Experiment No. 1

Atomic Line Spectra of Noble Gases and Metallic Vapors

I. OBJECTIVES

- To study the atomic spectra of certain noble gases and metallic vapors using diffraction grating and spectrometer

II. BACKGROUND

At any temperature, the molecules of a substance at a temperature above absolute zero (0 Kelvin) emit radiation in which a continuous band of wavelengths are present, though with different intensities. The spectrum of an incandescent solid, such as lamp filament for example, consists of a continuous band of wavelengths in the visible light spectrum -from the short wavelength violet to the long wavelength red. Such a spectrum is called a ***continuous spectrum***. The relative intensities of the colors depend on the filament temperature. The composite effect is “white light” only when all visible wavelengths are present in the relative intensity found in sunlight.

In a gas, the atoms or molecules are far apart on the average that their only mutual interactions occur during occasional collisions. Under these circumstances any emitted radiation would be characteristic of the individual atoms or molecules present. When an atomic gas or vapor at somewhat less than atmospheric pressure is suitably excited, usually by the passage of an electric current through it, the emitted radiation has a spectrum which contains certain specific wavelengths only that correspond to a transition from a higher energy state where the atoms were brought upon excitation to lower and more stable energy states. This spectrum is called the ***emission line spectrum***. Every element displays a *unique* line spectrum when a sample of it in the vapor phase is excited. The atomic line spectrum of an element is somewhat the “fingerprints” of that element. It uniquely characterizes the element. Therefore, by studying the line spectrum, we can analyze the composition of an unknown substance. In fact, when studying the spectrum of stars, results would reveal not only the composition of stars but also their physical state and whether the said stars are receding from us or approaching us.

When light from a lamp consisting of noble gas or metallic vapor is made to pass through a diffraction grating, the emission spectrum created by the diffraction of light can be viewed using a diffraction grating spectrometer as shown in Figure 21.

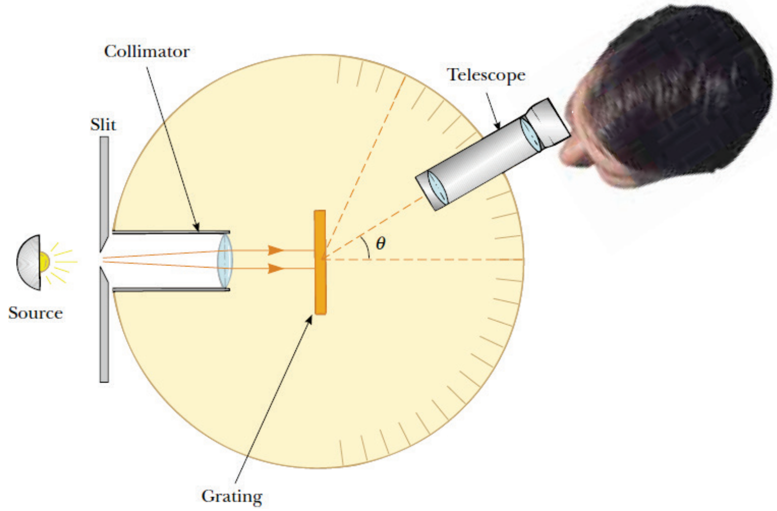

Figure 21. Diagram of a diffraction grating spectrometer

A vital component of the diffraction grating spectrometer is the diffraction grating. A diffraction grating basically consists of equally spaced parallel slits which are very close to each other. One type of diffraction grating is a *transmission grating*. Such a grating is manufactured by cutting parallel lines on a glass plate. A *reflection grating*, on the other hand, is manufactured by cutting parallel lines on a reflective material.

Figure 22 below shows a portion of the diffraction grating. As can be seen from the said figure, light is incident on the grating from the left, perpendicular to the plane of the diffraction grating, and a converging lens is used to focus the light rays at point *P* on the viewing screen. The pattern observed in the viewing screen results from the combined effects of diffraction of light from each individual slit of the diffraction grating and from the interference of the diffracted light beams.

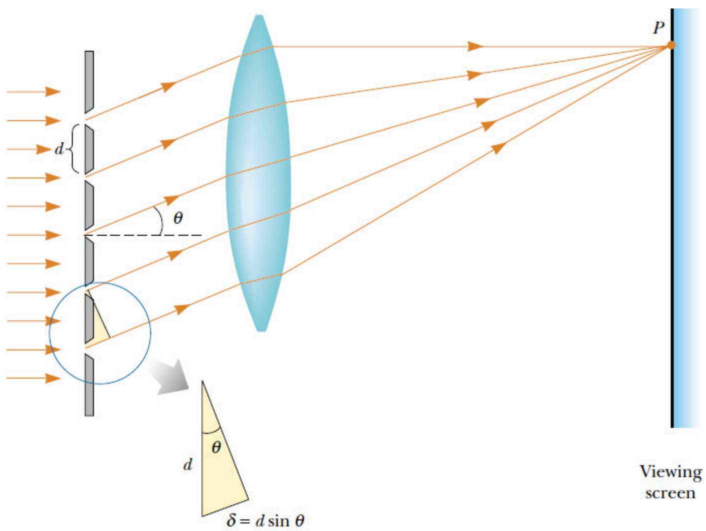

Figure 22. Side view of a diffraction grating

Figure 22 also shows that the waves from the slits are in phase as they leave the slits. For some arbitrary angle θ, however, the waves are seen to travel at different path lengths before reaching point *P*. The path difference δ between any two adjacent slits is equal to $d\sin\theta$. If this δ is equal to one wavelength or an integral multiple of a wavelength, then light waves from all the slits of the diffraction grating would arrive at point *P* with the same phase (that is, they are in phase) and hence a bright fringe will be observed at the viewing screen. In other words, the condition for the maxima in the interference pattern at the angle θ is

$$\boldsymbol{n\lambda = d\sin\theta} \text{ for } \boldsymbol{n = 0, 1, 2, 3, \ldots} \qquad (1)$$

where n refers to the order of diffraction, d is the distance between slits (note that $d = 1 / N$ if N, called the grating constant, is the number of lines per unit length), λ is the wavelength of the component of light diffracted at θ with respect to the normal position.

Equation (1) may be used to calculate the wavelength λ of the incident light the grating spacing and angle θ are known. If the incident light is made up of several component wavelengths, the n^{th}-order maximum for each wavelength occurs at a specific angle.

By calculating the wavelength λ of each of the component color of the light source and comparing it with the emission spectrum chart of known gases, one can determine what gas is present in the source.

III. PROCEDURES

1. Focus the viewing telescope of the spectrometer without the diffraction grating material so that the cross-hair in the telescope coincides with the collimated light coming from the lamp. Make sure that the zero mark in the movable telescope coincides with the zero mark of the fixed part of the spectrometer.
2. Place the diffraction grating material with its plane perpendicular to the viewing telescope.

<u>Determination of the grating constant *d* of the diffraction grating</u>

3. Use the *sodium light source*. Locate the angular position of the *first order* ($n = 1$) spectrum on each side of the direct image. The angular displacement θ will be nearly the same in both directions when the plane of the grating is perpendicular to the incident light.
4. Compute for the mean value of θ measured in #3 and calculate d using the diffraction formula with $\lambda = 589$ nm*.* Determine also the *number of lines per inch,* N, on the grating.
5. Repeat steps #3-#4 for the *second order* ($n = 2$).

6. Get the average of d found in #3 and #5. This value will be used for the remainder of the experiment. Solve also for the mean number *of lines per inch* N and compare it with the value specified on the grating material. Tabulate your results using Table 1.

Determination of the wavelengths of the lines in a known source

7. Replace the sodium lamp with a mercury lamp. Measure the angular position of each of the visible bright lines in the *first order* on both sides of the direct image. Get the mean value of θ for each line.
8. Calculate the corresponding wavelength for each of the lines using the diffraction formula with the value of d as calculated in #6 and compare it with the known standard value. Tabulate your results using Table 2.

Spectral identification of an unknown source

9. Have the technician place an unknown light source in the lamp holder.
10. Carefully measure the angular positions of the bright lines on both sides of the direct image in the first order. Get the mean value of θ for each line.
11. Compute for the wavelengths of the spectral lines using the diffraction formula and compare with the values expressed for different sources in the spectrum chart. Try to identify the substance in the unknown source. Tabulate your results using Table 3.

DATA

Table 1 Determination of the grating constant *d* of the diffraction grating

Light source = *Sodium*

Wavelength of light source = *589 nm*

Angular Displacement θ	**1st Order**		**2nd Order**	
	CW	**CCW**	**CW**	**CCW**
Average θ				
Grating Constant d				
Average d				
No. of lines/inch N				
Standard value of N				
Percentage Error				

Table 2 Determination of the wavelengths of the lines in a known source

Light source = *Mercury*

Spectrum Order (n) = *1*

Color	**Angular Displacement θ**			**Wavelength λ (nm)**	**Standard Value of λ (nm)**	**Percentage Error (%)**
	CW	**CCW**	**Ave**			
Yellow					579.1, 577.0	
Green					546.1	
Blue					453.8	
Violet					404.7	

Table 3 Spectral identification of an unknown source

Unknown light source = ___________

Spectrum Order (n) = *1*

Color	**Angular Displacement θ**			**Wavelength λ (nm)**	**Standard Value of λ (nm)**	**Percentage Error (%)**
	CW	**CCW**	**Ave**			

IV. EVALUATION

1. What would happen if the grating were not placed exactly perpendicular to the light beam? Would there be any experimental advantage to doing this? Any disadvantages?
2. What if the grating were, say 1 cm displaced from the center of the table, toward the collimator? Would this introduce an error in the experiment? If so, how much error would you get?

3. What would happen if the upper half of the grating is covered with opaque paper? How would this affect your measurements?
4. What would happen if a large portion of the sides of the grating is covered with opaque paper so that its effective area is reduced? How would this affect your measurements?
5. If a grating with smaller grating space (larger grating constant) is used, how will the observed angles or spread of the spectra be affected?