Diffraction Grating and Interference

APPARATUS

1. Spectrometer
2. Diffraction grating
3. Mercury arc lamp
4. Board for mounting glass plates
5. Two plane parallel plates of glass
6. Aluminum stand equipped with a lens, a mirror inclined at 45°, and an index.
7. Sodium lamp
8. Metric ruler (30 cm)

On the instructor's desk the student will find:

9. A hydrogen Geissler tube
10. Tissue paper for cleaning the glass plates
11. A thin strip of paper
12. A small strip of steel

INTRODUCTION

Part I: The Grating Spectrometer

A diffraction grating consists of a large number of fine, evenly spaced parallel slits. There are two types: transmission and reflection gratings. There are two kinds of transmission gratings; one kind has lines ruled on glass, the unruled portions acting as slits, the other kind is a replica of the reflection type. It consists of a piece of gelatin mounted between two pieces of glass, the thinner portions of the gelatin acting as the slits. The reflection grating is formed by ruling lines on a polished metal surface; the unruled portions produce by reflection the same result as is secured by transmission with the other type.

The purpose of this exercise is to measure the wavelengths of several spectral lines. The transmission grating, to be used in conjunction with a spectrometer, is a replica. It has from 5,000 to 6,000 lines per cm; the exact number is usually found on the grating.

Let the broken line, MN, in Fig. 1 represent a magnified portion of a diffraction grating. Waves start out from all of the slits in phase, so that the phase difference at F between waves from A and C corresponds to the path difference AB. This same difference at F will be present between waves from each two successive slits in the grating. Hence, if AB is equal to λ, or 2λ, or 3λ, etc. where λ is the wavelength of the light, waves from all the slits will constructively interfere at F and we shall get a bright image. The images at F when AB = λ, 2λ, 3λ, etc. are called the first order spectrum, second order spectrum, third order spectrum, etc., respectively. It is seen from Fig. 1 that, if θ is

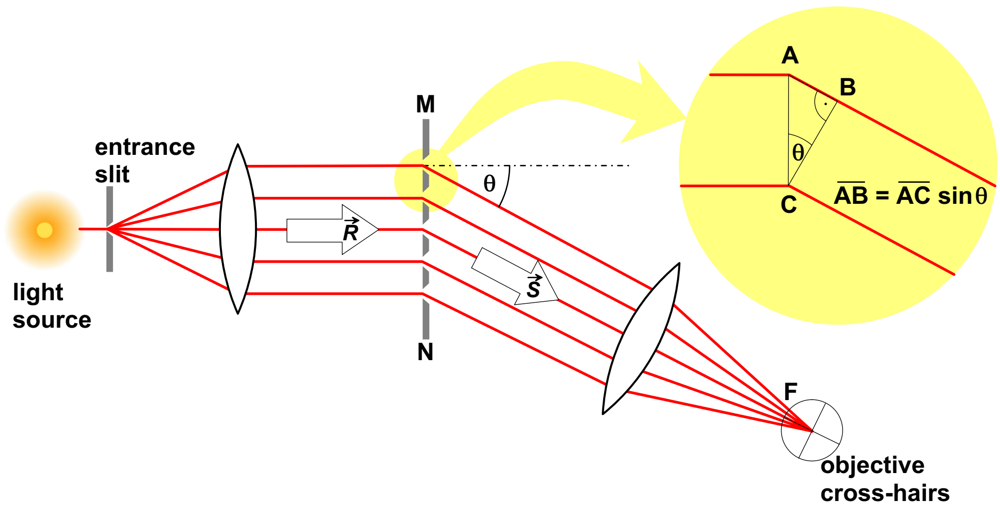

Figure 1: Schematic layout of the spectrometer.

the angle of diffraction, or the angle that the rays forming the spectrum make with the original direction of the light $\vec{R}$, d the grating spacing, or distance between the centers of adjacent slits, λ the wavelength of the light, and n the order of the spectrum, then

$$\frac{n\,\lambda}{d} = sin\,\theta \qquad \text{or} \qquad n\,\lambda = d\,sin\,\theta \tag{1}$$

is the condition that the waves from the various slits constructively interfere wich each other.

If the light is not monochromatic, there will be as many images of the slit in each order as there are different wavelengths in the light from the source, the diffracting angle for each wavelength (color) being determined by equation (1).

Part II: Interference at a Wedge

A method for measuring the wavelength of light is to allow monochromatic light to be reflected from the two surfaces of a very thin film of varying thickness, thus producing an interference pattern. Wherever the two waves reflected from the surfaces of the film meet in phase, a bright spot will be produced, and where they meet differing in phase by one-half a wavelength, a dark spot will appear. If the film varies regularly in thickness, the interference pattern will consist of a series of parallel bright and dark line, called interference fringes.

In this experiment, the thin film consists of the air space between two approximately plane parallel plates of glass, separated at one end by a thin strip of paper of thickness T, as shown in Fig. 2. When the ray A reaches the point x at the top of the air film (inset of Fig. 2), it is partially reflected, forming ray B. Part of ray A will also be reflected from the bottom of the air film at point y forming the ray C. if the phase difference between the rays B and C corresponds to an integral number of wavelengths, say 14, they will be in phase, which will result in a bright fringe

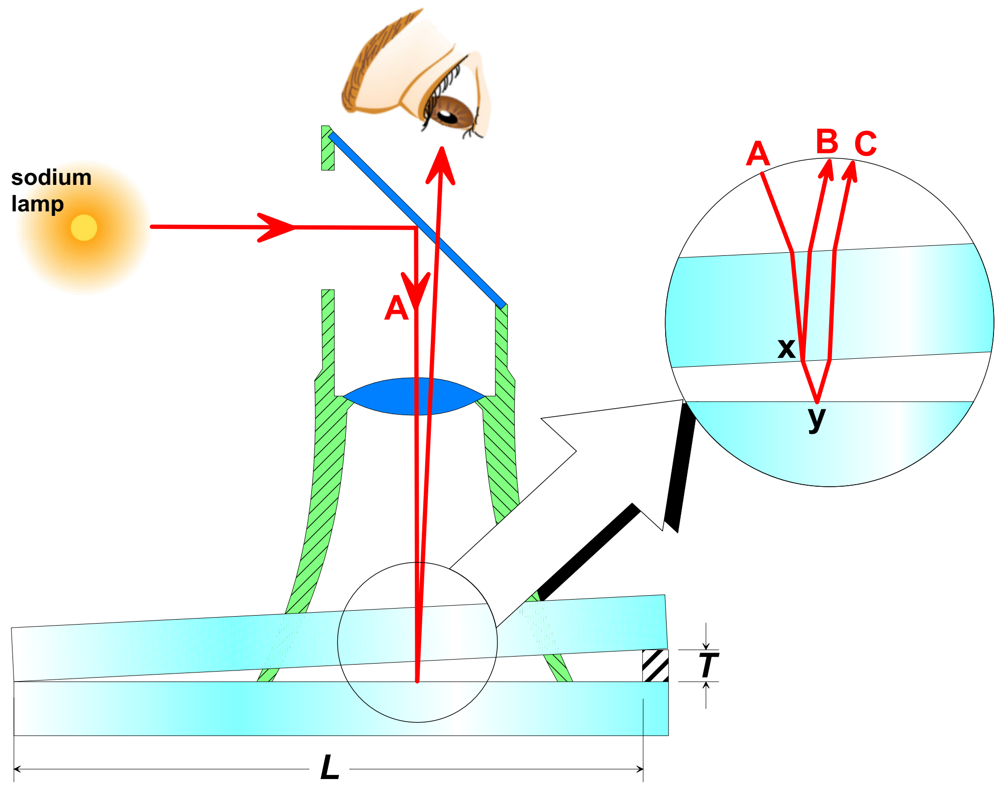

Figure 2: Setup for observation of interference fringes at two glass plates.

at this point of the air film. If we move toward the thicker end of the film, the next light fringe encountered, must correspond to the next integral number of wavelengths of phase difference; that is 15. To produce this one-wavelength increase in phase difference, the thickness of the film must have increased by a half-wavelength. (Why?) Therefore, if traveling from one fringe to the next corresponds to an increase in film thickness of one-half wavelength, traveling the entire length of the film, L must correspond to an increase in film thickness of N half-wavelengths, where N is the total number of fringes in the length L. Because the difference in thickness between the two ends of the film is known to be T, we have the equation

$$N\,\frac{\lambda}{2} = T \tag{2}$$

By measuring N and T, the wavelength of the light might be computed. However, since it is convenient to measure the number of fringes per centimeter, η, one may use the formula in the form

$$\eta\,L\,\frac{\lambda}{2} = T \tag{3}$$

Since the above reasoning will apply to the dark fringes as well as to the light, either set may be counted - whichever is most convenient.

PROCEDURE

Part I: The Grating Spectrometer

The appropriate device for producing the required parallel rays, holding the grating, focusing the diffracted light, and permitting the determination of angles from a graduated circular scaled is called a spectrometer (see Fig. 3). **PLEASE TREAT IT CAREFULLY - it is expensive to repair.**

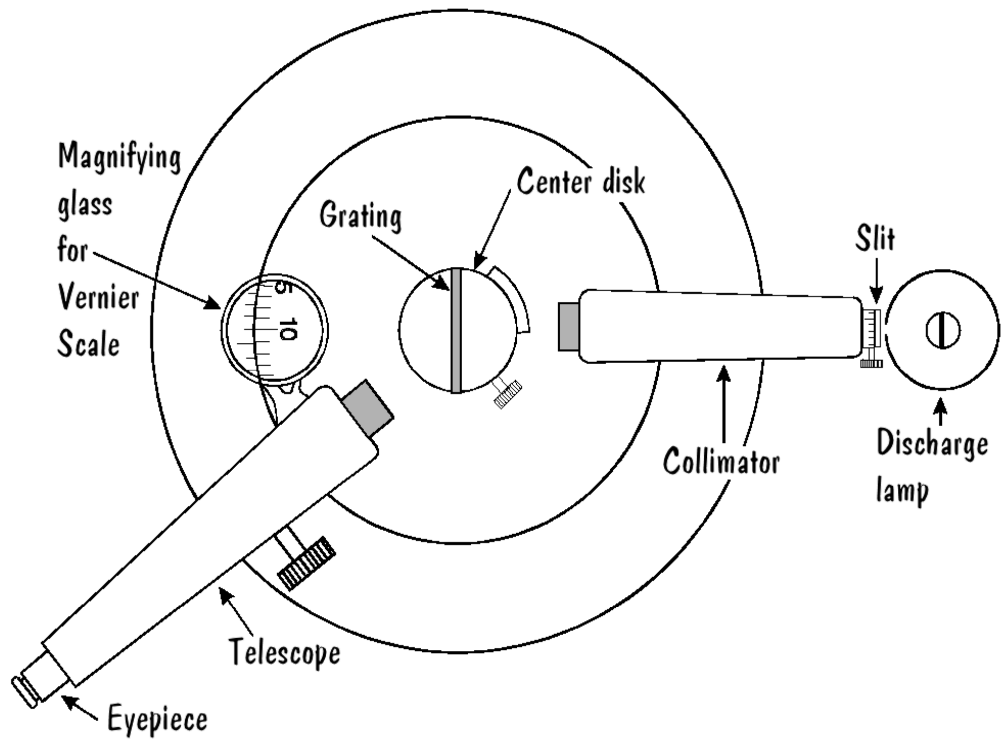

Figure 3: Parts of the grating spectrometer.

In order to use the instrument you will need only to vary the width of the slit (controlled by the knurled ring surrounding it) and to rotate the telescope. Your instructor will show you how the telescope can be moved quickly and then how the slow-motion screw can be engaged to permit very slow precise movement. Do not turn the leveling screws! The grating should be adjusted so that its surface is perpendicular to the axis of the collimator and then clamped in this position.

The magnifying glasses aid in reading the verniers which enable the setting of the telescope to be measured to the nearest minute of angle. See the notes on Angle Scale Verniers in the Introduction.

Place the Mercury lamp directly in front of the slit of the collimator. Upon looking with the unaided eye through the grating and collimator you will see the slit brightly illuminated. The slit should be made quite narrow. Now look through the telescope. First focus upon the cross-hairs by moving the tube holding the eyepiece lens. Next focus upon the slit by moving the tube that holds the slit without disturbing the focus of the cross hairs. Both must be in sharp focus. Set the cross-hairs on the image by use of the slow-motion screw, and note the reading of one of the verniers. This setting of the telescope corresponds to the direction $\vec{R}$ in Fig. 1.

Turn the telescope either to the right or to the left, make a similar setting on a line of the spectrum and read the same vernier. This position of the telescope corresponds to the direction $\vec{S}$ in Fig. 1. θ, the angle through which the telescope was turned, which is the difference between the two readings of the vernier, is the angle of diffraction. (**Attention:** If the vernier has passed through the 360° or 0° mark while turning the telescope, allowance for this will have to be made in the subtraction.) The wavelength λ of the line observed may now be calculated by use of equation (1).

In this manner determine the wavelengths of at least four lines in both first and second orders on both sides of the central image. Tabulate your values of λ and compare them with those found in the table at the end of this experiment (page 6).

Part II: Interference at a Wedge

Be sure that the glass plates are clean. Handle them carefully and avoid getting finger marks on the surfaces which are to be placed together. Your instructor will inform you of the thickness of the paper. Mount the glass plates on the board and place the strip of paper between the ends of the glass plates. Place the frosted surfaces down with the ruled lines on the inside. Measure the length L. Now place the aluminum stand containing the lens and the mirror over the center of the wedge-shaped air film, and place the sodium lamp at a convenient distance opposite the hole in the side of the aluminum stand. The interference pattern will consist of a series of dark lines across the image of the flame. These parallel lines should be perpendicular to the length of the air film. Make two counts of the number of dark lines in two centimeters of length. Now calculate the wavelength of the yellow light. Express your results in nm (1 nm = 10^{-9}m).

Part III: Measurement of the Thickness of a Steel Strip

Replace the paper strip by a strip of steel. Measure its thickness with the aid of the sodium lamp assuming your value of the wavelength of the light to be correct. Question: In deriving Equation 2, an expression of the type "phase difference corresponding to 14 wavelengths" was used instead of "path difference of 14 wavelenghts". Why do these two expressions differ in meaning for this experiment? (Refer to the text on phase change in reflection.)

Part IV: Hydrogen Lines

If time permits, measure the wavelengths of the three bright lines of the hydrogen spectrum, using the spectrometer.

Wavelength of Spectral Lines

Mercury (Mercury Lamp)

Bright Violet	404.7 nm
Violet	407.8 nm
Blue	435.8 nm
Dull Green	491.6 nm
Bright Green	546.1 nm
Yellow	577.0 nm
Yellow	579.1 nm

Hydrogen

H_γ, blue	434.0 nm
H_β, dull green	486.1 nm
H_α, red	656.3 nm

Potassium (KCl in flame)

Red	766.8 nm
Red	770.2 nm

Sodium

Orange	588.9 nm
Orange	589.5 nm