Atomic Spectra

Purpose: To study the emission spectra of dilute gases. To determine the wavelengths of light emitted by hot, dilute gases of atomic Hydrogen, Helium and Mercury. For the Hydrogen spectrum, to determine the values of the principal quantum numbers for the electron states prior to emission.

Equipment: Spectrometer, $\mathbf{15,000}\,\frac{\boldsymbol{lines}}{\boldsymbol{inch}}$ Diffraction Grating, High-voltage Power Supply, Helium, Mercury and Hydrogen Gas Tubes, Bubble Level, Auxiliary Light Source.

Introduction: In its simplest form, a spectrometer is nothing more than a prism and a protractor. However, because of the need for very sensitive detection and precise measurement, a real spectrometer is a bit more complicated. As shown in Figure 1, a spectrometer consists of three basic components; a collimator, a diffracting element, and a telescope. The light to be analyzed enters the collimator through a narrow slit positioned at the focal point of the collimator lens. The light leaving the collimator is therefore a thin, parallel beam, which ensures that all the light from the slit strikes the diffracting element at the same angle of incidence. This is necessary if a sharp image is to be formed. The diffracting element bends the beam of light. If the beam is composed of many different colors, each color is diffracted to a different angle. The telescope can be rotated to collect the diffracted light at very precisely measured angles. With the telescope focused at infinity and positioned at an angle to collect the light of a particular color, a precise image of the collimator slit can be seen. For example, when the telescope is at one angle of rotation, the viewer might see a red image of the slit, at another angle a green image, and so on. By rotating the telescope, the slit images corresponding to each constituent color can be viewed and the angle of diffraction for each image can be measured. If the characteristics of the diffracting element are known, these measured angles can be used to determine the wavelengths that are present in the light.

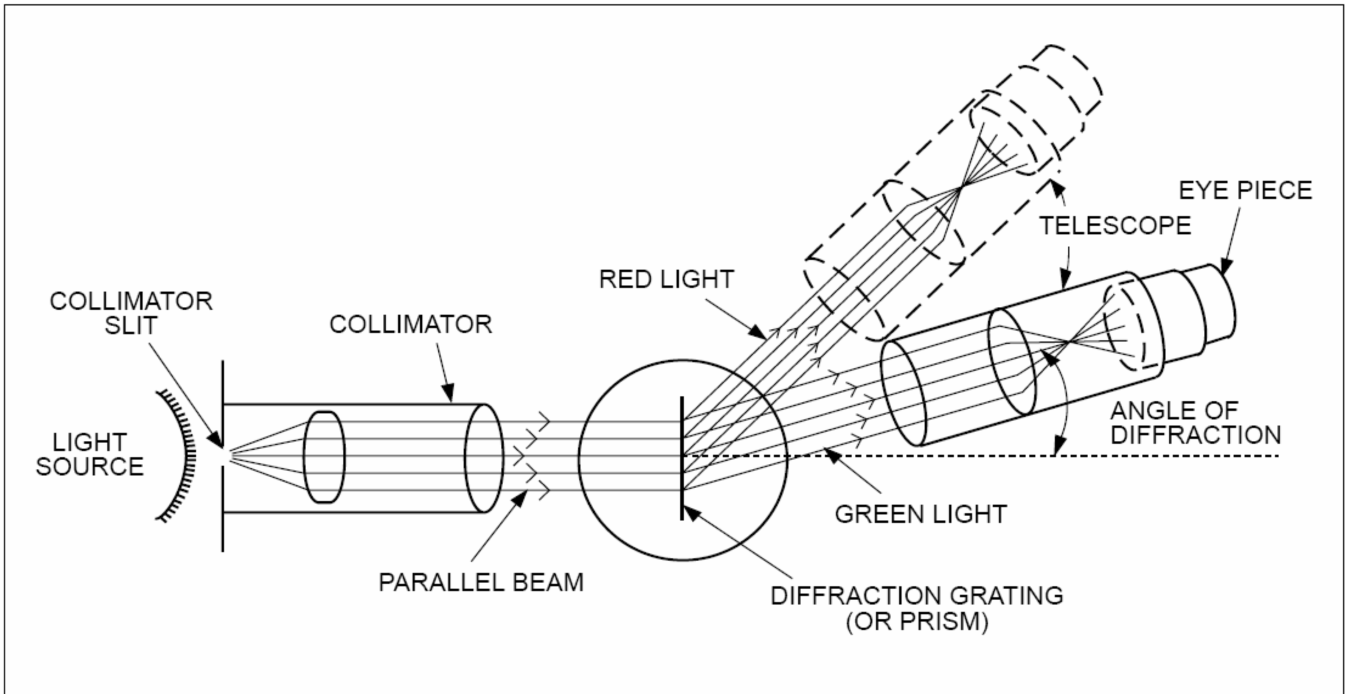

Figure 1 Schematic of Spectrometer Operation.

Procedure: For accurate results, the diffraction grating must be properly aligned with the optical axes of the telescope and collimator. Refer to Figure 2 to properly align the spectrometer. The spectrometer and the spectrometer table must be level.

Leveling the Spectrometer

1. Place the spectrometer on a flat surface, and place the bubble level on the spectrometer base. If necessary use paper or 3 X 5 cards to shim beneath the wood base until the fixed-base of the spectrometer is level.
2. Place the bubble level on the spectrometer table, and check that the spectrometer table is level. If necessary, the spectrometer table can be made level by adjusting the three thumbscrews on the underside of the table.

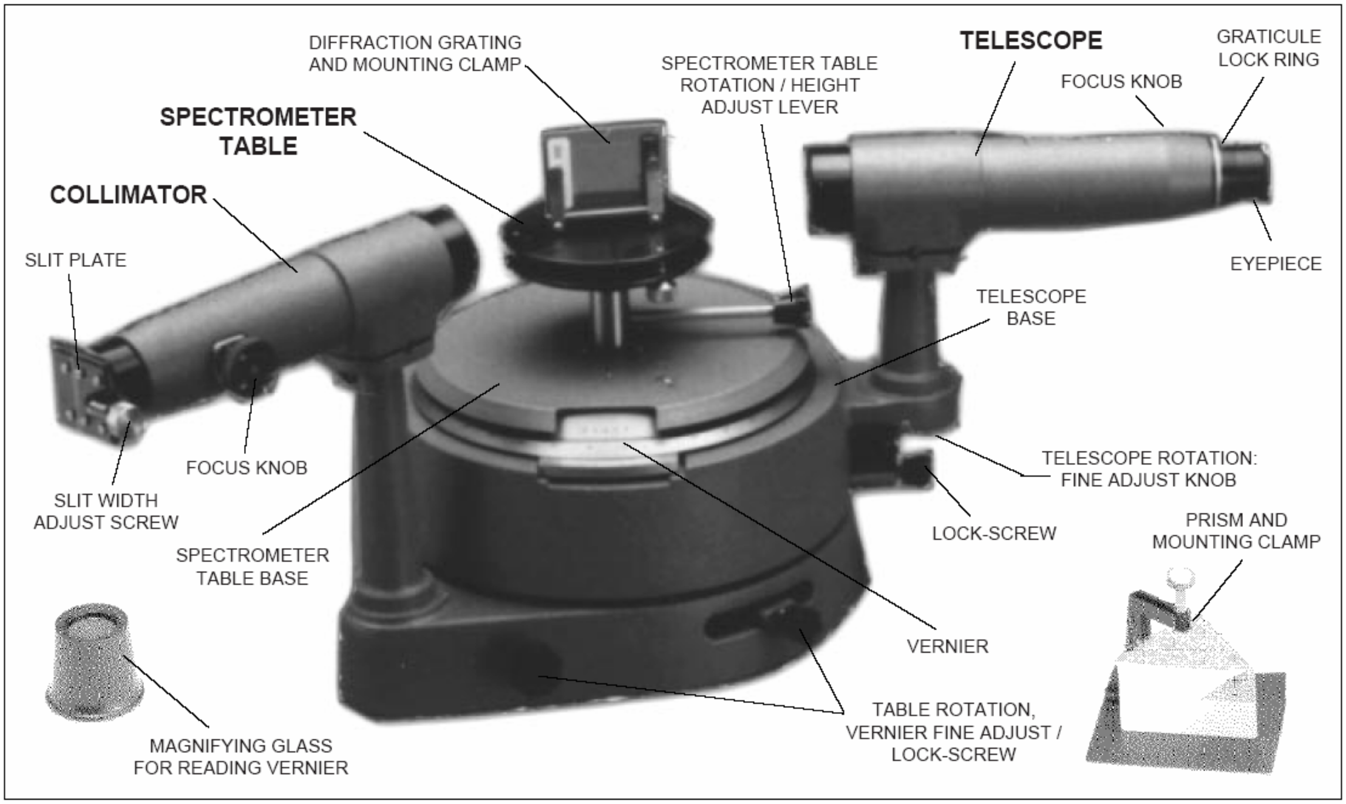

Figure 2 The Spectrometer and its Accessories.

Focusing the Spectrometer

3. While looking through the telescope, slide the eyepiece in and out until the cross-hairs come into sharp focus. Loosen the graticule lock ring, and rotate the graticule until one of the cross-hairs is vertical. Retighten the lock ring and then refocus if necessary.
4. Focus the telescope at infinity. This is best accomplished by focusing on a distant object (e.g.; out the window).
5. Check that the collimator slit is partially open (use the slit width adjust screw).
6. Align the telescope directly opposite the collimator as shown in Figure 3.
7. Looking through the telescope, *adjust the focus of the* ***collimator*** and, if necessary, the rotation of the telescope until the slit comes into sharp focus. ***Do not change the focus of the telescope during this step.***
8. Tighten the telescope rotation lock-screw, then use the telescope rotation fine adjust knob to align the vertical cross-hair with the fixed edge of the slit. If the slit is not vertical, loosen the slit

lock ring, realign the slit, and retighten the lock ring. Adjust the slit width for a clear, bright image.

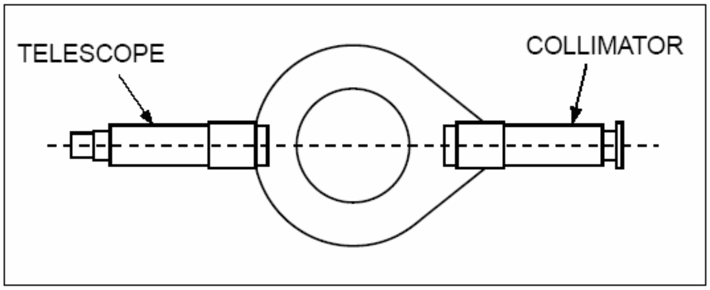

Figure 3 Telescope aligned opposite the collimator.

9. When the telescope and collimator are properly aligned and focused, the slit should be sharply focused in the center of the field of view of the telescope, with one cross-hair aligned with the fixed edge of the slit and the other perpendicular to the slit.

Measuring Diffraction Angles and Aligning the Diffraction Grating: When analyzing a light source, angles of diffraction are measured using the telescope vernier. Since first order spectra will be observed on both sides of the undiffracted beam, it is necessary to ensure that the diffraction grating is perpendicular to the beam of light passing through the collimator. Also, it's important to establish a vernier reading for the undeflected beam. All angles of diffraction are then measured with respect to that initial reading, as shown in Figure 4.

10. Refer to Figure 6. Loosen the spectrometer table lock-screw. Rotate the spectrometer table so that the engraved line on the spectrometer table is, as nearly as possible, colinear with the optical axes of the telescope and the collimator. Tighten the lock-screw.
11. Gently slide the diffraction grating into the clips of the mount at the center of the spectrometer table.

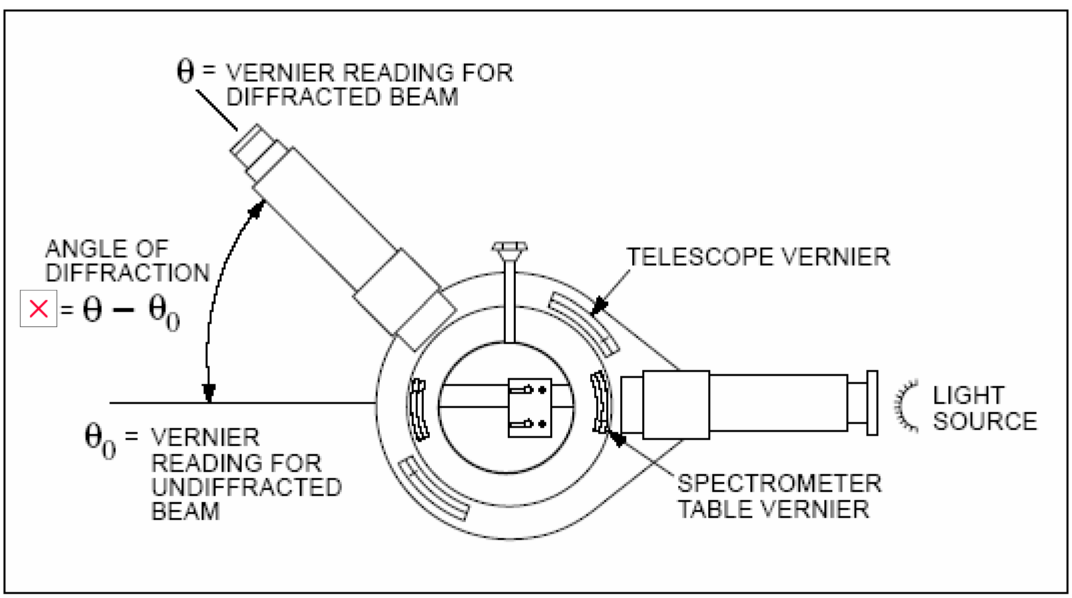

Figure 4 Measuring an angle of diffraction.

12. <u>Carefully</u> place the Helium gas tube into the high voltage power source. The tubes break easily, especially along the narrow mid-section. Plug in the power source and switch it on. The tubes

get very hot when operated for extended periods, and this reduces the lifetimes of the tubes as well, so endeavor to complete your measurements expeditiously! Place the glowing gas tube in front of the collimator's slit, as close to the slit as possible. Move the power supply to the left and right, very slightly, and observe what happens to the image when viewed through the telescope. Place the tube so that the slit is illuminated as uniformly as possible.

13. To obtain a vernier reading for the undeflected beam, align the vertical cross-hair of the telescope with the fixed edge of the slit image for the undeflected beam. Use the telescope rotation fine adjust knob, if necessary. Read the vernier scale. This is the zero point reading, θ_0.
14. Loosen the telescope rotation lock screw. With the room lights turned off, rotate the telescope counterclockwise until you see colored, diffracted images of the slit. When the cross-hairs are near the bright green line, tighten the telescope rotation lock screw and use the telescope rotation fine adjust knob to align the vertical cross-hair with the fixed edge of the bright green image. Read the vernier scale again. If this second reading is θ, then the actual angle of diffraction is $\theta' = \theta - \theta_0$, as shown in Figure 4. For Helium's green line $\theta' \cong 18°$.

Reading the Vernier Scale: NOTE: The scale on your spectrometer is slightly different than the following figure suggests. Unlike the figure, your spectrometer's degree plate has degrees and half degrees (30' of arc) only. Your vernier scale has minutes of arc only, while the figure's vernier scale has minutes and half minutes (30" of arc).

To read the angle, first find where the zero point of the vernier scale aligns with the degree plate and record this value. If the zero point is between two lines, use the smaller value. In Figure 5, below, the zero point on the vernier scale is between the 172° 20' mark and the 172° 40' mark on the degree plate, so the smaller value is 172° 20'. Now use the magnifying glass to find the line on the vernier scale that aligns most closely with any line on the degree plate. In the figure, this is the line corresponding to a measurement of 12' 30" of arc. Add this value to the reading recorded above to get the correct measurement to within 30 seconds of arc: that is, 172° 20' + 12' 30" = 172° 32' 30".

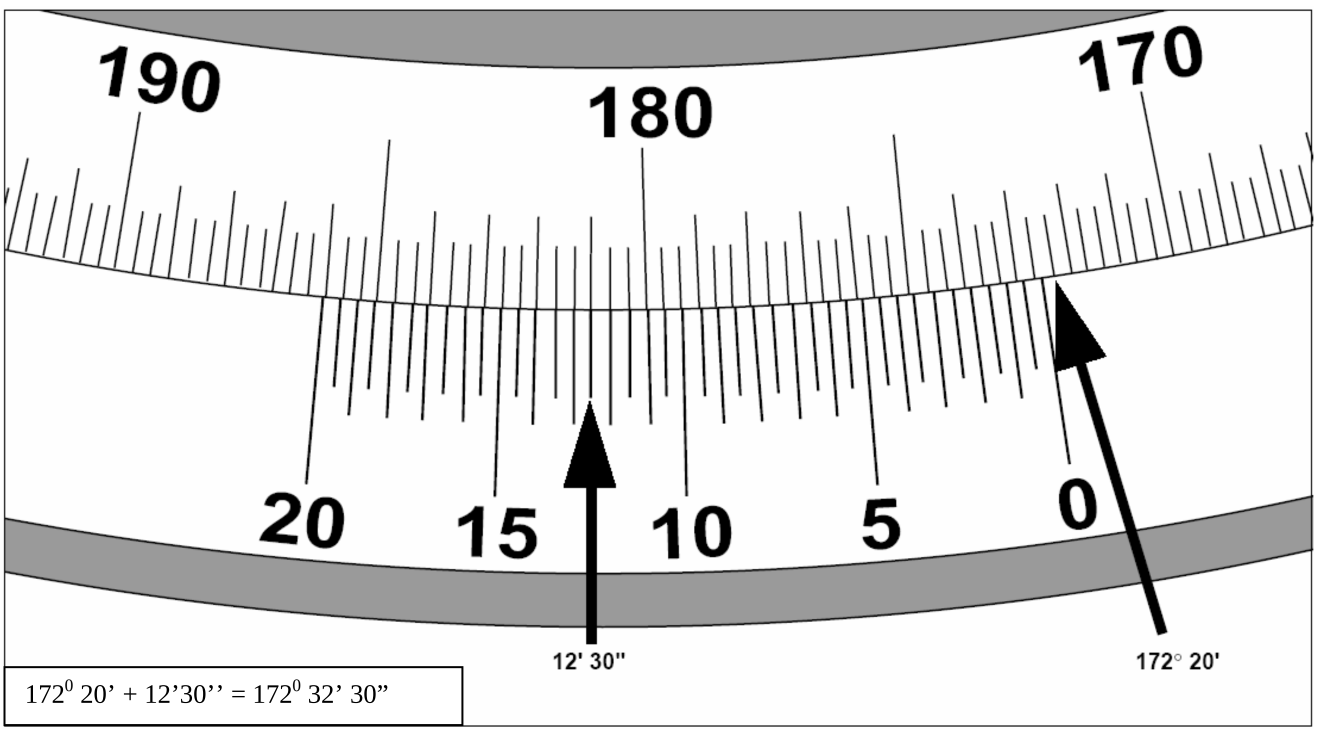

Figure 5 Reading the vernier scale.

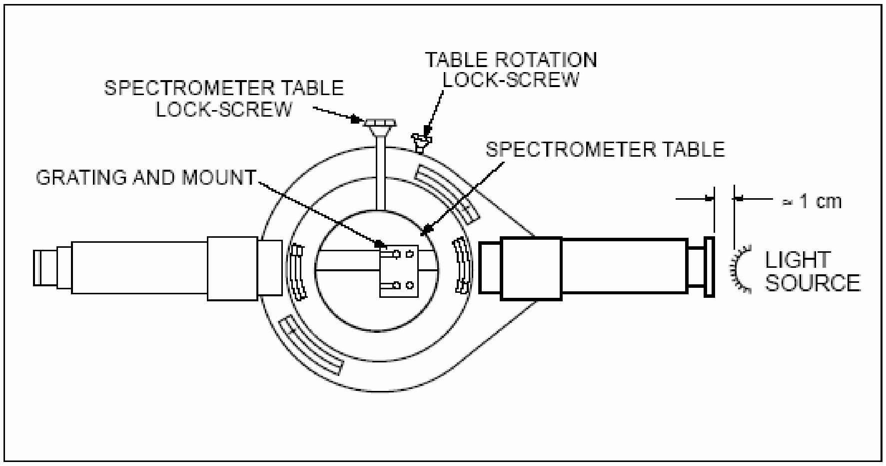

Figure 6 Aligning the diffraction grating.

Finally, you will verify that the alignment process is complete.

15. The diffraction grating diffracts the incident light into identical spectra on either side of the undiffracted beam, as shown in Figure 7. Loosen the telescope rotation lock screw and rotate the telescope clockwise, past the undiffracted beam, to find the corresponding slit image (the bright green line of Helium) on the other side. As before, tighten the telescope lock screw when you are near the image whose angle you wish to measure, then use the telescope fine adjust knob to align the cross-hair with the diffracted image. Measure the angle of diffraction for this image.
16. If the grating is perfectly aligned, the diffraction angles for corresponding slit images will be identical and you are finished with the alignment procedure and are ready to take data!
17. If the angles are not identical, calculate their average value. Loosen the telescope lock screw and rotate the telescope counterclockwise, past the undiffracted beam, until the telescope is set to the average angle you calculated. (Tighten the lock screw, and use the fine adjust knob while reading the angle on the vernier scale.) Now, loosen the table rotation lock screw (shown in Figure 6), and adjust the table rotation fine adjust knob (shown in Figure 7) as you look through the telescope. When the cross-hair is aligned on the bright green image, tighten the table rotation lock screw. The spectrometer should now be properly aligned.

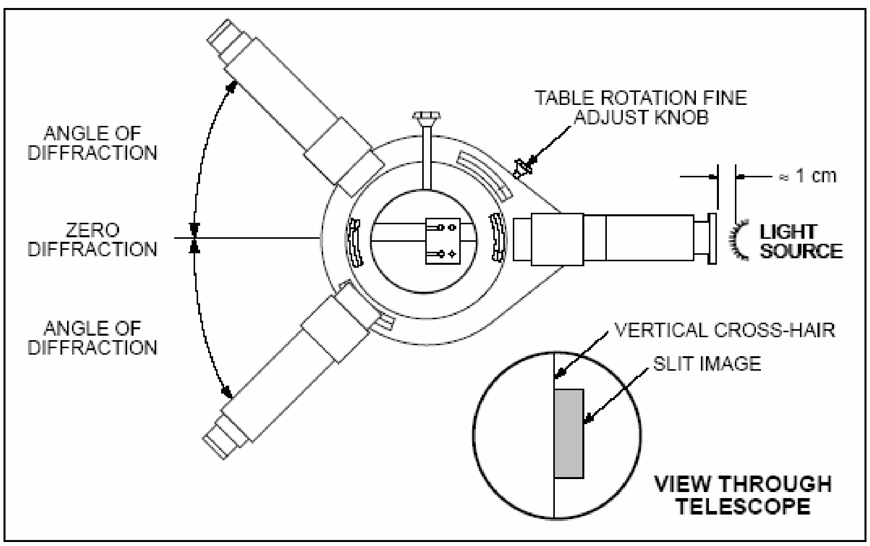

Figure 7 Ideal alignment yields identical angles of diffraction.

Emission Spectra Viewed Through the Spectrometer

When light passes through a diffraction grating each wavelength that is present in the incident beam is diffracted to an angle that satisfies the following expression: $\lambda = \frac{d \sin\theta}{m}, m = 0, 1, 2, \ldots \quad Eq.1$

For each of the three elements considered, you will measure the first order spectrum diffracted to either side of the zeroth order spectrum, so in each case $m = 1$ and d is the space between slits on the diffraction grating which you can calculate from the number of lines per inch. λ is the wavelength of the observed line, and you will calculate the wavelength from $Eq.1$ after you have measured the pair of angles for each line and determined their average value.

The Spectrum of Mercury

18. Replace the Helium gas tube with the Mercury gas tube. Take care that you do not make any adjustments to the alignment. Do make sure that the glowing Mercury source illuminates the slit uniformly.
19. Rotate the telescope counterclockwise and measure the angles for the 3 or 4 bright lines that you see. Two yellow lines may appear overlapping if your slit is fairly wide. In this case, adjust the width of the slit so that you can measure the angle for each line. Make a table in your lab notebook that records the color, relative intensity, θ_{ccw} and θ_{cw} for each of the spectral lines.

    Also include columns for $\bar{\theta} = \frac{\theta_{ccw} + \theta_{cw}}{2}$, $\sin\bar{\theta}$, λ, λ_{theory} (see Table 1), and $\%difference$.
20. Measure the angles θ_{cw} for each of the lines observed. Fill in the table with the calculated values.

The Spectrum of Helium

21. Repeat steps 18 – 20 using the Helium gas tube in place of Mercury, and collect data for at least 6 lines.

The Spectrum of Hydrogen

22. The Hydrogen gas tube is particularly susceptible to damage from overheating. It is recommended that you power the tube for only 30 seconds at a time; then wait 30 seconds before applying power again. Repeat steps 18 – 20 using the Hydrogen gas tube in place of Helium, and collect data for 3 or 4 lines.
23. The wavelengths of light that make up the Balmer Series satisfy

    $\frac{1}{\lambda} = R\left[\left(\frac{1}{2^2}\right) - \left(\frac{1}{n^2}\right)\right], n = 3, 4, 5, \ldots \quad Eq.2$, where $R = 1.097x10^7 m^{-1}$ is the Rydberg constant.

    In your lab notebook, solve $Eq.2$ for n, the initial principle quantum number for the state occupied by the electron before de-exciting to the $n = 2$ state with the emission of a photon with wavelength λ. For each wavelength you observed, determine the corresponding initial principle quantum number for the state occupied by the electron. The table in your lab notebook for Hydrogen should include these n values, as well as the data collected for the other gases.

The letters to the right of the wavelength numbers denote the color of the particular line.
<u>LEGEND:</u> r = red, o = orange, y = yellow, v = violet, b = blue, g = green, ro = red-orange, bg = blue-green.
<u>NOTE:</u> $\mathbf{1\AA = 10^{-10}\,m}$

Table 1 Known spectral wavelengths of some elements.

Element	***Wavelength***	***Element***	***Wavelength***	***Element***	***Wavelength***
Argon	v 4159 Å v 4164 Å v 4182 Å v 4191 Å v 4198 Å v 4201 Å b 4259 Å b 4272 Å b 4300 Å b 4334 Å b 4345 Å b 4511 Å b 4596 Å bg 4628 Å bg 4702 Å g 5496 Å y 5651 Å	**Neon**	g 5401 Å y 5852 Å y 5882 Å o 6030 Å o 6074 Å o 6164 Å ro 6217 Å ro 6266 Å r 6334 Å r 6383 Å r 6402 Å r 6506 Å r 6599 Å r 6929 Å r 7032 Å	**Strontium**	v 4077 Å b 4607 Å r 6878 Å r 7070 Å
Helium	b 4388 Å b 4471 Å b 4713 Å g 5016 Å y 5876 Å r 6678 Å r 7060 Å	**Mercury**	v 4047 Å v 4078 Å b 4358 Å g 4916 Å g 5461 Å y 5770 Å y 5791 Å r 6907 Å	**Potassium**	v 4046 Å r 6911 Å r 6939 Å
Hydrogen	v 4102 Å b 4340 Å bg 4861 Å r 6563 Å	**Lithium**	v 4132 Å b 4603 Å o 6104 Å r 6708 Å	**Sodium**	y 5890 Å y 5896 Å