ART. X.—*The Multiple Spectra of Gases*; by JOHN TROWBRIDGE and THEODORE WM. RICHARDS.

IN a recent paper upon the spectra of argon we have shown that the two different spectra of this gas are dependent primarily upon the electrical conditions which cause the gas to glow. The continuous discharge of a high tension accumulator through the gas produces the red spectrum, while the discharge of a condenser, provided that its oscillations are not damped by the resistance of the tube, or other resistance or impedance, produces the blue spectrum.

It becomes now a matter of great interest to determine if the same conclusions apply to other gases, a subject which has already been studied in detail by Wüllner and others. The chief difference between our work and the earlier investigations are: first, the use of a high tension accumulator instead of an electrical machine or Ruhmkorff coil as the source of electricity; and secondly, the introduction of varying ohmic resistance or impedance between the plates of the condenser in order to study the damping of the spark. It is the object of this paper to emphasize anew the importance of the electrical conditions of the circuit, and to call attention once more to the fact that the behavior of most elementary gases is in every respect similar to that of argon.

With regard to the spectrum of nitrogen, it has been known for a long time that two spectra could be obtained by means of appropriate changes in the density of the gas, as well as by the introduction of the condenser; but not all investigators have put the same interpretation upon their results. So varying are the views, that Ångström* and Thalen† believed the familiar channelled spectrum to be due to impurities in the gas. Plücker and Hittorf,‡ Wüllner§ and Salet|| have proved this view to be false, but they had not at hand the constant current of high tension at our disposal and their nitrogen was obtained from air containing argon, so that a revision of their work promised to be of great interest.

With our Planté battery of ten thousand volts we have obtained the usual two different spectra of nitrogen by varying suitably the electrical conditions of the discharge. By means of a continuous discharge with no spark gap or brush dis-

* Pogg. Annalen, cxliv, 300.

† Bull. soc. chim. (2), xxv, 183.

‡ Roy. Soc., Proc., xiii, 153. Phil. Mag. (4), xxviii, 64.

§ Pogg. Ann., cxxxv, 497, cxxxvii, 337, cxlvii, 321, cxlix, 103, cliv, 149.

|| Ann. Chem. Phys. (4), xxviii, 52. Hasselberg, Ames and others have also studied the nitrogen spectra.

charge in the circuit through nitrogen under varying pressure, we always obtained the channelled spectrum. The glow in the capillary tube, as well as the positive and negative light, was of a delicate pink color under these conditions; a color not unlike the red glow of argon. When an air-gap, over which the battery discharges in a brush, is introduced into this circuit, the glow becomes more violet in tinge, and the spectroscope shows that the red bands almost if not wholly disappear, while the blue and green ones retain their positions. Under these conditions the capillary tube is filled with a pure blue glow, less intense and vivid than that of the argon, however.

When the condenser is introduced, the whole appearance of the tube is utterly transformed. The blue color of the tube at once changes to a rich bluish green, and the channelled spectrum gives place to bright lines, already well known and mapped. This line spectrum corresponds to the blue spectrum of argon. When the oscillations of the condenser-discharge are damped by means of a suitable resistance or self-induction interposed between the condenser plates, a channelled spectrum reappears; but in this case the glow in the tube is of a bluish white color, the positive and negative lights being of a bright yellow. Whether or not this channelled spectrum is, as it seems, exactly like the one obtained by means of a continuous discharge, photographic measurement will show. This last appearance is probably the usual one obtained by means of the Ruhmkorff coil, for then the oscillations induced by the primary condenser are damped by the impedance of the secondary coil and the resistance of the tube.

The spectrum of hydrogen is usually supposed to consist of four bright lines, $H\alpha$ 6563.0 (C), $H\beta$ 4861.5 (F), $H\gamma$ 4340.7 (G'), $H\delta$ 4101.9 (h), as well as several in the extreme violet and ultra violet.*

Other spectra have been observed also; but owing to the partial understanding of the conditions required to produce them, the voluminous literature† upon the subject leaves a confused idea in the mind of the reader. The continuous discharge of a high tension accumulator through hydrogen gas at tensions varying from 0.05^{mm} to 3^{mm} and more yields a beautiful white glow in the capillary of a Geissler tube, while the strata in the positive and negative light are often alternately pale pink and pale blue. When examined by a spectroscope with a broad slit, the light from this discharge appears

* Ames, *Phil. Mag.* (5), **xxx**, p. 48 (1890).

† Ångström, Vogel, Lockyer, Fievez, Wiedemann, Huggins, Wüllner, Hasselberg, Balmer, Grünwald, Villari, Schuster, Salet, Smyth and others. For references see O. Dammer; *Anorgan. Chem.* i, 369.

to consist of bands similar to that of nitrogen, as well as of bright lines; but when the slit is narrowed every band is resolved into a multitude of sharp lines of varying intensities,* among which the four usual hydrogen lines, although present, are by no means especially prominent. A large capacity is required to change this spectrum into the familiar four-line spectrum which is comparable with the blue spectrum of argon. The change is marked by a sharp alteration in the color of the glow from white to a deep red. In the process, the bluish green line ($H\beta$) as well as the two in the violet, which retain their early position unaltered, become nebulous at their edges;† while the red line $H\alpha$ remains sharp and clear. The most marked change in the spectrum, however, is the complete obliteration of all the host of other lines covering the whole spectrum, and the obvious contrast between the oscillatory and non-oscillatory spectrum of this gas is quite as striking as in the case of nitrogen, although somewhat different in nature. This four-line deep red glow appears satisfactorily in a tension of gas of about a millimeter,—when the tension of the gas is much higher or lower the resistance is increased, the oscillations are damped, and other lines begin to appear. Curiously enough, however, the damping of the oscillatory discharge does not at first replace all the lines which were extinguished by the introduction of the condenser. At first only a sharp line in the yellow and one in the green begin to appear, and gradually others are added as the impedance is increased.

The relation of these conclusions to the varying spectra of hydrogen observed in stars leads to interesting speculations regarding the nature of the electrical and thermal conditions in the photospheres of these bodies.‡

Each of the halogens gives two spectra, one with and one without the condenser. With iodine, if any of the solid itself is present in the tube, the vapor tension is so soon altered by the heat of the discharge that the oscillatory discharge is damped and the non oscillatory substituted. Hence the former can be obtained only for a few moments.

A tube of helium made by Professor Ramsay, the kind gift of the Hon. R. J. Strutt, gave a brilliant yellow glow under the influence of the continuous discharge, and a brilliant blue with the condenser discharge, but since the bright helium lines remained in each, and every other important line in the blue spectrum proved to be an argon line, it is evident that the oscillations produced no considerable effect upon the helium.

* Smyth, Wied. Ann. Beiblätter (2), vii, p. 286. Wüllner observed this spectrum but did not measure the lines.

† E. Villari, Fievez, and Salet.

‡ E. Ebert, Wied. Ann., liii, 1894.

As Crookes and others have already pointed out, since many gases yield different spectra under the influence of varying electrical conditions, it is evident that the fact of the existence of two well-marked spectra of argon gives not the slightest presumption in favor of the hypothesis that the new gas is a mixture. In order to discover if argon possesses a dual nature, the gas must be split up in such a way that its components give different spectra under like electrical conditions; then alone would the evidence of the spectroscope be of weight in proving the dissimilarity of the several parts.

The results of this work are thus far only those which were to have been expected from a high tension galvanic battery, reasoning from the work of other investigators with the Toeppler-Holtz machine. The battery, however, gives a current so admirably constant and so easily regulated as to its tension, that we hope to be able to use it as a means of determining whether the oscillatory discharge produces its effect simply by increasing the temperature, or because of some inherent property in the manner of the discharge.

It is our intention to extend the investigation by the systematic photographic study of the action of the varying discharge upon all the elementary gases in the purest condition, as well as upon mixtures under widely varying conditions of temperature and pressure.

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