NEW LINES IN THE ARC AND SPARK SPECTRUM OF HELIUM

By P. Gerald Kruger*
Physikalisch-technische Reichsanstalt, Berlin

(Received July 28, 1930)

Abstract

Light source. The glow inside a Paschen hollow cathode was used as the light source. Carbon, tantalum, and tungsten were used as the cathode materials. Helium gas for these experiments was specially refined, so that only very slight traces of neon could be detected.

Apparatus. The spectra were photographed by two different gratings used alternately in a Sawyer vacuum spectrograph and in a grazing incidence vacuum spectrograph.

Results. The $1s^2S_{\frac{1}{2}}-np^2P_{\frac{1}{2},1\frac{1}{2}}$ series of He II was extended to nine members, and the wave-lengths of the intensity maxima were calculated, so that these wave-lengths can be used for standards in this region.

Lyman's line at 600.019A has been found to be a He band. The forbidden line $1s^2\ {}^1S_0-1s2s\ {}^1S_0$ is present. Another line, thought to be $1s2s\ {}^1S_0-2s^2\ {}^1S_0$, has been observed. The line 320.392A, first observed by Compton and Boyce, is surely a helium line, and very probably the transition $1s2p\,{}^3P^0{}_{012}-2p^2\ {}^3P_{012}$.

The 303 series is by far the strongest series in the helium spectrum when pure helium is used in the discharge lamp. When, however, slight impurities of oxygen or carbon are introduced, the 584 series of He I as well as the 600.019A band is greatly enhanced, and the 303 series is weakened.

The presence of the forbidden line $1s^2\ {}^1S_0-1s2s\ {}^1S_0$ is probably due to the fact that the levels concerned are metastable, and that the gas pressure in the discharge in the lamp was exceedingly low.

THE present investigation was carried out at the suggestion of Professor F. Paschen, and was an attempt to excite the $1s^2$ electrons of He I into the $2p^2$, $2s^2$, and corresponding states.

Light Source

The glow in the inside a Paschen hollow cathode was used as the light source. During the course of the experiments a carbon cathode 10 mm in diameter, a carbon cathode 22 mm in diameter, a tantalum cathode 10 mm in diameter, and a tungsten cathode 10 mm in diameter were used.

The helium gas used for these experiments was specially refined at the cold temperature laboratory of the Physikalish-technische Reichsanstalt to remove traces of neon. This was done by liquifying the helium. One sample was collected during the liquification process, the other while the liquified helium was allowed to evaporate. Both samples were very pure, and only showed traces of the strongest neon lines when the discharge was maintained in the helium gas at high pressure. At low pressures, such as

* National Research Fellow.

were used when all exposures were taken, not even traces of the strong neon lines were visible.

Apparatus

A vacuum one-meter spectrograph designed according to Sawyer[1] with a glass grating from Wood, ruled 30,000 lines per inch, was used to photograph the first thirteen exposures. The glass grating was then replaced by a spectrum metal grating from Hilger, ruled 15,000 per inch. Five more exposures were photographed with this set-up, repeating the most favorable conditions during the first thirteen.

In the meantime a grazing incidence spectrograph, built in the shops of the Physikalisch-technische Reichsanstalt largely according to the design of Siegbahn and described by Ericson and Adlen[2] was adjusted with the glass grating from Wood. This set-up gave a dispersion of about 3A per mm at 300A, and about 6A per mm at 1000A. Eight more exposures were made with this instrument, repeating the above experiments. The glass grating was then replaced by the metal grating, and seven more exposures taken in order to check completely all work. Thus a total of thirty-two photographs were taken under varying conditions of gas pressure, current density, cathode material, and type of apparatus and grating.

The essential difference between the grazing incidence spectrograph and the design of Siegbahn was that the slit, grating, and cassette were all mounted on a solid aluminum block which could be pulled out of the hull of the spectrograph without disturbing either the vacuum set-up or the adjustment in any way. This arrangement has several obvious advantages.

The reason for using the different cathodes mentioned above was to eliminate the possibility of attributing lines from the cathode substance to helium, and to find a cathode substance which sputtered as little as possible and which gave no lines in the vacuum region. Tungsten was found to be the most favorable.

Although various helium gas pressures and current densities were tried in the light source, it was found that the best conditions for exciting the helium spectrum were an exceedingly low gas pressure (i.e. a gas pressure so low, that it was just possible to maintain the glow discharge under a potential of 800 volts) and a current density of 150 to 200 m.a./cm^2.

Results

Table I gives all of the observed members of the $1s^2S_{\frac{1}{2}}-np^2P_{\frac{1}{2},1\frac{1}{2}}$ series of He II, and includes those members of the series which have previously been observed by Lyman[3] and Compton and Boyce.[4] Column one gives the estimated intensities of the lines; column three gives the calculated

[1] Sawyer, Jour. Opt. Soc. Am. **15,** 305 (1927).
[2] Ericson and Adlen, Zeits. f. Physik **59,** 656 (1930).
[3] Th. Lymann, Astrophys. J. **60,** (1924).
[4] K. T. Compton and J. C. Boyce, Journ. Franklin Inst. **205,** 497 (1928).

values which have been computed by using the formula given by F. Paschen[5] and which applies the general and special relativity correction. These values are much more accurate than the observed values, and make the best available standards for this region. The observed values of this series given in column two have been computed from plates taken with the grazing incidence apparatus according to the following formula:

TABLE I. *Helium II lines.*

Int.	$\lambda_{vac.}$ obs.	$\lambda_{vac.}$ cal.	ν cm^{-1}	Combination $1s-np$
50	303.782	303.7788	329,186.8	$1^2S_{\frac{1}{2}}-2^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
30	256.547	256.3145	390,145.6	$1^2S_{\frac{1}{2}}-3^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
20	243.222	243.0244	411,481.3	$1^2S_{\frac{1}{2}}-4^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
15	237.264	237.3297	421,354.7	$1^2S_{\frac{1}{2}}-5^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
10	234.340	234.3452	426,720.9	$1^2S_{\frac{1}{2}}-6^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
7	232.540	232.5821	429,955.5	$1^2S_{\frac{1}{2}}-7^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
4	231.472	231.4520	432,054.8	$1^2S_{\frac{1}{2}}-8^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
2	230.691	230.6836	433,494.1	$1^2S_{\frac{1}{2}}-9^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
1	230.208	230.1370	434,523.6	$1^2S_{\frac{1}{2}}-10^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$
0		229.7343	435,285.4	$1^2S_{\frac{1}{2}}-11^2P^{\circ}_{\frac{1}{2}}\ 1\frac{1}{2}$

$$n\lambda = e(\sin \phi - \sin (\phi - x/R))$$

where ϕ is the angle between the incident ray and the normal, R is the diameter of the Rowland circle, and x is the distance from the direct image to the line. ϕ was empirically determined to be $81° 34.225^{-1}$.

This computation, however, assumes that the plate, slit, and grating all lie accurately on the Rowland circle, and since this is probably not true, the deviations in column two may be explained in this way.

Column four gives the ν values in cm^{-1} for the wave-lengths in column three. Column five gives the spectroscopic transition.

Table II gives only those additional lines which have been photographed by both gratings used in both spectrographs, and which, therefore, may be attributed to the helium spectrum.

TABLE II. *Helium I lines*

Int.	$\lambda_{vac.}$ obs.	$\lambda_{vac.}$ cal.	ν cm^{-1}	Combinatiou
5	601.418	601.415	166,274.6	$1s^2\ {}^1S_0-1s2s\ {}^1S_0$
2	357.507		279,714.8	$1s2s\ {}^1S_0-2s^2\ {}^1S_0$(?)
8	320.392		312,117.6	$1s2p\ {}^3P_{012}{}^0-2p^2\ {}^3P_{012}$

Line 600.019A has been commented upon by Lyman,[3] Compton and Boyce,[4] Paschen,[5] and Sommer.[6] During the course of the present investigation it has been photographed under all conditions, and always appears as a band having the sharp edge on the violet and shading toward the red. The band undoubtedly belongs to the helium spectrum, and may therefore be attributed to He_2.

[5] F. Paschen, Sitzungsberichten der Preussischen Akademie der Wissenschaften **662,** Berlin (1929).

[6] Sommer, Proc. Nat. Acad. Sci. **13,** 213 (1927).

Line 320.329A was first observed by Compton and Boyce,[4] and is very likely the transition $2p^2\ {}^3P_{012}-1s2p\ {}^3P_{012}{}^0$. This places the $2p^{2\,3}P_{012}$ term at $-282894\ \mathrm{cm}^{-1}$ with respect to the He I limit. On the other hand, no trace of their line at 309.04A has been found on any of the plates taken during the present work. Other lines at 321.186A int. 2 and 322.517A int. 2, which would probably be $2p^2\ {}^1S_0-1s2p\ {}^1P_1{}^0$ and $2p^2\ {}^1D_2-1s2p\ {}^1P_1{}^0$ and which

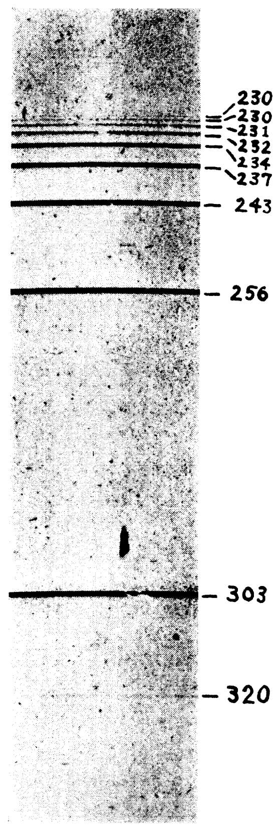

Fig. 1. *np* series of helium II.

would strengthen the classification of the line at 320.392A, have, however, only been photographed with the glass grating in the Sawyer spectrograph and are therefore not included in Table II.

Line 601.418A is without doubt the forbidden line $1s\ 2s^1S^0-1s^2\ {}^1S_0$.

Line 357.507A may be $2s^{2\,1}S_0-1s\ 2s\ {}^1S_0$, for it has the same characteristics as 601.418A, and never occurs when 601.418A is absent from the spectra. Moreover, G. W. Kellner[7] has very kindly computed that the $2s^2\ {}^1S_0$ should lie between 180,000 cm^{-1} and 200,000 cm^{-1} below the limit of He II. The

[7] Privately communicated to the author. and for which due thanks are acknowledged.

above value would give $2s^{2}\,{}^{1}S_0$ a value of $-247{,}681$ which is about 191,000 cm^{-1} below the limit of He II, thus fitting Kellner's calculation nicely.

A general survey of all plates taken shows the following results:

1. The 303 series is by far the strongest series in the helium spectrum, and appears most strongly when the pressure in the lamp is the smallest possible. In one hour, using the grazing incidence spectrograph, it was possible to photograph 8 members of the 303 series, and only four members of the 584 series which is the next strongest series in the helium spectrum. Increasing the time of exposure to six hours only added one member more to the 303 series. (See Fig. 1). It may also be remarked that under the same discharge conditions only four members of the 303 series could be photographed using the Sawyer spectrograph. This shows the enormous gain in light intensity which is obtained by the grazing incidence instrument when working in this region.

2. The 584 series as well as the band of He_2, 600.019A, is greatly enhanced by the presence of small quantities of O_2 or C.

3. The $1s2s\ {}^1S_0 - 1s^2\ {}^1S_0$ never appears when the band 600.019A is missing, although the band has been present when 601.415A was not present.

4. Line 357A appears only when 601.415A is present.

The presence of the forbidden line $1s^2\ {}^1S_0 - 1s2s\ \ {}^1S_0$ is probably due to the fact that the discharge in the lamp was maintained in a very low pressure of helium. It is estimated that the pressure was 0.1 mm or less. Moreover, the levels concerned in this jump are highly metastable, which may account for the phenomena.

If the present interpretation is assumed to be correct, one would expect to find other radiation from transitions of the nature $2s^2 - 2s2p$ or $2s^3 2s - 3p$, etc. Although the plates were examined for such radiation, none were found.

The author wishes to take the opportunity to thank Professor F. Paschen for placing at his disposal the apparatus and shop at the Physikalisch-technische Reichsanstalt, and for the constant interest and kindly criticism which has been given him during the course of these investigations.

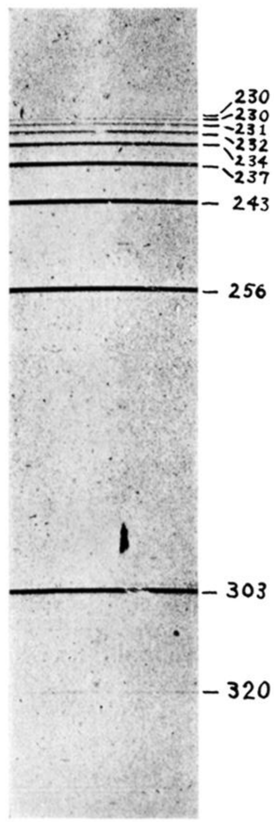

Fig. 1. *np* series of helium II.