UdeMM
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Marina Mercante

Ingeniería

UNIVERSIDAD DE LA MARINA MERCANTE
FACULTAD DE INGENIERIA

Laboratorio de Ciencias Básicas

Física IIIA
Física IIIB

Práctica I

ESPECTROMETRÍA
ANÁLISIS ESPECTRAL: DETERMINACIÓN DE LA CONSTANTE DE RYDBERG

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Práctica I : Espectrometría – Determinación de la Cte. de Rydberg

1. Objetivos Principales

Utilizando el dispositivo experimental adecuado se estudia el espectro de emisión de distintas sustancias dependiendo de los tubos espectrales a disposición en el laboratorio (Argón, Hidrógeno, Kryptón, Mercurio, Neón o Xenón) y de redes y/o prismas de dispersión.

1.$_{-1)}$ Específicamente se determinarán las longitudes de onda y las energías correspondientes a las radiaciones amarilla, verde y azul hidrógeno (H), con su correspondiente margen de error, y se las compararán con los valores tabulados. Dichos espectros serán obtenidos a partir de la difracción de una red que por cada mm tiene 570 líneas.

1.$_{-2)}$ Utilizando los valores tabulados de las longitudes de onda para la determinar la constante de otra red de difracción (D), cuyo valor sea desconocido.

2. Objetivos Secundarios:

Dado que cada sustancia tiene sus propias líneas de emisión y en consecuencia, su constante característica:

2. $_{1)}$ Nos proponemos a determinar experimentalmente la del hidrógeno a la cual Rydberg bautizó con su nombre.

2.$_{-2)}$ Cada equipo elegirá, ó le será asignada por el docente a cargo, alguna de las opciones para que discuta y fundamente las posibilidades concretas de su determinación y de los inconvenientes, en caso de que los hubiere:

* Otro elemento incógnita para su estudio, con el cual implementar los procedimientos y estrategias utilizados para el H, y así determinar experimentalmente alguna de las λ de dicho elemento para luego investigar su identidad por rastreo bibliográfico.
\- Repetir lo anterior midiendo directamente los ángulos por medio de un goniómetro.
* Repetir, pero ahora, obteniendo el espectro de emisión por la dispersión de un prisma.

3. Marco Teórico

EL marco teórico se fundamenta en el modelo atómico fisicomatemático que Niels Bohr utilizó en 1913 para formular su teoría. Este permite hacer el análisis de las series espectrales, que Balmer encontró experimentalmente, correspondientes a la parte visible del espectro de emisión del hidrógeno. Por lo que este experimento, se propone recrear dicha experiencia histórica con el material que tengamos a disposición, pero como Balmer, básicamente dispersando la luz por una red de difracción ó mediante prismas.

4. Esquema Experimental.

Los distintos gases a estudiar serán excitados eléctricamente mediante una fuente de alta tensión de 5 kv.

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Para su presentación y futuro análisis del dispositivo se insertará a continuación una foto del mismo.

5. Desarrollo de la experiencia.

Comentar el desarrollo de la experiencia, acompañando de esquemas geométricos de la disposición en el plano de los distintos elementos utilizados para determinar los ángulos de difracción. Puede ser útil ver manual del equipo. (pedir fotocopia)
La ley de difracción de ondas en redes que relaciona ángulos y longitudes de onda

$n\lambda = D\,\mathrm{sen}\alpha$; siendo D el nº de líneas por mm característico de la red y n es el nº de orden correspondientes a las líneas del espectro

$$\mathrm{sen}\alpha = \frac{l}{\sqrt{l^2 + d^2}}$$

debe ser empleada para completar tablas de valores como la que figura a continuación.

Elemento	color	orde	sen α	Δsenα	λ	Δλ	E	ΔE	D	Valor real	Error %

6. Conclusiones

Analizar los resultados:

- Comparando con los tabulados, estableciendo si los márgenes de error son aceptables según criterios experimentales
- Aclarar si se pudo ó no efectuar mediciones para n distintos del 1° orden
- Comparando el valor obtenido para la constante de Rydberg con el teórico ¿Es posible determinarla experimentalmente para otro elemento? ¿Por qué?
- Realizando un diagrama líneas observadas en escala de energías para el H
- Investigando por medio de deducciones los fundamentos teóricos del fenómeno observado
- Aportando observaciones que enriquezcan la experiencia y sugieran alternativas para futuras comisiones. ¿Qué dificultades tiene el sustituir le red por un prisma respecto del diseño de la experiencia? ¿Es equivalente usar indistintamente un elemento u otro, a pesar de sus magnitudes características (ángulo de refringencia ó densidad de la red)?
- En caso que por algún motivo no se haya podido cumplir con alguno de los objetivos es necesario aclarar la circunstancia (ej.: inadecuada calibración)

Tener en cuenta que el criterio de corrección pondera de la misma manera al desarrollo que a las conclusiones de la experiencia, con el objetivo de lograr como resultado de las exploraciones coherencia entre la acción, los instrumentos y el modelo teórico. Por este motivo la comunicación, a través del lenguaje escrito (conclusiones), del hecho experimental debe hacer de cada informe un vehículo de comunicación de significados propio de cada grupo.

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ETP
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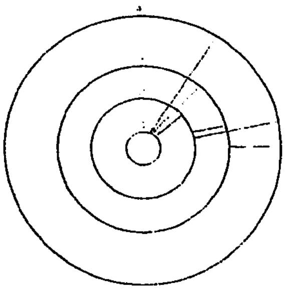
Phone: (773) 561-2349 • Fax: (773) 561-3130

SPECTRUM TUBES



Spectrum tubes contain one or more elements as gaseous atoms or molecules. Energy is supplied through an electric field applied between electrodes at the ends of the tubes. Ions and electrons formed by the field are accelerated; collisions convert the increased kinetic energy to other types, one being electronic. Electrons in energetic or excited atoms occupy one of many well-defined states. An electron with high energy E_3 will return to a lower energy state E_2, simultaneously emitting a photon of energy $E_3 - E_2 = \Delta E = hc/\lambda$; where $h = 6.63 \times 10^{-30}$ J-s is Planck's constant, $c = 3 \times 10^8$ m/s is the speed of light and λ is the wavelength of light (in meters) in the emitted photon.

Each excited atom type emits characteristic wavelengths determined by energy level differences ΔE present in that species. One may observe a particular color with the eye; analysis with a spectrometer will reveal a series of sharp (monochromatic) emission lines.

OBSERVING THE SPECTRA

Spectrum tubes manufactured by Electro-Technic Products, Inc. use research-grade gasses and vapors to provide bright-line spectral lines of the highest clarity. They are designed for optimum intensity and line resolution when examined in a student grade spectrometer equipped with a ca. 200 line/mm (5000 line/inch) diffraction grating.

The pressure of the various gasses in spectrum tubes is a carefully controlled value that will produce the maximum quality of brightness and clarity of the spectral lines.

For some tubes it is not necessarily the same value of pressure that produces maximum continuous operating life of the spectral lines. Tubes should be energized with the Electro-Technic Model SP-200 Spectrum Tube Power Supply, which is made expressly for this purpose. Tube life is extended if operation is cyclic for no more than 30 seconds "on", 30 seconds "off", etc., increasing the usable life of the tubes.

Some tubes using neon, helium and other gases found in cold cathode display signs can run continuously with less deterioration of the quality of the spectral lines. The others, such as hydrogen, the halogens and water vapor, require more care in processing to increase the life. Pure nickel electrodes and the best research grade of gases are used, and meticulous care is taken in processing to increase service life.

However, the tubes all start to contaminate at a very slow rate when used. How soon this can be detected by the user depends on the sensitivity of the measuring equipment. If the tubes are used as recommended and not allowed to get overheated, the useful life, or time it takes to detect contamination with the usual measuring equipment, is very long.

DESCRIPTIONS OF SPECTRA

Model 4605 HYDROGEN (H_2 gas). Strong violet, blue and red lines are obvious, although others may be seen.

Color	**Wavelength, Å**
Violet	4200
Violet	4400
Blue	4900
Red	6700
Red	6700

Model 4617 DEUTERIUM (isotopic variant of H_2). Spectrum is the same as for H_2, unaffected by neutron.

Color	**Wavelength, Å**
Violet	4200
Violet	4400
Blue	4900
Red	6700

Model 4604 HELIUM (He gas). Strong spectrum with 2 violet, 2 green, 1 yellow and 2 red lines being prominent.

Color	**Wavelength, Å**
Violet	4000
Violet	4000
Violet	4000
Blue	4500
Blue	4550
Blue	4550
Blue	4800
Green	5000
Green	5100
Yellow	5850
Red	6500
Red	6800
Red	7200

Model 4609 NITROGEN (N_2 gas). Strong spectrum of many lines from violet to red.

Color	**Wavelength, Å**
Violet	4000
Violet	4050
Violet	4100
Violet	4150
Violet	4200
Violet	4250
Violet	4400
Violet	4450
Blue	5000
Blue	5050
Blue	5200
Green	5300
Green	5400
Green	5500
Green	5600
Yellow	5800
Yellow	5850
Yellow	5900
Red	6000
Red	6150
Red	6200
Red	6250
Red	6300
Red	6350
Red	6400
Red	6450
Red	6500
Red	6600
Red	6700
Red	6750
Red	6800
Red	6850

Model 4610 OXYGEN (O_2 gas). Very weak spectrum covering violet, blue/violet, green and red (2 lines) regions.

Color	**Wavelength, Å**
Violet	4400
Violet	4400
Blue	4900
Green	5250
Green	5400
Green	5400
Green	5500
Green	5650
Red	6150
Red	6250
Red	6600
Red	6650

DESCRIPTIONS OF SPECTRA

Model 4611 WATER (H_2O vapor). Three strong hydrogen lines and weak spectrum from oxygen.

Color	Wavelength, Å
Violet	4300
Violet	4400
Blue	4900
Green	5200
Green	5400
Green	5500
Green	5600
Red	6050
Red	6100
Red	6650

Model 4612 AIR (about 80% N_2, 20% O_2 gases). Strong spectrum is effectively the same as that of pure N_2. See NITROGEN.

Model 4613 CARBON DIOXIDE (CO_2 gas). About 6 intense lines from carbon (C) superimposed on the spectrum from oxygen (O). See CARBONIC ACID.

Model 4602 CARBONIC ACID (H_2CO_3 vapor). Spectrum resembles that of carbon dioxide, plus conspicuous red line from hydrogen.

Color	Wavelength, Å
Violet	4150
Violet	4250
Violet	4450
Violet	4550
Blue	4900
Green	5100
Green	5200
Green	5300
Green	5400
Green	5650
Red	6100
Red	6200
Red	6300
Red	6600

Model 4608 NEON (Ne gas). Strong spectrum of multiple lines in green, yellow, orange, red. Note absence of violet lines. Used in "neon lights".

Color	Wavelength, Å
Blue	4750
Blue	4900
Green	5100
Green	5250
Green	5600
Green	5700
Yellow	5800
Yellow	5900
Yellow	6000
Red	6050
Red	6100
Red	6150
Red	6200
Red	6600
Red	6650
Red	6700
Red	6850
Red	7050
Red	7150

Model 4600 ARGON (Ar gas). Weak multiple lines, most intense in violet, least intense in red.

Color	Wavelength, Å
Violet	4200 (Hazy)
Violet	4400 (Hazy)
Violet	4600
Green	4950
Green	5250
Green	5500
Green	5500
Green	5600
Green	5700
Yellow	5950
Red	6100
Red	6250
Red	6300
Red	6400
Red	6500
Red	6600
Red	6700
Red	6800
Red	7100
Red	7200

DESCRIPTIONS OF SPECTRA

Model 4614 KRYPTON (Kr gas). Strong spectral lines in violet, green, orange and red portions.

Color	Wavelength, Å
Violet	4300 (Hazy)
Violet	4400 (Hazy)
Violet	4500
Violet	4550
Blue	4900
Green	5600
Green	5650
Green	5700
Yellow	5900
Red	6100
Red	6300
Red	6500
Red	6650

Model 4616 KRYPTON 86 (^{86}Kr gas). Isotopic variant of naturally occurring krypton, which is mainly ^{84}Kr. Spectrum is not noticeably changed, as with hydrogen and deuterium.

Model 4615 XENON (Xe gas). Weak spectrum of 2 violet and 2 green lines.

Color	Wavelength, Å
Blue	4700
Blue	4700
Green	4850
Green	4850
Green	5000
Green	5000
Red	6250
Red	6400

Model 4607 MERCURY (Hg vapor). Strong spectrum composed of 3 violet, 1 green, 1 yellow and 1 orange lines. Mercury lamps are used as light sources for these wavelengths.

Color	Wavelength, Å
Violet	4500
Violet	4500
Violet	4500
Violet	4600
Green	5000
Green	5050
Green	5600
Yellow	5900
Yellow	5900
Red	6100
Red	6250
Red	6600
Red	6800
Red	7200
Red	7300

Model 4603 CHLORINE (Cl_2 gas). Medium intensity multiline spectrum from violet to orange, with 3 stronger lines in the blue/green region.

Color	Wavelength, Å
Violet	4450
Violet	4550
Blue	4850
Blue	4850
Green	5100
Green	5200
Green	5200
Green	5400
Green	5450
Green	5700
Yellow	5900
Red	6000
Red	6250
Red	6350
Red	6550
Red	6650

Model 4606 IODINE (I_2 vapor). Strong spectrum with lines so closely spaced that appearance is "blurry", especially in orange/red region.

Model 4601 BROMINE (Br_2 gas). Strong, multiple line spectrum from violet to red, with about 7 prominent lines.

Color	Wavelength, Å
Violet	4200
Violet	4250
Violet	4500
Violet	4500
Blue	4750
Blue	4800
Blue	4800
Blue	4800

Balmer series / Determination of Rydberg's constant

LEP
5.1.07
-00

Related topics

Diffraction image of a diffraction grating; visible spectral range; single electron atom; atomic model according to Bohr; Lyman-, Paschen-, Brackett- and Pfund-Series; energy level; Planck's constant; binding energy.

Principle

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

Equipment

Spectrum tube, hydrogen	06665.00	1
Spectrum tube, mercury	06664.00	1
Holders for spectral tubes, 1 pair	06674.00	1
Cover tube for spectral tubes	06675.00	1
Connecting cord, 30 kV, l = 1000 mm	07367.00	2
Object holder, 5×5 cm	08041.00	1
Diffraction grating, 600 lines/mm	08546.00	1
High voltage supply unit, 0-10 kV	13670.93	1
Insulating support	06020.00	2
Tripod base -PASS-	02002.55	1
Barrel base -PASS-	02006.55	1
Support rod -PASS-, square, l = 400 mm	02026.55	1
Right angle clamp -PASS-	02040.55	3
Stand tube	02060.00	1
Meter scale, demo, l = 1000 mm	03001.00	1
Cursors, 1 pair	02201.00	1
Measuring tape, l = 2 m	09936.00	1

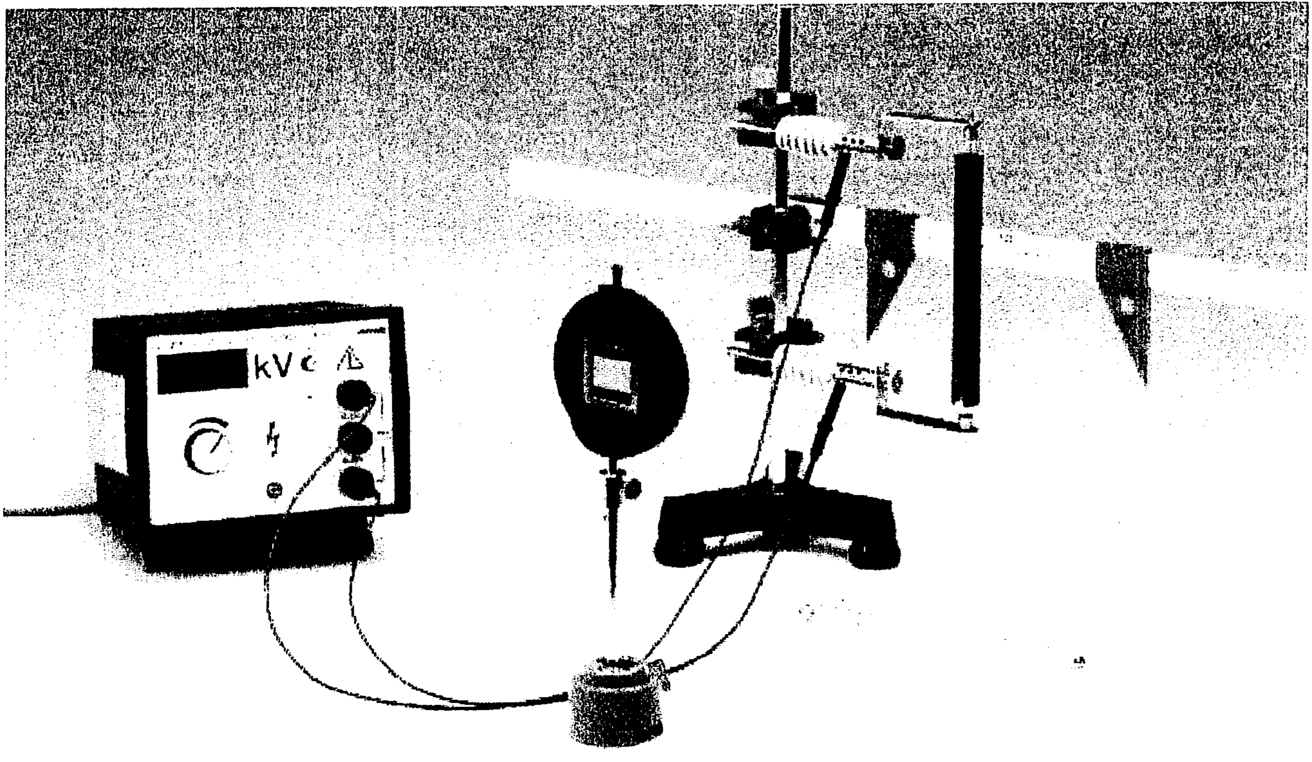
Tasks

1. Determination of the diffraction grating constant by means of the Hg spectrum.
2. Determination of the visible lines of the Balmer series in the H spectrum, of Rydberg's constant and of the energy levels.

Set-up and procedure

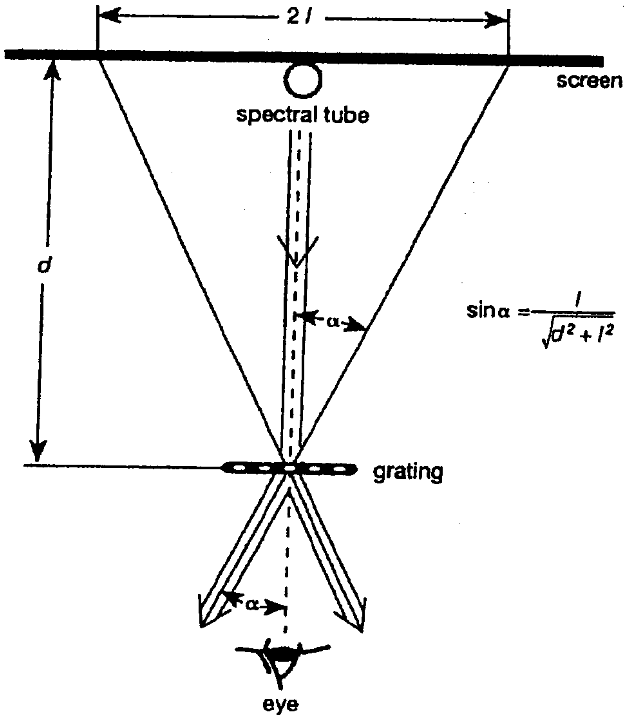
The experimental set-up is shown in Fig. 1. Hydrogen or mercury spectral tubes connected to the high voltage power supply unit are used as a source of radiation. The power supply is adjusted to about 5 kV. The scale is attached directly behind the spectral tube in order to minimize parallax errors. The 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. The distance 2 l between spectral lines of the same color in the right and left first order spectra are read without moving one's 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 g is determined by means of the wavelengths given in Table 1. Rydberg's constant, and thus the energy levels in hydrogen, are determined from the measured wavelengths by means of Balmer's formula.

Fig. 1: Experimental set-up to determine the spectral lines of the hydrogen atom.



8

Fig. 2: Diffraction at the grating.



Theory and evaluation

1. Diffraction grating

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

$$n \cdot \lambda = g \cdot \sin\alpha \; ; \quad n = 0, 1, 2, \ldots \qquad (1)$$

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 (Fig. 2):

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

In the examples given in Table 1, the average obtained for the three measurements of the grating constant is $g = 1.671\ \mu\text{m}$.

Tab. 1: Determination of the grating constant from the wavelengths of the Hg spectrum

Color	λ / nm	$2l$ / mm	g / μm
yellow	578.0	330	1.680
green	546.1	311	1.672
blue	434.8	244	1.661

2. Hydrogen spectrum

Due to collision ionization, H_2 is converted to atomic hydrogen in the spectral tube. Electrons from the H atoms are exited 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:

$$\Delta E = h \cdot f \qquad (3)$$

where h is Planck's constant.

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

$$E_n = -\frac{1}{8}\frac{e^4 m_e}{\varepsilon_0^2 h^2}\frac{1}{n^2} = n = 1, 2, 3 \ldots \qquad (4)$$

where $\varepsilon_0 = 8.8542 \cdot 10^{-34}$ 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:

$$f_{nm} = \frac{1}{8}\frac{e^4 m_e}{\varepsilon_0^2 h^3}\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \; n,m = 1, 2, 3 \ldots \qquad (5)$$

If the wave number $N = \lambda^{-1}$ is used instead of the frequency f, substituting $c = \lambda \cdot f$ one obtains:

$$N = R_{th}\left(\frac{1}{n^2} - \frac{1}{m^2}\right) \qquad (6)$$

$$\text{where } R_{th} = \frac{1}{8}\frac{e^4 m_e}{\varepsilon_0^2 h^3 c} = 1.097 \cdot 10^7\ \text{m}^{-1}$$

Here R_{th} is Rydberg's constant, which follows from Bohr's atomic model.

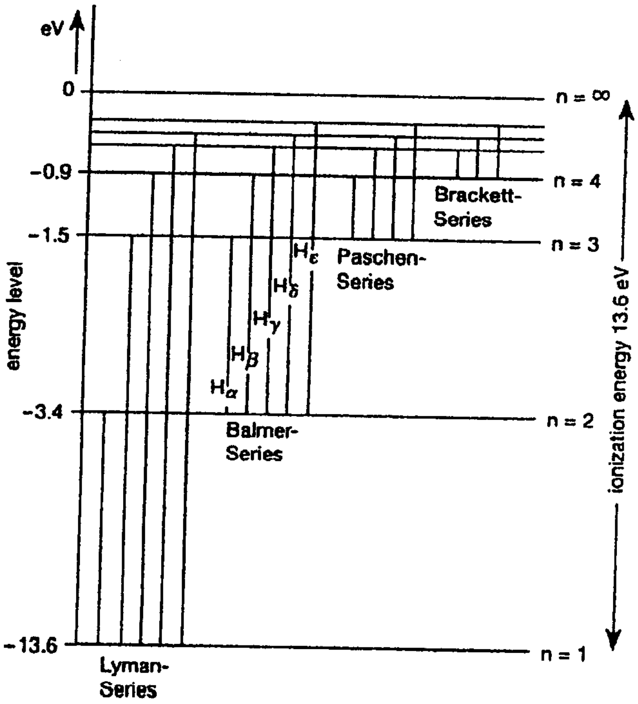


Fig. 3: Energy level diagram of the H atom.

$n = 1$: Lyman series
Spectral range: ultraviolet
$n = 2$: Balmer series
Spectral range: ultraviolet till red
$n = 3$: Paschen series
Spectral range: infrared
$n = 4$: Bracket series
Spectral range: infrared
$n = 5$: Pfund series
Spectral range: infrared

Fig. 3 shows the energy level diagram and the spectral series of the H atom. For $m \rightarrow \infty$, 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 $h = 6.6256 \cdot 10^{-34}$ J s = $4.13567 \cdot 10^{-15}$ eV s. The ground state is found to be 13.6 eV.

Tab. 2: Examples of measurements for the H spectrum
(Balmer series) Distance d = 450 mm

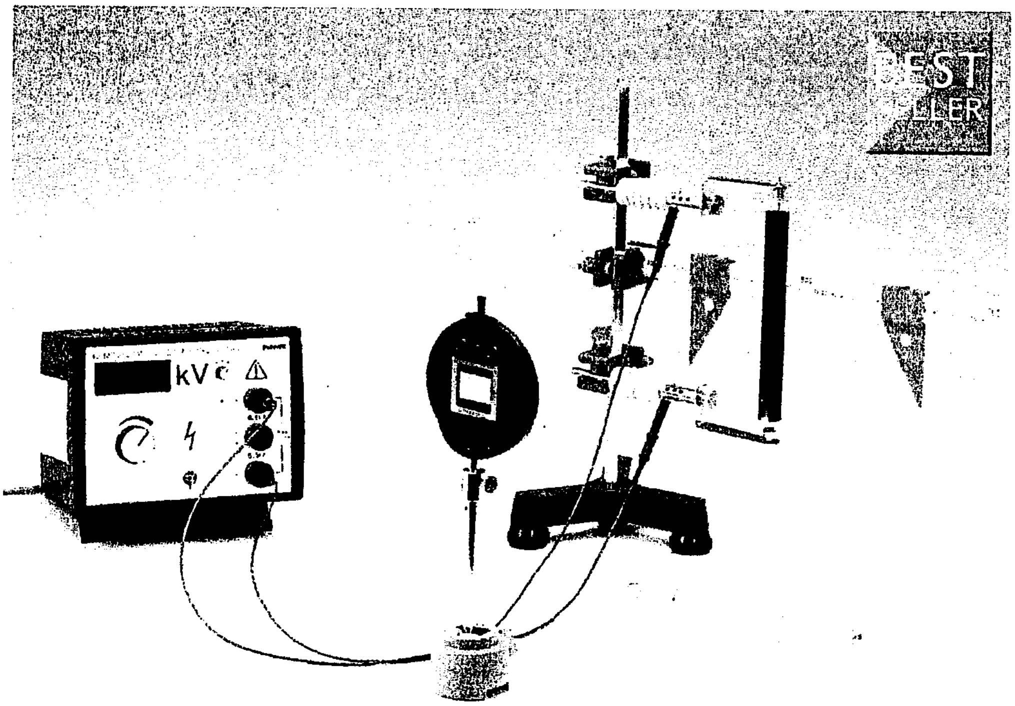
Line	$2l$	λ_{exp}	λ_{lit}	R_{exp}
H_α	384 mm	656 nm	656.28 nm	$1.097 \cdot 10^7$ m^{-1}
H_β	275 mm	489 nm	486.13 nm	$1.093 \cdot 10^7$ m^{-1}
H_γ	243 mm	436 nm	434.05 nm	$1.092 \cdot 10^7$ m^{-1}
H_δ	–	–	410.17 nm	–

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

Notices

- Next to the atomic hydrogen spectrum, the molecular H_2 band spectrum may be observed if the room is sufficiently darkened. The numerous lines, which are very close to each other, are due to the oscillations of the molecule.
- The H_δ line is situated on the border of the visible spectral range and is too weak to be observed 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.

Atomic spectra of two-electron systems: He, Hg 5.1.08-00



What you can learn about ...

- → Parahelium
- → Orthohelium
- → Exchange energy
- → Spin
- → Angular momentum
- → Spinorbit interaction
- → Singlet and triplet series
- → Multiplicity
- → Rydberg series
- → Selection rules
- → Forbidden transition
- → Metastable state
- → Energy level
- → Excitation energy

Principle:

The spectral lines of He and Hg are examined by means of a diffraction grating. The wavelengths of the lines are determined from the geometrical arrangement and the diffraction grating constants.

What you need:

Spectrum tube, mercury	06664.00	1
Spectrum tube, helium	06668.00	1
Holders for spectral tubes, 1 pair	06674.00	1
Cover tube for spectral tubes	06675.00	1
Connecting cord, 30 kV, l = 1000 mm	07367.00	2
Object holder, 5×5 cm	08041.00	1
Diffraction grating, 600 lines/mm	08546.00	1
High voltage supply unit, 0-10 kV	13670.93	1
Insulating support	06020.00	2
Tripod base -PASS-	02002.55	1
Barrel base -PASS-	02006.55	1
Support rod -PASS-, square, l = 400 mm	02026.55	1
Right angle clamp -PASS-	02040.55	3
Stand tube	02060.00	1
Meter scale, demo, l = 1000 mm	03001.00	1
Cursors, 1 pair	02201.00	1
Measuring tape, l = 2 m	09936.00	1

Complete Equipment Set, Manual on CD-ROM included

Atomic spectra of two-electron systems: He, Hg P2510800

Colour	λ/nm	Transition
red	665 ± 2	$3\ ^{1}D$ R $2\ ^{1}P$
yellow-orange	586 ± 2	$3\ ^{3}D$ R $2\ ^{3}P$
green	501 ± 2	$3\ ^{1}D$ R $2\ ^{1}P$
blue-green	490 ± 2	$4\ ^{1}D$ R $2\ ^{1}P$
blue	470 ± 3	$4\ ^{3}S$ R $2\ ^{3}P$
violet	445 ± 1	$4\ ^{3}D$ R $2\ ^{3}P$

Colour	λ/nm	Transition
yellow	581 ± 1	$6\ ^{1}D1$ R $6\ ^{1}P1$ $6\ ^{3}D1$ R $6\ ^{1}P1$
green	550 ± 1	$7\ ^{3}S1$ R $6\ ^{3}P1$
green	494 ± 2	$8\ ^{1}S1$ R $6\ ^{1}P1$
blue	437 ± 2	$7\ ^{1}S$ R $6\ ^{1}P1$

Measured spectral lines of He/Hg and the corresponding energy-level transitions.

Tasks:

1. Determination of the wavelengths of the most intense spectral lines of He.
2. Determination of the wavelengths of the most intense spectral lines of Hg.