Second Series *October 1, 1932* *Vol. 42, No. 1*

THE

PHYSICAL REVIEW

The Isotopic Weight of H^2

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(Received August 15, 1932)

The mass of neutral H^2 was measured on a mass-spectrograph as 2.01351 ± 0.00006 referred to He and 2.01351 ± 0.00018 referred to $O^{16} = 16$. The equivalent packing fraction of H^2 is 67.5 parts in 10,000. On the assumption that the nucleus is composed of two protons and one electron the energy of binding is approximately 2×10^6 electron-volts. If the H^2 nucleus is made up of one proton and one Chadwick neutron of mass 1.0067 then the binding energy of these two particles is 9.7×10^5 electron-volts. H_3^{1+} and He^+ provided the dispersion measurements for the spectra. The presence of $H^1\,H^{2+}$ can only introduce in the mass determination a possible *maximum* error of 0.00003 mass units. Lines of mass 4.02852 on the spectra were attributed to $H_2^1\,H^2$ ions because: (1) no lines of comparable intensity appeared in this position when commercial hydrogen of low H^2 content was used; (2) under the conditions existing in the discharge tube the abundance of H_2^{2+} was negligibly small compared to the abundance of $H_2^1\,H^{2+}$; (3) the mass is less than the mass of H_4^{1+} by an amount outside of the limits of error. Two samples of enriched hydrogen were used which had been prepared by Brickwedde; both had been tested spectroscopically by Urey and Murphy, and one of them was identical with Bleakney's Sample III. From the value for the mass of H^2, the energy balance is calculated for one process of noncapture disintegration of N^{14} by neutron impact, suggested by Feather, which would result in C^{12} and H^2. It is concluded that this disintegration could not possibly occur under the conditions of his experiments.

INTRODUCTION

THE H^2 nucleus represents the simplest complex nucleus and as such may be more amenable to theoretical attack than other nuclei. Whether the nucleus is composed of two protons and one electron, or one proton and one neutron, an accurate determination of the mass of the H^2 nucleus is of interest not only in relation to the packing fractions of other nuclei but also as a clue to the possible structure of the H^2 nucleus itself. Also, the possibility exists that together with the electron, proton, neutron, and alpha-particle, H^2 may play a part in the structure of heavier nuclei.[1]

In all calculations of the energy of binding of nuclear constituents it is essential to know the masses of the component parts. Bleakney[2] has placed a lower limit on the mass of the H^2 nucleus, but spectrographs of the Dempster

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[1] N. Feather, Proc. Roy. Soc. **136,** 726 (1932); J. Chadwick, ibid., 706; N. S. Grace, J. Am. Chem. Soc. **54,** 2562 (1932).

[2] W. Bleakney, Phys. Rev. **41,** 32 (1932); **39,** 536 (1932).

type such as Bleakney used are at present limited to a lower order of accuracy than mass-spectrographs which photograph mass-spectra and permit the reduction of observations from accurate mensuration of the photographic traces resulting from ionized atoms and molecules. In the future the ratio of the masses of H^1 to H^2 may possibly be obtained from band spectra with an error of only one part in 10^5. The present paper is a report of the measurement[3] of the mass of H^2 obtained with the mass-spectrograph recently described.[4]

The existence of an isotope of hydrogen of mass number two, predicted by Birge and Menzel,[5] was demonstrated by Urey, Brickwedde, and Murphy.[6] Their paper should be referred to for a bibliography of the subject and a review of previous work. Bleakney's work with his low-pressure spectrograph provided excellent confirmatory evidence of H^2, and splendid measurements were secured of the relative abundance of H^2 in various samples of hydrogen. More recently Kallman and Lasareff[7] were able to detect the presence of H^1H^2 in fractionated hydrogen.

Conditions for the Measurement of the Mass of H^2

If the mass of H^2 should be close to that of $H_2{}^1$ then the resolving power of the apparatus might not permit the separation of the doublets H^{2+}, $H_2{}^{1+}$, and $H_3{}^{1+}$, H^1H^{2+}, and the mass of H^2 could not be compared with H^1 directly. The most accurate method of measurement of the mass of H^2 by a mass-spectrograph would be by comparison of the mass of $H_2{}^1H^{2+}$ with He^+. Bleakney's value of a lower limit of the mass of H^2 showed clearly that $H_2{}^1H^{2+}$ if secured would be well separated from He^+ and the higher the mass of H^2 the greater the separation. From the suggested process of formation of triatomic hydrogen,[8] $H_2{}^+ + H_2 \rightarrow H_3{}^+ + H$, it is clear that a high concentration of ions in the discharge tube would favor the production of $H_3{}^{1+}$ and $H_2{}^1H^{2+}$. Brasefield[9] has shown that under proper conditions of current density and pressure, an ion beam can be secured with a concentration of $H_3{}^{1+}$ comparable to that of $H_2{}^{1+}$. Bleakney, and Kallman and Lasareff worked with very low pressures of hydrogen which would preclude secondary effects to a large extent and only permit measurements of ions produced by the primary process of electron impact. Relatively high current density and high gas pressure favor the formation of $H_2{}^1H^{2+}$.

Experimental Procedure

Fortunately the conditions essential to the production of triatomic hydrogen can be achieved in the discharge tube of the mass-spectrograph.

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[3] K. Bainbridge, Phys. Rev. **41**, 115 (1932).

[4] K. Bainbridge, Phys. Rev. **40**, 130 (1932). A detailed description of this apparatus will appear in the Journal of the Franklin Institute.

[5] R. T. Birge and D. H. Menzel, Phys. Rev. **37**, 1669 (1931).

[6] H. C. Urey, F. G. Brickwedde and G. M. Murphy, Phys. Rev. **40**, 1 (1932); **39**, 164 (1932).

[7] H. Kallman and W. Lasareff, Naturwiss. **20**, 472 (1932).

[8] H. D. Smyth, Rev. Mod. Phys. **3**, 370 (1931).

[9] C. Brasefield, Phys. Rev. **31**, 52 (1928).

A cylindrical discharge tube was used, 8 cm in diameter, with a 2.5 cm diameter aluminum cathode of the shape described by Thomson.[10] The top of the cathode was 2 cm above the surface of an iron plate which served as a magnetic shield for stray fields and also as a base for the discharge tube. The pressure of the gas in the discharge tube was in the range of 0.5 to 5 microns of mercury. The current was 75 ± 25 m.a. for different exposures at potentials from 7000 to 15,000 volts, which experience had shown produced $H_2^1H^{2+}$ with sufficient intensity.

Two Thordardson 1 K.V.A., 25,000 volt transformers, controlled by an induction voltage regulator, provided the current for the discharge. The combination of two kenetrons with two transformers gave full wave rectification. The output was not filtered in any way, as a wide range of energies in the discharge tube is essential to the proper functioning of the mass-spectrograph.

In addition to ordinary commercial tank hydrogen, two samples of enriched hydrogen were used which had been fractionated at the triple point by Dr. Brickwedde of the U. S. Bureau of Standards. These samples were placed at the disposal of the author through the kindness of Professor Urey, Dr. Brickwedde, Dr. Murphy, and Dr. Bleakney. One sample was from the same lot Bleakney used and designated *Sample III*. The other was fractionated later by Dr. Brickwedde and had been tested by Professor Urey and Dr. Murphy, who reported a greater concentration of H^2 than in *Sample III*.

The magnetic field and the potential across the velocity selector plates of the mass-spectrograph were adjusted to bring H_3^{1+} and He^+ within the first 8 cm of the recording plate. This region had been exposed for more than 15 spectra of C, CH_1, CH_2, CH_3, CH_4, and CH_5, and also for the series O, OH_1, OH_2, OH_3, and the mass scale had been found to be linear to within one part in 10,000.

The first 21 exposures showed that $H_2^1H^{2+}$, or possibly H_4^{1+} or H_2^{2+}, was present but in such small concentration that no measurements of the mass could be made to aid in determining the nature of the ion. In agreement with Thomson's results,[11] it was found that the presence of mercury vapor in the tube greatly weakens the triatomic hydrogen line. Subsequently, before photographing each series of spectra the discharge tube was cleaned out and baked by the energy of the discharge itself until no discharge could be run at voltages even as high as 25,000. The great amount of power dissipated in the discharge tube, about 500 watts, was sufficient to raise the walls of the tube to 200°C. At the same time the cathode and iron base were thoroughly cleaned by positive ion bombardment.

Ordinarily gases are admitted through a leak into the discharge tube and then are pumped out into the atmosphere. The valuable fractionated hydrogen, however, was not pumped out, but was circulated continuously by a diffusion pump. The gas was pumped out through the cathode slit, 0.005 cm × 0.3 cm, and then was readmitted to the discharge through a hole under the side of the cathode. The gas passed through two liquid air traps, one on

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[10] J. J. Thomson, *Rays of Positive Electricity*, 2nd. ed., p. 30.

[11] Reference 10, p. 200.

each side of the circulating pump. In certain cases still further concentration of the H^2 in the enriched samples was achieved in the discharge tube itself

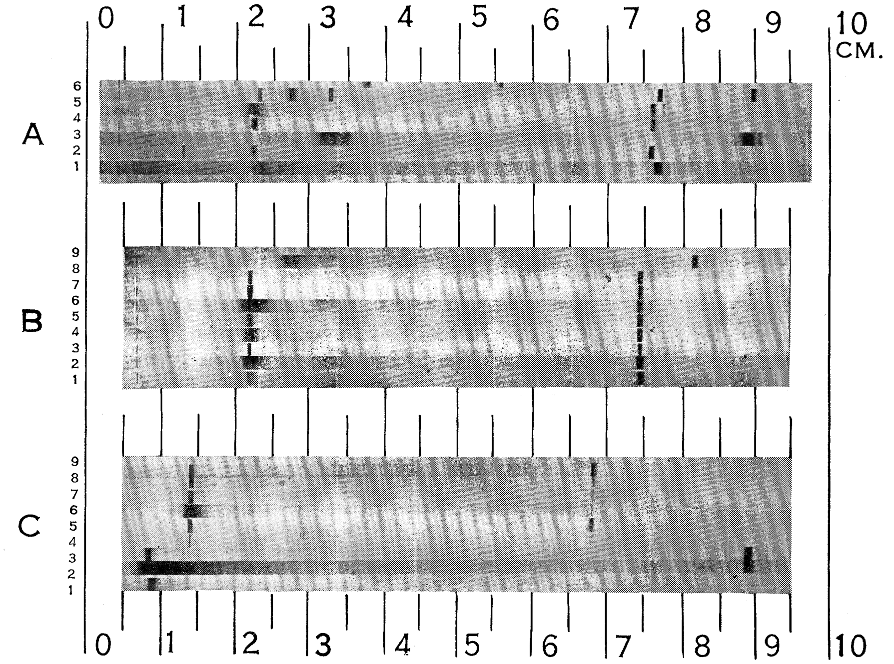

Fig. 1. Mass-spectra of hydrogen and helium ions. The descriptions of the spectra are given below in condensed form. The three samples of hydrogen used are designated: OH, for ordinary commercial tank hydrogen; BH, for Sample III Bleakney hydrogen; UH, for Urey-Brickwedde hydrogen. Spectra A June 10, Spectra B June 11, Spectra C June 14, 1932. Spectra are numbered in order as they were taken. T=exposure time in minutes. Description of ion is followed by number to nearest mm referring to attached cm scale as aid in locating specific lines. Lines which may not be or cannot be reproduced in half-tone are designated weak (w), or very weak (vw). Sharp lines on the left are fiducial lines to mark the plate position.

A1, BH, T63, H_3^1 2.3, He 7.7, $H_2^1H^2$ 7.8:
A2, BH, T .16 H_2^1 1.3; T 15, H_3^1 2.2, He 7.6, $H_2^1H^2$ 7.7 w:
A$_3$, UH, H_3^1 3.5 premature exposure before velocity selector potential and discharge potential were set, T60 H_3^1 3.2, He 8.9, $H_2^1H^2$ 9.0:
A4, UH, T 16H_3^1 2.3, He 7.6, $H_2^1H^2$ 7.7 vw taken with 60 sec.$^{-1}$ pulsating current, one transformer disconnected:
A5, UH, T 17.5, H_3^1 2.2, He 7.6, $H_2^1H^2$ 7.7:
A6, UH, three separate spectra, No. 1T5, H_3^1 2.3, He 7.7, $H_2^1H^2$ 7.8 w:
No. 2 T12.5, He 2.8, $H_2^1H^2$ 2.9 w, HeH 7.1:
No. 3 T4, H_3^1 3.3, He 9, $H_2^1H^2$ not reproducible on print.

B1, OH, T16, H_3^1 2.2, He 7.5:
B^2, OH, T30, H_3^1 2.2, He 7.5:
B3, OH, T3, H_3^1 2.2, He 7.5:
B4, BH, T15, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6 vw:
B5, BH, T30, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6 w:
B6, UH, T30, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B7, UH, T15, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B8, UH, T4, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B9, UH, T15, H_3^1 2.7, He 8.15, $H_2^1H^2$ 8.3:

C1, UH, T5, H_2^1 .9, H_3^1 9 w, Hg present:
C2, UH, T30, H_2^1 .8, H_3^1 8.9:
C3, UH, T1, H_2^1 .8, H_3^1 8.9:
Pressure in discharge changed.
C4, UH, T1, H_3^1 1.4, He 6.8 w:
C5, UH, T15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 6.9 vw:
C6, UH, T30, H_3^1 1.4, He 6.8, $H_2^1H^2$ vvw:
Discharge voltage too low.
C7, UH, T15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7:
H^2 content increased by separation by diffusions.
C8, OH, T15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7 vw:
C9, OH, T33, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7 vw.

by the method of differential diffusion. A dose of hydrogen was admitted and the excess gas pumped out through the slit while the discharge was running. When the gas pressure had been reduced to the right value for an exposure the process of circulation was started. Small but positive and useful increased concentrations of H^2 were obtained in this way.

Fig. 1 is a reproduction of contact prints of the spectra of hydrogen. A small amount of helium was added to the hydrogen to provide a reference mass.

IDENTIFICATION OF $H_2{}^1H^2$ ION

A line adjacent to and on the heavier mass side of He^+ might be due to $H_4{}^1$, $H_2{}^2$, or $H_2{}^1H^2$ ions. However, the following considerations demonstrate that the trace actually observed at that position on the plate could only be produced by $H_2{}^1H^2$ ions.

From Aston's data,[12] the mass of He is taken as 4.00216 ± 0.00013, of H^1 as 1.00778 ± 0.00005,[13] and of the electron as 0.000547 mass units, all referred to $0^{16} = 16$. The measurements of the separation of He^+ and the adjacent heavier ion gave 0.02691 ± 0.00006 mass units, as will be described later. This value added to the mass of the helium ion results in a mass of 4.02852 ± 0.00015 for the line adjacent to $He^+ \cdot H_4{}^{1+}$ is ruled out as a possibility since its mass, 4.03057 ± 0.00010 is quite outside of the limit of error of the measurements.

$H_4{}^{1+}$ is also ruled out, because no lines adjacent to helium appeared when ordinary commercial hydrogen was used in the discharge tube. Spectra 1, 2 and 3B, Fig. 1 were taken with tank hydrogen in the spectrograph discharge tube and no lines appeared near the helium traces. The discharge tube was then evacuated and fractionated enriched hydrogen was admitted which produced lines corresponding to a mass of 4.02852 units on the immediately succeeding spectra 4, 5, 6, 7, 8, 9B. The lines are weak for spectra 4 and 5B as the electrodes and walls of the tube were still contaminated with ordinary hydrogen which reduced the concentration of H^2 in the first dose of fractionated hydrogen. The objection might be raised that the possible presence of mercury in the tube for the first few spectra so inhibited the appearance of a line at 4.0285 that such a line would have been absent in any case regardless of the source of the hydrogen. In order to disprove any such contention spectra 7, 8 and 9C were taken. Spectra 8 and 9C were photographed using commercial hydrogen in the discharge tube *after* successful runs had been made in which $H_2{}^1H^{2+}$ appeared. Faint lines did appear, but as may be seen in Fig. 1, they are weaker on 8C, a 15 minute exposure, and on 9C, a 33 minute exposure, than the $H_2{}^1H^2$ lines on spectrum 7C (15 minutes exposure). All three exposures were taken under conditions as nearly identical as possible. The faint traces of $H_2{}^1H^2$ on 8 and 9C were present owing to the practical impossibility of washing out the tube and cleaning the electrodes entirely free from the gas used in earlier exposures taken immediately before 8C and 9C. As the

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[12] F. W. Aston, Proc. Roy. Soc. **115**, 502 (1927).

[13] All succeeding calculations are made on the basis that Aston's limits of error are three times the probable error of his measurements.

line at 4.0285 only appeared in abundance when fractionated hydrogen was used, it was concluded that the ions responsible for that line contained H^2 and might be $H_2^1H^2$ or H_2^2 but could not be H_4^1 ions.

H_2^{2+} is eliminated as a possibility when the relative abundance of H_2^{2+} and $H_2^1H^{2+}$ is considered. From Bleakney's measurements the ratio H^1H^{2+}/H_2^{1+} is approximately 0.002. The atomic ratio of H^2/H^1 is 0.001 and the ratio H_2^{2+}/H_2^{1+} is 10^{-6}. The suggested mode of formation of triatomic hydrogen is

$$H_2^+ + H_2 \rightarrow H_3^+ + H.$$

The production of $H_2^1H_2^{2+}$ is given by

$$H_2^{1+} + H^1H^2 \rightarrow H_2^1H^{2+} + H^1$$

$$H^1H^{2+} + H_2^1 \rightarrow H_2^1H^{2+} + H^1$$

and for each reaction of this type, assuming that H^1 and H^2 behave similarly, the probability is that three out of every four triatomic molecules will contain H^2. If these reactions proceed in proportion to the product of the partial pressures of the constituents, the ratio $H_2^{2+}/H_2^1H^{2+}$ can be calculated. In the discharge tube the partial pressures for different molecules and ions are respectively: for H_2^1, p; for H_2^{1+}, ap; for H^1H^2, 0.002 p; and for H^1H^{2+}, 0.002 ap, where a is proportional to the amount of ionization extant. The amount of $H_2^1H^{2+}$ is $2\times 3/4\times 0.002\ ap$ and the abundance of H_3^{1+} is ap. The ratio of $H_2^{2+}/H_2^1H^{2+}$ is equal to

$$H_2^{2+}/H_2^{1+} \times H_2^{1+}/H_3^{1+} \times H_3^{1+}/H_2^1H^{2+}$$

wherein all ratios are known except H_2^{1+}/H_3^{1+} which is a function of the conditions existing in the discharge tube. The value of H_2^{1+}/H_3^{1+} must be obtained experimentally. From Fig. 1, spectra 2, 3 and 4C, the ratio H_2^{1+}/H_3^{1+} was estimated at from 1 to 20 under varying conditions in the discharge tube. If the measured values of this ratio are substituted, the ratio of abundance of $H_2^{2+}/H_2^1H^{2+}$ is in the range 0.67×10^{-2} to 0.33×10^{-3}. The low abundance of H_2^{2+} precludes its appearance on the mass-spectra and the line of mass 4.02852 must be attributed to $H_2^1H^{2+}$.

Exactly the same relative abundance of $H_2^{2+}/H_2^1H^{2+}$ is obtained if the calculations are made without regard to the process of formation of triatomic hydrogen, on the basis of unweighted probability considerations alone.

Dispersion Measurements

The separation of H_3^{1+} and He^+ was measured by a comparator to secure the dispersion measurements for these spectra. The presence of H^1H^{2+} can only introduce a negligible correction to the mass scale measurements. If H^1H^{2+} were present to an abundance equal to that of H_3^{1+} then the dispersion figure would be in error by one part in 1100, equivalent to 0.00003 mass units in the value for the mass of H^2. This possible systematic error is only one half of the probable error in the measurement of the isotopic weight of H^2. As the ratio of abundance of H^1H^{2+}/H_3^{1+} could not be greater than 0.002×20 or

1/25, the effect of H^1H^2 ions was negligible and no correction to the dispersion measurements is necessary.

Method of Measurement of He^+ $H_2{}^1H^{2+}$ Separation

The faintness of the $H_2{}^1H^{2+}$ lines in most cases prevented direct measurements by a comparator. The separations of the $H_2{}^1H^{2+}$ and He^+ lines on different spectra were measured by running the plates through a Goos-Koch microphotometer at a ratio of plate distance to record distance of approximately 1 to 40. For the first report[3] of this work the densitometer records of 14 spectra had been measured and reduced to plate distances by a subsequent determination of the ratio of densitometer travel to plate travel. The microphotometer does not maintain the same multiplication ratio throughout its travel so that for this report, twelve spectra were remeasured with a glass reticle, (1/20 mm divisions), directly superimposed on the spectrum plates. The reticle was compared with one ruled on the Swarthmore College Observatory comparator and also measured directly on a Gaertner comparator. Two of the spectra measured for the first report of this work could not be measured by this method. The densitometer records were coated with a frosting coating and smooth curves were drawn in by pencil. Fig. 2 is a reproduction of some of the records of spectra used in the measurement of the mass of $H_2{}^1H^{2+}$. These records, taken without the superposition of the reticle, illustrate the remarkable symmetry of the ion traces.[14] Record No. 2 is of the

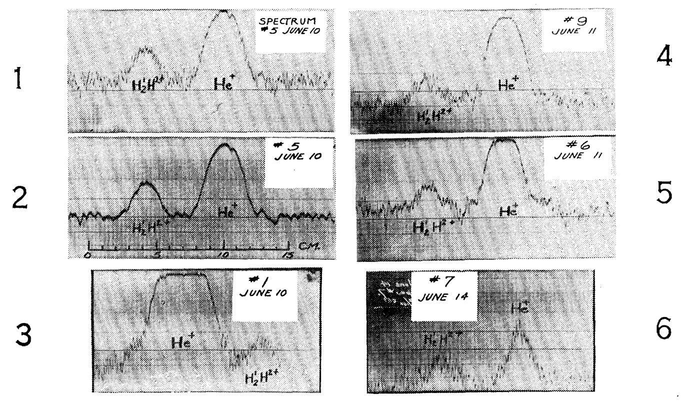

Fig. 2. Densitometer records of several $He^+-(H_2{}^1H^2)^+$ doublets. Scale under record No. 2. Ratio of densitometer record distance to spectrum plate distance approximately 40 to 1. Micrometer slit 0.002 cm wide.

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[14] The symmetry of the spectral lines is a direct consequence of the design of the mass-spectrograph. *Measurements of the separation of lines can be made referred to the centers of traces of unequal density,* an advantage which can hardly be overestimated in cases in which it is impractical or impossible to obtain traces of equal density. The symmetry of the traces is a result of the fact that *the ion beams are not brought to a focus at the surface of the recording plate. Any focussing action takes place in the circular path of the ions* 90° *from the ion source,* or last slit of the velocity selector in the mass-spectrograph. The velocity selector introduces an essentially

same spectrum as No. 1 but it was made with a different adjustment of the densitometer to minimize the effect of the grain of the plate.

The separation of the traces was measured by superposition of the densitometer records on accurate millimeter cross-section paper and by direct scale measurement of the centers of the peaks. The probable error of a single observation, ±0.00024 mass units, corresponds to an error of about ±0.5 mm in a distance of 43 to 60 mm on the densitometer records of different spectra.

RESULTS

The results and their weight values for the mass difference between He^+ and $H_2{}^1H^{2+}$ are given in Table I.

TABLE I.

Fig. 1 spectrum	1A	2A	3A	4A	5A	6A
Mass difference Weight	0.02749 1	0.02702 2	0.02688 1	0.02721 1	0.02688 3	0.02668 1
Fig. 1 spectrum	5B	6B	7B	8B	9B	7C
Mass difference Weight	0.02627 1	0.02657 3	0.02742 2	0.02627 1	0.02714 1	0.02703 2

The averaged difference is 0.02691±0.00006. The probable error is a composite value of a probable error of one part in one thousand in measuring the reticle and the probable error of the above mass difference *per se.*

The mass of neutral H^2 is $M_{He}+0.02691-M_{H_2^1}=2.01351\pm0.00006$ when referred directly to Aston's value for helium. The masses of He^+ and $H_2{}^{1+}$ were compared directly by Aston with a probable error of only ±0.000008 mass units in the determination of the mass of H^1 in terms of helium.[15]

The absolute value of H^2 is 2.01351 ± 0.00018 mass units referred to $0^{16}=16$ and calculated on the basis that Aston's limits of error are equal to three times the probable error of his measurements. The equivalent packing fraction of H^2 is 67.5 parts in 10,000.

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parallel beam of ions into the uniform magnetic field, or camera section of the spectrograph, so that the ions converge at 90°, then diverge, and at 180° from the source are again traveling in a parallel beam where the beam is normally incident on the surface of the recording plate. Spectrographs which deal with divergent nonparallel beams of ions bring the beams to a focus at the recording plate. A sharp edge (W. A. Wooster, Proc. Roy. Soc. **114,** 729 (1927)), or high density of ions at one position results, but the position of the edge of a trace shifts with changes in density and the separation of two adjacent traces of different density cannot be measured accurately (F. W. Aston, Proc. Roy. Soc. **115,** 496 (1927)). A complete discussion will appear in the Journal of the Franklin Institute.

[15] Aston (Proc. Roy. Soc. **115,** 502 (1927) gives three measured values for the difference in the packing fractions of helium and hydrogen, 73.7, 73.6 and 73.9. The correction for the mass of the electron gives a value of 72.4 for the excess of the packing fraction of hydrogen over that of helium. Ordinary error theory, of course, cannot be applied for the calculation of the probable error of only three measurements, but the theory of errors for small samples (W. A. Shewhart, Bell System Tech. J. **5,** 308 (1926)) may be applied and the error in Aston's measurements was calculated on that basis.

Discussion

Nuclear structure of H^2

The energy of binding of the H^2 nucleus corresponds to 0.00205 mass units or approximately 2×10^6 electron-volts if the nucleus is composed of two protons and one electron. It is interesting to speculate that if the H^2 nucleus is composed of one proton and one Chadwick neutron,[16] of mass 1.0067, then the binding energy would be 9.7×10^5 electron-volts. The energy of binding of the neutron itself has been given as 1 to 2×10^6 electron-volts. When more concentrated samples of H^2 are available, it may be possible to distinguish between the two suggested structures of the H^2 nucleus.

The possibility of H^2 as a nuclear structural unit

The binding energy of H^2 is small compared to the 35×10^6 electron-volts accorded helium nuclei. Grace[1] has suggested that the H^2 nucleus may be a constituent of other nuclei and suggests its inclusion in Li^6 and B^{10}. On this basis the binding energy of a Li^6 nucleus, composed of one H^2 nucleus and one helium nucleus, is 3.7×10^6 electron-volts. The binding energy of two helium nuclei and one H^2 nucleus combined as a B^{10} nucleus is 4.3×10^6 electron-volts. Such structures appear possible but the presence of H^2 in heavier nuclei, above mass 22, seems doubtful. While there is good evidence from various sources that α-particles retain their identity inside of nuclei, the small energy of binding of H^2 may not be sufficient to maintain the structure of that entity when it is subjected to the fields and perturbing forces of other particles in heavy complex nuclei.

Feather[17] has suggested the process

$$N^{14} + n^1 \rightarrow C^{12} + H^2 + n^1$$

for noncapture disintegration of nitrogen by neutron impact. When the known masses of the constituents are substituted the result is that at least 9×10^6 electron-volts energy must be supplied by the impacting neutron in order that this disintegration may proceed. The maximum energy of neutrons resulting from the disintegration of Be^9 is 5.7×10^6 electron-volts, entirely insufficient to promote the suggested noncapture disintegration of nitrogen. Feather decided on different grounds that H^2 does not result as a disintegration product of N^{14} but left the possibility open. Until positive evidence is obtained of the inclusion of H^2 in nuclei it is best not to complicate further the structure of nuclei by the addition of H^2 as a possible component, since what evidence is available militates against the addition of this unit.

The author is particularly indebted to Dr. Brickwedde who made this investigation possible by his preparation of the samples of enriched hydrogen at the U. S. Bureau of Standards, to Professor Urey and Dr. Murphy of Columbia University who placed a tested sample at the disposal of the author, to Br. Bramley and Dr. Bleakney for their interest and helpful discus-

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[16] J. Chadwick, Proc. Roy. Soc. **136,** 270 (1932).

[17] N. Feather, Proc. Roy. Soc. **136,** 721, 726 (1932).

sions, and to Professor John A. Miller and the members of the Swarthmore College Observatory for their generous permission to use their measuring instruments.

Note added in proof: It has been the author's privilege to see the manuscript of a paper on the infrared spectrum of H^2Cl by J. D. Hardy, E. F. Barker, and D. M. Dennison. They have observed and measured the fundamental absorption bands due to H^2Cl^{35} and H^2Cl^{37} which lie in the neighborhood of 4.8μ. The value obtained for the mass of H^2 is 2.01367 ± 0.00010 if H^1 is 1.00778 as given by Aston. The details will be published shortly.

Professor R. T. Birge has pointed out to the writer that Aston's values for the mass of H^1 and He are probably too low. If the chemical value for the mass of H^1 is correct (R. T. Birge, Phys. Rev. Supplement 1, 1 (1929)), then the mass of H^1 is 1.00796 on the $0^{16}=16$ scale and Aston's value is too low by 1.8×10^{-4} units. The calculation of the mass of H^1 is made on the basis that the abundance of H^2 is 1 in 30,000 (W. Bleakney, Phys. Rev. **41,** 32 (1932)) and that Mecke and Childs' value for the relative abundance of the oxygen isotopes is correct (Zeits. f. Physik **68,** 362 (1931)).

If $H^1=1.00796$, then from the measurements of Hardy, Barker, and Dennison, the mass of $H^2=2.01403 \pm 0.00010$. The measurement of the mass of H^2 on the mass-spectrograph involves a knowledge of the mass of H^1 and of He also. Aston measured the ratio H/He and He/O. If the error 1.8×10^{-4} in H^1 is divided equally between H^1 and He then the mass of $H^1=1.00796$ and $He=4.00252$. On this basis my measurements give $H^2=2.01351 \pm 0.00018$ referred to O^{16}, a result identical with the value obtained before. The agreement between the band spectrum and mass-spectrograph values for the mass of H^2, calculated on this new basis, can no longer be considered satisfactory.

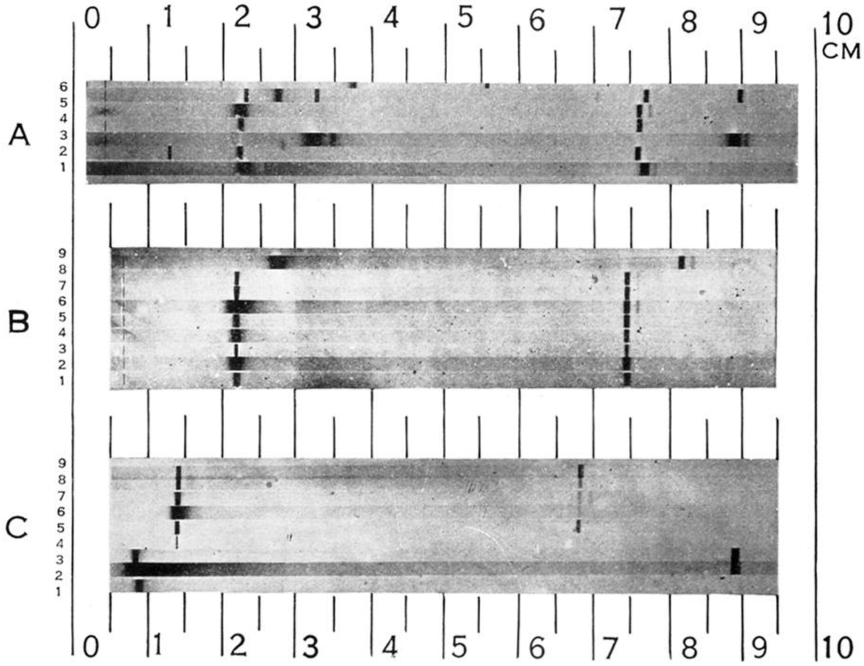

Fig. 1. Mass-spectra of hydrogen and helium ions. The descriptions of the spectra are given below in condensed form. The three samples of hydrogen used are designated: OH, for ordinary commercial tank hydrogen; BH, for Sample III Bleakney hydrogen; UH, for Urey-Brickwedde hydrogen. Spectra A June 10, Spectra B June 11, Spectra C June 14, 1932. Spectra are numbered in order as they were taken. *T* = exposure time in minutes. Description of ion is followed by number to nearest mm referring to attached cm scale as aid in locating specific lines. Lines which may not be or cannot be reproduced in half-tone are designated weak (w), or very weak (vw). Sharp lines on the left are fiducial lines to mark the plate position.

A1, BH, T63, H_3^1 2.3, He 7.7, $H_2^1H^2$ 7.8:
A2, BH, *T* .16 H_2^1 1.3; *T* 15, H_3^1 2.2, He 7.6, $H_2^1H^2$ 7.7 w:
A_3, UH, H_3^1 3.5 premature exposure before velocity selector potential and discharge potential were set, *T*60 H_3^1 3.2, He 8.9, $H_2^1H^2$ 9.0:
A4, UH, *T* 16H_3^1 2.3, He 7.6, $H_2^1H^2$ 7.7 vw taken with 60 sec.$^{-1}$ pulsating current, one transformer disconnected:
A5, UH, *T* 17.5, H_3^1 2.2, He 7.6, $H_2^1H^2$ 7.7:
A6, UH, three separate spectra, No. 1*T*5, H_3^1 2.3, He 7.7, $H_2^1H^2$ 7.8 w:
No. 2 *T*12.5, He 2.8, $H_2^1H^2$ 2.9 w, HeH 7.1:
No. 3 *T*4, H_3^1 3.3, He 9, $H_2^1H^2$ not reproducible on print.

B1, OH, *T*16, H_3^1 2.2, He 7.5:
B^2, OH, *T*30, H_3^1 2.2, He 7.5:
B3, OH, *T*3, H_3^1 2.2, He 7.5:
B4, BH, *T*15, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6 vw:
B5, BH, *T*30, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6 w:
B6, UH, *T*30, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B7, UH, *T*15, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B8, UH, *T*4, H_3^1 2.2, He 7.5, $H_2^1H^2$ 7.6:
B9, UH, *T*15, H_3^1 2.7, He 8.15, $H_2^1H^2$ 8.3:

C1, UH, *T*5, H_2^1 .9, H_3^1 9 w, Hg present:
C2, UH, *T*30, H_2^1 .8, H_3^1 8.9:
C3, UH, *T*1, H_2^1 .8, H_3^1 8.9:
Pressure in discharge changed.
C4, UH, *T*1, H_3^1 1.4, He 6.8 w:
C5, UH, *T*15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 6.9 vw:
C6, UH, *T*30, H_3^1 1.4, He 6.8, $H_2^1H^2$ vvw:
Discharge voltage too low.
C7, UH, *T*15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7:
H^2 content increased by separation by diffusions.
C8, OH, *T*15, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7 vw:
C9, OH, *T*33, H_3^1 1.4, He 6.8, $H_2^1H^2$ 7 vw.

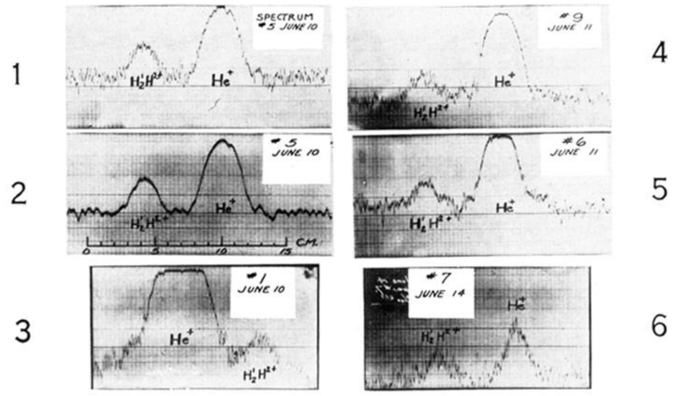

Fig. 2. Densitometer records of several $He^+ - (H_2{}^1H^2)^+$ doublets. Scale under record No. 2. Ratio of densitometer record distance to spectrum plate distance approximately 40 to 1. Micrometer slit 0.002 cm wide.