

## Line Spectra

### RECORD AND INTERPRET THE BALMER SERIES OF LINES FOR HYDROGEN AND OTHER LINE SPECTRA IN THE VISIBLE REGION.

- Record the line spectrum of hydrogen.
- Determine the frequencies of the  $H_\alpha$ ,  $H_\beta$ ,  $H_\gamma$  and  $H_\delta$  lines of the Balmer series for hydrogen.
- Calculate the Rydberg constant.
- Record and interpret line spectra of inert gases and metal vapours.

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Fig. 1: Measurement set-up.

## GENERAL PRINCIPLES

Light emitted by atoms of an electronically excited gas gives rise to spectra consisting of many individual lines, which are clearly distinguishable from one another, although they may be quite tightly packed in some parts of the spectrum. The lines are uniquely characteristic for each chemical element, because each line corresponds to a transition between particular energy levels in the electron shell of the atom.

The emission spectrum of hydrogen atoms has four lines,  $H_\alpha$ ,  $H_\beta$ ,  $H_\gamma$  and  $H_\delta$ , in the visible region. The spectrum continues into the ultra-violet region to form a complete series of spectral lines. In 1885 *J. J. Balmer* discovered that the frequencies of this series fit an empirical formula:

$$(1) \quad \nu = R \cdot \left( \frac{1}{2^2} - \frac{1}{n^2} \right)$$

$n = 3, 4, 5, 6, \dots$

$R = 3290 \text{ THz}$ : the Rydberg constant

Later, with the aid of the Bohr model of the atom, it was shown that the frequency series could be explained simply in terms of the energy released by an electron when it undergoes downward transitions from higher shells to the second shell of a hydrogen atom.

The line spectrum of a helium atom, which contains only one more electron than hydrogen, is already much more complex, because the spin of the two electrons can be oriented in parallel or anti-parallel, so that they occupy completely different energy levels in the helium atom.

The complexity increases further for all other chemical elements. However, in every case the line spectrum is uniquely characteristic of the element.

## LIST OF EQUIPMENT

1	Digital Spectrometer LD	U22028	1018103
1	Spectrum Tube Power Supply	U418001	1000683/4
1	Spectrum Tube Hydrogen	U41817	1003409
1	Cylindrical Stand Base, 1000 g	U13265	1002834

Additionally recommended:

1	Spectrum Tube Helium	U41816	1003408
1	Spectrum Tube Neon	U41821	1003413
1	Spectrum Tube Argon	U41811	1003403
1	Spectrum Tube Krypton	U41819	1003411
1	Spectrum Tube Mercury	U41820	1003412
1	Spectrum Tube Bromine	U41812	1003404
1	Spectrum Tube Iodine	U41818	1003410

## NOTES

- Some spectrum tubes are filled with an additional “carrier” gas. When turning on spectrum tubes, wait a few minutes until only the spectral lines for the specified element are seen to be dominant.
- Do not operate the spectrum tubes for long periods, however, as this can adversely affect their lifespan. Take note of the recommendations in the instruction manual for the spectrum tubes.

## SET-UP AND PROCEDURE

- Set up the digital spectrometer, the spectrum tube power supply with its built-in hydrogen spectrum tube and the computer as shown in Fig. 1.
- Screw the optical fibre to the spectrometer and the optical fibre holder. Attach the holder for the optical fibre to the rod on the stand base and position it directly in front of the opening of the spectrum tube power supply.
- Turn on the computer.

- Connect the spectrometer to the power supply.
- Connect the spectrometer to the computer with the help of the USB cable.
- In the window that opens, click “Run EsaoStudio.exe”. The software will start to run automatically.

In the program, the user interface window is displayed in “Emission” operating mode and measurements start to be made at once.

### Note:

The tabs on the left-hand side can be used to switch between operating modes (from top to bottom) “Emission”, “Absorbance”, “Manual acquisition”, “Kinetic” and “3D Kinetic”.

- Turn on the spectrum tube power supply use the “Emission” operating mode to record an emission spectrum.
- Stop recording the emission spectrum by clicking the “Run/Pause button as soon as the spectral lines can be seen clearly (Fig. 2). Save the spectrum, entering a file-name under “Name”, then clicking the “Save” button.
- Match the spectral lines to the quantum numbers of their energy levels. Read off the wavelengths of the lines in the spectrum and make a note of them (Table 1). To read them off, simply move the mouse over the lines in question. It may be, though, that you need to select a different tool from the “Tools” menu.
- If possible, fit some different spectrum tubes to the tube power supply and record their emission spectra as described above (Figs. 3, 4, 5).

## SAMPLE MEASUREMENT

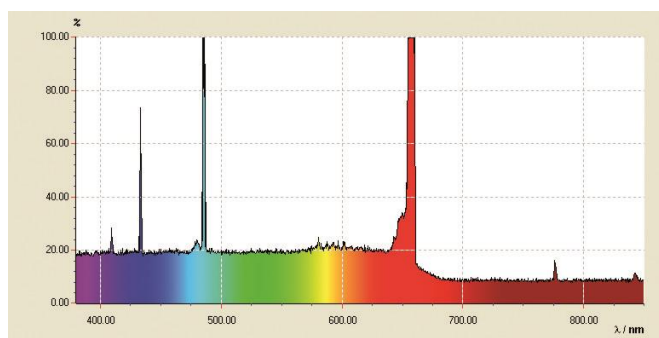


Fig. 2: Line spectrum of hydrogen atoms.

Tab. 1: Energy level quantum numbers  $n$ , their inverse squares  $1/n^2$ , measured wavelengths  $\lambda$  and frequencies  $\nu$  of the Balmer series lines for hydrogen in the visible spectrum as calculated from those wavelengths.

$n$	$1/n^2$	$\lambda / \text{nm}$	$\nu / \text{THz}$
3	0.111	656	457
4	0.063	487	616
5	0.040	432	694
6	0.028	410	732

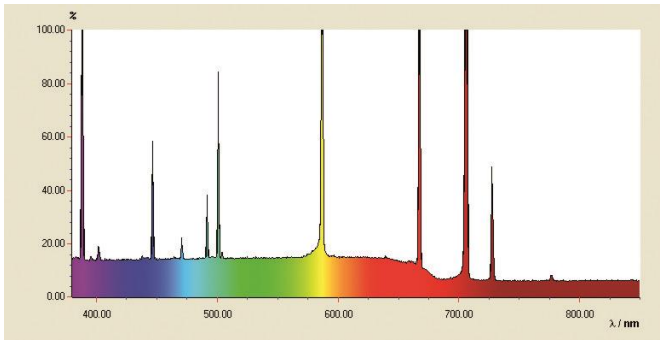


Fig. 3: Line spectrum of helium.

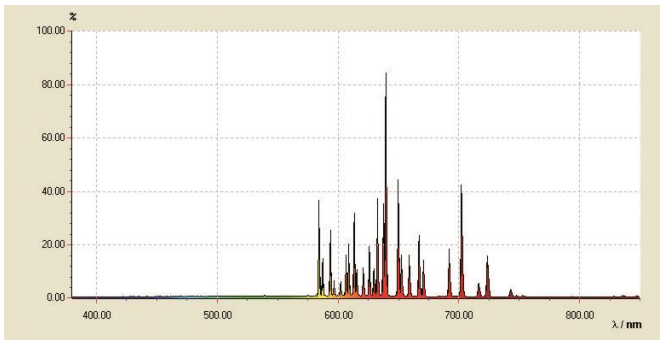


Fig. 4: Line spectrum of neon.

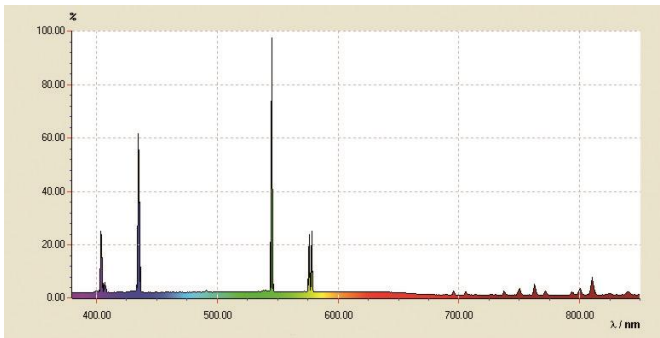


Fig. 5: Line spectrum of mercury vapour.

## EVALUATION

- Calculate the inverse squares  $1/n^2$  of the energy level quantum numbers  $n = 3, 4, 5, 6$  (Table 1).
- Calculate the line frequencies  $\nu$  from their wavelengths  $\lambda$  (Table 1):

$$(2) \quad \nu = \frac{c}{\lambda}$$

$c = 3 \cdot 10^8$  m/s: velocity of light in a vacuum

- Plot the frequencies  $\nu$  against the inverse squares of the level quantum numbers  $1/n^2$  in a graph (Fig. 6).

On the graph of  $\nu = f(1/n^2)$ , the frequencies of the Balmer series lie along a straight line as predicted by equation (1) when the  $H_\alpha$  line is attributed to the energy level quantum number  $n = 3$ , the  $H_\beta$  line to number  $n = 4$  etc.

- Fit a straight line to the measurement points (Fig. 6).

From equation (1):

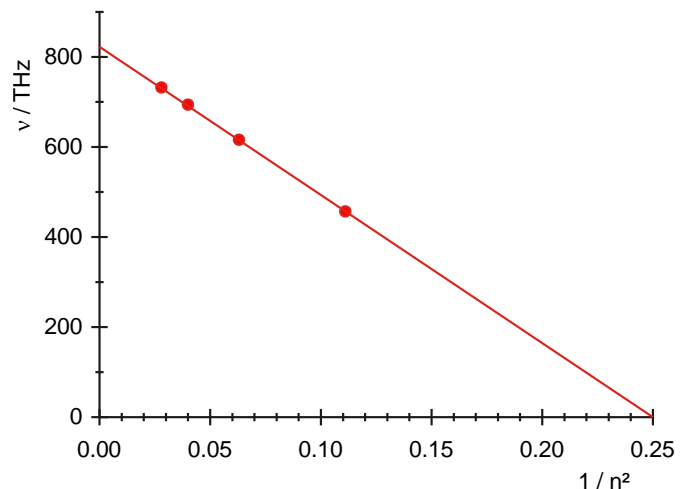
$$(3) \quad \nu = R \cdot \left( \frac{1}{2^2} - \frac{1}{n^2} \right) = -R \cdot \left( \frac{1}{n^2} - \frac{1}{4} \right)$$

The Rydberg constant  $R$  can therefore be derived from the gradient  $a$  as follows:

$$(4) \quad a = -3320 \text{ THz} = -R \Rightarrow R = 3320 \text{ THz}.$$

This agrees very well with the value quoted in literature.

The line crosses the x-axis at 0.25, since the transitions in the Balmer series are down to the energy level with quantum number  $n = 2$ .

Fig. 6: Transition frequencies of the Balmer series as a function of  $1/n^2$ .

