ATOMIC SPECTRUM OF HYDROGEN

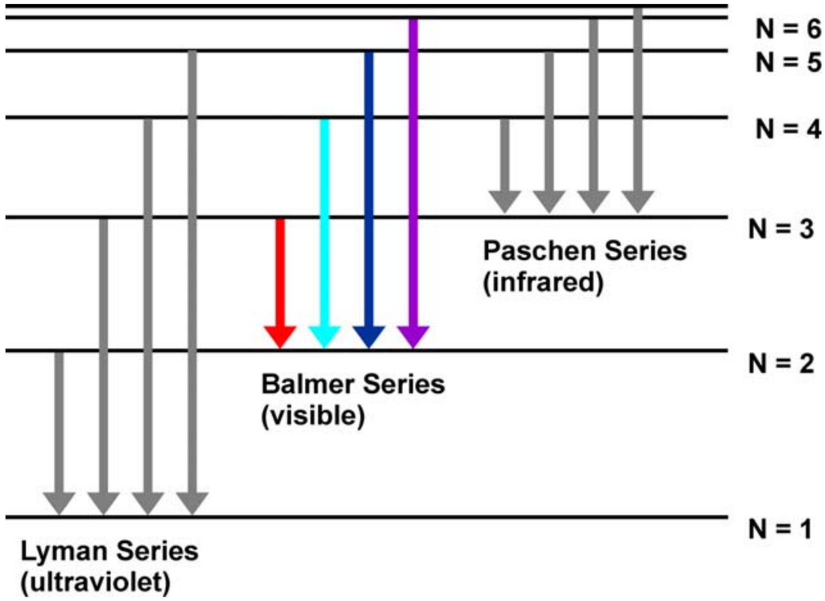
Introduction

White light is a combination of light of many different wavelengths. When passed through a prism, white light is spread into its constituent wavelengths, resulting in a **band spectrum**. A band spectrum resembles a rainbow and contains many different wavelengths of light. When light from a gas discharge tube is passed through a prism, the result is a **line spectrum**. In contrast to a band spectrum, a line spectrum contains only certain discreet wavelengths of light.

Each element gives a characteristic line spectrum, the lines arising from electron transitions within the atom. With one electron and one proton, hydrogen is the simplest element and gives the simplest line spectrum. For example, there are only four lines in the visible region of the hydrogen spectrum, at 656 nm (red), 486 mm (blue-green), 434 nm (blue-violet), and 411 nm (violet).

There are actually three series of lines in the hydrogen spectrum, one in the infrared region, one in the visible region, and one in the ultraviolet region. The ultraviolet series involves transitions to the first energy level (n = 1) of the hydrogen atom, the visible series involves transitions to the second energy level (n = 2), and the infrared series involves transitions to the third energy level. The energy of electromagnetic radiation is indirectly related to wavelength, meaning that the longer the wavelength the lower the energy. Therefore, given the four visible lines above, the red line at 656 nm is the longest wavelength and must correspond to the lowest energy transition ($3 \rightarrow 2$). Similarly, the blue-green line at 486 nm corresponds to the next lowest energy transition ($4 \rightarrow 2$), and so on.

Figure 1. The Hydrogen Spectrum



The lines of the hydrogen spectrum can be calculated from the equation $1/\lambda = R\,(1/n_1^2 - 1/n_2^2)$, where R is the Rydberg constant and has a value of $1.096776 \times 10^7\ m^{-1}$. The Rydberg constant is an empirical constant; meaning that it was not derived but rather was adjusted so that the Rydberg equation would fit the known wavelengths of the hydrogen spectrum. In this experiment we will use a spectroscope to determine the wavelengths of the visible lines in the hydrogen spectra. This data will then be used to calculate four experimental values the Rydberg constant, one for each wavelength.

The Experiment

The experimental setup to be used is shown in Figure 2. Rather than a prism, we will use a **diffraction grating** to spread the hydrogen spectrum into its constituent wavelengths. Diffraction refers to the bending of light waves around sharp edges or corners. A diffraction grating is simply a piece of glass with a series of closely spaced slits. As light passes though the grating, it bends around each of the slits. The angle through which light is diffracted depends upon the wavelength of the light, so a grating can spread light into its constituent wavelengths just as a prism can. The longer the wavelength the greater the angle of diffraction, so that the red line experiences the greatest angle of diffraction.

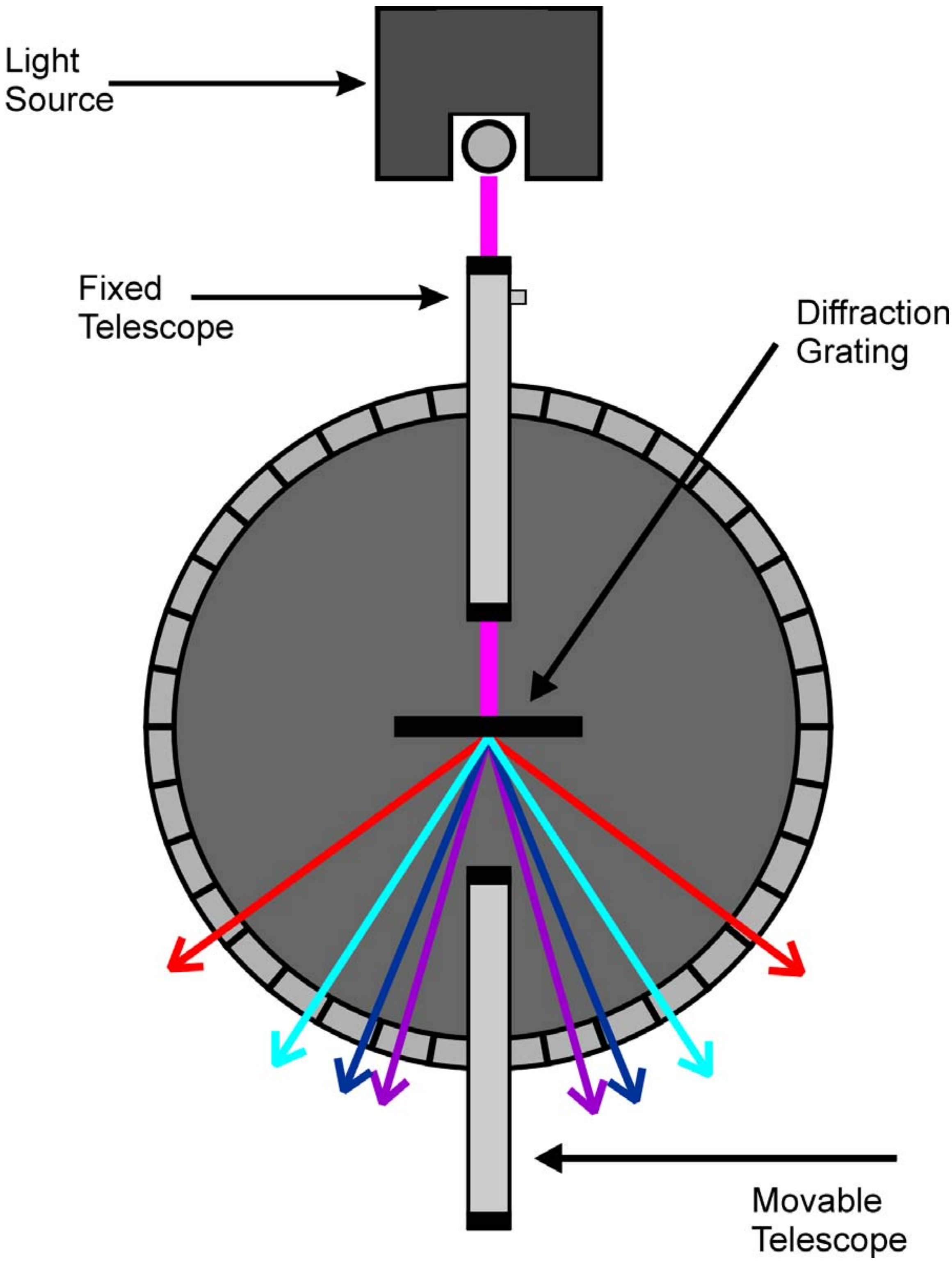
It is relatively simple to calculate wavelength from the angle of diffraction. For a diffraction grating, the **grating constant** is given by the equation $d = 1/N$ where N is the number of slits per unit length. For a particular wavelength of light, the wavelength of the light can be determined from the angle of diffraction using the equation $d \sin \theta = \lambda$. Suppose, for example, that a grating has 600 lines per millimeter. If the angle of diffraction is 20.65 degrees, what is the corresponding wavelength?

$$D = 1/N = 1/600\ mm^{-1} = 1.67 \times 10^{-3}\ mm$$

$$\lambda = d \sin \theta = (1.67 \times 10^{-3}\ nm)\ (\sin 20.65) = 5.89 \times 10^{-4}\ mm = 589\ nm$$

The spectroscope itself consists of several components. A large metal disk, called a **divided circle**, is used to measure the angles of diffraction. This employs a vernier scale, and is capable of recording the angle to a tenth of a degree. The spectrometer contains two telescopes, one that is fixed and one that is movable. The fixed telescope has a slit that controls the amount of entering light. A small knob at the end controls the slid width. If the slit width is too wide, a blurry image will be produced. If the slit width is too narrow, not enough light will enter. The movable telescope is fitted with cross hairs, which may be fixed on a particular spectral line. Each telescope also has a focusing ring on the end.

Figure 2. A bird's-eye view of the experimental setup



Procedure

1. Load the hydrogen lamp into the power supply and turn it on. Be careful not to touch the lamp sockets during operation as the lamp operates off very high voltage.

2. Be sure the spectroscope is lined up with the hydrogen lamp. The slit in the rear of the fixed telescope is rather narrow and must be lined up with the lamp.

3. Without the grating in place, line up the movable telescope with the fixed telescope and locate the image of the lamp in the eyepiece. Experiment with the slit width and the focusing rings to obtain a satisfactory image.

4. Place the grating in its holder. Since there is no angle between the two telescopes there is no diffraction, and you should still see the image of the lamp.

5. Rotating the movable telescope slowly to the left, locate each of the four lines and record the angle at which each line is observed.

6. Return the movable telescope to the center. Now rotate the movable telescope slowly to the right, and again record the wavelength at which each line is observed.

7. For each wavelength, calculate the angle of diffraction by taking the absolute value of the difference between the two readings. By recording each angle twice, from the left and then from the right, any errors which might arise from the grating not being perfectly perpendicular to the light are cancelled.

8. Based the angles of diffraction, determine the wavelengths of each lines.

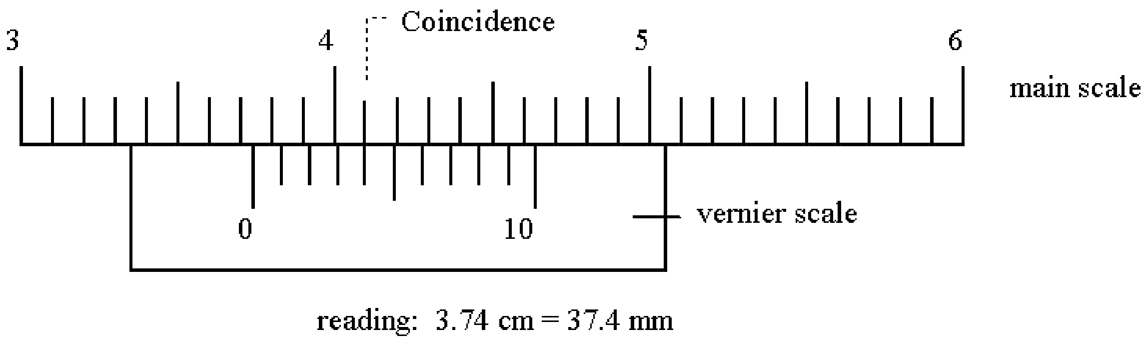
9. Using the Rydberg equation, determine an experimental value for the Rydberg constant, one for each wavelength. Remember that you must match each wavelength with the appropriate transition.

You may or may not see the line at 411 nm. This line is barely within the range of human vision, which only extends to 400 nm, and is often very faint or not visible at all. If you only see one violet line, it is the line at 434 nm you are seeing. If this is the case, simply base your calculations on the remaining three lines.

Reading A Vernier Scale

The spectroscope you will be using will most likely have a vernier scale. A vernier scale actually consists of two scales, a main scale and a movable scale. The gradations are smaller on the movable scale than on the main scale, so that 10 gradations on the smaller scale are equal to the 9 gradations on the larger scale.

Figure 3. A vernier scale



In reading a vernier scale, you first find the "0" on the vernier scale and find the first number immediately to the left on the main scale. In above example "0" on the vernier scale lies between the "7" and "8" so first two numbers of the measurement should be "3.7". Recall that in most measurements we estimate one more digit than we can read directly off a scale. If you were "eyeballing" this measurement you might guess 3.72, 3.73, or 3.74. But the vernier scale allows a better estimate of the last digit. To obtain the last digit, look for the line on the vernier scale that lines up with one the lines from the main scale. In this case, the fourth line on the vernier scale appears to line up with one line on the main scale; therefore the measurement should be recorded as 3.74.

Pre-Laboratory Exercise	**Name:**

1. Define the terms **refraction** and **diffraction**.

2. What is the difference between a continuous spectrum and a line spectrum? What type of spectrum is obtained from gas discharge tubes?

3. Use the Rydberg equation to calculate the first four lines of the visible portion of the hydrogen spectrum.

4. If a grating with 600 lines per mm were used, calculate the angle at which each of the above wavelengths would be observed.

Report Page 1	**Name:**

Number of lines per mm on grating:____________________

Grating Constant:_____________________________

Divided Circle Reading		**2θ**	**θ**	**sin θ**	**Computed wavelength**
Left	**Right**				

Transition	**Computed Wavelength (units in nanometers)**	**Rydberg Constant (units in meters)**
$n = 3 \rightarrow n = 2$		
$n = 4 \rightarrow n = 2$		
$n = 5 \rightarrow n = 2$		
$n = 6 \rightarrow n = 2$		