INTENSITY RELATIONS IN THE HELIUM SPECTRUM

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Abstract

Low-voltage arc in pure helium.—Inside a blown quartz tube, electrons from a tungsten spiral were accelerated into the equipotential space inside a hollow copper anode. Unusual purity was obtained by heating the anode red hot by high frequency induction to remove gases, in addition to other precautions. *Minimum operating potential* was found to be 21.5 volts, just above the resonance potential. The relative importance of the ionizations at 20.5 and at 25.5 volts depends on the pressure and current density; after the current has risen to a high value the 25.5 point is obscured, indicating probably a decrease in the proportion of normal atoms under the increased radiation. *Change in relative intensity of arc spectrum lines with voltage* was studied for 25 to 85 volts, using the neutral wedge method of Nicholson and Merton. The crossed orbit lines λ 4437 (*1P—4S*), λ 4387 (*1P—4D*), λ 4922 (*1P—3D*), λ 5016 (*1S—2P*) all increase with voltage, though not uniformly; while the coplanar lines λ 4713 ($1\pi-3\sigma$), λ 5875 ($1\pi-2\delta$), λ 4471 ($1\pi-3\delta$) all diminish to a minimum at about 50 volts.

SOME of the earliest observations on intensity relations in the helium spectrum as affected by energy considerations were made visually by Richardson and Bazzoni[1] who, in the course of experiments on the successive stimulation of lines under increasing energy of bombardment found that, while most of the lines increased steadily in intensity with the bombarding voltage, line λ4713 of the sharp series of orthohelium increased to a maximum soon after its appearance, decreased to faintness at 40 volts and then increased again. The blue line 4472 ($1\pi-3\delta$) was found to require about $\frac{1}{2}$ volt and the blue line 4713 ($1\pi-3\delta$) about $\frac{1}{4}$ volt more energy for stimulation than the yellow line 5875 ($1\pi-2\delta$).

These facts seemed of sufficient importance to warrant further investigation which was undertaken by Bazzoni and reported on in a paper read before the Amer. Phil. Soc. in April, 1921.[2] In this work the spectrum was produced by suitably accelerated thermions in a field-free space and was photographed through Hilger neutral tinted wedges. The results obtained at the time were not of a positive character and after a reconstruction of the apparatus the work was repeated beginning in October, 1922. The present paper contains a report on the first series of results obtained with the new apparatus.

[1] Richardson and Bazzoni, Nature **88,** 5 (1916)

[2] Read in full but published by title only.

Fig. 1 is a sketch of the discharge chamber, which is of blown quartz, and was constructed by the Thermal Syndicate, New York. A window of optical quartz is fused on at *W*. Projecting downward is a tube *O* closed at the bottom which can be inserted into a Thermos flask filled with liquid air. The cathode *C* is a tungsten spiral which can be replaced by removing the stopper *F*. This stopper is accurately ground and is vacuum tight but can be sealed into position with hard wax when desired. The anode *K* is a flat pill-box of copper having numerous holes in the face opposite the filament *C* forming a grid, and a rectangular opening in the side opposite the quartz window *W* for spectroscopic examination. This box can be moved back and forth by means of a piece of iron sealed into a quartz stem wired to it but in use it was found easier to adjust the filament distance by moving the filament. This distance was generally kept as short as possible.

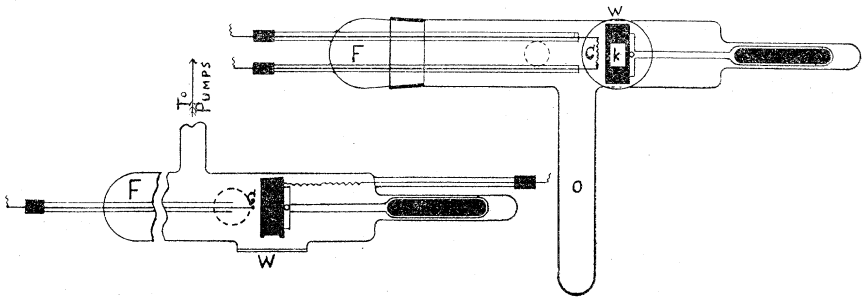

Fig. 1. Discharge chamber, of blown quartz.

The device was set up so that the coil of an induction furnace could be slipped over it and the box brought to a brilliant red heat and held so as long as desired. A Hilger constant deviation spectrometer provided with a camera attachment and with Hilger neutral tinted wedges of suitable density in front of the slit, was used in analyzing the light from the arc. The spectrometer slit was set as close as possible to the quartz window. The lenses and prism of this instrument and also the wedges were of glass.

The helium used was from a lot very kindly supplied by Dr. R. B. Moore of the Bureau of Mines, the original source being natural gas. This was purified in an apparatus and by a procedure identical with that described by Richardson and Bazzoni.[3] Hydrogen can be burned out by sparking in an atmosphere of pure oxygen over phosphorous pentoxide. The excess oxygen and other gases are then removed by charcoal in liquid

[3] Richardson and Bazzoni, Phil. Mag. **34**, 285 (1917)

air and, since the operations are controlled by mercury traps instead of stopcocks, a final liquid air trap is inserted to remove the mercury vapor. The whole arrangement was evacuated by a Langmuir metal condensation pump backed by large oil pumps. The pressure could be measured with a McLeod gauge suitably placed with reference to the last liquid air trap.

After the quartz device had been held at a red heat for a sufficient time, the copper box had been heated with the induction furnace and the filament had been glowed out, helium of the most unusual purity could be produced and worked on for a long time. Even after six hours of continuous use with filament glowing and potentials applied, absolutely no trace of any contamination from hydrogen or mercury could be detected spectroscopically. This degree of purity could only be obtained by the most stringent heat treatments. If the box was not held at a red heat over liquid air and charcoal for a long enough time mercury lines appeared after a few minutes use.

The driving potential was obtained from a potential divider across a 110 volt battery of high capacity storage cells and was measured by a Weston standard voltmeter. The filament current was drawn from a similar 50 volt battery and was adjusted through a set of resistances in parallel. The thermionic current was measured with Weston microammeters or milliammeters as required.

The primary purpose of the investigation at this stage was to study the intensities of the lines of the spectrum as functions of the driving potentials but since the helium was recognized to be of a degree of purity seldom obtained it was thought desirable to make certain preliminary observations on the critical potentials of arc production in it. Previous experiments as well as considerations of theory had led the authors to believe that an arc and the associated ionization can be maintained in pure helium at any potential above the first resonance potential but not at a lower potential. It seemed probable that experiments of other investigators leading to very low values of the potential for maintaining the arc were conducted in tubes containing metal parts which could not be heated in the clean-up, wherefore mercury vapor or hydrogen might have been present in sufficient quantities to have produced, through radiation or contact, a disturbance of the normal helium atoms.

It was found impossible, when proper conditions of cleanliness had been obtained, to hold an arc in our purest specimens of gas below 21.5 volts, the transformation voltage for producing co-planar helium. On the other hand the slightest trace of contamination, especially of mercury, made it possible to carry a faint but definite glow down to 12

volts. If the copper box were allowed to stand in the apparatus without liquid air (therefore in an atmosphere of mercury vapor) over night it would absorb sufficient mercury to produce this effect, which could subsequently be eliminated only by bringing the box to a distinct red heat over liquid air. These observations strengthen the idea that if there is nothing in the arc space except helium, an arc cannot be held below the first resonance point of the gas. It is probable that stimulated mercury atoms can transfer energy to helium atoms by contact or otherwise as observed by Franck and Cario[4] with mercury and hydrogen.

In the absence of mercury a marked ionization below 25 volts could be obtained only under heavy bombardment or with high pressures. Fig. 2, Curve A is characteristic of runs under moderate bombardment

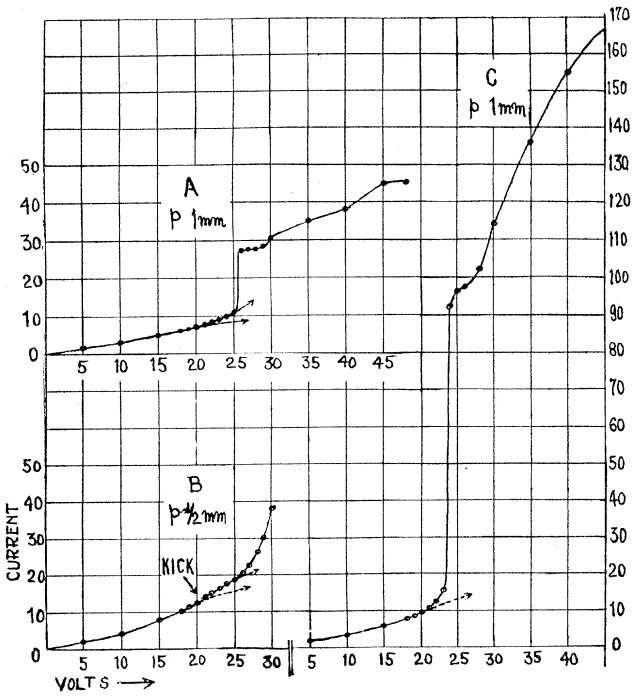

Fig. 2

(pressure 1 mm). Curve B is still more typical (pressure ½ mm). Here the ionization which sets in at 20.5 volts is relatively inconspicuous compared with that which starts around 25.5 volts. Curve C shows the modification produced under heavy bombardment. The sharp rise in the neighborhood of 23 volts on this curve is due to an alteration of the

[4] Franck and Cario, Zeits. f. Physik **11**, 161 (1922)

space-charge and is not associated with an ionization point. Once this "kick" has taken place the 25.5 volt point, the generally accepted ionization point of normal helium, is obscured. This supports the hypothesis of Richardson and Bazzoni[1] that normal helium is altered in a field of intense radiation to a form of less stability with a lower ionization point. The curves of Fig. 3 illustrate this point. Here a tungsten filament was used with the heating currents indicated at the ends of

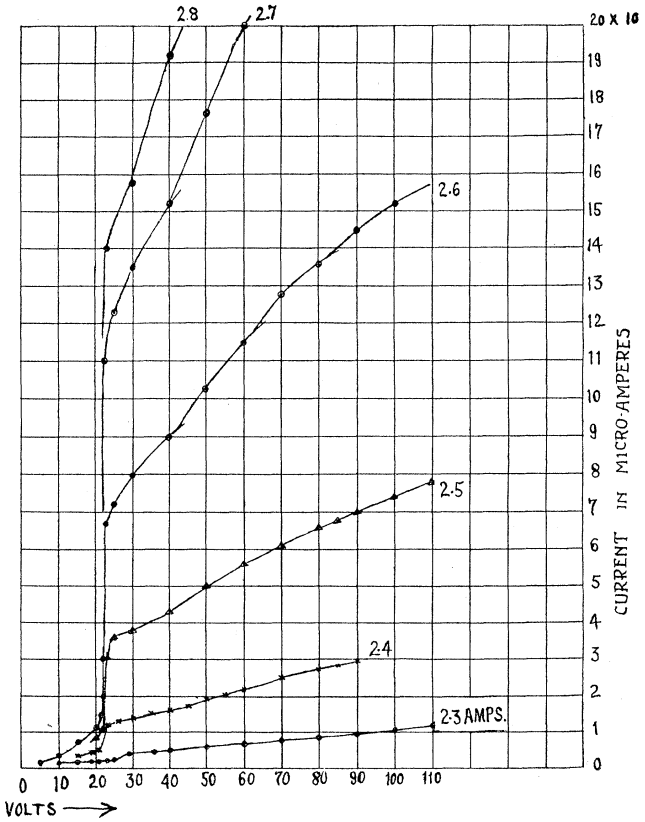

Fig. 3. Current curves for various heating currents of the tungsten filament.

each curve. Additional ionization points are observable on these curves at multiples of 20 volts including 80 volts, the supposed potential of double ionization. Throughout this work whenever there was a glow a spectrum could be observed which consisted of the full visible spectrum of helium including both series.

These observations, made at various times during the past year, are in accordance with those published by Desjardin[5] and also with those given by Richardson and Bazzoni.[3]

[5] Desjardin, Jour. Phys. et Rad., April 1923

After the completion of these preliminary observations attention was turned to the intensity measurements.

The method of the neutral tinted wedge for spectro-photometry has been most carefully worked out, both in practice and in theory, by Nicholson and Merton[6] who applied it in investigations of the fine structure of lines. A wedge of Schott neutral tinted glass is cemented to a similar wedge of clear glass to form a block of rectangular section with a certain ratio of transmission between that of the thin edge, which is clear, and that of the thick edge. This ratio depends on the thickness of the wedge and on the composition of the melt from which the glass is made. When the wedge is in front of the slit the heights of the images of the various spectrum lines on the plate will be in proportion to the intensities of the lines. In our work we followed the method of Nicholson and Merton—enlarging the original $3\frac{1}{4}$ by $4\frac{1}{4}$ plates on to 8 by 10 plates and printing these plates on contrast paper through a half-tone screen cross-lined 100 lines to the inch, thus obtaining the line images made up of small dots. To determine the height of a line it is then merely necessary to locate the last visible dot, which is a fairly definite procedure but little affected by personal error. It is of course understood that any attempt to compare the intensities of lines in different parts of the same spectrum, or in different spectra, is complicated by considerations of the variation of transmission of the wedge for different wave-lengths and by the variation in sensitivity of the photographic plate in different parts and for different wave-lengths. These complications can to some extent be corrected for by preliminary determinations of the wedge transmission and of the color sensitivity of the plate but variations of emulsion on the same plate are entirely accidental. Results obtained by this method must therefore, to be precise, depend on measurements made on a very small area of the emulsion where it may be supposed uniform—as, for instance, in studies of the fine structure of a single line such as Nicholson and Merton made. Nevertheless, for work which is not carried to a fine point, experience shows that it is safe to assume the emulsion on selected plates properly handled to be uniform excepting at the edges, intensity curves from the same source on different parts of the same plate or even on different plates of the same lot being indistinguishable by the methods used. The wedge measurements are furthermore free from certain sources of error unavoidably associated with intensity determinations through photometry and have obvious advantages in convenience.

[6] Nicholson and Merton, Phil. Trans. A **216,** 459, 1916, and A **217,** 237, 1917

In making experiments to produce plates to show intensity variations with voltage it is necessary to keep both the pressure and the bombardment current constant. This, in practice, is not easy—the pressure in particular being subject to interesting and probably significant changes under the action of the discharge. Fig. 4 (a), (b), (c), (d) and (e), are spectra from a plate secured under satisfactory conditions. These spectra were taken with a fixed thermionic current under potentials respectively of 25, 35, 55, 75, and 85 volts. The exposures were in each

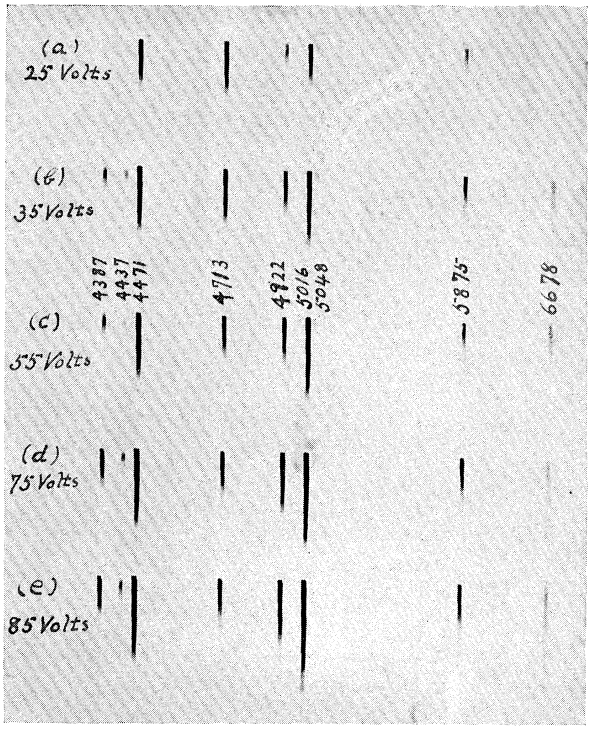

Fig. 4. Spectra obtained with potentials 25 to 85 volts.

case one half hour, the arc being maintained in helium at 0.33 mm pressure by a bombarding current of 60 milliamperes which was kept constant by altering the filament current. The tungsten filament carried 2.7 amperes at 25 volts driving potential and 2.4 amperes at 85 volts. The utmost care having been exercised in preparing the helium and in cleaning up the apparatus the gas remained spectroscopically pure throughout the work. The plate was a Wratten and Wainwright panchromatic, specially backed.

The lines which are clearly measurable on this plate are

crossed orbit			coplanar		
S	4437	$1P-4S$	S	4713	$1\pi-3\sigma$
D	4387	$1P-4D$	D	5875	$1\pi-2\delta$
D	4922	$1P-3D$	D	4471	$1\pi-3\delta$
P	5016	$1S-2P$			

Those in the first column belong to the singlet series ascribed to parhelium; those in the second column belong to the series of doublets ascribed to orthohelium. It will be recalled that according to recent theory normal helium atoms (parhelium) have their two electrons moving in crossed orbits and that a metastable form (orthohelium), produced from the normal generally by radiation absorption or impact, is supposed to have its electrons moving in coplanar orbits, one outside the other.

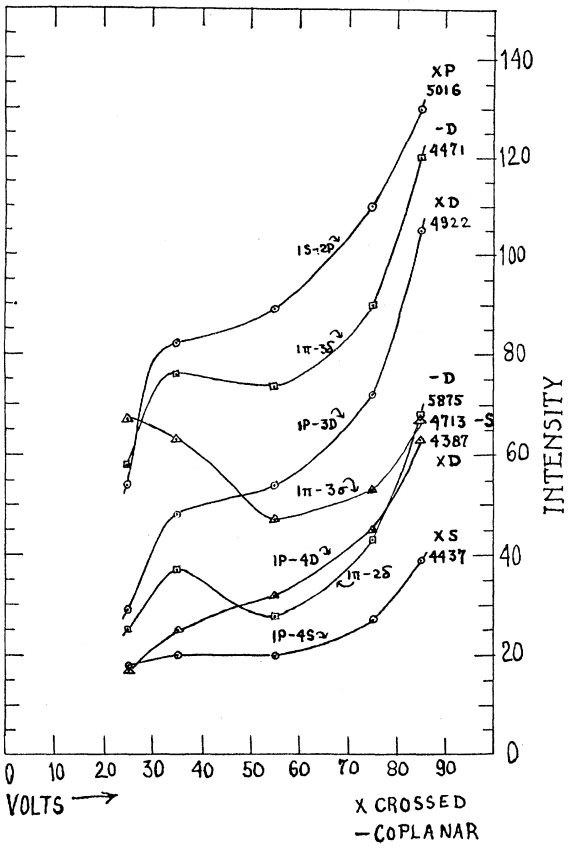

Fig. 5. Intensity of various lines as a function of the voltage.

When the intensities of these lines, as determined by measuring their heights, are plotted against the driving voltages the curves shown in Fig. 5 are obtained; one curve for each of the seven lines. It will be observed that there is a marked difference in the behavior of the lines of the coplanar helium as compared to the lines of crossed orbit helium in that the coplanar lines all show a definite drop in intensity between 35 and 55 volts. All the lines of both series, with the exception of 4713, increase in intensity between 25 and 35 volts and again above 55 volts. The rate of increase is apparently greater above 75 volts than between 55 and 75.

Although 55 volts is the potential for the appearance of the enhanced or spark line 4686, no trace of this line was found at any potential up to 110 volts. The development of the spark (double ionization) lines, of which 4686 is the first, as well as the development of the band spectrum requires a pressure adjustment not suitable for the clearest production of the arc lines.

Line 4713 is apparently somewhat anomalous in that its intensity diminishes above 25 volts and does not increase notably until in the neighborhood of 80 volts. This observation is in accordance with the one made visually by Richardson and Bazzoni and reported in Nature in 1916.

With reference to the potentials of appearance of these lines—no lines can be observed visually or on the photographic plate even with exposures of 18 hours before a glow develops in the tube. The appearance of the glow is associated with some alteration of the space charge evidenced by a rise in current and a drop in potential across the arc—the kicks of the instrument needles being generally a safe indication that the glow has formed. In the particular sample of gas from which the above photographs were made the glow appeared with no observable kick at 22 volts. With increasing voltage a marked kick occurred at 32 volts accompanied by the formation of a heavy glow behind the cathode. On lowering the potential a reverse kick took place at 28 volts, the voltage rising to 29. On again reaching 28 volts another kick occurred, the glow shrinking behind the cathode but remaining in the box. At 23.5 volts the glow disappeared from the box without any definite instrumental kicks. The glow showed a change in color with change in voltage, being a weak blue at 35 volts, a greenish or robin's egg blue at 55 volts and an intense bright blue at 75 volts and above. As far as a cursory observation showed the green and yellow lines appeared and disappeared together but since the observations made in 1916 indicated definitely that the 3δ lines required a higher voltage to excite them than did the 2δ lines the examination is to be repeated with proper refinements.

Little can be said of the significance of the results here given since theories of atomic structure are not yet sufficiently developed to explain the facts shown. Coplanar helium being presumably produced by impacts of 20.5 to 21 volts energy or by the absorption of a corresponding radiation we might possibly expect a greater number of these atoms to be present at voltages in the lower twenties which might lead to an intensity maximum there and to a minimum at somewhat higher voltages, as is observed. The number of normal atoms being reduced as the coplanar ones are formed we might also expect a decrease in the rate of increase of intensity of the normal lines during the period of formation of the coplanar atoms. This is seen to be roughly the case.

The value of these observations would be greater if they were extended further into the ultra-violet. The experiments are being continued along these lines, using quartz wedges, lenses and prisms.

Since this work was completed an abstract has appeared by A. L. Hughes[7] reporting on a similar investigation made on helium using a similar method. The results given by Hughes are in general agreement with those obtained by us.

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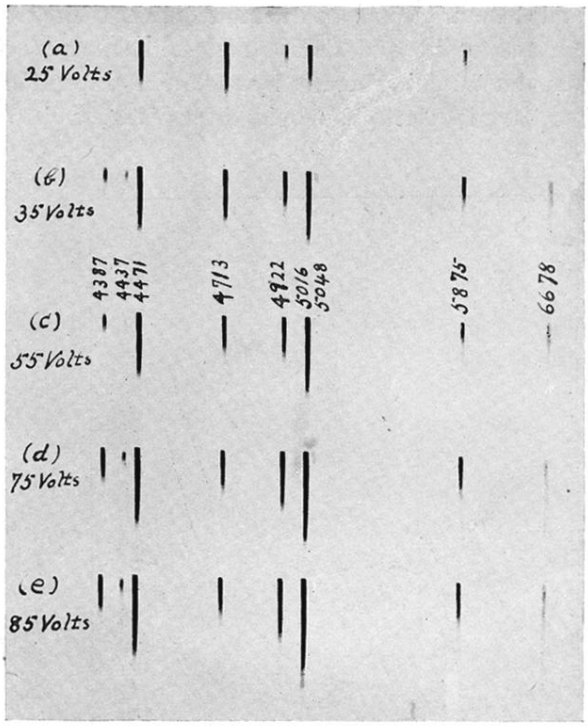
September 15, 1923.

[7] Hughes and Lowe, Phys. Rev. **21**, 714 (1923)



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