existence of a mass so great as 160 (or even the minimum assigned value 137) appears to be statistically impossible if we have regard to even the largest reasonable estimate of the number of binaries accessible to observation irrespective of parallax. It will require a good many more cases to bring back the previous appearance of statistical stability.

† While this article was in press Ludendorff (*Sitz. Preuss. Akad. Wiss.*, 1924, VIII–IX, p. 67) has announced minimum masses of 260 and 54 for the components of υ Sagittarii.

THE IONIZATION POTENTIALS OF HYDROGEN AS INTERPRETED BY POSITIVE RAY ANALYSIS

BY T. R. HOGNESS AND E. G. LUNN

CHEMICAL LABORATORIES, UNIVERSITY OF CALIFORNIA

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Up to the time that one of the authors first began this investigation, the interpretation of the data on ionization potentials of polyatomic gases had been almost wholly a matter of conjecture, since no attempts had been made to resolve the group of ions, produced by impact electrons of various velocities, into their constituent parts. It was with the object of interpreting these data that the present investigation was started, and, while the work was in progress, several announcements[1] of experimentations similar to that conducted by the authors have appeared.

After the apparatus had been perfected, hydrogen was the first gas to be investigated and, although the investigation of this gas has not been completed, it seemed that a preliminary note on the apparatus, together with the results so far obtained, would be of interest to those engaged in ionization potential and allied work.

General Description of Method.—The gas is ionized by impact electrons emitted by a hot tungsten filament, and, by means of an electric field the positive ions formed are drawn through a narrow slit into a magnetic field, where they are resolved into constituents of different ratios of charge to mass by a method very similar to that employed by Dempster[2] in his positive ray analysis. The ionization potential necessary to produce each ion is determined by gradually reducing the potential applied to the impact electrons until no trace of the particular ion can be detected.

Detailed Description of the Apparatus and the Method Employed.—After several trials the apparatus finally adopted is the one shown in Fig. 1. The gas enters the apparatus at A, passing into the ionization chamber H, through the slit at B, into the magnetic chamber C, through D, and im-

mediately into a liquid air trap and mercury diffusion pump of the type made by Mr. W. C. Cummings of this laboratory. The slit at B is 3 mm. long, and for these experiments was 0.5 mm. wide. With this slit opening, a fifteen-fold difference of pressure could be maintained between the chambers H and C.

The electrons are emitted by the tungsten filament E, accelerated toward the gauze G, and pass into the ionization chamber H. The potential between E and F is kept constant and, whenever desirable, the potential between F and G is varied. While varying the applied potential, a more constant stream of electrons should be obtained, with the extra gauze G, than with only one gauze; thereby causing a sharper break in the ioniza-

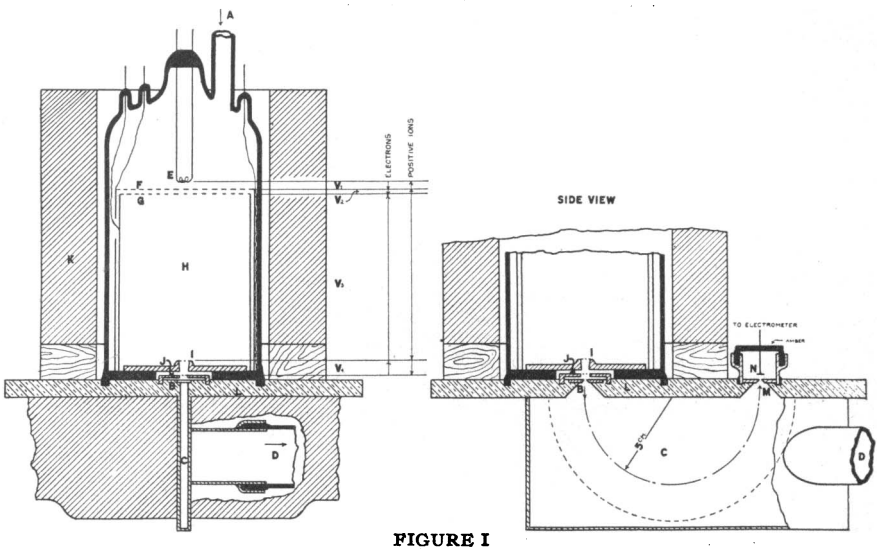

FIGURE I

tion potential curves. The platinum gauzes F and G are mounted on copper cylinders, to give them support and to insure equipotential walls within the ionization chamber H. All metallic parts of the apparatus are insulated from each other by glass cylinders or plates. The distance from the filament to the gauze F is about 5 mm., and the distance between the two gauzes F and G is 3 mm.

The positive ions are produced in the chamber H and are accelerated toward the small gauze I by a small field V_3, then accelerated again toward the gauze J by a large field V_4, and pass through the slit B. The gauze J and the slit B are at the same potential. The gauzes I and J are mounted on discs of the shape shown in the drawing. These discs and the knife edges of the slit are made of iron to act as magnetic shielding against the stray field of the magnet, and they are copper-plated to minimize the

desorption of the foreign gases held on the surface of the iron. The ionization chamber is 10 cm. long. This length allows a lower pressure in the chamber H, with a consequent lower pressure in the chamber C. No effects due to the stray magnetic field in H were observed since the whole glass portion of the apparatus is surrounded by a heavy iron casting K, which acts as a magnetic shield. The plate L and the walls of the chamber C were constructed of rolled brass plate. The chamber C has an internal width of 3 mm. The glass portion of the apparatus, together with the line and the McLeod gauge, were constructed entirely of Pyrex glass, and the glass portion of the apparatus was sealed to the plate L by means of de Khotinsky cement. The filament was run at so low a temperature and was so far removed from the glass walls that these never became warm; baking being therefore unnecessary.

On entering the chamber C the ions are bent in a circular path, (refer to side view of fig. 1) pass through the slit M which is 1 mm. wide, and impinge on the plate N which makes electrical connection with the insulated quadrants of the electrometer. The electrometer was the Compton type, specially constructed in this laboratory. With a 75 volt potential on the vane, the electrometer had a sensitivity of 6500 divisions per volt. Under the conditions prevailing during these experiments, this gave a calculated current sensitivity of 1×10^{-16} amperes.

In resolving any group of ions into its constituent charge-to-mass ratios, $V_1 + V_2$ is kept constant at some convenient value greater than the ionization potential, usually 30 volts. V_3 is kept constant at 2.0 to 4.5 volts, the magnetic field is kept constant and, as V_4 is varied, the electrometer deflections are noted. The electrometer deflections are plotted against V_4, and sharp distinct peaks are obtained (see fig. 2). From the values of V_4 for these peaks the ratio of the charge to the mass can be calculated from the usual formula,

$$e/m = 2V_4/H^2r^2.$$

Here r is the radius of curvature of the rays in the magnetic chamber, and in this work was 5 cm. V_3, V_4, and the current through the field coils are equipped with double-throw reversing switches, so that negative as well as positive ions could be studied.

The magnetic field was roughly calibrated by analyzing the positive rays of air. The peak representing the greater value of the charge to the mass was taken to be N^+, and the peaks for O^+, H_2O^+, $N_2{}^+O_2{}^-$ and a very small peak for A^+ appeared in their respective places. The relative intensities of these ions were also of the right order of magnitude; the sum of the maximum intensities of the N^+ and $N_2{}^+$ was about four times the sum of those for O^+ and $O_2{}^+$. A rough value of the field strength could be calculated from the above formula, and from this the positions of the peaks

for the ions of hydrogen determined. These ions invariably appeared in their calculated positions. An oxide-coated platinum filament was used in the calibration.

The Postive Rays of Hydrogen.—The hydrogen was prepard by electrolysis of a solution of sodium hydroxide and was dried over phosphorous pentoxide. The vacuum line and apparatus were washed out repeatedly to insure against contamination by residual gases. With a pressure of 1×10^{-4} mm. in the apparatus, it was possible to detect foreign gases to the extent of one part in a thousand, and in all of the later runs no trace of

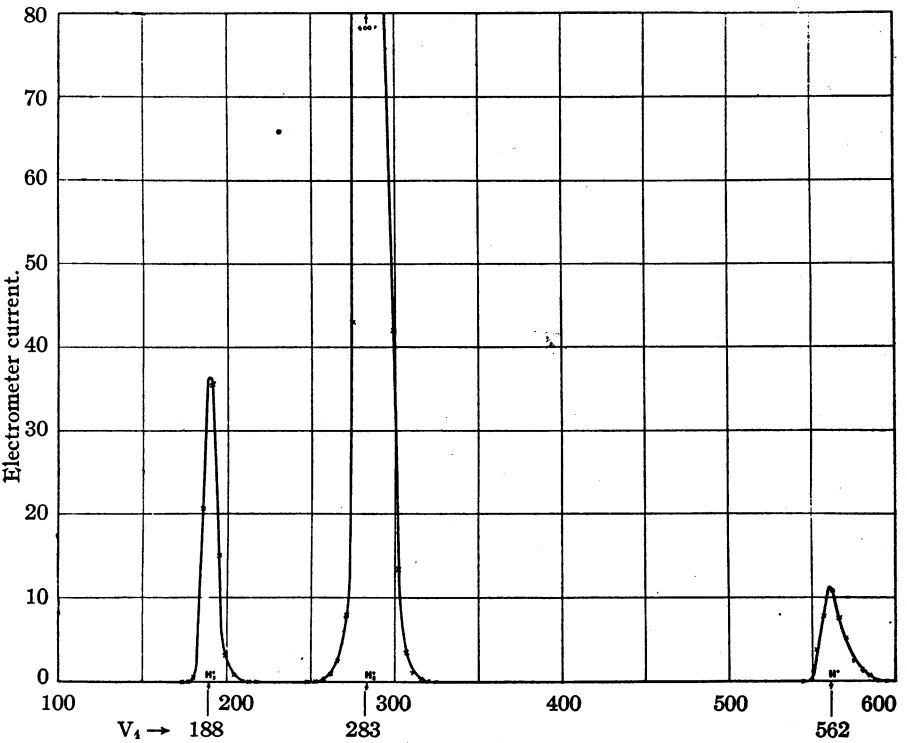

FIGURE II

foreign gas could be observed. The hydrogen was stored in a two-liter reservoir and was allowed to enter the vacuum line through a small capillary tube. With a pressure of one atmosphere in the reservoir, the pressure of the gas in the apparatus could be maintained indefinitely at 30×10^{-4} mm. To vary the pressure of the gas in the apparatus, the pressure of the gas in the reservoir was varied accordingly.

Three positive ions of hydrogen, H^+, H_2^+, and H_3^+ were found. In figure 2 a typical run is plotted with V_4 as abscissæ and the electrometer readings in centimeter scale divisions per 10 seconds as ordinates. $m/e = 1$ cor-

responds to the peak at 562 volts, $m/e = 2$ at 283 volts, and $m/e = 3$ at 188 volts. It will be observed that the intensity of the H_2^+ is very much greater than either the H_3^+ or the H^+. The pressure of the hydrogen at which this particular run was made, was 30×10^{-4} mm. With diminishing pressure H_2^+ continues to predominate, but the ratio of H_3^+ to H^+ becomes smaller. The relative intensities were often difficult to reproduce. To obtain appreciable deflections for either H_3^+ or H^+, the deflections for H_2^+ were so great that large errors were introduced in the stop-watch readings. A discussion of the relative intensities of the ions is postponed until more data are available.

Negative ions of hydrogen were also sought, especially the ion H^-, by reversing the electric and magnetic fields. The accelerating voltage of the

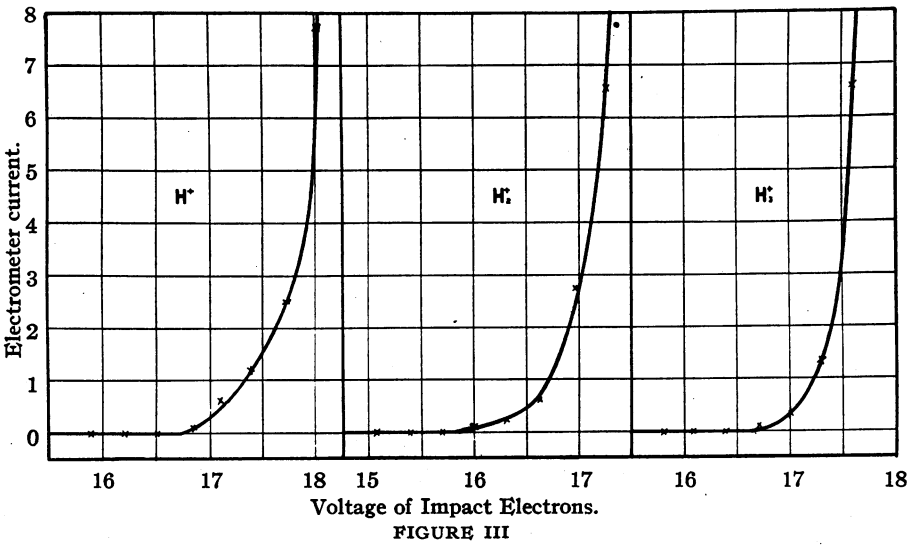

FIGURE III

impact electrons was varied from 2 to 30 volts, but no negative ions were found in sufficient quantity to be detected. Negative ions of hydrogen have been found by Thomson but at relatively high pressures and under other conditions that indicate that their formation is an effect secondary to ionization. Under the conditions prevailing during these experiments, it would hardly be expected that these should appear.

Ionization Potentials.—In determining the ionization potentials of any one of the ions, the filament was raised to a sufficient temperature to give a large electrometer deflection, such as shown for H_2^+ in figure 2, V_4 was set to give the maximum intensity for the ion, and the voltage of the impact electrons was diminished in steps of 0.3 volt until no electrometer deflection was detectable. The electrometer deflections were plotted against the

accelerating voltage of the impact electrons (fig. 3), and the ionization potential was taken to be that point at which the curve cut the zero ordinate. As a further check the accelerating voltage of the electrons was maintained at a value just below and above the ionization potential determined in this way, and the electrometer deflections were noted over a period of ten to fifteen minutes. In all of these checks the electrometer showed no deflections below the critical potential, while above this critical potential a very definite deflection was obtained.

Figure 3 shows one of these curves for each ion. The accelerating voltage of the electrons ($V_1 + V_2$) plus their initial velocities was plotted as abscissæ and the electrometer deflections as ordinates.

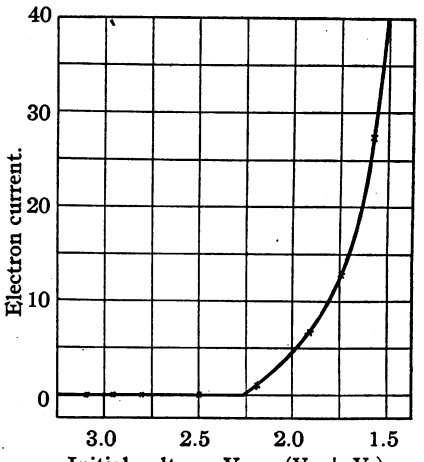

FIGURE IV

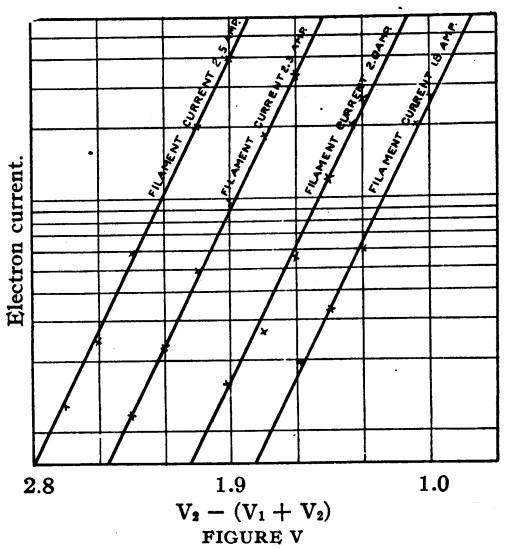

FIGURE V

The initial velocity of the electrons, together with any difference of contact potential and potential drop along the filament, was determined for different filament temperatures by placing a galvanometer with a sensitivity of 2500 megohms in the electrical circuit between the grid G and the grid I. As V_3 was increased the electron current flowing from G to I diminished. At the point at which no electrons penetrated to the plate I the correction was taken to be $V_3 - (V_1 + V_2)$. This value was best taken from a plot of the electron current against $V_3 - (V_1 + V_2)$. A typical curve of this kind is shown in figure 4. The correction was taken to be the point at which the curve cut the zero ordinate. The upper portion of the curve was logarithmic so that by plotting the electron current on a logarithmic scale a straight line

was obtained (fig. 5). Although the initial velocities could not be obtained from this plot, the differences of the velocities at different temperatures could. This afforded a check on the initial velocities selected from the curves of the type shown in fig. 4.

A summary of the results of the ionization potentials of the different ions is given in the following table.

H^+			H_2^+			H_3^+		
OBSERVED VOLTAGE	INITIAL CORRECTION	IONIZATION POTENTIAL	OBSERVED VOLTAGE	INITIAL CORRECTION	IONIZATION POTENTIAL	OBSERVED VOLTAGE	INITIAL CORRECTION	IONIZATION POTENTIAL
14.4	2.2	16.6	14.0	1.4	15.4	14.3	2.2	16.5
14.9	1.6	16.5	14.2	1.4	15.6	14.7	2.1	16.8
14.5	2.2	16.7	13.5	2.2	15.7	14.6	1.9	16.5
14.0	2.6	16.6	14.9	1.0	15.9	14.7	2.2	16.9
			13.7	2.2	15.9	14.0	2.6	16.6
Average		16.6			15.7			16.7

All of the above runs were made at a pressure of 30×10^{-4} mm.

Discussion.—It will be observed that, within the limits of error, H_3^+ appears at the same ionization potential as H^+. Since, as has been stated, the amount of H_3^+ increases with respect to H^+ with increase of pressure, it is natural to assume that H_3^+ is formed by the combination of H^+ with the neutral H_2 molecule, a spontaneous process which occurs with the evolution of energy. From energy considerations, it is possible that an H_2^+, sufficiently accelerated, could, upon collision with an H_2 molecule, break up to form either H^+ or H_3^+, yet the results here obtained indicate that no such reaction takes place to any detectable extent. If such a process took place we should expect to find either H^+ or H_3^+ at 15.7 volts, which is the ionization potential for the formation of the H_2^+. In no case was H^+ or H_3^+ found below 16.5 volts. At higher pressures, where the probability of collision is greater, such a phenomenon might appear.

The fact that the ionization potentials of hydrogen are different by only 0.9 volt may account for the difficulties encountered by other observers in arriving at concordant values for the ionization potential of hydrogen. Olson and Glockler[3] in their study of the critical potentials of hydrogen, found three potentials which they ascribed to the hydrogen molecule. It is exceedingly interesting that the greatest of these, 15.62 volts, coincides, within the limits of error of this experiment, with the value 15.7 volts, which represents the ionization of hydrogen to form the H_2^+. The ionization potential to form H^+, 16.6 volts, is also in agreement with their value of 16.68. We may therefore assume that the interpretation of the data of these observers is the correct one. Since the method which they employed is adapted to greater refinements than can be obtained with the apparatus used in this experiment, their values are undoubtedly the more correct ones.

These results show conclusively that there are two distinct primary processes taking place:

(1) $H_2 = H + H^+ + E^-$; 16.6 volts,
(2) $H_2 = H_2^+ + E^-$; 15.7 volts,

and one secondary process,

$H^+ + H_2 = H_3^+$.

Further discussion will be postponed until more experiments have been made.

[1] Kallmann and Knipping, *Naturwis*, **10**, 1014 (1922), preliminary notice.
H. D. Smyth, *Proc. Roy. Soc.*, **104**, 121 (1923); **105**, 116 (1924).
[2] A. J. Demptster, *Physic Rev.*, **9**, 316 (1918).
[3] Olson and Glockler, *Proc. Nat. Acad. Sci.*, **9**, 122 (1923).

THE POLARIZING ANGLE FOR X-RAYS SCATTERED BY PARAFFIN

BY G. E. M. JAUNCEY AND H. E. STAUSS

WASHINGTON UNIVERSITY, ST. LOUIS, MO.

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Jauncey[1] has recently described a corpuscular quantum theory of the scattering of polarized X-rays, in which a formula for the intensity of the scattering in any direction ϕ is derived. From this formula an expression for the linear scattering coefficient per unit solid angle in any direction ϕ may be obtained. In particular this linear scattering coefficient for the case where plane polarized X-rays are scattered in the plane of the electric vector of the primary X-rays is given by

$$s = (Npd/W)\,(e^4/m^2c^4)\{(1+\alpha)\cos\phi - \alpha\}^2/(1+\alpha\,\mathrm{vers}\phi)^5, \qquad (1)$$

where N is Avogadro's number, d is the density of the scattering substance, W its molecular weight, p the number of electrons per molecule, and α is the quantity $h/mc\lambda$, λ being the wave-length of the primary X-rays. It is seen that s becomes zero at an angle ϕ_p such that

$$\cos\phi_p = \alpha/(1+\alpha) \qquad (2)$$

ϕ_p may be called the polarizing angle of scattering since when unpolarized primary X-rays are scattered at this angle the scattered X-rays are completely plane polarized. The present work was undertaken to test the truth of Eq. (2).

X-rays from a Coolidge X-ray tube with a tungsten target were directed on to a slab of paraffin A. By a suitable arrangement of apertures