ON THE EXCITATION OF THE HELIUM SPECTRUM BY ELECTRONIC BOMBARDMENT

By A. Udden[1] and J. C. Jacobsen

Abstract

Variation in relative intensity of the ortho- and parhelium spectra with the energy of the exciting electrons, 25 to 100 volts.—In the tubes used, electrons were accelerated from a Wehnelt cathode through a platinum grid 1 mm away into a metal box, and the spectrum of the light produced inside the box was photographed. A pressure of about 1mm was used. At the higher voltages, the two spectra were of about equal intensity, but at low voltages the orthohelium spectrum was relatively much the stronger (see Plate I). This is explained by supposing that the orthohelium spectrum is to a large extent due to bombardment of metastable atoms by electrons with energies corresponding to less than 5 volts. A special experiment, however, in which the helium was bombarded by both 5 volt and 21 volt electrons, gave a negative result, no additional light being excited by the slower electrons; but this is not considered as conclusive.

Introduction

As is well known, the arc spectrum of helium contains two complete systems of lines, the ortho- and parhelium spectra, each composed of a principal and two subordinate series. In strong electric fields combination lines appear within each of the spectra while no combination has ever been observed between the ortho- and parhelium terms. According to the theories which have been developed by Bohr, Sommerfeld, Lande and others, the orthohelium lines originate from transitions between stationary states where the two electrons in the helium atom revolve in co-planar orbits, and the parhelium lines from transitions between stationary states with crossed orbits. The fact that no combination has ever been observed between the ortho- and parhelium terms proves that transitions from crossed to co-planar orbits or vice versa are impossible.

By the experiments of Franck and Knipping[2] and Horton and Davies[3] it has been shown that the helium atom has two resonance potentials, 19.5 and 20.3 volts, corresponding to the transference of the atom from the normal state to stationary states with co-planar and crossed orbits

[1] On account of his illness and subsequent decease Mr. Udden has been prevented from taking part in the final writing of this report of our common experiments.

[2] Franck and Knipping, Zeit. f. Phys. **1**, 320, 1920

[3] Horton and Davies, Proc. Roy. Soc. **95**, 408, 1919

respectively. The ionisation potential has been found to be 24.5 volts.[4] By the investigations of Franck[5] it has further been shown that the stationary state with co-planar orbits which has the lowest energy is metastable; when the helium atom has been brought into this state, it can return to the normal state only by impact of electrons or by combining chemically with impurities.

The present investigation was undertaken with the view of obtaining by spectroscopic means some information concerning the excitation of the different quantum steps of the helium spectrum. Such information may be obtained by observing the appearance of the helium lines when excited by electrons of varying velocity. Although we have not succeeded in bringing out all the features claimed by theory, a report of the experiments may be of interest, because it seems to offer a support for the existence of the metastable state of the helium atom.

Experiments

The apparatus was a two-electrode tube with a cathode consisting of a platinum strip coated with calcium oxide, which was fused to copper rods (see Fig. 1); the electrons were accelerated to a platinum grid forming the bottom of a small rectangular metal box open on the side facing the spectrograph. The distance from cathode to grid was about 1 mm.

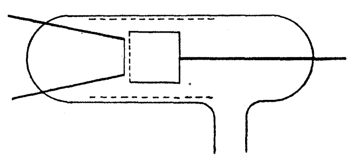

Fig. 1

The metal parts were enclosed in a glass tube consisting of two parts fitting together in a ground glass joint (not shown in the figure) and were sealed into the tube by means of sealing wax. A silver screen, which was connected to the ground, surrounded the grid and cathode and served to protect these from stray fields.

Before making any observation the tube was carefully evacuated, was heat treated as far as possible and the cathode was glowed out for several hours. Helium was then admitted through a U-tube with charcoal immersed in liquid air, which was kept on during the whole experiment. With suitable potentials on the grid a glow appeared in the metal box allowing the helium spectrum to be photographed with exposures

[4] The values here given are corrected in accordance with the recent measurements of the ultra-violet helium series by Lyman, Nature, August 26, 1922

[5] Franck, Zeit. f. Phys. **1**, 154, 1920

ranging from 1 minute to 1 hour. The accelerating potentials (from 25 to 100 volts) were read on a voltmeter, the terminals of which were connected to the grid and the negative end of the cathode. The pressure usually was about 1 mm. The spectrograph was a Hilger glass spectrograph with constant deviation, giving on ordinary plates the region from 3800 to 5200 A in our exposure.

Photographs of the helium spectrum obtained with different accelerating potentials are shown on Plate I. The potential read on the volt-

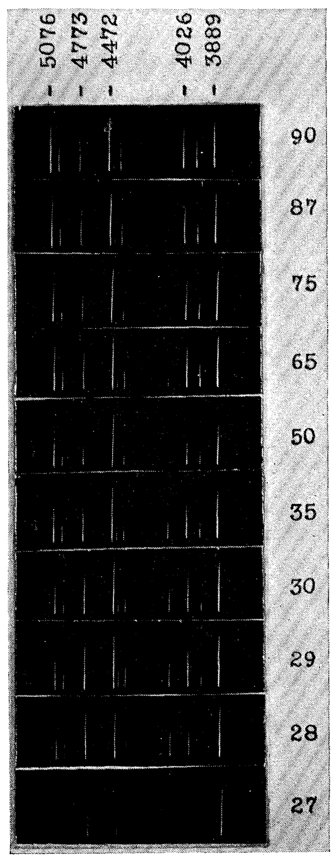

Plate I
Helium spectrum with accelerating voltage 27 to 90.*

meter is indicated opposite the photograph and the identity of the most prominent lines is shown at the top of the figure. At relatively high accelerating potentials (90 volts) the parhelium and orthohelium spectra as a whole appear with the same intensity, but as the potential decreases,

* Wave-lengths should be 5016 and 4713 instead of 5076 and 4773.

the intensity of the parhelium lines is reduced and at a potential of 27 volts the parhelium lines are hardly visible, while the orthohelium lines exhibit a marked intensity at this potential. The time of exposure was chosen according to the intensity of the glow so as to get a suitable impression on the plate; for the lower potentials the time of exposure was about 1 hour. The current varied from 0.1 to 1 milliamp.

The photographs shown on Plate I were chosen from among a number of plates taken with various tubes differing slightly in geometrical design. At a definite voltage the appearance of the spectrum was not always the same but varied somewhat according to pressure and electron current; the voltage given is correct only for certain conditions. A trace of hydrogen, which manifested itself on some of the plates did not seem to be of any influence on the appearance of the helium lines.

The results are somewhat contradictory to those of Rau,[6] Horton and Bailey,[7] Compton and Lilly,[8] Davies[9] and Déjardin.[10] These authors found that the different quantum steps of the helium spectrum were all excited at the same time and especially that no difference could be detected between the voltages for the excitation of the ortho- and parhelium spectra. Whatever the reason may be for this discrepancy, it appears from the photographs on Plate I that a difference in the behavior of the ortho- and parhelium spectra, when excited by relatively slow electrons, is established beyond any doubt, the orthohelium spectrum coming out much more strongly than the parhelium spectrum.

Discussion

The most reasonable explanation of the experimental results is to be looked for in the existence of the metastable state of the helium atom. When a helium atmosphere is bombarded by electrons of sufficient velocity, at least part of the collisions will result in the formation of atoms in the metastable state and these atoms can only return to the normal state by impact of electrons or by combining chemically with impurities present. In this way a state of equilibrium is reached where a certain number of atoms in the metastable state are present, depending upon the number and velocity of the electrons and the amount of impurities. If the electrons have a high velocity practically all collisions with metastable atoms will result in ionisation. When the ionized atom returns to

[6] Rau, Würzb. Phys. Med. Ges. Ber. Feb., 1914
[7] Horton and Bailey, Brit. Ass. Rep. 1919, 153
[8] Compton and Lilly, Astrophys. J. **52**, 1, 1920
[9] Davies, Proc. Roy. Soc. **100**, 599, 1922
[10] Déjardin, Journ. de Phys. **4**, 121, 1923

the normal state the parhelium lines may be emitted just as well as the orthohelium lines so that the spectrum emitted contains the parhelium and orthohelium lines with the same intensity on the average.

If on the other hand electrons with low velocities are being used, the metastable atoms present may give rise to an increased intensity of the orthohelium spectrum. If a metastable atom collides with an electron of say 4 volts the atom will ordinarily be brought into a second stationary state with co-planar orbits and the spectrum emitted during the return of the atom to the metastable state, which is the only one possible, can contain only orthohelium lines. When a helium atmosphere is bombarded by electrons with velocity of 26-27 volts, electrons with low velocity will be present in considerable number and this fact in connection with the existence of the metastable state of the helium atom may probably offer an explanation of the phenomenon observed.

If this explanation is correct the following experiment ought to be possible. Let a helium atmosphere be bombarded by electrons with a velocity of say 21 volts so that a number of metastable atoms are formed while the intensity of the visible helium spectrum at least with moderate electron currents is very small. If from a second cathode electrons with a velocity of say 5 volts are supplied this ought to result in an increased intensity of the visible helium spectrum. We have carried out this experiment with an apparatus where electrons from two separate cathodes were sent into a metal box, the sides of which consisted of platinum gauze, the direction of the two electronic streams being at right angles to one another.

The result of the experiments has so far been negative. It was not found possible to excite the helium lines by simultaneous bombardment with electrons of two different velocities of which one was about 21 volts and the other one much lower. But even if we have not been able to establish a definite proof of the explanation given above of the difference in the behaviour of the ortho- and parhelium spectra, the question can not be regarded as settled by such a negative result. The problem is to find the proper conditions.

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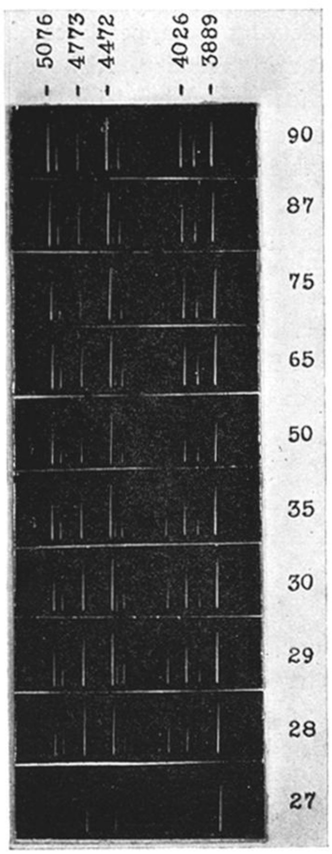

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