-
tions for constructive interference are given by

\[ n\lambda = d \sin \theta \]  

where \( n \) is the order of diffraction, \( d \) is the distance between adjacent slits, and \( \theta \) is the angle
between the incident and exit wave.

References
Read the section on the hydrogen spectrum in your textbook.

Apparatus
For this lab you will need the following:

- spectrometer
- diffraction grating
- spectrum tubes
- spectrum tube power supply
- desk lamp
- fluorescent lamp
- sodium arc lamp

INVESTIGATION 1: OPTICAL SPECTRA

In this Investigation, you will measure the wavelengths of spectral lines in the visible parts of the
hydrogen spectra. We will use the spectrometer shown in Figure 11.2. The diffraction grating is
placed at the center of the apparatus, and light enters the collimator tube through the slit plate.
The diffracted light is observed through the eyepiece of the telescope.

Activity 1-1: Hydrogen Spectrum
Figure 11.2: Spectrometer

Hydrogen, being the simplest atom of one proton and one electron, has the simplest spectroscopic spectrum. We can interpret the lines we see in the hydrogen spectrum and measure one of the most fundamental numbers of atomic physics, the Rydberg constant $R$.

The three most prominent lines in the hydrogen spectrum are a red line at a wavelength of 656.3 nm, a blue-green line at 486.1 nm, and a purple line at 434.1 nm. These are members of the famous Balmer series. You may also be able to see the fourth line of the series at 410.2 nm in the deep purple. The wavelengths of the hydrogen spectral lines are given by the Rydberg equation

$$\frac{1}{\lambda} = R \left( \frac{1}{m^2} - \frac{1}{n^2} \right),$$

where $m$ and $n$, ($m < n$), are integers; $n$ represents the initial, higher, energy state from which the atom makes a transition to the final, lower, energy state represented by $m$. In the case of the Balmer series, $m = 2$ while $n$ is equal to 3 for the red line, 4 for the blue-green line, and 5 for the purple line, as shown in Figure 11.3.

In other words, the three lines that you see are caused by the electrons falling from the third, fourth, and fifth levels into the second level. In each case the energy difference between the two levels is converted into light energy according to

$$E_m - E_n = \frac{hc}{\lambda},$$

where $h$ is Planck’s constant and $c$ is the speed of light.
The ionization energy of hydrogen is the energy needed to remove the electron from the ground state \((m = 1)\) to an unbound state \((n = \infty)\). In this case Equation (11.6) gives for \(1/\lambda\) the value

\[
\text{Ionization} : \frac{1}{\lambda} = R \left( \frac{1}{1^2} - \frac{1}{\infty^2} \right) = R \tag{11.8}
\]

The ionization energy \(E_{\text{ion}}\), from Equation (11.7), becomes

\[
E_{\text{ion}} = \frac{hc}{\lambda} = hcR \tag{11.9}
\]

We could determine the Rydberg constant if we knew the ionization energy, because \(h\) and \(c\) are constants.

**We now begin the experiment!**

1. In order to prepare for a later experiment, **plug in the sodium lamp as soon as you enter the lab room.** It needs 15-20 minutes to warm up.

   **WARNING: PLEASE DO NOT TOUCH THE SURFACES OF THE DIFFRACTION GRATING. FINGERPRINTS WILL DESTROY IT.**
   **DO NOT TOUCH THE GLASS HOLDING THE DIFFRACTION GRATING**
   **PLEASE DO NOT TOUCH THE ENGRAVED SCALES OF THE SPECTROMETER. FINGERPRINTS WILL CORRODE THEM**

2. The spectrometer table (see Figure 11.2) is the black circular device about 9 cm in diameter to which the diffraction grating is attached. Loosen the long stem knob, hold the spectrometer table, lift upwards, and remove the spectrometer table. Set it aside for now.
3. Make sure that the eyepiece is fully inserted into the telescope tube. Focus the eyepiece until the cross hairs are in sharp focus. Check that the cross hairs ("crossline graticule" in Figure 11.2) in the telescope look like this: ×. If not, contact the TA to fix it for you.

4. Now we want to check the focus of the telescope lens. Rotate the telescope until you are observing something far away on the other side of the room. The focus adjustment is the knurled knob on the side of the telescope. Focus the telescope until you see the distant object clearly. You now have parallel light entering the telescope. You may need to go back and focus the cross hairs again. **Note that there are two focus knobs: one on the telescope and one on the collimator.**

![Diagram of angle of diffraction](image)

Figure 11.4: Lacing the light source, aligning the telescope, and measuring the angle of diffraction

5. Now we want to focus the collimator lens (see Figure 11.2). Position the desk lamp in front of the slit (as shown in Figure 11.2) and make the slit narrow, without closing it completely. Align the telescope with the collimator: Swing the telescope arm until, looking through the telescope, you can see the collimator slit. Focus the collimator by turning the knurled knob on the side of the collimator until the slit is in sharp focus. You may need to make very fine adjustments to the telescope’s focus as well. **After this you will only need to make very fine adjustments to the two telescope knobs. If you change them greatly, you may have to return and do all these steps again!** Remember that we all will not see the focus with the same parameters. The focus will be a little different for us because of our own vision properties. Normally only a small adjustment of the telescope focus is needed.

**NOTE: A reasonable number of us are color blind or have difficulty detecting colors. In that case, please please just look at the spectra and have another student perform the measurement.**
**Question 1-1:** Note how the image in the telescope changes as you adjust the width of the slit. Look carefully at what happens. The left side of the slit should remain fixed, while the right side moves as you open and close the slit. When making measurements you will set the cross hairs on a vertical spectral line that you observe in the eyepiece. Therefore, when making measurements of the angle, where should you place the intersection of the crosshairs on the spectral lines? Explain.

**Question 1-2:** Is it bad to open the slit wider to allow more light to come in? Explain.

6. Adjust the slit width to a size consistent to what you decided in Question 1-2 that allows sufficient light to pass through.

7. Lock the telescope rotation. You can use the fine adjust knob to make finer rotations of the telescope.

8. Note the parameters of your grating. They should be on the order of 600 lines/mm. The uncertainties in these values are about ±0.05%. Fill in the information below:

   Grating parameters: ____________ lines/mm
   d, distance between slits: ____________ mm
   ____________ nm

9. Replace the spectrometer table (which holds the diffraction grating) on the spectrometer and align it by eye so that the diffraction grating is perpendicular to the collimator tube. This is very important! The side of the glass with the grating should be on the side with the telescope. Screw in the knob to lock the position of the spectrometer table. Ask your TA if this is not clear.

10. Turn on the digital readout that displays the angular position of the spectrometer if it is not already on. You can set the angle on the digital display to zero by pushing the PRESET button. The SELECT is always on Low. It is best to measure a spectral line on the far left side of the collimator first (then set the display angle to zero) followed by the same line on the right side of the collimator. Note that the display will then read a number equal to twice the angle of interest because you have swung through $2\theta$. If you are making measurements for multiple lines, start at the far left line, set the angle to zero and measure the angle of each line as you move right and to the other side.

   **WARNING: BE CAREFUL NOT TO BUMP OR DISCONNECT THE CONNECTOR FOR THE DIGITAL METER ON THE TURNTABLE**
CAUTION: THE SPECTRUM TUBES REQUIRE A HIGH OPERATING VOLTAGE. MAKE SURE THE POWER SUPPLY IS TURNED OFF WHENEVER YOU INSERT OR TAKE OUT A SPECTRUM TUBE.

11. Make sure the power supply for the spectrum tubes is off. Put the hydrogen spectrum tube into the spring-loaded holders of the power supply, and then turn it on. Remove the desk lamp and set the hydrogen tube as close as possible to the collimator slit. Look at the slit through the telescope and position the spectrum tube with respect to the spectrometer for maximum light intensity. It may help to sit on the stools provided while looking. Have a partner move the spectrum tube until you obtain maximum intensity.

12. Unlock the telescope; swing it out to the left slowly while looking for the first order spectral lines of hydrogen’s Balmer series. Make sure you can see at least 3 of them: one violet, one blue-green, and one red. (If you cover the spectrometer with the blackout cloth and look carefully, you may be able to see the fourth deep violet line. Some can, some can’t!) You may have to open the slit somewhat to see the spectral lines clearly. Consider your answers to Questions 11.1 and 11.2 earlier. It may not be bad to open the collimator slit. It may help to see the cross hairs by lifting the cloth somewhat to allow light into the telescope. If you cannot make the necessary adjustments to the apparatus to see sharp lines, call your TA.

13. Carefully position the cross hairs appropriately on the far left of the first order lines (the red line). Set the display angle to zero by pressing the PRESET button. Then measure the other visible lines and record your angles in Table 11.1. After you have measured the three easily visible ones, swing the telescope over to the right and position the cross hairs on the same first order line. Fill out the data in Table 11.1. Note that by moving from one side of zero diffraction to the other, you are passing through $2\theta$.

<table>
<thead>
<tr>
<th>Line Color</th>
<th>Display angle – left (deg)</th>
<th>Display angle – right (deg)</th>
<th>$2\theta$ (deg)</th>
<th>$\theta$ (deg)</th>
<th>Wavelength $\lambda$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue-green</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>violet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11.1: Hydrogen Spectrum Wavelength

14. Use these results and Equation 11.5 to calculate the wavelengths of the lines you have measured. Show your results in Table 11.1.

15. Compare your measurements for the three main spectral lines with the expected results in Table 11.2.
<table>
<thead>
<tr>
<th>Line Color</th>
<th>Expected wavelength (nm)</th>
<th>Measured wavelength (nm)</th>
<th>Difference (nm)</th>
<th>Percentage difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>656.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>blue-green</td>
<td>486.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>violet</td>
<td>434.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11.2: Wavelength Comparison

**Question 1-3:** Do your experimental results agree within 0.5% of the expected wavelength? Discuss briefly your agreement.

**Question 1-4:** Discuss possible errors in your measurement. Suggest how this measurement could give better results.

16. Turn off the spectrum tube power supply.

**Activity 1-2: Determination of Rydberg Constant**

**Question 1-5:** Think of a way to use your experimental measurements to determine the Rydberg constant. In particular, how can you utilize Equation (11.6) to produce a plot that has $R$ as the slope?

1. Use the Excel file [L11.A1-2 Rydberg.xls](#) to produce a plot using your experimental wavelength measurements for which the slope is the Rydberg constant $R$. Hint: you did this in the prelab homework. After discussing how to do this, one or two students can be working on this, while the next Investigation is being started by the other students. Add a trendline to the data and fit it with a linear line. Add the equation and the goodness of fit parameter $R^2$ to your plot.
2. Write below the equation that fit the data, the value of the Rydberg constant from the fit, and the $R^2$ fit parameter.

Fitting equation: ____________

Rydberg constant: ____________ m$^{-1}$

$R^2$ parameter: ____________

3. **Print** out the data and the plot and include it in your report.

**Question 1-6:** Compare your value of the Rydberg constant with the known value for hydrogen of $R_H = 1.09678 \times 10^7$ m$^{-1}$. What is the percentage difference? Is this within your expected uncertainty? Explain.

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**INVESTIGATION 2: SODIUM SPECTRA**

Sodium produces a strong yellow light when excited and is often used for street lighting. One consequence of widespread public lighting is that on cloudy nights, cities with sufficient public lighting are illuminated by light reflected off the clouds. As sodium vapor lights are often the source of urban illumination, this turns the sky a tinge of orange. If the sky is clear or hazy, the light will radiate over large distances, causing large cities to be recognizable by an orange glow when viewed from many kilometers away.

**Activity 2-1: Sodium D Line Spectra**

The energy levels of an atom depend not only on the electrostatic force between its nucleus and its electrons but also (very slightly) on effects due to the intrinsic **magnetic moment** of the electrons. The electron is actually a charged object spinning around its own axis. It is this spinning that creates the magnetic moment. Consider the sodium atom, whose outer most electron orbits both the nucleus and other electrons. From this electron’s point of view, the rest of the atom (which is positively charged) orbits around this electron. This moving positive charge gives rise to a current, which in turn gives rise to a magnetic field $B$. It is with this magnetic field that the electron’s magnetic moment interacts. If the electron’s magnetic moment $\mu$ is aligned **with** the magnetic field, its energy state is slightly lower than if $\mu$ is aligned **opposite** to the field. The difference in this energy $\Delta \varepsilon$ can be calculated and is found to be $\Delta \varepsilon = \mu \cdot B$, where $\mu = \frac{e \hbar}{2m_e}$.

(Note that $\hbar = \frac{h}{2\pi}$. You can find the values of these constants in Appendix A.)

This effect can be most easily seen in the bright yellow line from sodium, called the *sodium D line* or “**doublet**”. This ‘line’ ($\lambda \approx 589.3$ nm) is actually two closely spaced lines that are due to transitions of outer electrons (of different atoms) from the two states discussed above. (Hence, the $d$ stands for doublet.) By careful adjustment of the spectroscope you should be able to separate the lines belonging to these two energy levels.
1. You have already turned off the hydrogen spectrum tube from the last measurement. Move the assembly out of the way and replace it with the sodium light. You should have turned it on earlier, because it takes 15-20 minutes to warm up. If it is not yet warm, you may need to go to Investigation 3 and return to the present investigation later.

2. Rotate the telescope over to the left side and look to see if you can see the bright yellow line(s) in both the first and second order. If you only see one line, you may need to reduce the size of your collimator slit as well as adjust the focus of the telescope. Make adjustments until you can clearly see both lines. You may have difficulty seeing multiple sets of lines due to reflection. If so, try flipping the grating to see if that helps.

   Question 2-1: For the hydrogen line measurements you probably found that you could open up the collimator slit to allow more light to come through. That made it easier to identify the spectral lines. Why will that not work in the present case?

3. Let’s agree to make our measurements on only the second order spectrum. Adjust the telescope on the far left line of the doublet and zero the digital readout by pressing PRESET. Then look at the right line and measure the angle for the second line. Write your values below:

   Left line readout: ___________ (should be zero)
   Right line readout: ___________ degrees

4. Now swing the telescope around to the right side of the light source and measure the angles for the two lines in the second order spectrum. Write your values below:

   Left line readout: ___________ degrees
   Right line readout: ___________ degrees

   Question 2-2: Next you will use the readouts to determine the wavelengths of the two sodium doublet lines. You need to think very carefully here about which pair of readouts to use. When looking at the left line on the left side, which is its corresponding line on the right side? Explain. Draw diagrams if helpful.
5. Show your calculations below and determine the wavelengths of the two yellow lines in sodium.

Wavelength 1: ___________ nm  
Wavelength 2: ___________ nm

Wavelength difference: ___________ nm

6. Unplug the sodium light power supply and set the apparatus aside.

**INVESTIGATION 3: SPECTRA OF VARIOUS ELEMENTS**

In this investigation we will look at the characteristic spectra of various other elements. As electrons are added in an atom, the possible atomic spectrum becomes more complex, because the number of possible transitions increases. We will not try to unravel these more complicated atomic spectra, but we will note that each element has its own characteristic spectra. We will only be observing the *visible* spectra in this investigation. But scientists now have a multitude of detectors that allow us to look at other regions of an element’s spectrum including infrared, ultraviolet, etc that are not visible to the human eye.

In this Investigation you will examine the spectra of three elements in order to discern their identity. You will want to compare your results with those on the website at http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/atpect2.html.

You will be using handheld diffraction gratings to observe the spectra. Each student will have a diffraction grating.

**WARNING: DO NOT TOUCH THE FILM PART OF THE HAND HELD DIFFRAC-TION GRATINGS. HOLD THEM CAREFULLY BY THE SIDES!**

Each of your gas tubes has a number. Be sure to write your tube number down when you examine the spectra. You will examine **three of the unknown tubes**. Follow the following procedure for each tube.

1. Remove the sodium light assembly and place it off somewhere out of the way on the table.

2. Replace the hydrogen spectrum tube with your first tube. **Make sure the power supply is turned off when you do this.** Then turn on the power supply and place it so all three of you can see the light.

3. Each student should examine the first order spectrum using your handheld diffraction grating. Note particularly the colors and intensities.

   1) Tube # ___________

   Description:
4. Write below what you believe the element is and your reasons for thinking so. Write also any discrepancies which you do not understand.

Element: ______________
Reasons for choosing element:

2) Tube # ______________
Description:

Element: ______________
Reasons for choosing element:

3) Tube # ______________
Description:

Element: ______________
Reasons for choosing element:

**INVESTIGATION 4: INCANDESCENT AND FLUORESCENT LAMPS**

The sources of light that we commonly use in our homes and work are from incandescent and fluorescent bulbs. In an incandescent bulb, a current runs through a tungsten filament placed in a glass tube typically filled with a low pressure noble gas. Scientists, including Thomas Edison, worked on them throughout the 1800s and early 1900s to improve their light output, reliability, and cost. As current passes through the filament, it becomes very hot and produces electromagnetic radiation over a wide range including visible light. Much of the radiation is lost as heat.

Your lab room has fluorescent lighting. Fluorescent lamps consist of a sealed glass tube with two electrodes. See Figure [11.5] The tube is filled with an inert gas like argon and a small amount of a specific element, which we will call Z for now. We will determine the specific element Z in this experiment. Electrons are accelerated by the high voltage between the two electrodes and collide with element Z atoms, changing some of them from a liquid to a gas. As the electrons collide with the gaseous Z atoms, some of the electrons will be excited to higher energy levels
in Z. When the electrons eventually decay back to the lower levels, light photons are produced, mostly in the ultraviolet range. Because humans are not sensitive to ultraviolet light, the inside of the tube is coated with a phosphor. The ultraviolet light photons interact with the atoms of the phosphor and excite their electrons. When those electrons subsequently decay back to lower energy levels, visible light is produced. The color of the final visible light can be varied by using different combinations of elements in the phosphors. Fluorescent lamps of various hues are produced by varying the phosphors.

![Diagram of a fluorescent tube](image)

**Figure 11.5: Diagram of a fluorescent tube**

1. By now you are expert at looking at various spectra. Turn off the power supply with the spectrum tube and set the assembly aside.

2. Look at the incandescent desk lamp with your handheld grating. **Describe it below.**

3. Insure that the black slit adapter is over the opening on the fluorescent lamp to form a narrow vertical slit. Look at the spectra for the fluorescent lamp with the handheld diffraction grating. You should see some spectral lines superimposed on the rainbow of colors due to the white light. If this does not work, try looking at it with the spectrometer. **Describe what you see below.**
**Question 4-1:** Have you seen a spectrum similar to the fluorescent lamp? Although most of the light from Element Z in the tube is in the ultraviolet range, some of it is in the visible region. Some of the visible light from Element Z in the tube comes through the phosphor, and that is what we are observing through the telescope. You should now be able to identify element Z, because you have seen it before. What is element Z and explain why you chose it?

**Question 4-2:** If you were not completely certain as to which of the previous elements were Element Z, could you think of a precise measurement you could make with the equipment you have available on your table? Describe what you might do.

4. If time permits, carry out your experiment to be certain about element Z. Describe the measurement and show all your data. Hint: you will probably need to use the optical spectrometer.

**Please clean up your lab area**