Comparison of the Masses of He and H^1 on a Mass-Spectrograph[1]

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The ratio of the masses of He and H^1 was measured by comparison of He^{++} with H_2^{1+} on fourteen spectra, and the measurements give He : $H^1 = 3.971283 \pm 0.000042$. If He = 4.00216 ± 0.00013 on the O^{16} scale as given by Aston, then $H^1 = 1.007775 \pm 0.000035$ in excellent agreement with the value 1.00778 reported by Aston. A method is suggested for the determination of the mass of H^2 in terms of He and C.

ASTON[2] has pointed out the difficulties and advantages encountered in comparing the mass of helium with that of the light hydrogen isotope by measurement of the separation of the components of the $He^{++} - H_2^{1+}$ doublet, and has recommended this method as the most direct and trustworthy for the determination of the He : H^1 ratio, so important in nuclear physics.

Experimental Procedure

Fortunately with the present mass-spectrograph[3, 4] it is not essential to obtain traces of identical density. Because of the difficulty in securing He^{++} on the first trial spectra photographed it was found necessary, however, to decrease the amount of hydrogen present in the discharge. "Pure" helium, which evidently contained some hydrogen, was mixed with oxygen, and before admission to the discharge tube, the mixture was passed over hot tantalum filaments and then over spongy palladium at the temperature of liquid air. The tantalum was used to absorb any hydrogen present which did not combine with the oxygen in the presence of the hot filaments. It was hoped that the greater part of any remaining hydrogen would be adsorbed by the palladium.

Fig. 1, spectra *A* and *B*, is a contact print of sixteen spectra of $He^{++} - H_2^{1+}$. The spectra were taken with one minute exposures. As may be noted H_2^{1+} is still present in abundance compared with the less easily obtainable He^{++}. The H_2^1 had its source either in a minute amount of water released from the walls and glass of the discharge tube even after the most careful baking and washing out, or in the failure of the tantalum and palladium to clean up the hydrogen present initially in the helium.

The spectra were measured directly on a Gaertner comparator. The separation of $He^{++} - H_2^{1+}$ was also measured for all the spectra on a Koch-Goos recording microphotometer at a ratio of record distance to plate distance of approximately 40 to 1. The densitometer records also serve to detect any possible distortion of the traces which might result from overlapping or might be produced by the Eberhard and Kostinsky effects.[5] As the traces were well separated no distortion was present. The measurements by both methods were in excellent agreement with a difference in the averages in measuring the separation of the traces of one part in 2000, equivalent to 0.000007 mass units.[6]

The separation of the $He^{++} - H_2^{1+}$ doublets for

[1] This paper was presented before the American Physical Society at the Atlantic City meeting, December 28, 1932.

[2] F. W. Aston, Nature **130**, 21 (1932), *Isotopes*, p. 70, second edition.

[3] K. T. Bainbridge, Phys. Rev. **42**, 7 (1932).

[4] K. T. Bainbridge, Phys. Rev. **40**, 130 (1932), and a paper shortly to appear in the Journal of the Franklin Institute.

[5] F. E. Ross, Astrophys. J. **53**, 349 (1921). *Photography as a Scientific Implement*, pp. 200, 201.

[6] The densitometer measurements were taken as the most reliable because, although the comparator measurements were more consistent internally, there is a possibility of systematic subjective influences in the comparator measurements. With a comparator, the cross hair is moved to what is estimated as the center of a line, an operation which may be performed with a high degree of accuracy on single lines. If one other line is viewed in the microscope at the same time, as in the case of measuring doublets, it is not known whether or not the influence of that adjacent line interferes with the bisection of the line being measured. If an effect exists it is believed that it would tend to make the measured separation less than the actual separation by a small amount.

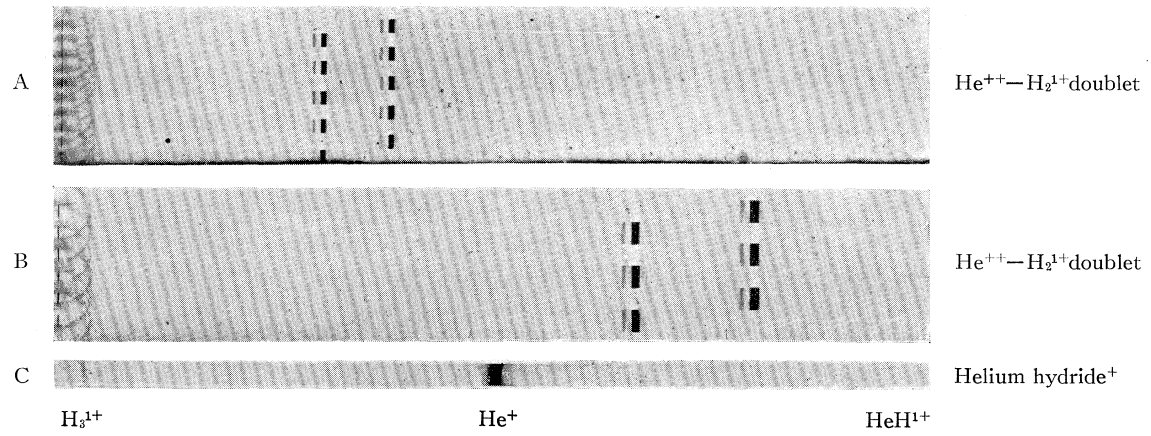

FIG. 1. Contact print of sixteen spectra of He^{++} and H_2^{1+}.

fourteen spectra is given in Table I in mass units referred for convenience to $H^1=1.007780$.

The average mass separation $H_2^{1+}-He^{++}$ is 0.014470 ± 0.000020. The dispersion of the plate in the region of the doublets was determined from spectra of carbon and its hydrides. The dispersion was determined to better than one part in 2000 so

TABLE I. *Mass separation of $He^{++}-H_2^{1+}$ doublets on $H^1=1.007780$ scale.*

Spectra[7]		Spectra	
A3	0.014408	A10	0.014372
4	464	B1	500
5	435	2	660
6	544	3	566
7	546	4	363
8	530	5	566
9	408	6	223

that if the measurement of the separation of the doublets could be made without error it would be possible to determine, with an accuracy of one part in 280,000 the mass of He^{++} referred to H_2^{1+}. Any error introduced by the uncertainty in the dispersion would be less than 0.000007 mass units. When the uncertainty in the dispersion is included the probable error becomes ±0.000021 mass units.

RESULTS

The ratio of the mass of He to the mass of $H^1=3.971283\pm0.000042$. If $He=4.00216\pm0.00013$ on the O^{16} scale, as given by Aston[8,9] then by these measurements $H^1=1.007775\pm0.000035$, a value in excellent agreement with Aston's which had been obtained on a different mass-spectrograph by a different method. Finally for convenience in comparison with figures already familiar, if H^1 is taken as 1.007780, $He=4.002180\pm0.000042$ referred to H^1 alone.

The present measurement of the He : H ratio makes it improbable[10] that Aston's He : H ratio might be in error by 0.9×10^{-4} and indirectly that Aston's determination of the mass of He by means of the ratios $He^+ : O^{++} :: C^{++} : C^+$ could be in error by 1.8×10^{-4}.

H^1 may conveniently be used as a common reference mass for the comparison of values of the mass of H^2 derived from different experiments. The mass-spectrograph value[3] of the mass of H^2 is raised and the band spectrum value[11] decreased by one part in 2×10^5 when referred to the present value of H^1.

[7] The top spectrum of *A* is number 10. Nos. 1 and 2 were not measured. The top spectrum of *B* is No. 6. The reproduction is natural size. The sharp lines on the left are used to mark the position of the plate.

[8] F. W. Aston, Proc. Roy. Soc. **A115**, 487 (1927).

[9] The probable errors of Aston's mass determinations are taken as one-third of the published limits of error unless otherwise noted. This convention has been used before for the purposes of calculation by J. Chadwick, J. E. R. Constable and E. C. Pollard, Proc. Roy. Soc. **A130**, 480 (1931). K. Bainbridge, reference 3, p. 5. J. Chadwick has also used the factor 1/4, Proc. Roy. Soc. **A136**, 702 (1932).

[10] Reference 3, p. 10.

[11] J. D. Hardy, E. F. Barker and D. M. Dennison, Phys. Rev. **42**, 279 (1932).

A Suggested New Method for the Measurement of the Mass of H^2 with Respect to He and C

Spectrum[12] *C*, Fig. 1, shows the presence of He H^{1+} and suggests that when more concentrated H^2 is available the mass of H^2 may be measured by comparison of HeH^{2+} with C^{++}. The two traces would differ in mass by approximately one part in 430, a difference greater than the proportional separation of O^{16} and CH_4^1, a doublet which has been measured by Aston.[7]

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[12] Spectrum *C* provides an interesting example of the linearity of the mass-scale and an alternative method of measuring He : H. The ratio He : H may be measured from the reproduction to an accuracy of about one part in 500 if the positions of the lines H_3^{1+}, He^+ and HeH^{1+} are measured to 0.1 mm. In general the dimensions of the velox prints from which the reproductions are made are some 1 percent less in linear dimensions than the original spectrum plates. In this case the shrinkage was uniform.

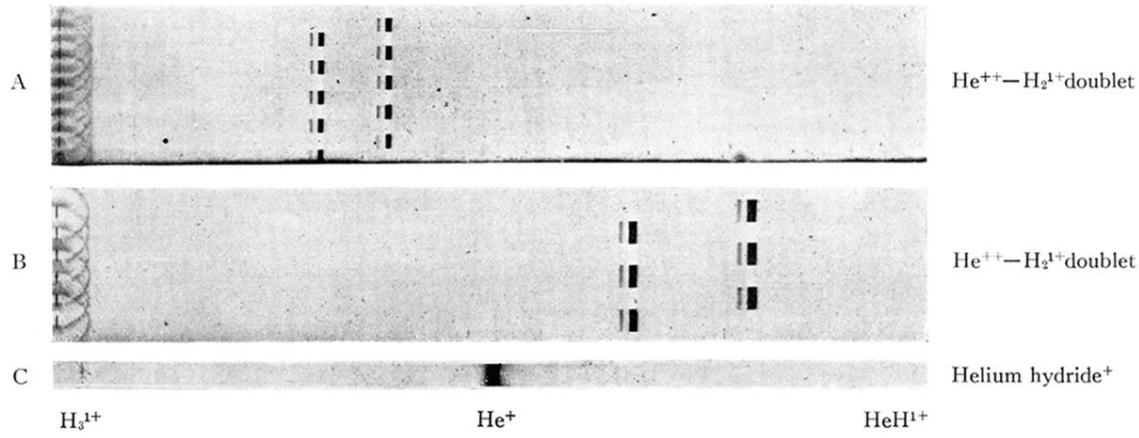

FIG. 1. Contact print of sixteen spectra of He^{++} and H_2^{1+}.