DIFFRACTION GRATING

OBJECTIVE: To use the diffraction grating in the formation of spectra and in the measurement of wavelengths.

THEORY: The operation of the grating is depicted in Fig. 1 on page 3. Lens 1 produces a parallel beam of light from the single slit source A to the diffraction grating. The grating itself consists of a large number of very narrow transparent slits equally spaced with a distance D between adjacent slits. The light rays numbered 1, 2, 3, etc. represent those rays which are diffracted at an angle θ by the grating. Lens 2 is used to focus these rays to a line image at B. Notice that ray 2 travels a distance $x = D \sin\theta$ more than 1, ray 3 travels x more than 2, etc. When the extra distance traveled is one wavelength, two wavelengths, or N wavelengths, constructive interference occurs. Thus, bright images of a monochromatic (single color) source of wavelength λ will occur at position B at a diffraction angle θ if

$$\mathrm{Sin}(\theta_N) = N\lambda / D \quad \text{where } N = 0, 1, 2, 3, ... \tag{1}$$

The images generally are brightest for $N=0$ ($\theta_0 = 0$), and become corresponding less bright for higher N. Since, for a given value of N, the angle at which constructive interference occurs depends on λ, a polychromatic light source will produce a SERIES of single color bright images. There will be an image for each wavelength radiated by the source. Each image will have a color corresponding to its wavelength, and each image will be formed at a different angle. In this manner a spectrum of the light source is formed by the grating. If the grating constant D is known, then a measurement of the angle θ_1 for each color **allows the wavelength of each color in the spectrum to be determined** with the above equation. In this experiment, the first order spectrum ($N = 1$), will be used so that Eq. (1) becomes

$$\lambda = D \sin\theta \quad . \tag{2}$$

PROCEDURE:

Your lab instructor will tell you how to focus the various lenses on the grating spectrometer. Make the adjustments according to the instructions.

In the following steps, the spectra of five different sources will be formed and the angle at which each color is diffracted will be measured. A first order spectrum can be observed on both sides of the zero order spectrum. In order to correct for misalignment of the spectrometer, record the angular positions of each color in both first order spectra and use the average value of θ in Eq. (2) to calculate the wavelength. The three parts below may be performed in any order, depending on which light source is available.

Part 1: Calibration: Determining *D* with a Sodium light

Using the **sodium** light source, measure the angles for the first order spectral line for the yellow color (the only color!). Record your data in the table on the last page.

REPORT:

With the information that the sodium yellow light has a wavelength of **589.3 nm**, calculate the grating constant *D*. The manufacturer of the grating says that there are 600 lines per millimeter. (The number of slits or lines per length is called the *grating constant.*) Thus, the distance D between lines should be (1/600)mm = 1,667 nm. Compare your value of *D* with that derived from the manufacturer's information of 1,667 nm.

Part 2: Determining Wavelengths for Hydrogen, Helium and Mercury

1. Using the **hydrogen** light source, measure the angles for the first order spectral lines for the three brightest colors in the spectrum that you see. Record your data in the table.

2. Using the **helium** light source, do the same for at least five colors in the spectrum.

3. Using the **mercury** light source, do the same for at least four colors in the spectrum.

REPORT:

Using your **experimental value for *D***, calculate the wavelength for each color observed for Hydrogen, Helium and Mercury. Compare your results with the standard values listed on the last page and compute a percent error.

Part 3: White Light and Range for Visible Wavelengths

The **white light** source is an ordinary incandescent bulb. A tungsten filament is heated by sending a current through it. The tungsten gets so hot and the electrons on its surface vibrate with so much energy that they emit visible light. This light does NOT come from transitions between atomic energy levels, but from the energetic electrons. This type of light is called *thermal radiation.* Instead of having only certain wavelengths in the light, the light from thermal radiation has a continuous distribution of wavelengths. Its spectrum is said to be *continuous* instead of *discrete.* Measure the angles of the **far ends** (far red and far violet) of the visible spectrum and calculate the shortest and longest wavelength of light that you can see.

REPORT:

Calculate the wavelengths of the ends of the visible light.

OVERALL REPORT:

1. What is a generally stated range of wavelengths for visible light? Do all your wavelengths (from Parts 1,2,3) fall within this range?

2. Are your wavelengths for the same colors about the same?

3. Is your D close to the manufacturer's D (Part 1)?

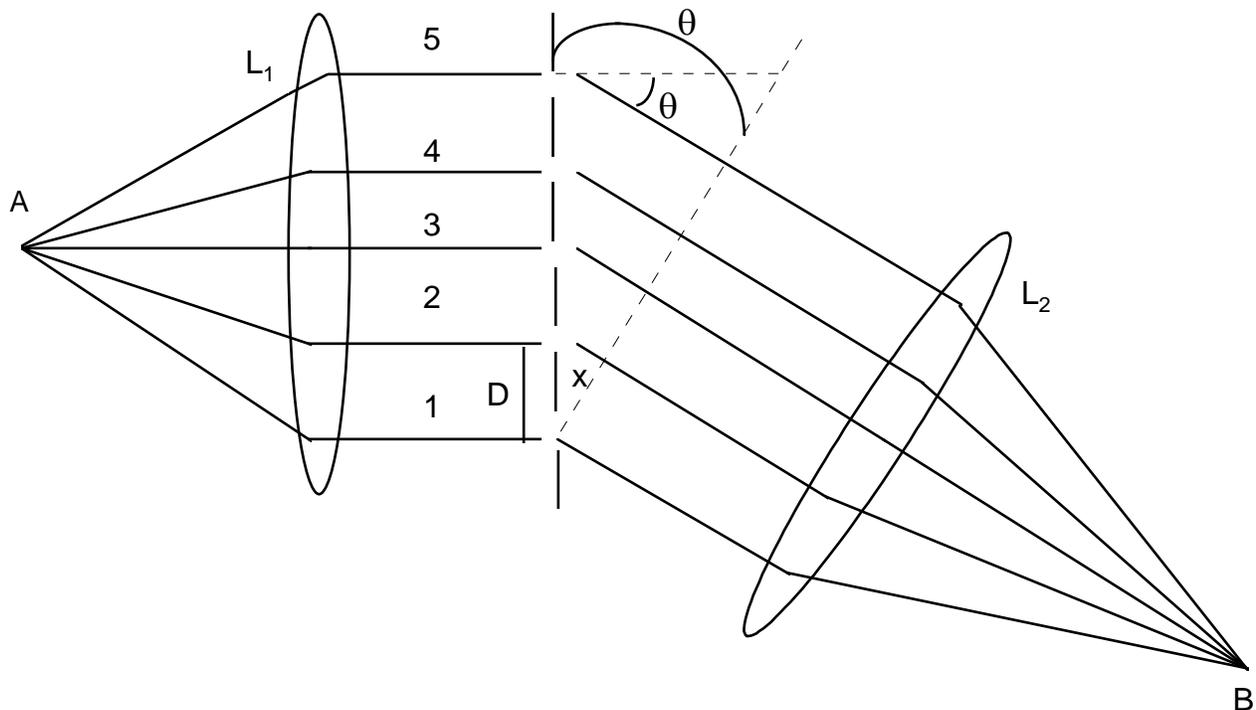## The Diffraction Spectrometer

Fig. 1

In the above figure, point A indicates a point source. (Actually A is usually a line source where the line is directed out of the page. This is accomplished with a slit.) L_1 is a lens to make the diverging rays from the slit become parallel. D is the distance between adjacent lines in the diffraction grating. The distance x is the extra distance each beam of light goes from its neighbor. This extra distance depends both on D and on the angle θ [$x = D \sin\theta$]. The angle θ can be measured on the spectrometer (actually it is the angle between the straight-through direction and the direction of the telescope arm of the spectrometer). L_2 is a lens used to focus the parallel light coming from the diffraction grating to a point (e.g., the lens of the eye focusing the light to a point on the retina, or the lens of a camera focusing the light onto film). In our case, L_2 is the first of two lenses used as a telescope to capture more of the light. It is followed by a cross-hair (mounted on a plate of glass) and the second lens of the telescope. Both L_2 and the third lens as well as the cross-hairs are mounted on the movable arm of the spectrometer. A bright image is seen at point B only if $x = N\lambda$, the condition for constructive interference. A

measurement of θ, then, allows for the determination of the wavelength λ. By moving the arm, the angle θ changes, which causes the distance x to change, which allows for the measurement of different wavelengths, i.e. a measurement of the wavelength spectrum.

DATA TABLE

note: $\theta\text{-ave} = |\theta_{left} - \theta_{right}| / 2$

color	θ_{left}	θ_{right}	θ-ave	D-calc	D-manufacturer	% diff
Sodium						
yellow					1,667 nm	

color	θ_{left}	θ_{right}	θ-ave	λ-calc	λ-standard	% diff
Hydrogen						
1.						
2.						
3.						
Helium						
1.						
2.						
3.						
4.						
5.						
Mercury						
1.						
2.						
3.						
4.						
Visible						
violet						
red						

Spectrum Information:

color	HYDROGEN	MERCURY	HELIUM
deep violet	411 nm	406 nm	403 nm
blue/violet	435 nm	436 nm	439 nm, 447 nm
green/blue	487 nm	492 nm	471 nm, 492 nm, 505 nm
yellow /green	*none*	546 nm, 578 nm	588 nm
red/orange	658 nm	623 nm	668 nm, 706 nm

*Note: Color names are somewhat subjective; choose your wavelengths based on which are closest to your values, and then comment on your names for these colors.