EXPERIMENT 10 Fine Structure and One-electron Spectrum

Objective

1. Calibration of the spectrometer using the He spectrum, and the determination of the constant of the grating.
2. Determination of the spectrum of Na.
3. Determination of the fine structure splitting.

Principle

The well-known spectral lines of He are used for calibrating the diffraction spectrometer. The wavelengths of the spectral lines of Na are determined using the spectrometer.

Equipment

Lamp holder, Pico 9, f. spectr. lamps	1	Spectrometer/Goniometer W. Vernier	1
Spectral lamp He. Pico 9 base	1	Diffraction grating, 590 lines/mm	1
Spectral lamp Na. Pico 9 base	1	Tripod base "PASS"	1
Power supply for spectral lamps	1		

Theory

1. If light of a wavelength λ falls on to a grating of constant d it is diffracted. Intensity maxima are produced if the angle of diffraction (φ satisfies the following conditions:

$$n\lambda = d \sin \varphi; \qquad n = 0, 1, 2 \ldots$$

Table 1 Wavelength of the He spectrum

red	yellow	green	greenish blue	bluish green	blue
667.8 nm	587.6 nm	501.6 nm	492.2 nm	471.3 nm	447.1 nm

The calibration curve of the diffraction spectrometer (Fig. 1) is plotted for the first order ($n = 1$) and the measured angles φ. The grating constant is determined by

$$d = \frac{\lambda}{\sin \varphi}$$

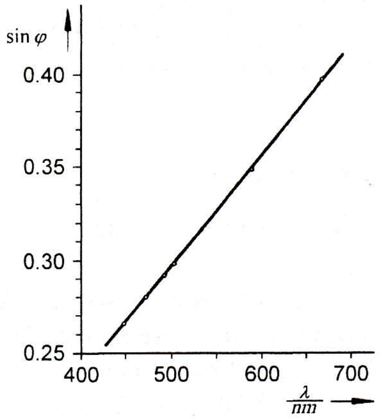

Fig. 1 Calibration curve of the diffraction spectrometer

2. The excitation of the Na atoms is produced by electron impact. The energy difference produced by the return of electrons from the excited level E_1, to the original state E_0 is emitted as a photon, of frequency f, given by:

$$hf = E_l - E_o$$

where h = Planck's constant = 6.63×10^{-34} J s

To a first approximation the electrons of the inner complete shell produce a screening of the potential V due to the charge on the nucleus, as regards the single external electron,

$$V(r) = -\frac{e^2 Z_{\text{eff}}(r)}{4\pi\varepsilon_o r}$$

where e is the charge of the electron. The energy levels are similar to those of hydrogen, with reduced degeneracy of angular momentum.

$$E_{n,l} = -\frac{me^4}{8\hbar^2} Z_{nl}^2 \frac{1}{n^2}$$

An approximation formula for E_{nl} is given below:

$$E_{n,l} = -\frac{me^4}{8\hbar^2}\frac{1}{(n-\mu_{nl})^2} \qquad (1)$$

The quantum defect μ_{nl} depends to some slight extent on n and decreases as l increases.

l / n	0	1	2	3	4
3	1.35	0.85	0.01		
4				0.00	
5					0.00

Table 2 μ_{nl} of the Na atom

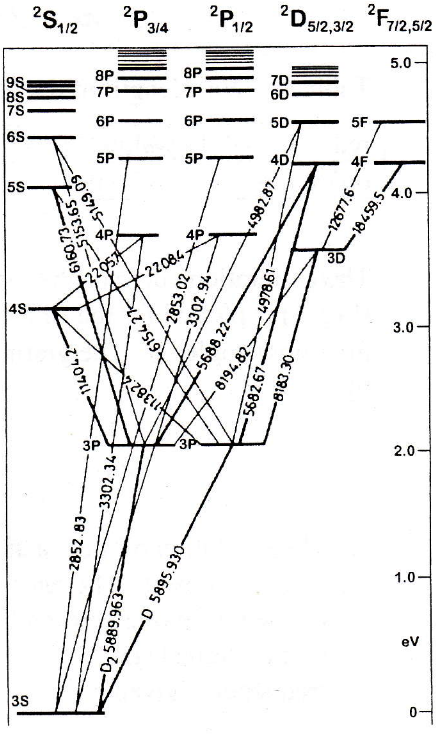

Figure 2 Spectrum of sodium

The interaction of the spin of the electron with its orbital angular momentum gives rise to the so-called fine structure, which only could be proved by using the perturbation theory.

In the case of sodium, the spin-orbit interaction gives rise to a doubling of energy levels 3P and therefore to a doubling of spectral lines. The sodium doublet corresponds to the transition 3P → 3S.

Experimental

The experimental set up is as shown in Fig. 3.

To start with, the telescope is adjusted to infinite distance. Then both tubes are adjusted horizontally with the adjusting screws and finally they are adjusted so that the directions of their axes coincide. The spectral lamp is placed directly before the slit and must illuminate it completely. A sharp image of the slit is formed in the plane of the eyepiece scale and is observed using the eyepiece lens as a magnifying lens. The slit should be selected as narrow as possible. To start with, the grating constant of the high resolution Rowland grating is determined. For this, the grating is set perpendicular to the collimator axis and the grating table is fixed. The diffraction angles of the intense He spectral lines are determined.

The angle 2φ of a spectral line of the same order of diffraction is measured to the right and to the left of the zero order. Two measurement readings are taken for every angle (two verniers).

Usually, the eyepiece scale is difficult to see, due to reduced brightness for higher orders diffraction. In these cases, better visibility may be obtained by lightning the grating askew from the direction of the telescope with a torch light.

In order to determine the wavelengths of the two sodium D-lines, the doublet should be observed in the second-order spectrum.

The spectral lamps attain their full illuminating power after being warmed up for about 5 minutes. The lamp housing should be adjusted so that air can circulate freely through the ventilation slits. Before changing the spectral lamps a cooling period must be allowed since the paper cloths or dusters used in this operation might otherwise stick to the glass of the lamp.

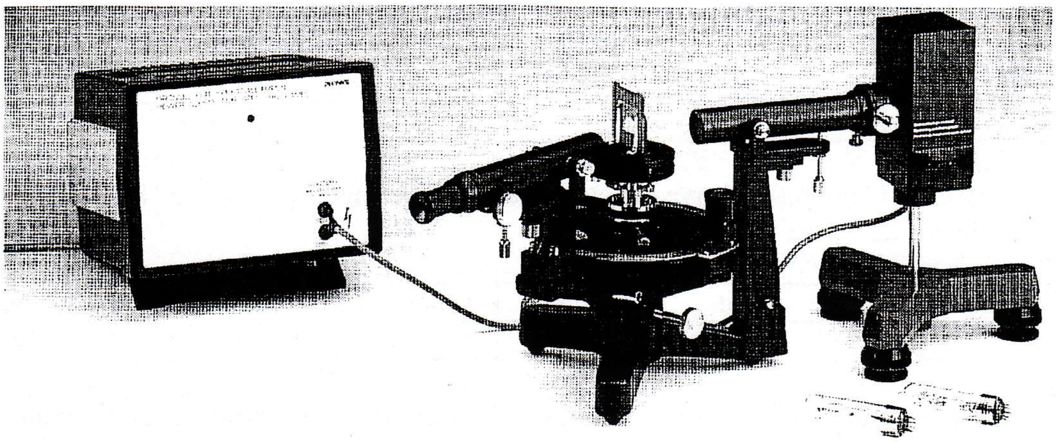

Figure 3 Experimental set up for determining the spectral line of Na

Data and results

Hand in this report at the start of the next practical session. Marks are in brackets.

1) Calibrate the spectrometer with the 6 He lines as shown in Table 1. Record the date in the following table: [2]

λ (nm)	667.8	587.6	501.6	492.2	471.3	447.1
2φ						
φ						
$\sin \varphi$						
d						

Plot a calibration curve similar to Fig. 1. [1]

Determine the constant grating, *d*, by taking the average, or by linear regression, of the *d's* in the above table.

Report : $d =$ ___________ nm ± ______ nm [1]

2) Determine the 2φ of the five lines of the Na atom in the first order spectrum. Report the data in the following table: [2]

Colour	red	yellow	yellowish green	green	green
2φ					
φ					
$\sin \varphi$					

3) Use your calibration curve to determine the wavelengths of the five Na lines. Report the results in the following table: [1]

Colour	red	yellow	yellowish green	green	green
λ (nm)					

4) The separation of the yellow D-lines is determined in the second-order spectrum. First of all, determine the wavelength of the shorter sodium D-line (λ_1 = 5??.? nm), then, determine the long-wave (λ_2).

Report : λ_1 = ___________ nm λ_2 = ________ nm [1]

5) Calculate the difference (the fine structure splitting) between the long-wave (λ_2) and the short-wave (λ_1) sodium D-line:

Report : $\lambda_2 - \lambda_1$ = 0.??? nm [1]

6) Discuss the main source of error in this experiment. [1]