Physics 233
Experiment 52

Atomic Spectra

References

Any first year text, sections on atomic structure, spectral lines and spectrometers

Any modern physics text, eg F.K. Richtmeyer, E.H. Kennard and J.N. Cooper, *Introduction to Modern Physics*, 6th ed., McGraw-Hill (1969) pp. 233-239

Gaertner-Peck Spectrometer Manual (available in the lab).

Introduction

The emission of light from atoms only at definite spectral frequencies demonstrates that atomic electrons exist in distinct energy levels.

In the Bohr model of the atom the energy of an electron in an energy level designated by a principal quantum number n ($n = 1,2,3,...$) is given by:

$$E_n = -\frac{\mu e^4 Z^2}{8 \epsilon_o^2 h^2 n^2}$$

where μ is the reduced mass of the electron

$$\mu = \frac{m}{1 + m/M}$$

for an electron of mass m in orbit about a nucleus of mass M, e is the electron charge, Z is the atomic number of the atom, ϵ_o is the permittivity of free space and h is Planck's constant.

When an electron makes a transition from a higher to a lower energy level it may give off energy in the form of a quantum of radiation whose energy $h\nu$ is equal to the difference in energy of the two energy levels. If the quantum numbers of the lower and higher energy levels are n_2 and n_1 respectively ($n_2 < n_1$), then

$$h\nu = E_{n_1} - E_{n_2} = \frac{\mu e^4 Z^2}{8 \epsilon_o h^2} \left(\frac{1}{n_2^2} - \frac{1}{n_1^2} \right)$$

where ν is the frequency of the radiation emitted.

Quite often the frequency of the emitted spectral line is measured in wavenumbers $\bar{\nu}$, where

$$\bar{\nu} = 1/\lambda$$
$$= \nu/c$$
$$= \frac{\mu e^4 Z^2}{8 \varepsilon_o h^3 c} \left[\frac{1}{n_2^2} - \frac{1}{n_1^2} \right]$$
$$= \frac{R_\infty Z^2}{1 + m/M} \left[\frac{1}{n_2^2} - \frac{1}{n_1^2} \right]$$
$$= R_M Z^2 \left[\frac{1}{n_2^2} - \frac{1}{n_1^2} \right]$$

The factor R_∞ is called the Rydberg constant and would be correct if the mass of the nucleus were infinite; R_M is the Rydberg constant corrected for the reduced mass of the system.

The energy level diagram of hydrogen, for which $Z = 1$, is shown in Figure 1. We see here that the wavelengths (or wavenumbers) of the hydrogen spectrum can be grouped into series, each characterized by the quantum number n_2 of the lowest energy level. The Lyman series corresponds to $n_2 = 1$, the Balmer series to $n_2 = 2$, etc.

Balmer Series
$\lambda = 656.28$ nm
$\lambda = 486.13$ nm
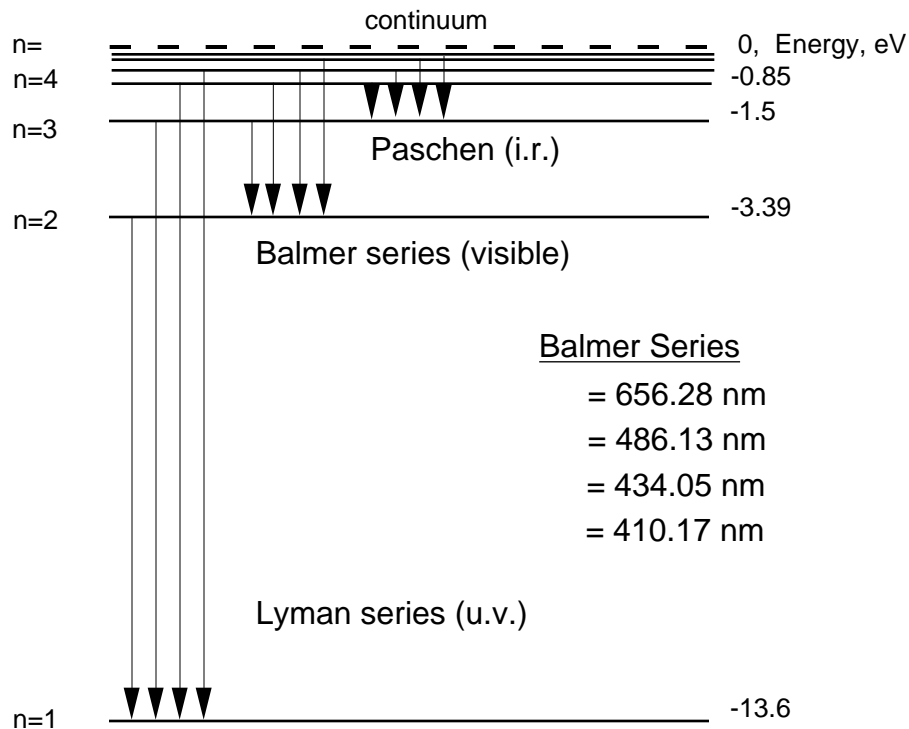$\lambda = 434.05$ nm
$\lambda = 410.17$ nm

Fig. 1 Energy level diagram for hydrogen.

In this experiment you will use a grating spectrometer to measure the hydrogen spectrum and so to determine the Rydberg constant. If parallel light of wavelength λ is incident normally on a diffraction grating, then the transmitted light has a diffraction pattern which consists of a number of sharp beams at angles θ such that $d \sin(\theta) = m\lambda$, where m is defined as the order of the spectrum and d is the spacing between the grating rulings. Knowing d and measuring θ allows you to determine the wavelengths in the spectrum.

Apparatus

- Spectrometer and diffraction grating
- Gauss eyepiece and mirror
- sodium lamp
- discharge tube power supply and gas discharge tubes: hydrogen and unknown elements

Experiment

1. Alignment of the spectrometer

The spectrometer used in this experiment is shown in Figure 2. It consists of a collimator, a telescope, a rotatable table, and a scale. Careful alignment is essential to the success of the experiment.

When making measurements the table must be locked so that it is fixed relative to the scale and the scale must be locked so that it is fixed relative to the base. There is a screw which permits fine adjustments of the scale position once the scale is locked .

The telescope may be rotated about a central vertical axis. This rotation can be measured precisely by means of the scale. The telescope may be rotated by hand or locked and rotated by means of a screw for fine positioning.
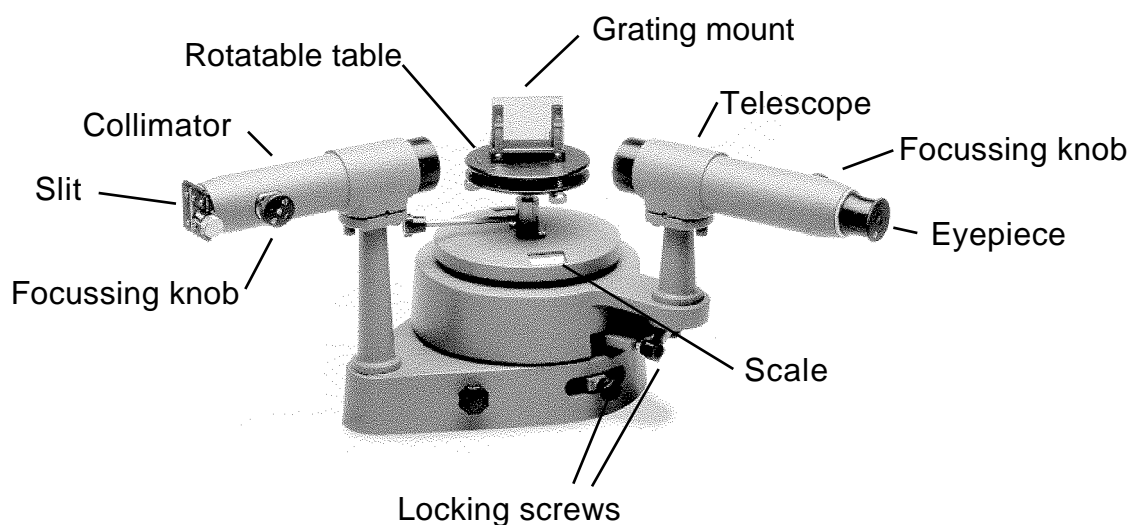

Fig. 2 The spectrometer.

Setting up the spectrometer before taking data involves:
 a) focussing the telescope for parallel light,
 b) focussing the collimator for parallel light,
 c) adjusting the collimator and telescope so that their axes are coincident and
 perpendicular to the axis of rotation,
 d) mounting the diffraction grating,
 e) illuminating the slit

a) Focussing the telescope

Focussing the telescope can be done with the regular eyepiece used while taking data (see the spectrometer manual), but a better procedure involves using a Gauss eyepiece and a flat mirror. After the spectrometer has been aligned the Gauss eyepiece should be removed and replaced with the regular eyepiece.

The Gauss eyepiece is shown in Figure 3. A thin piece of glass, D, is located between the lenses of the eyepiece, L1 and L2, at an angle of 45 degrees to the optic axis. This acts as a partial mirror which reflects light from the small lamp along the telescope axis towards the objective. This illuminates the crosshairs.
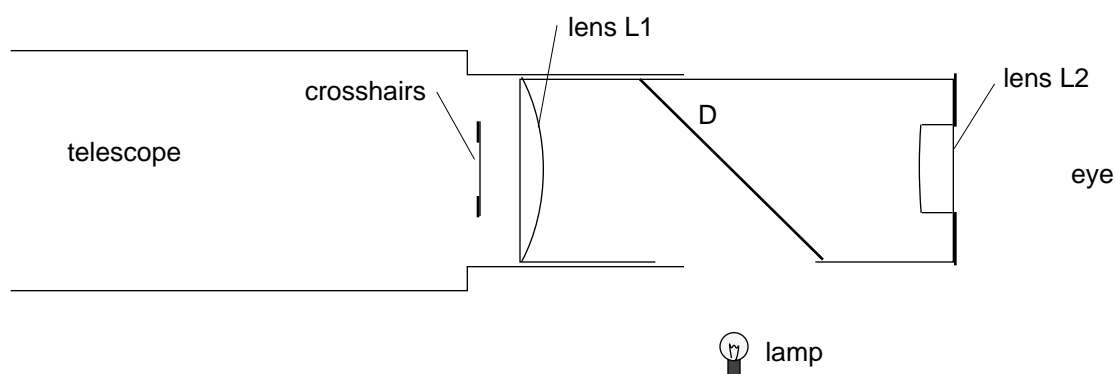

Fig. 3 The Gauss eyepiece in the telescope.

Place the mirror in the grating mount on the spectrometer table. Remove the regular eyepiece and insert the Gauss eyepiece. Focus the Gauss eyepiece on the crosshairs by sliding it in or out of its holder. The eyepiece may be regarded as a simple magnifier . The telescope must now be adjusted so that the crosshairs are in the focal plane of the objective lens. This is a critical adjustment. The position of the focal plane relative to the crosshairs is adjusted by means of the focussing knob on the telescope.

The objective lens will form an image of the crosshairs. When the light from this image is reflected from the mirror an image of the crosshairs will be reflected back through the objective lens of the telescope. If the crosshairs are positioned in the focal plane of the objective lens then the reflected image will also be in the focal plane. Thus an observer will see the crosshairs and their image approximately superposed. If the crosshairs are closer to the objective than the focal plane the image will be further from the objective and vice versa. Whether the crosshairs and their image lie in the same plane can be determined by moving the eye across the eyepiece and watching for any relative motion (parallax) of

the image and the crosshairs. No relative motion means that the telescope is correctly focussed.

Adjust the focussing knob until there is no parallax between the crosshairs and the image.

b) Focussing the collimator

The Gauss eyepiece is not needed for this adjustment but it may be left in the instrument. Remove the mirror from the grating mount. Make the slit narrow and illuminate it. Aim the telescope so that the fixed edge of the slit is lined up with the crosshairs. The collimator is focussed by moving the slit by means of the focussing knob on the collimator. Correct focus occurs when there is no parallax between the slit image and the crosshairs.

c) Setting the telescope axis in a horizontal plane and levelling the collimator

The student may assume that these operations have already been done.

d) Mounting the diffraction grating

HANDLE THE GRATING CAREFULLY, DO NOT TOUCH THE RULED SURFACE.

Place the grating in the mount on the rotating table. The table must then be adjusted so that light from the collimator is incident normally on the grating. This is accomplished by rotating and tilting the table. There are three screws on the table which allow tilting.

Arrange the telescope to look directly at the slit and lock it in this position. Using the Gauss eyepiece adjust the screws so that the image of the crosshairs, reflected from the grating surface, is at the same height as the crosshairs. The image may be difficult to see but it is there. Then rotate the table until the crosshairs and the image are coincident. Lock the table and scale in this position.

e) Illuminating the slit

The light source should be positioned so that the slit is completely illuminated. The width of the spectral lines seen through the telescope is determined by the width of the slit. A narrow slit makes setting of the crosshairs more accurate. A wider slit allows more light through and gives brighter lines. This is useful when looking at weaker lines.

Remove the Gauss eyepiece and slide the original eyepiece in until the crosshairs are in focus. This will not affect the focus of the telescope.

2. Measurement of the grating spacing

Using the sodium lamp as a light source measure the position of the sodium lines in first and second order on both sides of the zero order line. If the angles on the two sides are not the same you should check the alignment of the spectrometer. Using the known value for the wavelengths of the sodium doublet, determine the grating spacing by using $d \sin(\ ) = m\ $.

3. Determination of the Rydberg constant

DISCHARGE TUBES SHOULD BE OPERATED ONLY WHEN OBSERVING THE SPECTRUM.
The tubes have a short life if operated continuously.

Replace the sodium lamp with the hydrogen discharge tube and measure the spectrum. The Balmer series lines are given by:

$$\overline{\nu} = 1/\lambda = R_H \left(\frac{1}{2^2} - \frac{1}{n^2} \right)$$

A plot of $1/\lambda$ versus $\left(1/2^2 - 1/n^2 \right)$ should yield a straight line. Fit the best straight line to the points and determine R_H from the slope of this line.

4. Identifying the unknown elements from their spectra

Measure the spectra of the two sources, Unknown A and Unknown B, and identify them. A list of prominent wavelengths is given in the Handbook of Chemistry and Physics.