Diffraction gratings and spectrometers.

Physics introduction

Physics concepts covered in this lab

- The wave nature of light (see Appendix).

- Diffraction gratings (see Appendix).

- Quantization of energy in atomic spectra (see Appendix).

Pre-lab questions about the physics

Discussion question: For the examples in the double-slit experiment, we were often given numbers like $d = 5 \times 10^{-4} m$. For a diffraction grating with 600 lines/mm, what is d?

The experiment

Introduction

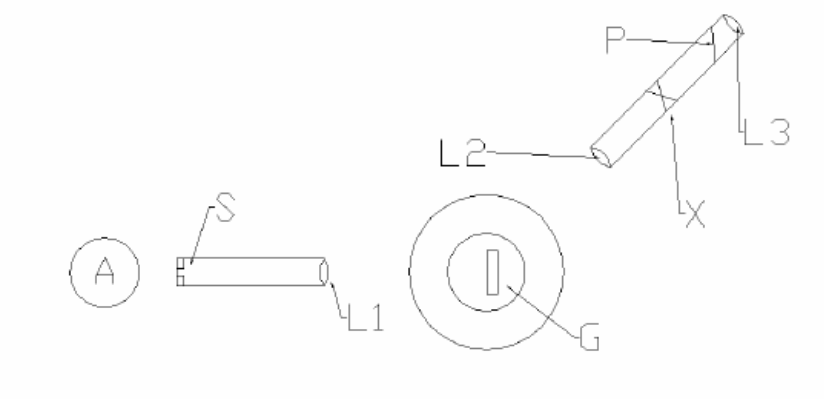

Figure 1: Schematic of experimental setup.

Introduction

In this lab you will use a diffraction grating spectrometer to measure the spectra of sodium vapor. Fig. 1 provides a schematic of the spectrometer. Light generated by a lamp A enters the spectrometer through slit S. Lens L1 collimates the light from the slit onto the grating G. After passing through the grating the light diffracts at angle

$$\theta = \arcsin \frac{\lambda}{d}$$

. Here d is the line spacing of the grating (1/600 mm) and λ the wavelength of the light.

Lens L2, focuses the light from the grating to an image point near the focus of the eyepiece L3. Lens L3 magnifies the image for your eye. Halfway down the barrel which holds L2 and L3 is a cross hair, X. This is used for centering the diffraction lines. There is also a small glass plate P, just in front of the eyepiece that can be used to direct an external light to illuminate the cross hair.

Alignment

Set up the spectrometer on a circular wooden stand and one of the Sodium lamps on one of the thinner square pieces of wood. The slit of the spectrometer should fit neatly into the aperture on the lamp.

Initial alignment

1. Set the slit opening to 0.25 mm.
2. Place a 600 line/mm diffraction grating at the center of the spectrometer. Avoid touching the face of the grating or any of the lenses. Use the release knob on the base of the spectrometer to coarsely align the face of the spectrometer parallel to the collimating lens, L1.
3. Check that the three thumbscrews on the grating mount are adjusted so that the grating is perpendicular to the ground.

Fine alignment

1. Sight along the viewing barrel directly at the slit. Adjust the vertical height of the collimating barrel with the thumbscrew to center the line vertically in the eyepiece.
2. Swing the viewing barrel clockwise until you have the spectrometer centered on the first bright yellow diffraction line. The vertical height of the slit image has probably moved. Adjust the three thumbscrews that hold the grating until the image of the slit is again centered.
3. Swing the viewing barrel counterclockwise to the symmetrically located diffraction line at the other side of the center. Check that the slit remains centered vertically on the image of the line.

Measurement of the Sodium Spectra

1. Swing the spectrometer arm clockwise to the position of the first order yellow line (this line is call the sodium "D" line). Find the exact position of the center of the line using the cross hair. For fine adjustment of the spectrometer you can lock the detector arm with the thumbscrew and use the fine adjust screw. Read the position of the center of the peak using the magnifying glass over the dial. There is a vernier scale above the gauge that will allow you to read the dial to within 1 minute of arc (1/60 of a degree).
2. Swing the spectrometer to measure the position of the "D" line at negative angle and measure the position.
3. Even after careful alignment, the diffraction grating will not be exactly parallel to the incident light. One way to overcome this problem is to calculate the wavelength as

$$\lambda = d\frac{\sin(\theta_+) + \sin(\theta_-)}{2} \tag{1}$$

By calculating the average of the sines of the angle you will remove most of the error associated with the light not being incident completely perpendicular to the grating. If you see a significant difference between + and - then you should make a small adjustment to the grating angle in order to make the angles come out closer to even.

4. Each lab partner should now measure both the first order ($d \sin\theta = \lambda$) and second order ($d \sin\theta = 2\lambda$) diffraction peaks for the yellow sodium line. Estimate the uncertainty in your value for the wavelength. You can determine the uncertainty from the variation in your results. If your measurements are the same, then you should try to determine the positions with more precision by interpolating between numbers on the dial. Describe carefully in your notebook how you calculate the uncertainty.

Measure the other spectral lines of sodium

1. Measure the angles corresponding to the other colored lines from Sodium. Measure both orders and both positive and negative angles.

2. Combine all your measurements with your lab partners and estimate the uncertainty in the wavelengths of the lines.

3. Estimate the relative intensity of the lines. (E.g. Very bright, bright, weak, very weak).

Measure the splitting of the sodium D lines

1. The D line is a doublet with wavelengths 589.6 nm and 589.0 nm. Adjust the incident slit as narrow as you can, while still getting a single, well- defined line when viewed at =0 through the eyepiece.

2. Go to the first- and second-order peaks for the yellow line and measure the splitting. Make careful notes in your notebook describing what steps you take to get the most accurate measurement of the line splitting that you can.

3. Now go on and measure the splittings of the other colored lines.

Measure the spectrum of atomic hydrogen

1. There is one hydrogen lamp source available for the laboratory. When the lamp is available, use this to measure the wavelengths of the lines from hydrogen.

Diffraction Grating Pre-Lab Questions

1. Explain why the light has to be collimated before hitting the grating.
2. The zero-angle of the spectrometer is defined by the position where the viewing telescope directly images the source slit. For a perfectly aligned spectrometer, the normal to the surface of the diffraction grating will be exactly aligned to zero. Suppose that, due to mis-alignment, the face of the diffraction grating is tilted by an angle, α. Consider a diffraction peak which would normally appear at angles $+\theta$ and $-\theta$, (depending on which side of the zero angle you are looking). Calculate which angles the peak appears when the grating is tilted by α.
3. In order to correct for a misalignment of the diffraction grating you measure the position of a peak on either side of the spectrometer. Derive formula 1 for the wavelength terms of the two measured angles θ_- and θ_+ which you find when the grating is tilted by α.

Diffraction Grating Lab Report Guidelines

1. Introduction
   - Briefly describe what the lab is about.
2. Procedure
   - Discuss specifically how you aligned the spectrometer. Which steps were very easy and which steps required particular care?
   - Discuss what you had to do to measure your lines most accurately. What value of slit size did you choose? Why didn't you use a smaller or a wider size?
   - Discuss any special precautions you took. How did you align the cross hairs? Was it necessary to turn off the room lights. When did you need to use the fine adjustment screws? Did you ever have to
3. Other
   - Answer any questions you find throughout the lab procedure.