Experiment 6.

Determination of wavelength of a laser using a grating spectrometer

Theory

The diffraction of classical waves refers to the phenomenon wherein the waves encounter an obstacle that fragments the wave into components that *interfere* with one another. Interference simply means that the wavefronts add together to make a new wave which can be significantly different than the original wave. For example, a pair of sine waves having the same amplitude, but being 180° out of phase will sum to zero, since everywhere one is positive, the other is negative by an equal amount.

Although the diffraction of light waves ostensibly appears the same as the diffraction of classical waves such as water or sound waves, it is an intrinsically quantum mechanical process. Indeed, while the diffraction pattern of a wave of water requires the simultaneous presence of a macroscopic number of water molecules, (of the order of 10^{24}), an optical diffraction pattern can be built up over time by permitting photons to transit the diffracting obstacle *one at a time!*. This is really pretty amazing if you think about it.

It is important to understand the physical processes that are occuring that give rise to the diffraction phenomenon. For the sake of concreteness, we will consider the diffraction of light through a *diffraction grating*, which is the device that we will be using in today's lab. A diffraction grating consists of a transparent material into which a very large number of uniformly spaced wires have been embedded. One section of such a grating is shown in figure 1. As the light impinges on the grating, the light waves that fall between the wires propagate straight on through. The light that impinges on the wires, however, is absorbed or reflected backward. At certain points in the forward direction the light passing through the spaces (or slits) in between the wires will be in phase, and will constructively interfere. The condition for constructive interference can be understood by studying figure 1: Whenever the difference in pathlength between the light passing through different slits is an integral number of wavelengths of the incident light, the light from each of these slits will be in phase, and the it will form an image at the specified location. Mathematically, the relation is simple:

$$d \sin\theta = m\lambda$$

where d is the distance between adjacent slits (which is the same is the distance between adjacent wires)[1], θ is the angle the re-created image makes with the normal to the grating surface, λ is the wavelength of the light, and $m = 0, 1, 2, \ldots$ is an integer.

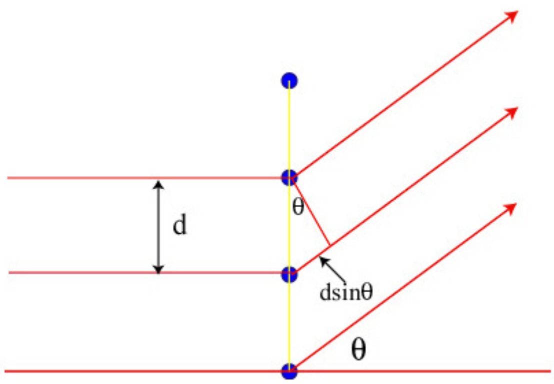

FIG. 1: Geometry determining the conditions for diffraction from a multi-wire grating

Diffraction gratings can be used to split light into its constituent wavelengths (colors). In general, it gives better wavelength separation than does a prism, although the output light intensity is usually much smaller.

By shining a light beam into a grating whose spacing d is known, and measuring the angle θ where the light is imaged, one can measure the wavelength λ. This is the manner in which the atomic spectra of various elements were first measured. Alternately, one can shine a light of known wavelength on a regular grid of slits, and measure their spacing. You can use this technique to measure the distance between grooves on a CD or the average spacing between the feathers on a bird's wing.

Consider figure 2, which shows the set-up for a diffraction grating experiment. If a monochromatic light source shines on the grating, images of the light will appear at a number of angles—θ_1, θ_2, θ_3 and so on. The value of θ_m is given by the grating equation shown above, so that

$$\theta_m = \arcsin\left(\frac{m\lambda}{d}\right)$$

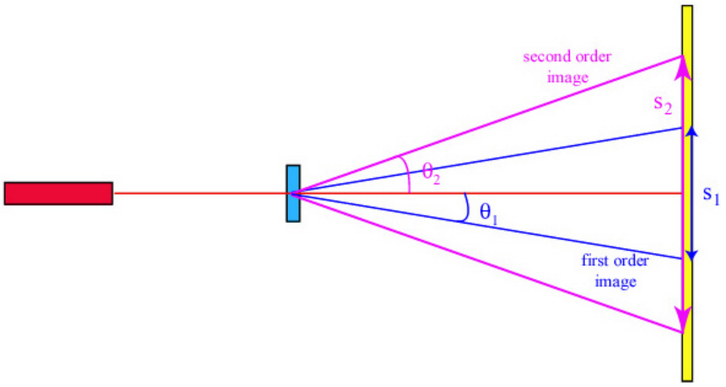

FIG. 2: Experimental set-up for measuring wavelengths with a diffraction grating

The image created at θ_m is called the m^{th} order image. The 0^{th} order image is the light that shines straight through. The image created by this interference pattern appears at an angle of $\theta = 0$ no matter what the wavelength or grating spacing is. Since it gives you no information about the wavelength λ, it is not particularly interesting. In this lab we will be looking at the first and second order diffraction images of a laser whose wavelength is known, measure d of the grating using that, and then use that d to find out the wavelength of an unknown laser.

Apparatus and Procedure:

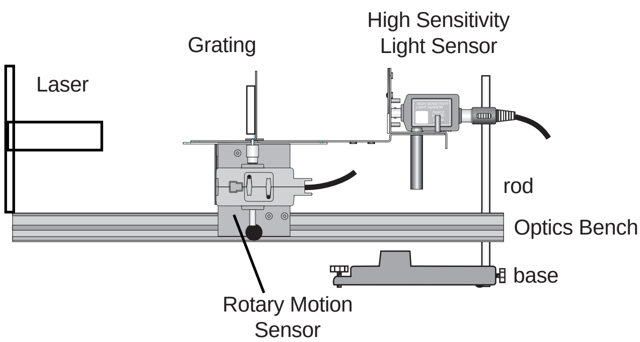

Figure 1: Equipment Setup

1. Align the laser into the grating and check for the zero and higher order diffracted spots. Ensure that the spots fall directly on a certain slit mounted on the detector plate.

2. Connect the ScienceWorkshop interface to the computer, turn on the interface. Start Data Studio .

3. Connect the High Sensitivity Light Sensor cable to Analog Channel A. Connect the Rotary Motion Sensor cable to Digital Channels 1 and 2. For the light sensor, select both light intensity and voltage options and set gain to 1.

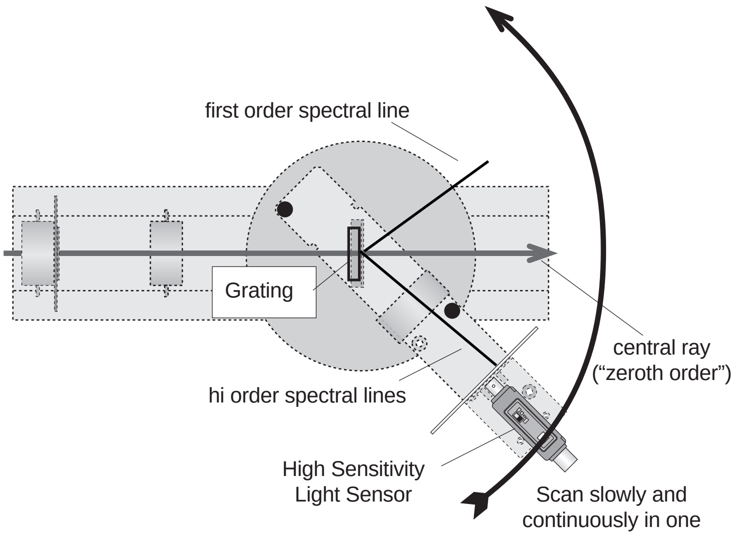

Figure 2: Scanning the Spectrum

3. In the *Data Studio* program, select the Rotary Motion Sensor and connect it to Digital Channels 1 and 2 and select the Light Sensor and connect it to Analog Channel A.
4. In the program, set up the Rotary Motion Sensor for high resolution (1440 Divisions per Rotation) and set the sample rate to 20 Hz, or 20 measurements per second.
5. In the Data Studio program, use the Calculator to create a calculation of Actual Angular Position based on the Angular Position measurement made by the Rotary Motion Sensor and the ratio of the radius of the Spectrophotometer's Degree Plate to the radius of the small post on the Pinion. Alternarely, find out a calibration between movement of the motion sensor and the degree plate by moving the degree plate by a known amount and noting the angle measured by the motion sensor. Repeat this for several angles of the degree plate to get the average scale factor.
6. Start a new experiment in Data Studio, select the graph display and plot a graph between the voltage of the detetor and scaled angle.
7. Find out the values of angle for different orders and obtain the value of d assuming a value of 650 nm as wavelength of the laser.
8. Try different slit-widths and obtain an average value of d with SD.
9. Repeat the experiment with the unknown laser. Find out the wavelength of the laser by measuring the first and second order diffracted patterns for the unknown laser. Give values of mean wavelength along with SD.

Results and Discussions:

1. All measurements need to be given with associated errors. Propagate errors to find out the total error in the unknown wavelength.
2. Discuss the effect of increasing slit width especially in the context of resolving closely spaced spectral lines.