EP14 Refractive index with the Prism Spectrometer

Light is made up of many different colors, each of which has a definite wavelength. When a beam of light is passed through a glass prism, it is broken up into a spectrum. Each chemical element produces its own characteristic spectrum, so that by analyzing the light given off by a substance it is possible to identify the elements it contains.

A prism can make incident rays deviate, and then disperses them into a spectrum. With it, we can measure helium spectra and refractive index of glass.

OBJECTIVE

1. To learn the principle of dispersion by a prism.
2. To learn how to measure angle of minimum deviation.
3. Further to understand how a spectrometer employed.

THEORY

1. Description of the instrument (see EP13).
2. The spectrum

In general, light is made up of many component wavelengths, each of which corresponds to a definite color. When a beam of light is passed through a glass prism, refraction takes place when the beam enters the prism and again when it leaves, with the result that the beam is bent through an angle φ, called the angle of deviation. This angle is a function of the index of refraction n of the glass Since n is different for different wavelengths (because they propagate with different velocities in transparent materials such as glass), each component wavelength in the incident beam is bent through a different angle. The incident beam is thus separated into beams of its component colors (wavelengths) that may then be displayed as a spectrum. We say that the incoming light has been dispersed into a spectrum, and the property exhibited by the prism of separating this light into its constituents is called dispersion.

Spectrum analysis is the decomposition of a beam of light into its constituent wavelengths and the examination of the image so formed. A spectrometer (or spectroscope, as instruments not provided with means for recording the analyzed light are often called) is an optical instrument for producing and analyzing spectra.(*A diagram of a prism spectrometer is shown in experiment 13).*The image of the spectrum can be viewed through the eyepiece of the telescope(its object lens and eyepiece are already adjusted). If the light is all of one color (or monochromatic), a single image of the slit appears. If a source contains several colors, several images of different color will appear side by side, each being an image of the slit formed by one component of the light. The telescope can be rotated about the prism so that light emerging at different angles can be viewed, and the angular position of each slit image can be read off from the circular scale.

There are three main types of spectra: continuous, bright-line, and absorption. A continuous spectrum is produced by light from an incandescent solid or liquid. It contains all wavelengths and hence appears as a continuous gradation of colors, merging with one another with very gradual changes from red to violet. The bright-line spectrum is produced by exciting an element in the gaseous state by means of an electric discharge or by heating. Such a spectrum consists of bright lines, each an image of the spectrometer slit formed by light of a definite color, separated by dark spaces. The number and relative positions of the lines depend on the element used and the method of excitation employed.

In the experiment, Helium spectrum will be measured. The spectral tube of Helium can be formed by confining a small amount of Helium gas (600Pa~700Pa) into a sealed glass-tube, at each end of which an electrode is exposed (one is positive, the other is negative). Discharging and glowing could be observed once a high voltage is applied to the electrodes, the light generated passes through a prism to give out visible spectra. The principal lines in the helium spectrum are given in Figure1, and the color and wavelength corresponding to the brightest seven lines are given in table 1.

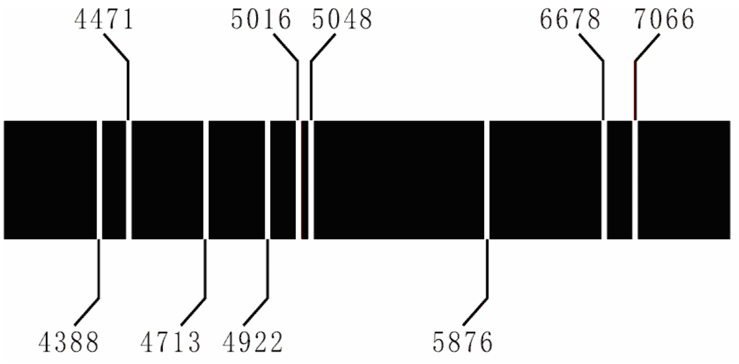

Figure.1 Helium spectrum dispersed by a prism (the unit of λ is $10^{-10}m$)

Table1 the wavelengths of helium spectra

wavelength ($10^{-10}m$)	4471	4713	4922	5016	5876	6678	7066
colors	deep blue	blue	blue-green	light green	yellow	red	dark- red

3. Refractive index

Light incident on a prism in the direction OM (Figure 2) will be refracted along some line MN and then emerge from the prism in the direction NP. Angle A is called the angle of the prism, and angle φ is called the angle of deviation, with line OM being the original direction of the beam, and NP being the direction of the deviated beam. If the angle of incidence i_1 is varied, angle φ also varies, but it has a minimum value for one particular angle of incidence. This minimum value of angle δ is called the angle of minimum deviation of the prism for the wavelength of light being studied.

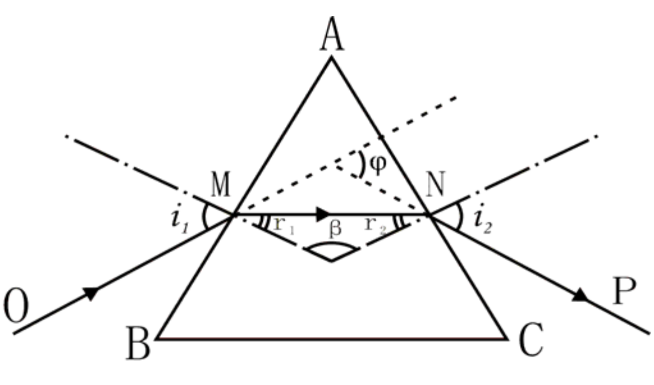

Figure 2 angle of minimum deviation

Geometrically, as shown in Figure2, the angle of deviation $\varphi = (i_1 - r_1) + (i_2 - r_2)$,

where r_1 is the angle of refraction on plane AB when light rays traveling from air to glass, and r_2 is the angle of incidence to plane AC when light rays traveling from glass to air.

if $i_1 = i_2 = i$,according to refractive law, then $r_1 = r_2 = r$

replace φ by δ , then

$$\delta = 2(i - r) \qquad (1)$$

$$\because \quad r_1 + r_2 = 2r = \pi - \beta = \pi - (\pi - A) = A$$

$$\therefore \quad r = \frac{A}{2} \qquad (2)$$

combine expressions (1) and (2), the index of refraction n is given by:

$$n = \frac{\sin\frac{1}{2}(A+\delta)}{\sin\frac{1}{2}A} \qquad (3)$$

A major portion of this experiment is concerned with the measurement of the angle of minimum deviation (providing that the angle of the prism has been measured), from which the index of refraction is calculated.

4. Angular verniers and the reading of an angle on a spectrometer (see EP 13).

CAUTION

1. The prism or other optical instruments should be gently handled, and you should avoid touching the optical surfaces of such apparatus with your naked hands (you can touch the gross surfaces of these instruments).
2. A spectrometer is a precision instrument. It wound be damaged if you forcibly rotate the telescope or platform when they are locked..
3. Before you record the data you should be sure that the related screws have been locked so that the data you will record are right.
4. The helium discharge tube operates at a high voltage, and its power supply can deliver enough current to give a painful shock. Do not touch either the tube or the wires leading to it while the power supply is in operation.

PROCEDURE

1. The spectrometer should be already adjusted when you come to the laboratory, with the collimator and telescope properly focused. CAUTION: Do not handle the spectrometer until the instructor has demonstrated its operation to you. This instrument is easily thrown out of adjustment, and needless delay or even permanent damage can be caused by careless handling. Be extremely careful when using it.
2. Turn on the helium light source and place it immediately in front of the slit at the end of the spectrometer's collimator. The spectrometer should be positioned so that the slit faces directly into the center of the helium light.
3. Position the prism well on the platform as shown in Figure3
4. With the unaided eye trace the direction of colorful departing rays until you see the spectrum of colors. Now move the telescope in the same position where your eyes were.

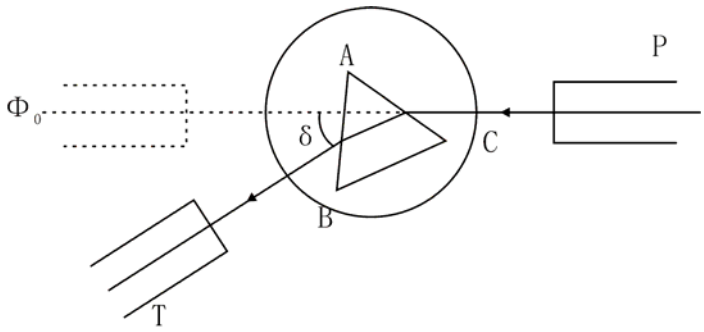

Figure3 measurement of angle of minimum deviation

5. Adjust the angular position of the telescope so that the helium spectrum is visible when you look into the eyepiece. A small adjustment of the eyepiece position may be necessary to bring the spectrum into sharp focus. Note that the spectrum consists of a number of vertical lines of different colors. Each of these lines is an image of the collimator slit formed by the pertinent wavelength, but because most optical spectrometers use such slits, the word "line" has come to mean a particular wavelength in a spectrum.

6. Now adjust the spectrometer for minimum deviation. To do this, move the telescope so that the bright yellow line at 5876 A is roughly in the center of the field of view. Slowly rotate the platform (or prism table) backward and foreward and follow the movement of the image. Note the reversal of the direction of motion of the image while the platform is still rotating in the same direction. When the prism is set for the position of the reversal of the motion of the image, it is in the position for minimum deviation. Now view the image in the telescope. Fine tune the reversal position by rotating the platform while viewing through the telescope. When the cross hairs have been set on the image in the minimum-angle position, Lock the prism table in the position (screw 11 in Figure 1 in EP13, at the same time lock screw 15, 16), read the divided circle with the help of the vernier and record them, that is, φ_1 and φ_2 . Do not change the prism table position after the minimum deviation setting just described has been found.

Note that directly under the arm supporting the telescope is a clamping device that rotates with the arm and permits the telescope to be clamped to the base by means of a radial screw (screw16). A slow-motion screw (screw17) on the arm allows a fine adjustment of the telescope setting; however, the slow-motion screw can be used only after the telescope has been clamped with the radial screw.

7. Unlock screw 16 **(screw 11 and 15 are still locked),** then Adjust the position of the telescope so that the red line of the helium spectrum falls exactly on the intersection of the eyepiece cross hairs. Rotate the telescope until the red line is near the vertical cross hair and then clamp it by means of the radial screw (screw16). Use the slow-motion screw(screw17) to set the intersection of the cross hairs exactly on the red line. Read the divided circle with the help of the vernier and record them, Also record the red line's color and known wavelength (see Table 1).

8. Repeat Procedure 7 for the other lines of the helium spectrum, taking readings of the telescope setting for each of the lines that can be recognized.

9. Now remove the prism and rotate the telescope until the optical axis of the telescope and that of the collimator are in a straight line (figure 3). Now the image of the slit is near the vertical cross hair, then clamp it by means of the radial screw (screw16). Use the slow-motion screw (screw17)

to set the intersection of the cross hairs exactly on the image of the slit. Read the divided circle with the help of the vernier and record them, that is, φ_{01} and φ_{02}

10. With the information now at hand, compute the index of refraction of the glass for the sources used by means of Equation (3).

DATA RECORDING AND PROCESSING

Serial No. of prism: A=

Direction of incident ray: φ_{01} = φ_{02} =

wavelength ($10^{-10} m$)	colors	φ_1	φ_2	$\delta_1 = \varphi_1 - \varphi_{01}$	$\delta_2 = \varphi_2 - \varphi_{02}$	$\delta = \frac{1}{2}(\delta_1 + \delta_1)$	$\frac{A+\delta}{2}$	$n = \frac{\sin\frac{1}{2}(A+\delta)}{\sin\frac{1}{2}A}$
4471								
4713								
4922								
5013								
5876								
6678								
7066								

PRE-QUESTION

What precautions should be taken when using a prism and helium discharged tube?

QUESTIONS

When considering red and violet light, which one, has the smaller refractive index with respect to the same material? Which of them results in a smaller angle of deflection? In which direction, towards the red or the violet ray, should the prism rotate to look for the angle of minimum deviation?