NOVEMBER, 1928 PHYSICAL REVIEW VOLUME 32

A STUDY OF THE ENERGY RELATIONS IN THE HELIUM SPECTRUM

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Abstract

Intensity variation at critical points in the helium spectrum.—Photographs of the helium spectrum produced in an equipotential space using an equipotential cathode have been studied photometrically in order to determine the variation of line intensities on passing the various critical potentials. The results here reported cover the 54.2 volt point, at which double ionization is first possible. Spectra were taken at suitable values between 50 and 60 volts, often at intervals of 0.1 volt. The plates show a marked maximum of intensity near 54.2 volts for all lines measured.

Introduction

ONLY a small amount of quantitative work seems to have been done on the relations between line intensity and accelerating difference of potential in helium. Among the early investigations is that of Richardson and Bazzoni.[1] Later work is that of Bazzoni and Lay,[2] and of Hughes and Lowe.[3] These investigations are all characterized by the use of non-equipotential cathodes.

The object of the present investigation is to study further the relations between the lines of the helium spectrum as functions of the accelerating difference of potential alone, particularly in the neighborhoods of the critical points of the gas. This report has to do with the 54.2 volt critical point, at which value of the accelerating P.D. the complete enhanced spectrum of helium first appears.

Apparatus

The discharge chamber is shown in Fig. 1. It is of blown quartz, with a window of optical quartz fused on at *W*. Projecting downward is a charcoal tube *O* which may be inserted into a liquid air bath. At *D* is a Hale-Pirani resistance pressure gauge, which was used to follow pressure changes in the gas, and next to this was a stop-cock by means of which the discharge tube could be cut off from the rest of the apparatus. The two leads *L* and *L*, of No. 14 B. & S. nickel wire, support both cathode and anode. These leads are firmly waxed to the ground stopper *F*, which is in turn sealed into the tube with Pizien cement. The support *D* for the anode *K* is fastened to the insulated clamp *A′* and is insulated with mica from both clamp and anode.

The anode and cathode are shown in Fig. 2. The cathode proper is a cylinder made of 0.005 in. (0.0127 cm) sheet nickel and is about 0.6 in. (1.52 cm) long and 0.040 in. (0.1016 cm) inside diameter. It is fastened to

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

[2] Bazzoni and Lay, Phys. Rev. **23,** 327 (1924).

[3] Hughes and Lowe, Proc. Roy. Soc. **A104** (1923).

the heavy nickel tips of the leads *L* and *L* by means of a screw at each end, and is insulated from one tip by means of mica. This cathode has a pin stripe of a mixture of 60 percent barium oxide and 40 percent strontium oxide painted down the part of its area that faces the anode. The active substance is applied as a finely divided suspension of the hydroxides in water. The cylinder is heated by means of a tungsten wire of 0.015 in. (0.381 cm) diameter that passes axially through it. This filament is fastened to one tip by a set screw and is held straight by a small spring *S* on the other tip. This cathode represents the only highly successful one of several types that were tried.

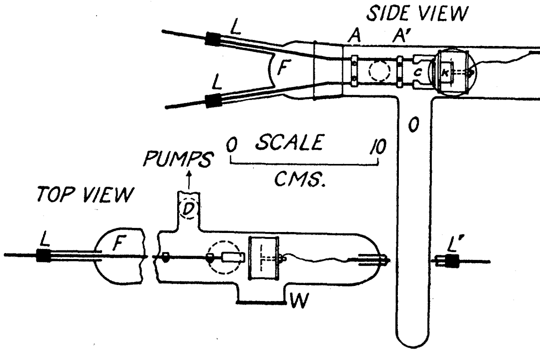

Fig. 1. The discharge chamber.

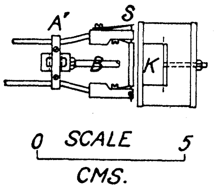

Fig. 2. The anode and cathode.

The anode *K* is a pill box of thin nickel. In the front of this, facing the cathode, is a rectangular opening 1.5 cm × 0.5 cm, which is covered with 80-mesh nickel gauze and through which electrons can pass into the box. A second opening, for spectrographic examination of the radiation within the box, is in front of the window *W*. The interior of the box is covered with camphor soot to prevent reflection. The window *W* is shielded from the visible cathode radiation by means of a shield fixed to the box. For best working conditions the anode is placed 1.25 mm from the cathode.

The spectrometer used was a Type E Hilger spectrometer giving a 30 inch spectrum. It accommodated 10-inch plates and as many as 17 spectra have been photographed on the same plate. The latter procedure gave rise to pre-exposure of the plate, which will be referred to later. The optical system was quartz throughout. The slit of the instrument was placed less than a millimeter distant from the window *W*, and in front of the most uniform part of the glow seen through the window *K*.

The microphotometer used to determine the relative densities of the line images on the plates was constructed during the investigation. It is essentially the same as that of Moll,[4] Harrison,[5] and Barnes,[6] although nonrecording. Two outstanding characteristics of the instrument are the use

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[4] Moll, Phys. Soc. Lond. Proc. **33** (1921).

[5] Harrison, J.O.S.A. **10,** (1925).

[6] Barnes, J.O.S.A. **15** (Dec. 1927).

of a Moll vacuum thermo-element, which gives a highly desirable instrumental stability, and the fact that the very narrow slit (0.1 mm to 0.2 mm) can be placed so that it touches the photographic film.

The precision of the instrument was entirely satisfactory. In seven absolutely independent measurements on a given line-image, the greatest difference between readings was 0.4 percent of the smallest reading. This is the greatest value of the percent error encountered in the photometric measurements. However, an examination of the literature pertaining to the use of the photographic plate for intensity measurements[7] shows that the real limitation of precision in such work is in the plate itself. With the most careful procedure the resulting precision lies between 1 and 4 percent.

PROCEDURE

The usual high vacuum technique was employed in evacuating the system. The anode was held for a sufficiently long time at red heat by means of an induction furnace, and filament and cathode were held for several hours at a temperature considerably higher than their working temperature. Pressures of the order of 10^{-6} mm of mercury were obtained in the cleaned apparatus.

The helium used was from a lot supplied by the Bureau of Mines, the original source being natural gas. The gas was allowed to stand for 15 to 20 minutes surrounded by liquid air and was then admitted very slowly to the apparatus through a capillary tube. It passed through two charcoal traps and through two U traps, all under liquid air, into the tube, whose charcoal trap was also thus cooled. In the cases of a great many specimens of helium admitted to the discharge chamber, the presence of mercury vapor or of any other gases could not be detected spectroscopically, either before use or after many hours of use. Samples of gas have been held during use for as long as five days, always under liquid air, after which plates of as long as an hour exposure have shown no lines other than those of helium.

The procedure of exposure was as follows: Having determined the product of accelerating P.D., electron current, and time of exposure (VIT) which would give a suitable photographic plate corresponding to the conditions existing within the apparatus, the electron current was thereafter kept, by manipulation of cathode temperature, at the same value during the exposure of a plate which might have on it, finally, a dozen or more spectra, each photographed under unique voltage conditions. For each of these spectra there was an assigned value of P.D., the time of exposure being determined in such a way that the product (VIT) was the same for all. In this way the same amount of energy was supplied to the arc, and presumably to the plate, during the exposure for each of the spectra that appeared on the plate. Provided that the configuration of discharge does not change with time or with potential adjustments thus affecting the

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[7] Monographs on the Theory of Photography, from the Research Laboratory of the Eastman Kodak Co., No. 5, "The Physics of the Photographic Image," F. E. Ross. D. Van Nostrand Co. (1924).
Bureau of Standards Bull. No. **439**, (May 5, 1922).

luminosity of that part of the discharge in front of the spectrometer slit, and providing that other conditions including pressure remain fixed, it is assumed that the intensity of a given line in the source remains the same so long as the accelerating P.D. and the electron current remain the same.

The accelerating P.D. used varied between 50 and 60 volts. In the neighborhood of the critical point (54.2 volts) the variation was by 0.1 volt steps. Any given value, as measured with a Weston Standard voltmeter, could be held well within ±0.1 volt. The voltmeter of course measured the total P.D. between its terminals, which might be different from the accelerating P.D. To determine the true value of the latter the relation between voltmeter reading and electron current in the neighborhood of the 24.5 volt ionization point was plotted. In this curve a sharp break occurs at the ionization point, and the difference between the accepted value of this P.D. and the break-point value shown on the curve gives the total voltmeter correction for the particular cathode arrangement used. There seems to be no reason to suppose the correction at 24.5 volts to be different from that at 54.2 volts. This correction for the particular cathode described here was 0.0 volts, the possible error being considerably less than ±0.1 volt.

It was found that if the conditions of the initial exposure were repeated at intervals during the production of a plate having on it several spectra, the corresponding measured values of the intensity of a given line fell off progressively in value. It would seem, therefore, that the measured intensities of all lines need some correction in order to give the true values. To determine this correction the conditions of the initial exposure on any particular plate were repeated five times during a run of, say, sixteen exposures. The difference between the measured intensity of any one of these repeated values and that of the initial value gave the correction to be applied in order to get the true value of the intensity of the line under consideration. The time from the beginning of the first exposure to the mid-point of each individual exposure was known. The above corrections plotted against the corresponding times from the start gave a correction curve for the particular wave-length in question. To get the correction for a given line image, it was necessary only to use its time of exposure referred to the start in conjunction with its particular correction curve. These corrections varied up to 25 percent of the measured value of the intensity in the case of plates during the exposure of which the arc ran for two hours. For a plate of six hours arc time the correction might be as high as 100 percent of the measured intensity.

This effect was at first ascribed to change in gas pressure, but tests made with the Hale-Pirani[8,9] resistance pressure gauge showed no changes of pressure as great as 1 percent of that within the tube. Neither could the effect be due to the decay of the active cathode deposit, since the electron current was maintained at a constant value. It was finally shown conclusively that the effect is due to exposure of the plate in the spectrometer

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[8] High Vacuum, S. Dushman, Pub. by General Electric Review (1922).

[9] Skellett, J.O.S.A. **15**, (July 1927).

to light scattered or reflected over its face outside the zone of the principal image. The net effect of this pre-exposure is equivalent to a progressive decrease of plate sensitivity with time. This observation has an important bearing on the use of spectrometers of this kind for photometric work in all cases where there is a possibility of scattering of light over the face of the plate. Our tests show that this difficulty is effectively remedied by the use of a light-proof diaphragm placed directly against the emulsion in such a way as to permit exposure of only one part of the plate. These diaphragms were not used in the work upon which this report is based. It seems, however, entirely legitimate to apply the correction curves as above described to the observed line densities.

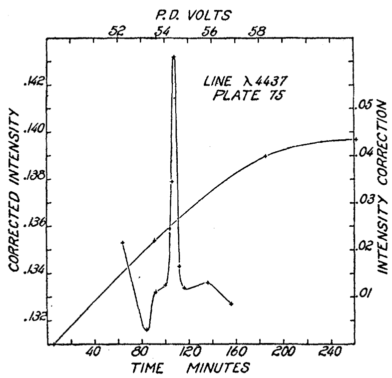
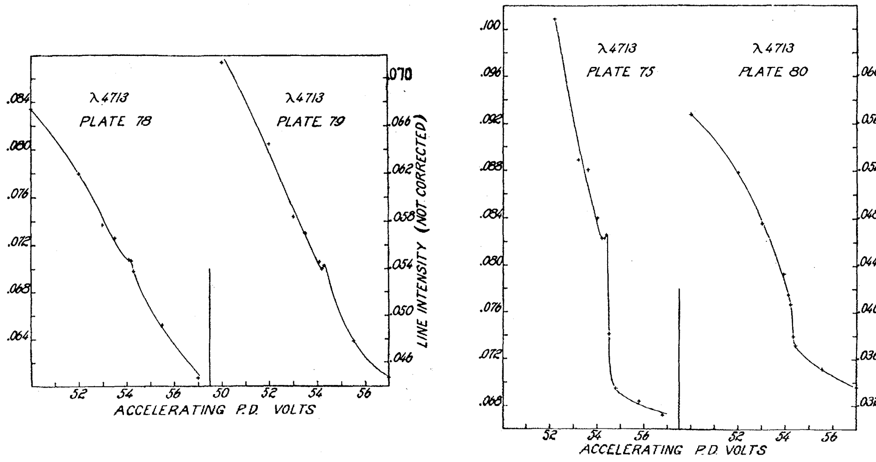


Fig. 3. A typical correction curve and the corresponding corrected curve for the variation of intensity of a spectral line with voltage.

The corrected values of the intensity of each spectral line having been obtained (all for the same wave-length), these were plotted against the corresponding corrected accelerating potential differences. Fig. 3 shows a typical correction curve and the corresponding corrected curve. Figs. 4A and 4B show typical uncorrected curves.

So far most of the photographs have been made on Eastman "Speedway" plates. Time development was carried out according to data for "Rodinol," the developer used, and the tray was rocked throughout.

The gas pressure at which this work was done was 0.33 mm of mercury, which was read on a McLeod gauge.

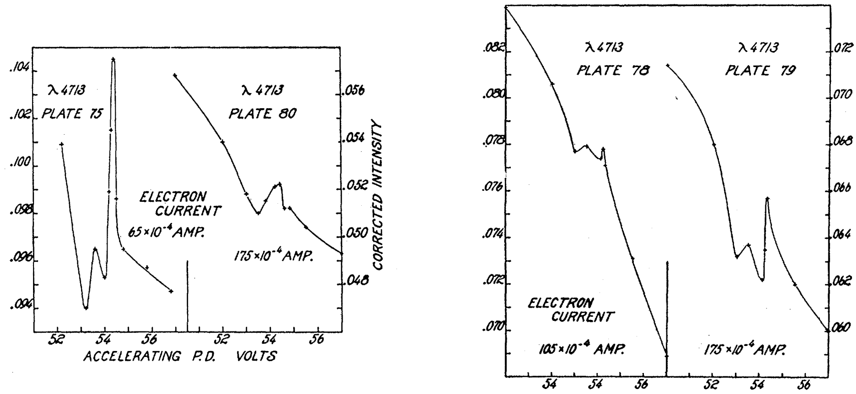


4A 4B

Figs. 4A, 4B. Typical uncorrected curves.

RESULTS

A study of the spectral line λ4713A as it appears on four different plates is shown in Figs. 5A and 5B. These plates are independent in every way, with the exception that the same sample of gas was used for plates 75 and 78, although these were taken on different days. The curves are plotted between line intensity corrected as explained above and the corresponding accelerating potential differences.



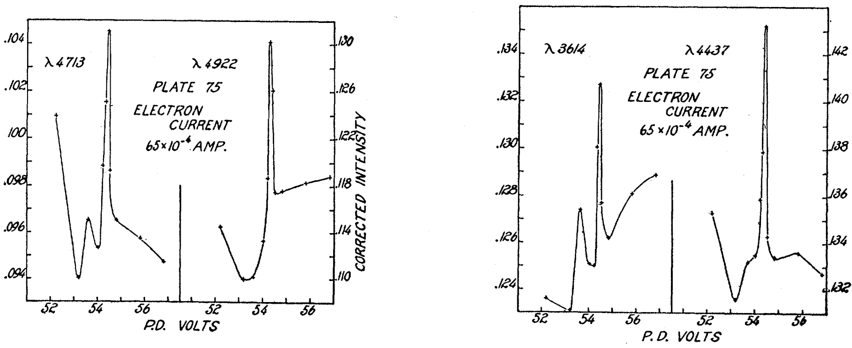
5A 5B

Figs. 5A, 5B. Variation of intensity of λ4713A with voltage.

Figs. 6A and 6B show a group of characteristic corrected curves, all from plate 75 and for the lines

λ4922 $(1P-mD)$ λ4713 $(i\pi-m\sigma)$
λ3614 $(1s-mP)$ λ4437 $(1P-mS)$

All these curves show well defined maxima in the neighborhood of the 54.2 volt point.



6A 6B

Figs. 6A, 6B. Variation of intensity of λλ4922, 3614, 4713, and 4437 with voltage.

It is difficult at the present time to offer any adequate theoretical explanation relating these intensity changes to the contributory causes. The changes are, in part at least, dependent upon the number of atoms per cubic centimeter, the number of states of ionization existing coincidentally among the atoms, and the distribution of kinetic energy among the impinging electrons. When the accelerating P.D. is the critical one of 54.2 volts, the spectrum intensity relations are further complicated by the energy distribution in the newly appearing enhanced series. The remarkable peak that occurs in these intensity curves at this critical P.D. has to do with the sudden rearrangement of spectral energy relations and is apparently significant. Just what its significance is, however, does not appear at the present stage of the investigation.

The curves in Figs. 4A and 4B, all for the line λ4713A, are plotted from the same original measurements as are the curves in Figs. 5A and 5B but without correcting the photometer measurements as described above. It will be noted that on plates 75 and 79 well defined maxima are nevertheless observable in the neighborhood of the 54.2 volt point. Plates 78 and 80 admit of the possibility of such maxima, but these plates were unsatisfactory, first, because the points were not chosen in such a way as to show a maximum if such did exist, and second, because the respective correction curves show that the conditions within the tube during the exposure were not steady. It might be remarked at this point that the correction curve represents a net effect consisting of at least two components, viz., the pre-exposure effect commented upon above, which probably follows some logarithmic law, and any accidental fluctuation in the intensity and configuration of the arc. Even so, there is in each of these curves a well defined change of slope at the 54.2 volt point.

The work and results described in this report were first presented under the same title at the Washington, D. C., meeting of the American Physical Society, April 28 and 29, 1928.[10]

In conclusion, I wish to express my appreciation of the unremitting labor of my colleague, Mr. J. T. Lay, and of the equally sincere and helpful interest of Professor C. B. Bazzoni.

Randal Morgan Laboratory of Physics,
University of Pennsylvania,
May 1, 1928.

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[10] Cornog, Lay, and Bazzoni, Phys. Rev. **31**, 1109 (1928).