Investigating the spectrum of a high pressure mercury lamp

Experiment objectives

- Observe spectral lines on a screen
- Determine wavelength using the Littrow configuration
- Investigate and measure differences in wavelength between lines that are close together
- Observe pressure broadening

Principles

Spectral lines arise due to transitions of electrons from higher energy levels in the shells of excited atoms to lower ones. The wavelength of the light emitted due to such transitions is given by the following energy differential:

$$\Delta E = h \cdot \nu = \frac{h \cdot c}{\lambda}$$

A Grotrian diagram of energy levels in mercury, also called a term diagram, reveals a large number of lines of different intensity (transition probabilities). In the near UV and visible ranges, the following lines in particular may be observed:

Wavelength $\frac{\lambda}{\mathrm{nm}}$	Relative intensity	Transitions
365.02	2800	$6\,^3D_3 - 6\,^3P_2$
404.66	1800	$7\,^3S_1 - 6\,^3P_0$
433.92 434.75 435.83	250 400 4000	$7\,^3D_2 - 6\,^1P_1$ $7\,^1D_2 - 6\,^1P_1$ $7\,^3S_1 - 6\,^3P_1$
546.08	1100	$7\,^3S_1 - 6\,^3P_2$
576.96 579.07	240 280	$6\,^3D_2 - 6\,^1P_1$ $6\,^1D_2 - 6\,^1P_1$

Table1: Selection of certain visible mercury lines

In the first and second parts of the experiment, the various lines will be observed and their wavelengths determined.

In the third section, the two yellow lines are to be investigated in greater detail and the difference in their wavelengths found.

In the fourth section, the double yellow line will be viewed after the high-pressure mercury lamp has been turned on for various lengths of time. As the temperature increases, so does the temperature and this causes the lines to become less sharply defined. The key effect responsible is called pressure broadening, although Doppler broadening also contributes to a lesser extent.

During the experiment, spectral lines are to be investigated using a high-resolution spectrometer set-up. This involves using a holographic grating from which interference arises due to reflection.

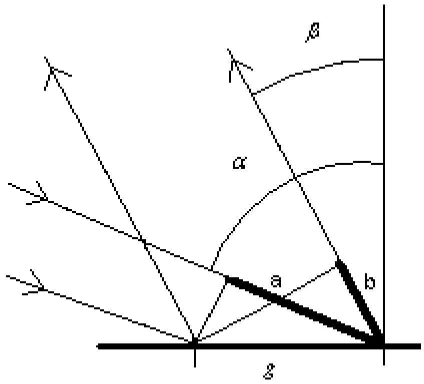

Fig. 1: Determination of wavelength

The difference in path length between two rays at a first-order maximum is given by the following: $\Delta s = \mathrm{a} + \mathrm{b} = \lambda$

With an angle of incidence α and angle of diffraction β ($\frac{\mathrm{a}}{g} = \sin\alpha$ and $\frac{\mathrm{b}}{g} = \sin\beta$) the wavelength can be determined as follows:

$$\lambda = g \cdot (\sin\alpha + \sin\beta) \quad (1)$$

where *g* is the grating constant.

In this set-up, the angles α and β can be derived from the angle of the holographic grating to the optical axis $\omega_{\mathrm{Pointer}}$ (Angle of inclination) and the angle between the optical benches $\omega_{\mathrm{Benches}}$ (direction of refracted light beam).

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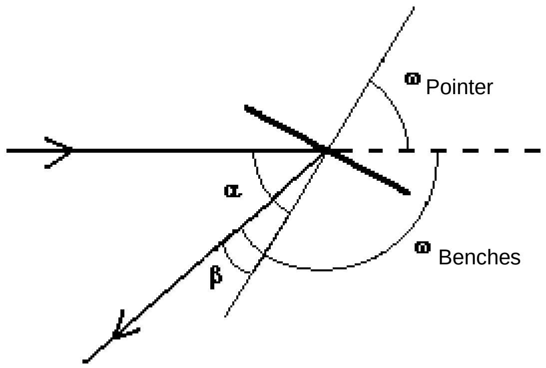

Fig. 2: Determination of angles

The angle of incidence α corresponds to the angle to which the column, on which the holographic grating is placed, is turned:

$$\alpha = \omega_{\mathrm{Pointer}} \qquad (2)$$

The angle of reflection β is given by the following (see Fig. 2):

$$\beta = \omega_{\mathrm{Pointer}} + \omega_{\mathrm{Benches}} - 180° \qquad (3)$$

In the so-called Littrow configuration, the first-order maximum is reflected in the direction of the incident light beam, i.e. $\alpha = \beta$

Using equation (1) to obtain the wavelength:

$$\lambda = 2 \cdot g \cdot \sin\alpha \qquad (4)$$

i.e. $\alpha = \omega_{\mathrm{Pointer}}$(3):

$$\lambda = 2 \cdot g \cdot \sin\omega_{\mathrm{Pointer}} \qquad (5)$$

The angular split between the lines $\Delta\beta$ is also derived from equation (1)

$$\frac{\mathrm{d}\lambda}{\mathrm{d}\beta} = g \cdot \cos\beta \text{ or } \Delta\lambda = g \cdot \cos\beta \cdot \Delta\beta \qquad (6)$$

The splitting of the lines is viewed using a telescope arrangement. The angular split can be determined from the separation *d* between the lines and the focal length *f* of the objective:

$$\Delta\beta = \frac{d}{f} \qquad (7)$$

Therefore, the difference in wavelength between two lines is:

$$\Delta\lambda = \frac{d \cdot g \cdot \cos\beta}{f} \qquad (8)$$

Equipment

1 Optical bench with standard profile, 1 m 460 32
1 Optical bench with standard profile, 0.5 m 460 335
1 Swivel joint with circular scale 460 341
4 Optics rider 90/50..460 374
1 Optics rider 60/60..460 373
1 Tilting rider...460 382

1 High pressure mercury lamp 451 15
1 Power supply for high pressure mercury lamp ...451 195

1 Lens in frame, *f* = 50 mm...................................460 02
1 Adjustable slit...460 14
1 Lens in frame, *f* = 150 mm.................................460 08

1 Holographic grating, 2400 lines/mm 471 27

1 Lens in frame, *f* = 300 mm.................................460 09
1 Screen..441 531
1 Ocular with scale 460 135

Set-up

Fig. 3: Experiment set-up

– First use the adjustable bases to set up the optical benches such that they are parallel and at the same height and then secure them in place with the fixing screws.

– Connect the two benches together by means of the swivel joint.

– Set up the high-pressure mercury lamp roughly in the middle of the 1-m optical bench. Fit a lens (*f* = 50 mm) in the tilting rider and set it up about 10 cm from the lamp. Place the adjustable slit another 10 cm or so beyond it, in such a way that the slit is well illuminated. It may be necessary to incline the tilting rider a little.

– Position another lens (*f* = 150 mm) about 15 cm beyond the adjustable slit in order to obtain a parallel beam of light.

– Set up the pointer on the swivel joint to exactly 0° and turn the holographic grating on its column in such a way that it reflects the light beam back along itself and secure it with the knurled screw. It may be necessary to move the 150-mm lens so that the image of the slit is sharply focused alongside the actual slit (autocollimation). For fine adjustment, use the knurled screws belonging to the holographic grating (in order to help, the column can be fixed in place using the knurled screw at the bottom, which should then be loosened again afterwards).

– Set up the screen at the end of the 0.5-m optical bench with a lens (*f* = 300 mm) about 30 cm in front of it.

Procedure

a) Observation of spectral lines

– Turn the 0.5-m optical bench clockwise until $\omega_{\mathrm{Benches}} = 130°$.

– Turn the holographic grating anti-clockwise until a line is clearly visible on the screen. The 300-mm lens may have to be moved slightly in order to obtain a well focussed image of the slit.

– Turn the holographic grating further in order to observe other spectral lines.

– Lines in the ultra-violet region can be made visible with the help of white fluorescent paper. This should be held directly in front of the screen.

Note: an alternative method is to keep the holographic grating still and turn the 0.5-m optical bench.

b) Determination of wavelength in Littrow configuration: $\alpha = \beta$

– Turn the holographic grating anti-clockwise (positive angle) until the first-order maximum of the yellow line is reflected back along the incident light beam. Observe the reflection on the adjustable slit fitting.

– Read off the inclination angle $\omega_{\mathrm{Pointer}}$ of the holographic grating

– Reduce the inclination angle and measure the other easily seen lines (positive angle). The UV line can be made visible by holding paper in front of the screen.

– Then turn the holographic grating and repeat the measurement (negative angle).

c) Investigation of individual (split) lines

– Use the same set-up as in part a). Turn the holographic grating until the yellow lines can be seen on the screen.

– Remove the screen and replace it with the micrometer ocular.

– Set up the micrometer ocular in such a way that the scale is easy to read.

– Move the 300-mm lens to bring the yellow lines into focus. Turn the holographic grating slightly till one of the lines is exactly in the middle of the scale.

– Read off the inclination angle $\omega_{\mathrm{Pointer}}$ of the holographic grating from the angle scale and read the separation of the two *d* lines from the scale on the ocular.

– Repeat the experiment for the blue lines.

d) Observation of pressure broadening of yellow lines

– Use the same set-up as in part a). Set up the ocular such that the yellow lines are well in focus.

– Turn off the high-pressure mercury lamp and wait several minutes for it to cool down.

– Turn on the mercury lamp and observe the double yellow line as the lamp heats up.

Example measurements

a) Observation of spectral lines

– Many spectral lines can be seen on the screen.

a) Determination of wavelength in Littrow configuration

– Wavelength can be calculated using the following equation

$$g = \frac{1}{N} = \frac{1}{2400\,\frac{1}{\text{mm}}} \approx 417 \cdot 10^{-9}\,\text{m}$$

Colour	Positive angle	Negative angle	Aver-age	Wave-length from (5)	Quoted values
	ω_{Pointer}	ω_{Pointer}	ω_{Pointer}	λ	λ
Yellow	43.5°	44.5°	44°	579 nm	578 nm*
Green	40.5°	41.5°	41°	547 nm	546 nm
Blue	31.5°	31.5°	31.5°	436 nm	436 nm
Violet	29°	29.5°	29.25°	408 nm	405 nm
UV	26°	26°	26°	366 nm	365 nm

* Double line

– The calculated wavelengths are well in agreement with the values quoted in literature.

b) Investigation of individual (split) lines

– Calculate wavelength λ from (1), (2) and (3) for $\omega_{\text{Benches}} = 130°$.

Colour	Angle	Wave-length	Split	Wave-length differential	Quoted values
	ω_{Pointer}	λ	d	$\Delta\lambda$	$\Delta\lambda$
Yellow	76°	587 nm	1.7 mm	2.1 nm	2.11 nm
Blue	60.5°	439 nm	0.85 mm	1.1 nm	1.08 nm
			1.5 mm	2.1 nm	1.91 nm

– The calculated differentials are well in agreement with the values quoted in literature (see Table 1).

d) Observation of pressure broadening of yellow lines

– Initially the two lines are both very narrow. With increasing temperature, and therefore pressure, of the mercury vapour in the lamp, the two lines become broader and less well focussed.