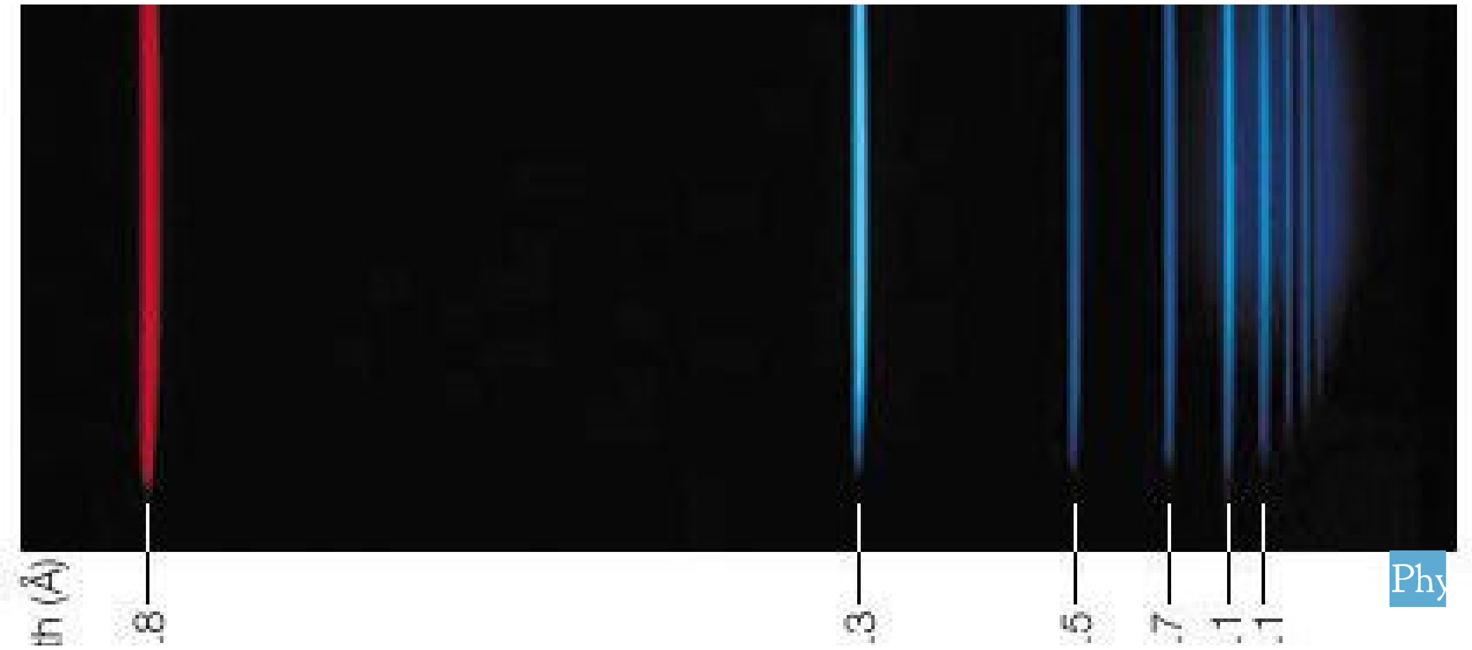
Balmer series / Determination of Rydberg's constant



Physics → Modern Physics → Atomic & Molecular Physics

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

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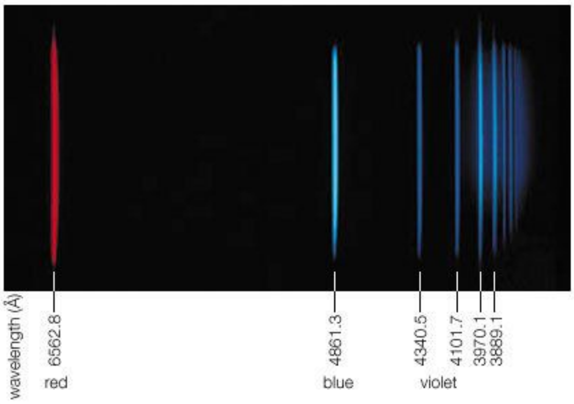
General information

Application



Balmer series of hydrogen lines

The spectral series, or particularly Balmer series, are important in astronomical spectroscopy for detecting the presence of hydrogen in the universe. Spectral lines can appear as atoms and molecules emit and absorb radiation at distinct wavelengths, depending on the nature of the object.

Those spectral lines in a spectrum give astronomers information about physical properties of the object, such as chemical composition, density, mass, temperature and so on.

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Other information (1/2)

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Prior knowledge

If enough energy is absorbed by an atom, its electrons will occupy the outer orbits, which correspond to the higher energy levels or they will be removed from the atom. The atom is then said to be ionized. In this way, the absorption lines in a spectrum give information about the atom.

Scientific principle

The spectral lines of hydrogen and mercury are examined by means of a diffraction grating. The known spectral lines of mercury are used to determine the grating constant. The wavelengths of the visible lines of the Balmer series of hydrogen are measured.

Other information (2/2)

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Learning objective

To learn about the Balmer series of hydrogen with wavelengths given by Rydberg constant

Tasks

1. Determine the diffraction grating constant by means of the mercury spectrum.
2. Determine the visible lines of the Balmer series in the hydrogen spectrum, of Rydberg's constant and of the energy levels.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

The hydrogen and mercury tubes are powered by high voltage and the tubes get hot. Do not touch the tubes anywhere especially near the ends where the electrical contacts are made.

Theory (1/6)

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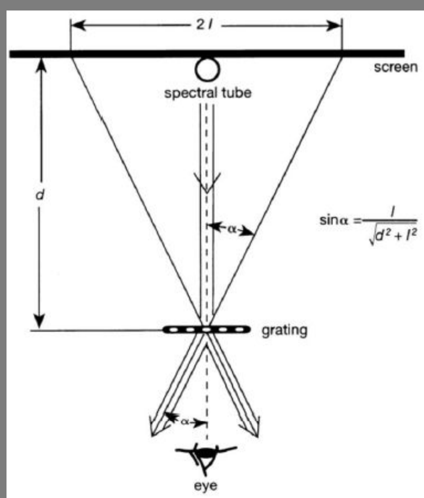
Diffraction grating

If light of wavelength I impinges on a grating with constant g, it is diffracted. Intensity peaks occur when the angle of diffraction α fulfills the following condition:

$$n \cdot \lambda = g \cdot \sin\alpha \; ; \quad n = 0, 1, 2, ...$$

Light is collected by the eye on the retina, therefore the light source is seen in the color of the observed spectral line on the scale in the prolongation of the light beams. For the diffraction of the n-th order, the following relation is deduced from the geometrical structure:

$$n \cdot \lambda = g \cdot \left(\frac{l}{\sqrt{d^2+l^2}}\right)$$



Diffraction at the grating

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Theory (2/6)

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Hydrogen Spectrum

Due to collision ionization, H_2 is converted to atomic hydrogen in the spectral tube. Electrons from the H atoms are excited to higher energy levels through collisions with electrons.

When they return to lower energy levels, the atoms emit light of frequency f given by the energy difference of the concerned states:

$$E = h \cdot f$$

where h is Planck's constant.

Theory (3/6)

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Applying Bohr's atomic model, the energy E_n of a permitted electron orbit is given by:

$$E_n = \frac{1}{8} \frac{e^4 m_e}{\epsilon_0^2 h^2 n^2}, \text{ n = 1, 2, 3, ...}$$

where $\epsilon_0 = 8.8542 \cdot 10^{-34} As/Vm$ is the electric field constant, $e = 1.6021 \cdot 10^{-19} C$ is the electronic charge and $m_e = 9.1091 \cdot 10^{-31} kg$ is the mass of the electron at rest.

The emitted light can therefore have the following frequencies:

$$f_{nm} = \frac{1}{8} \frac{e^4 m_e}{\epsilon_0^2 h^3} \left(\frac{1}{n^2} - \frac{1}{m^2} \right), \text{ n, m = 1, 2, 3, ...}$$

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Theory (4/6)

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If the wave number *N = I - 1* is used instead of the frequency *f*, by substituting *c = I . f* one obtains:

$$N = R_{th}(\frac{1}{n^2} - \frac{1}{m^2})$$

where $R_{th} = \frac{1}{8}\frac{e^4 m_e}{\epsilon_0^2 h^3 c} = 1.097 \cdot 10^7 m^{-1}$. Here R_{th} is Rydberg's constant, which follows from Bohr's atomic model.

For $m \to \infty$, one obtains the limits of the series; the associated energy is thus the ionization energy (or the binding energy) for an electron in the n-th permitted orbit. The binding energy can be calculated by means of the equation:

$$E_n = -R_{th} \cdot h \cdot c\frac{1}{n^2}$$

where $c = 2.99795 \cdot 10^8 m/s$and $h = 6.6256 \cdot 10^{-34} Js = 4.13567 \cdot 10^{-15} eVs$

Theory (5/6)

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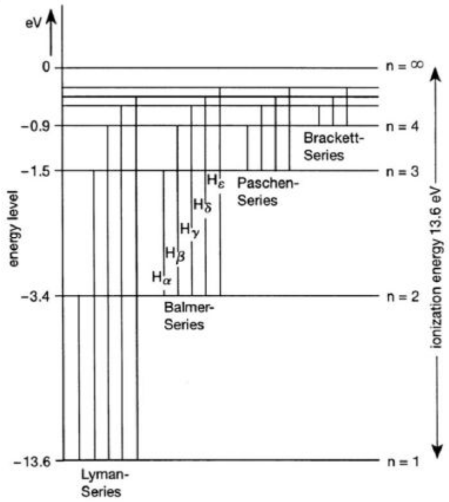

Energy level diagram of the H atom

n	Series	Spectral range
n = 1	Lyman series	Ultraviolet
n = 2	Balmar series	Ultraviolet till infrared
n = 3	Paschen series	Infrared
n = 4	Bracket series	Infrared
n = 5	Pfund series	Infrared

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Theory (6/6)

Note:

- If the room is sufficiently darkened, next to the atomic hydrogen spectrum, the molecular H_2 band spectrum may be observed. The numerous lines, which are very close to each other, are due to the oscillations of the molecule.
- The H_σ line is situated on the border of the visible spectral range and is too weak to be ob-served by simple methods.
- The treatment of more complex atoms requires quantum mechanics. In this case, the energies of the states are determined by the eigenvalues of the hamiltonian of the atom. For atoms similar to hydrogen, calculations yield the same results as Bohr's atomic model.

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Equipment

Position	Material	Item No.	Quantity
1	PHYWE High voltage power supply with digital display, 10 kV DC: 0... ± 10 kV, 2 mA	13673-93	1
2	Spectrum tube, hydrogen	06665-01	1
3	Spectrum tube, Hg	06664-01	1
4	Holders for spectral tubes, 1 pair	06674-01	1
5	Cover tube for spectral tubes	06675-00	1
6	Universal Holder, rotational	08040-02	1
7	Diffraction grating, 600 lines/mm	08546-00	1
8	Barrel base expert	02004-00	1
9	Support rod, stainless steel, 500 mm	02032-00	1
10	Right angle clamp expert	02054-00	3
11	Stand tube	02060-00	1
12	Meter scale, l = 1000 mm	03001-00	1
13	Cursors, 1 pair	02201-00	1
14	Measuring tape, l = 2 m	09936-00	1
15	Connecting cord, 30 kV, 1000 mm	07367-00	2
16	Insulating support	06020-00	2
17	Tripod base PHYWE	02002-55	1

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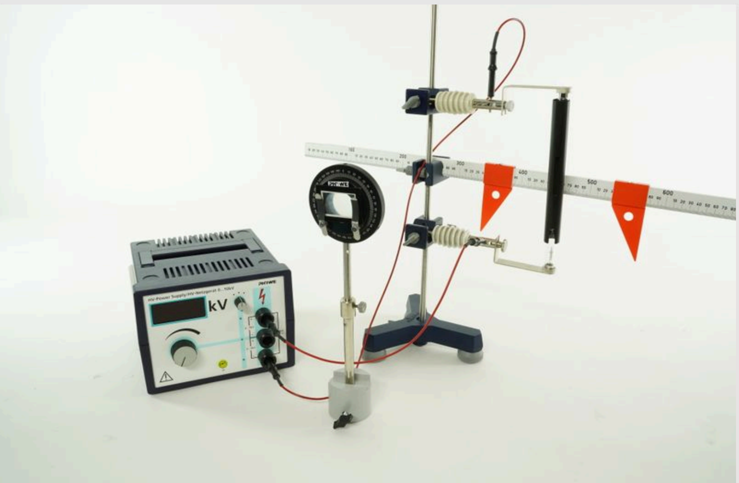
Setup and procedure

Setup



The experimental setup

Hydrogen or mercury spectral tubes connected to the high voltage power supply unit are used as a source of radiation. The power supply is adjusted to about 5 kV. The scale is attached directly behind the spectral tube in order to minimize parallax errors.

The diffraction grating should be set up at about 50 cm and at the same height as the spectral tube. The grating must be aligned so as to be parallel to the scale. The luminous capillary tube is observed through the grating.

The room is darkened to the point where it is still possible to read the scale.

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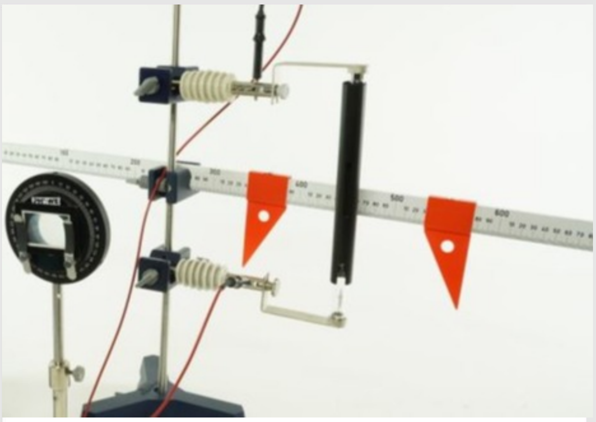
Procedure

The distance $2I$ between spectral lines of the same color in the right and left first order spectra are read through the grating. The distance between the grating and the eye should be so short, that both lines are visible at the same time without moving the head.

The distance d between the scale and the grating is also measured. Three lines are clearly visible in the Hg spectrum.

The grating constant is determined by means of the wavelengths. Rydberg's constant, and thus the energy levels in hydrogen, are determined from the measured wavelengths by means of Balmer's formula.



Grating and spectrum tube

Evaluation (1/3)

Color	λ/nm	$2I/mm$	$g/\mu m$
yellow	578.0	330	1.680
green	546.1	311	1.672
blue	434.8	244	1.661

$\bar{g} = 1.671\ mm$

Determination of the grating constant from the wavelengths of the Hg spectrum

Diffraction grating

The average obtained from the three measurements of the grating constant g is determined by means of the wavelengths

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Evaluation (2/3)

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Hydrogen spectrum

Rydberg's constant, and thus the energy levels in hydrogen, are determined from the measured wavelengths by means of Balmer's formula.

Distance d = 450 mm

Compare the experimental wavelengths with literature values.

Line	$2I/mm$	λ_{exp}/nm	λ_{lit}/nm	$R_{exp}/10^7 m^{-1}$
H_α	384	656	656.28	-
H_β	275	489	486.13	1.093
H_γ	243	436	434.05	1.092
H_σ	-	-	410.17	-

$$\overline{R_{exp}} = 1.094 \cdot 10^7\ m^{-1}$$

Measurements for the H spectrum

Evaluation (3/3)

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Which fall corresponds to the series of Balmar series?

- From the 2nd to 1st orbit
- From the 3rd to 2nd orbit
- From the 4th to 3nd orbit

Check

Which spectral lines are in the visible region?

- H_β
- H_γ
- H_σ
- H_α

Check

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Slide	Score / Total
Slide 18: Multiple tasks	0/5

Total Score 0/5

Show solutions

Retry

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