



Related concepts

Diffraction spectrometer, Na spectrum, spin, angular momentum, spin-orbital angular momentum interaction, multiplicity, energy level, excitation, energy, selection rules, doublets.

The equipment marked * is designed for connection to 220 V a.c., 50 Hz mains. It can also be supplied for other mains voltages or frequencies.

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.

Problem

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.

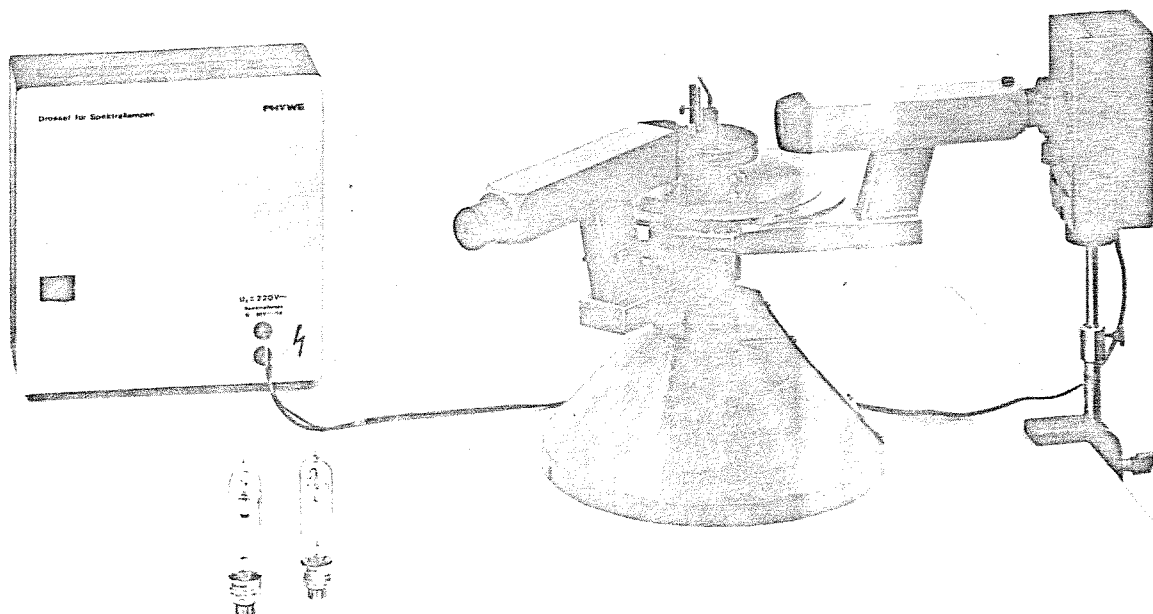
Equipment

LAMP HOLDER, PICO 9, F.SPECTR.LAMPS	08119.00	1
SPECTRAL LAMP HE, PICO 9 BASE	08120.03	1
SPECTRAL LAMP NA, PICO 9 BASE	08120.07	1
POWER SUPPLY FOR SPECTRAL LAMPS	11727.93*	1
SPECTROMETER/GONIOMETER W.VERNIER	35635.02	1
DIFFRACTION GRATING, 590 LINES/MM	35675.00	1
BENCH CLAMP, -PASS-, SMALL	03948.55	1
STAND TUBE	02060.00	1

Set-up and procedure

Fig. 1: Experimental set up for determining the spectral lines of Na.

The experimental set up is as shown in Fig. 1. The spectrometer/



5.1.2 Fine structure and one-electron spectrum

goniometer and the grating must be set up and adjusted according to the operating instructions.

In the second-order spectrum, the sodium D-line is split. The micrometer screw is set to 0 and the cross hairs in the telescope positioned to coincide with the red line (2nd-order). The telescope is locked by means of the knurled head screw. The cross hairs are first positioned at the long-wave and then at the short-wave sodium D-line, with the micrometer screw, the particular micrometer positions being noted each time. It is also possible to measure the splitting starting from the short-wave side. The only essential is that the direction of rotation of the micrometer screw is maintained, otherwise the play in the micrometer spindle might lead to errors. When measuring in the reverse direction, the micrometer screw must be set to 10 and the cross hairs in the telescope again positioned to coincide with the red line (2nd-order). For quantitative determination of wavelengths, the micrometer screw must be calibrated round the entire circle. 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.

Theory and evaluation

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 α satisfies the following conditions:

$$n \cdot \lambda = d \cdot \sin \alpha; \quad n = 0, 1, 2 \dots$$

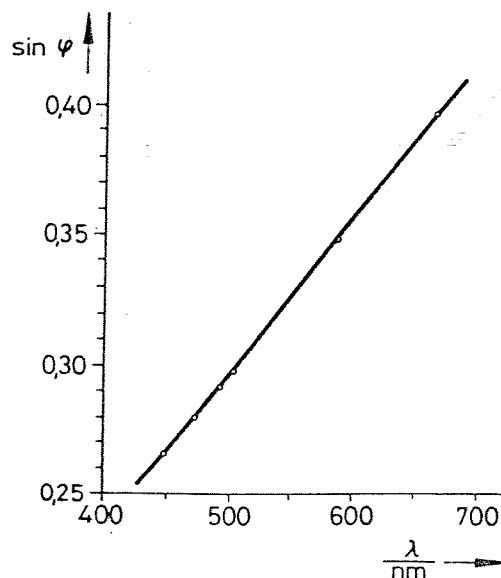
red	667.8 nm
yellow	587.6 nm
green	501.6 nm
greenish blue	492.2 nm

bluish green	471.3 nm
blue	447.1 nm

Table 1: Wavelength of the He spectrum.

The calibration curve of the diffraction spectrometer (Fig. 2) is plotted for the first order ($n = 1$) and the measured angles α .

Fig. 2: Calibration curve of the diffraction spectrometer



The grating constant is

$$d = 1684 \text{ nm.}$$

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:

$$hf = E_1 - E_0$$

where

h = Planck's constant

$$= 6.63 \cdot 10^{-34} \text{ Js.}$$

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, but the potential is position-dependent:

5.1.2 Fine structure and one-electron spectrum

$$V(r) = - \frac{e^2 Z_{eff}(r)}{4\pi\epsilon_0 r}$$

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

$$E_{nl} = - \frac{me^4}{8\hbar^2} Z^2 \frac{1}{nl^2}$$

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

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

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

$n \setminus l$	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.

The interaction of the spin \vec{S} of the electron with its orbital moment gives rise to a reduction in the degeneracy of the total angular momentum:

$$j = |l + \frac{1}{2}| \dots |l - \frac{1}{2}| ,$$

where l is the orbital angular momentum of the external electron.

If we consider the interaction term in perturbation theory:

$$H = \xi(r) \vec{S} \cdot \vec{l}$$

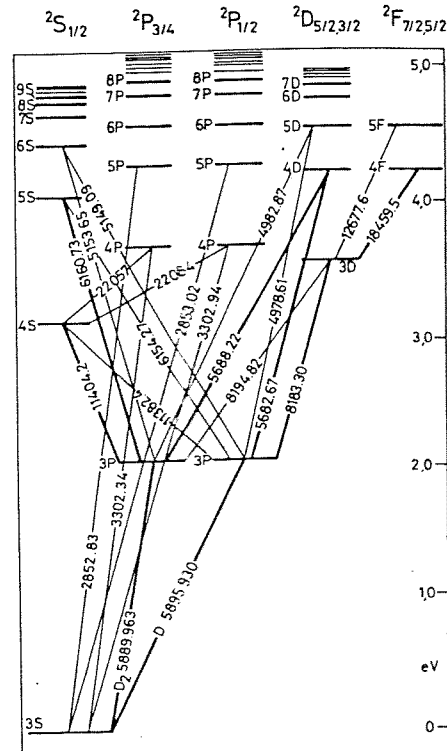
we obtain the following for (1):

$$E_{nlj} = E_{nl} + \xi_{nl} \frac{1}{2} (j(j+1) - S(S+1) - l(l+1))$$

and as splitting:

$$E_{nlj=l+\frac{1}{2}} - E_{nlj=l-\frac{1}{2}} = \frac{1}{2} (2l+1) \xi_{nl} .$$

Fig. 3: Spectrum of sodium



The following lines of the Na atom were measured in the first order spectrum:

red	617.2 nm
yellow	588.4 nm
yellowish green	567.7 nm
green	514.1 nm
green	498.7 nm

Table 3: Experimentally determined Na wavelengths.

The separation of the yellow D-line was determined in the second-order spectrum. First of all, the wavelength of the shorter sodium D-line in the second order spectrum was determined:

$$\lambda_1 = 588.6 \text{ nm} .$$

The difference between the short-wave and the long-wave sodium D-line was then determined using the micrometer screw:

$$\lambda_2 - \lambda_1 = 0.614 \text{ nm} .$$