

MODERN PHYSICS I.  
(V85.0103)

ALIGNMENT AND ADJUSTMENT OF THE SPECTROMETER

1. INTRODUCTION

The spectrometer used in the laboratory is shown in Figure S.1. It consists of:

- 1) a collimator, which is a telescope-like device that produces a beam of parallel light rays.
- 2) an adjustable mounting table, used to support the optical device being used (in most cases a reflection grating).
- 3) a telescope, which is used to observe the light reflected from the grating.

However, any high precision instrument, such as a spectrometer, is useful only so long as it is carefully adjusted. Adjustment is the key to precision. As one might expect, there is at least one adjustment for each of the previously mentioned components. These adjustments are:

- 1) focusing of the collimator to produce a non-divergent beam.
- 2) focusing of the telescope for a collimated light beam.
- 3) alignment of the telescope and collimator so that their optical axes are perpendicular to the axis of rotation of the mounting table.

2. TELESCOPE ADJUSTMENT

There are two parts to this adjustment. First, the eyepiece must be removed and adjusted so that the cross hairs appear as sharp as possible to the relaxed eye. The eye may be relaxed by focusing it on a distant object.

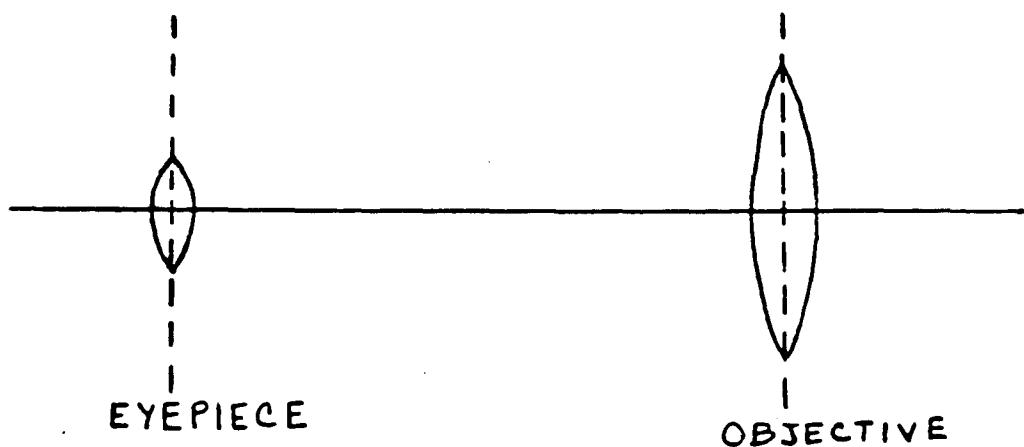


Figure S-2

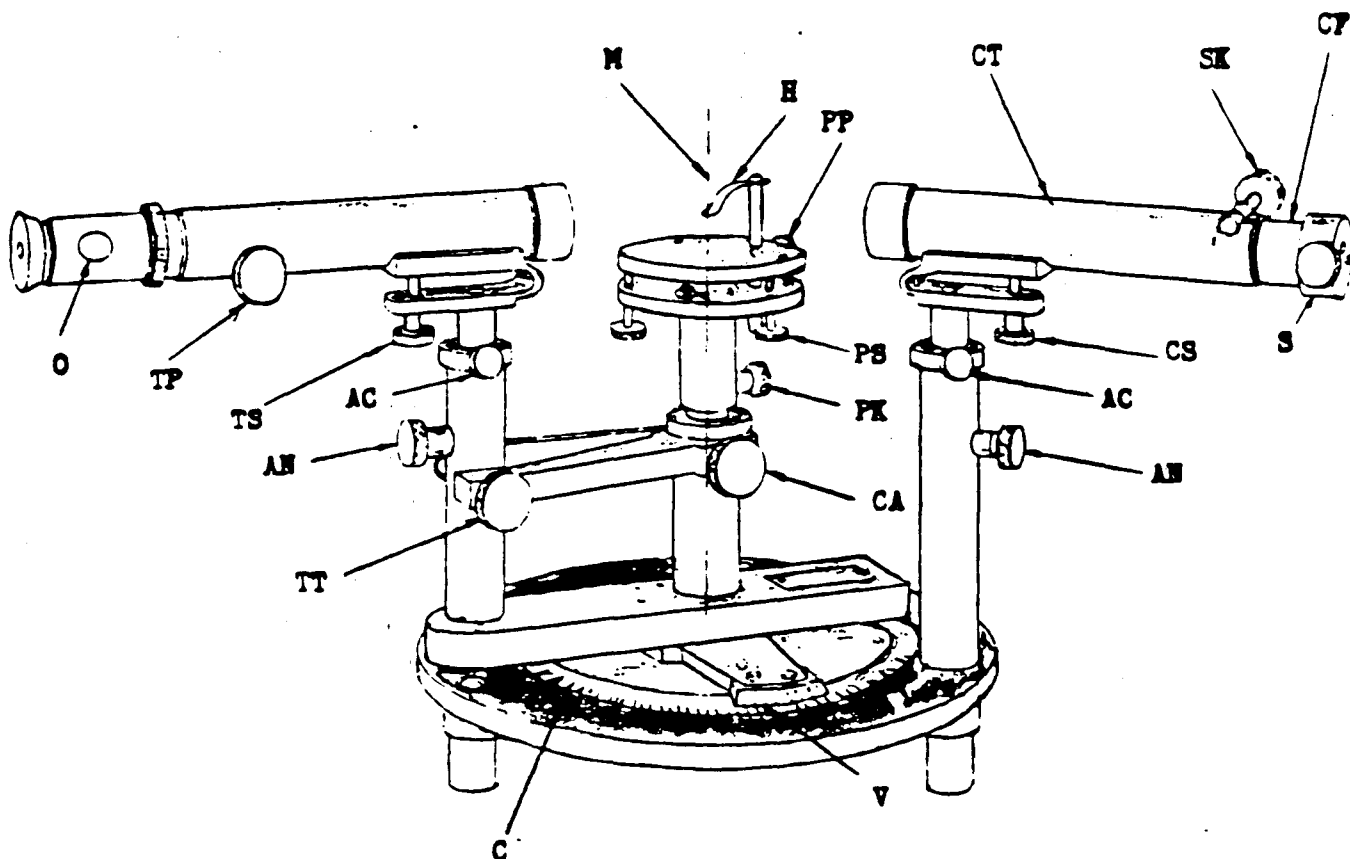


Figure S-1

- AC - Clamp screw on adjustable collar, to preserve height adjustment.  
 AN - Clamp screws to permit elevation and rotation adjustments of telescope and collimator.  
 C - Circle graduated in 1/2 degrees.  
 CA - Telescope tangent arm clamp screw, clamps arm to stationary vertical shaft.  
 CF - Slit focusing tube.  
 CS - Leveling screw of collimator tube.  
 CT - Collimator tube.  
 H - Spring clamp, for holding prism on table.  
 M - Main axis of instrument.  
 O - Opening of Gauss eyepiece.  
 PK - Clamp of prism table.  
 PP - Clamp screw for prism holding post.  
 PS - Leveling screws of prism table.  
 S - Slit  
 SK - Clamp of slit tube.  
 TP - Rack and pinion focusing motion.  
 TS - Leveling screw of telescope tube.  
 TT - Tangent screw adjustment for telescope.  
 V - Vernier reading to 1 minute.

Next, look through the eyepiece and adjust for sharp cross hairs. Alternate this procedure until the adjustment is complete. This insures that eyestrain will be reduced to a minimum. (Note that this whole procedure fixes the relative distance of the eyepiece lens and the cross hairs).

Next, focus the telescope itself for parallel rays by directing it towards some distant object (at least 100 times the focal distance of the objective lens) and focusing by means of the rack and pinion (NOT THE EYEPIECE) until the image of the object is sharp and the parallax between the image and the cross hairs is minimized. (Note that this procedure fixes the relative distance of the objective and the cross hairs).

### 3. ADJUSTMENT OF THE COLLIMATOR

To focus the collimator for parallel light rays, replace the telescope in the spectrometer. Rotate the telescope until its optical axis is collinear with the optical axis of the collimator. Illuminate the slit of the collimator with sodium light, and adjust the distance of the slit from the objective lens until the image of the slit as seen through the telescope is as sharp as possible and parallax between image and cross hairs is minimized.

The last adjustment employs the Gaussian eyepiece, whose design will be discussed next in conjunction with alignment of the collimator and telescope.

### 4. ALIGNMENT OF COLLIMATOR AND TELESCOPE

This adjustment entails setting the optical axes of both telescope and collimator perpendicular to the axis of rotation of the table.

First, set either a clear plate of glass or a 2-sided mirror on the mounting table, as parallel to the axis of rotation as possible.

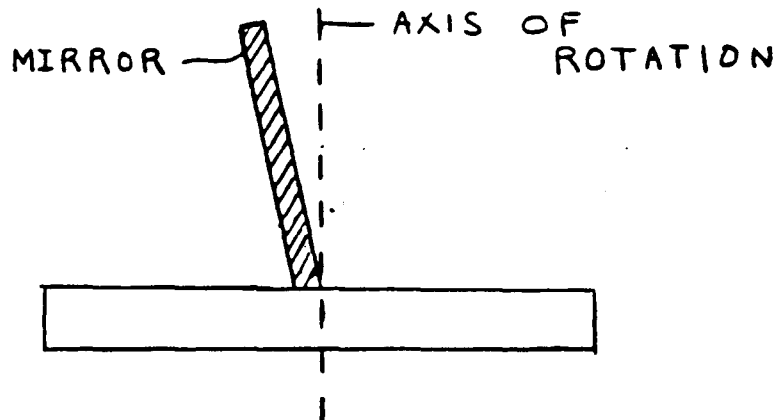


Figure S-3

Note that the plate does not need to be coincident with the axis of rotation of the table.

Next, direct a beam of light down the Gaussian eyepiece (A). The light will illuminate the reticule (R), and, hence, the cross hairs. Encountering the beam splitter (S), these rays will traverse the telescope tube. If the

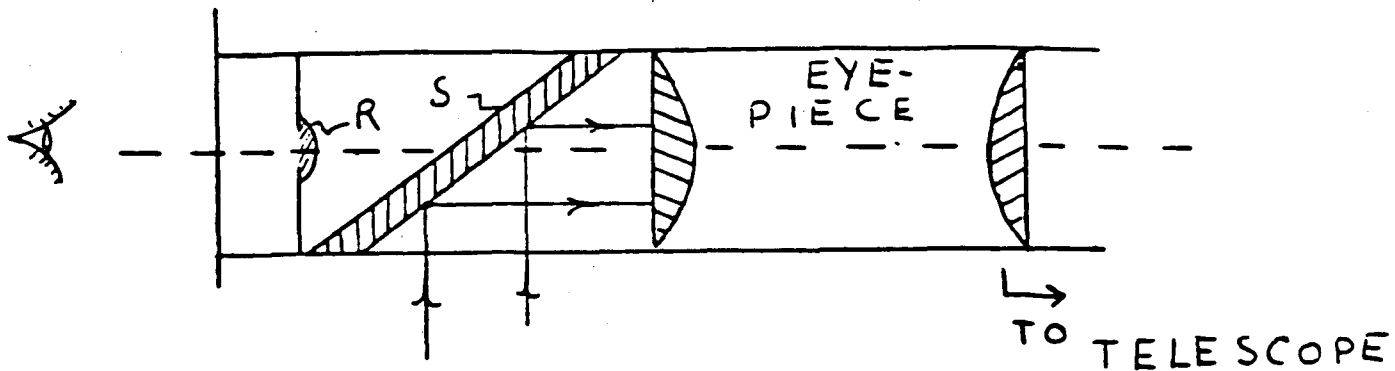


Figure S-4

mounting table is rotated so that the mirror (or glass plate) reflects the light back down the tube, the observer will see both the actual cross hairs and their image. If this image is made as sharp as possible by adjusting the rack and pinion, and if the parallax between image and object is removed, the telescope will be adjusted for parallel rays. (This is an alternate method to that described above). Now, it will also be apparent that the image and object do not coincide. This is due to the fact that the two-sided mirror (or glass plate) is not parallel to the axis of rotation of the mounting table. Rotate the table through  $180^\circ$ , and the image will appear again, but in a different area of the field of view. Adjust the leveling screws of the table until rotation of the table through  $180^\circ$  does not change the image position in the field of view. When this is accomplished, the telescope may be adjusted until image and object coincide. The axis of the telescope is now perpendicular to the axis of rotation, and the mirror, or plate, is parallel to the latter. Finally, the inclination of the collimator should be adjusted until the cross wires appear halfway up the image of the slit. (Note that this is done when the axes of collimator and telescope are collinear). The axis of the collimator is now perpendicular to the axis of the rotating table.

#### References:

- 1) Houston, R.A. A Treatise on Light, Longmans, Green and Co., London, New York, Toronto, 1938, pp. 102-107.
- 2) Brown, T.B. The Taylor Manual, Addison-Wesley, Reading, Mass., 1961 pp. 202-204
- 3) Valasek, J., Theoretical and Experimental Optics, John Wiley and Sons, New York, 1965, pp. 358-359

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MODERN PHYSICS II  
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ANALYSIS OF ATOMIC SPECTRA

A.1. Introduction

When a beam of light is sent through a prism or diffraction grating of a spectrometer it is dispersed into a spectrum. The prism or grating thus separates the light into its component colors. The character of the spectrum depends upon the source. An incandescent lamp, for instance, gives off a continuous spectrum. A electrically excited gas at low pressure, on the other hand, emits a line spectrum that is characteristic of the gas being used. The study of these spectra has played an extremely important role in the development of quantum physics. The emission of the line spectrum was one of the experimental facts that could not be explained by classical physics. Only the atomic structure proposed by Bohr and subsequently developed in modern quantum theory is able adequately to explain the line spectrum.

A.2. Continuous Spectrum

A.2.1. Observation with a Prism

Mount a prism in the spectrometer and align the instrument as described in the notes ALIGNMENT AND ADJUSTMENT OF THE SPECTROMETER. Record the angle  $\theta$  when the telescope is aligned along the collimator axis (See Fig. A.2).

Position an incandescent lamp in front of the collimator of the spectrometer. Turn on the lamp and observe the spectrum through the telescope of the spectrometer. Make a rough sketch of the angular dependence of the spectrum, indicating the colors observed. Include your estimate of how the brightness varies across the spectrum (note: this is not a physical quantity but a description of what you perceive).

A.2.2. Observation with a Diffraction Grating

Mounting the Grating

Mount a diffraction grating in place of the prism in the spectrometer and align the instrument. Touch only the brass parts. The face of the grating should approximately bisect the mounting table and be perpendicular to the line joining two of the leveling screws.

Align the face of the grating parallel to the axis of the spectrometer by adjusting it perpendicular to the axis of the telescope. Use the grating as a

mirror, and employ the Gauss eyepiece as described in the notes ALIGNMENT AND ADJUSTMENT OF THE SPECTROMETER.

Be sure the diffraction grating lines are parallel to the vertical axis of the spectrometer. Observe the continuous spectrum of the incandescent lamp with the slit almost closed, so that the spectrum shows dark horizontal bands. Adjust the proper mounting-table leveling screw so that these bands stay at constant height as the grating is rotated about the axis. The bands are caused by dust on the jaws of the slit.

### Observe the Spectrum

Study the spectrum of the incandescent lamp. Make a rough sketch of the angular dependence of the spectrum, indicating again the colors that you observe. How many higher order maxima can you detect?

### A.3. Spectrum of Helium

Use the helium discharge lamp as a light source by placing the tube adjacent to the collimator slit and by connecting the electrodes at the ends of the tube to a 5000 volt AC power supply. The supply is dangerous.

DO NOT TOUCH THE TUBE OR ASSOCIATED CIRCUIT CONNECTIONS WHEN THE VOLTAGE IS ON.

With the diffraction grating adjusted as described in the previous section, examine the helium spectrum with the diffraction grating in the spectrometer. Use a small incident angle  $\theta_i$  with respect to the normal to the grating (see Fig. A.2). As the telescope is moved you will see a sequence of lines, and for larger angles higher order maxima for each line. Figure A.1 illustrates the line spectrum for helium, together with the color of each line. Dotted lines in the figure indicate emission lines that are faint. Identify in your spectrum an image corresponding to each of the solid lines in the diagram.

Set the crosshairs of the telescope on each image in turn and record the corresponding angular scale positions  $\theta$ . Note the color of each image. Compute the wavelength for each observed line.

Discuss the accuracy and precision of your measurements.

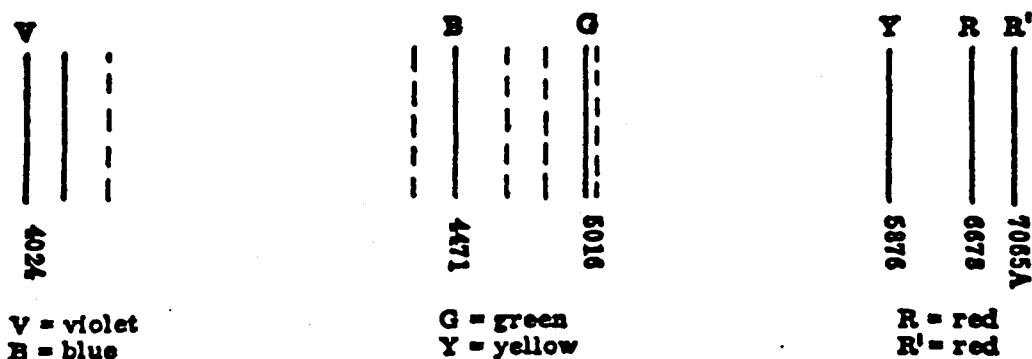


Figure A.1. The line spectrum of atomic helium.

#### A.4. Analysis of the Hydrogen Spectrum

##### A.4.1. Spectral Measurements

Turn off the power supply, remove the helium discharge tube, put a hydrogen discharge tube in its place, and turn on the power supply. Be sure that the diffraction grating is still well shielded from ambient light to avoid producing spurious lines from unwanted sources.

Keeping the positions of the collimator and grating fixed, record the telescope angle  $\theta$  (Figure A.2) for as many lines as you can see, noting the color of each line. Determine the corresponding diffraction angle  $\theta_D$ . Take these measurements for two positions of the grating:

- (1) with the normal to the grating at a large angle  $\theta_I$  with respect to the collimator axis and
- (2) with the normal at a small angle with respect to the collimator.

For each grating position, determine the angle of incidence  $\theta_I$ . Check that the grating axis is still aligned with the spectrometer's vertical axis for the second position.

Estimate the angular error in determining the positions of a spectral line and the error in measuring  $\theta_I$  by repeating the telescope setting and measurement several times.

##### A.4.2. Analysis of the Data

- 1) Derive the expression

$$n\lambda = d (\sin\theta_D - \sin\theta_I)$$

relating the incident angle  $\theta_i$  and the diffraction angle  $\theta_p$  for constructive interference with the wave length  $\lambda$  of an emission line (Fig. A.2). What is the maximum order  $n$  that can be observed? Derive formulas relating  $\theta_i$  and  $\theta_p$  to the  $\theta$  angles measured. For each measured line  $j$  taken with the grating in position (1) calculate  $\theta_p$  and plot  $\sin\theta_p$  with its error as a function of the observed order number  $n$ . Perform a least squares fit to the points to obtain the slope  $\lambda_j/d$  and intercept  $\sin\theta_i$ , with their respective errors. Compare  $\sin\theta_i$  found from the fit with that measured directly. Incorporate the direct measurement into the fit by plotting it at  $n=0$  and refitting. Assume 600 lines/mm as the nominal grating spacing and compute the best value of  $\lambda_j$  and its uncertainty.

- 2) Find an expression for the dispersion  $d\theta_p/d\lambda$ . Compute  $\lambda$  and its error for, say, every red line measured, assuming the nominal grating spacing. Compare the measured wavelengths of the line as a function of the order and as a function of the two grating positions with the accepted value of the red-line wavelength. Also compare the uncertainty in the measured wavelength with that expected from the dispersion expression. What position of collimator, telescope, and grating maximizes the precision of the  $\lambda$  measurement?
- 3) Verify that the lines you have measured correspond to those of the Balmer series

$$\frac{1}{\lambda n_i} = R \left\{ \frac{1}{n_f^2} - \frac{1}{n_i^2} \right\} \quad n_f = 2 \quad (A.1)$$

by plotting the best estimate of  $\lambda n_i$ , found in step 1) of the analysis, versus  $1/n_i^2$ . Again perform a least square analysis to find a best value for the Rydberg constant  $R$ . What is the error in  $R$  and what is the probability for measuring your value of  $R$  when compared with the accepted value?

- 4) Estimate the angular width of an observed spectral line. What is the minimum wavelength difference that you can resolve in this measurement?
- 5) Are there other sources of error in determining  $\lambda$  other than the angular errors?
- 6) How would you perform a more accurate measure of  $R$ ?

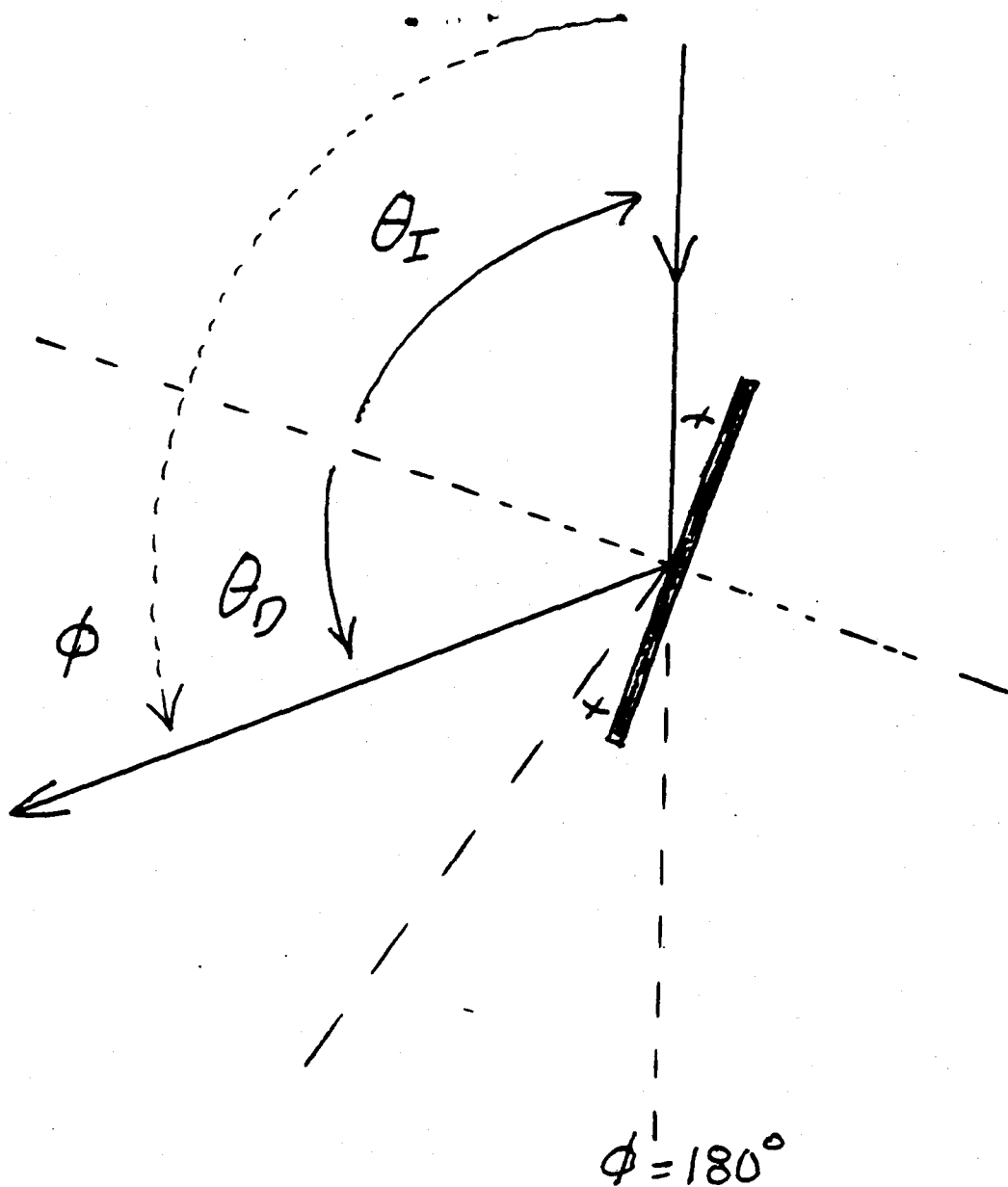


Figure A.2. Incident angle  $\theta_I$  and diffraction angle  $\theta_D$  with respect to the normal to the grating; and observation angle  $\phi$  with respect to the collimator's axis.

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REFERENCES:

- Mellisinos, EXPERIMENTS IN MODERN PHYSICS, page 32.  
 Harnwell and Livingood, EXPERIMENTAL ATOMIC PHYSICS, page 255.