Masses of isotopes of H, He, C, N, O, and F

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The mass differences of 17 doublets involving the atoms ^{3}H, ^{3}He, ^{4}He, ^{13}C, ^{14}C, ^{14}N, ^{15}N, ^{16}O, and ^{19}F have been measured with a rf mass spectrometer. By least squares adjustment, best values are obtained for the masses of these eight atoms for which the estimated errors are materially less than for previously published values. By using Einstein's mass energy relation, very accurate values are derived for the β decay energies of ^{3}H and ^{14}C and for the neutron binding energies in ^{13}C, ^{14}C, and ^{15}N. The last ones offer a possibility to improve the calibration for multi-MeV (capture) γ rays by an order of magnitude.

[NUCLEAR STRUCTURE ^{3}H, ^{3}He, ^{13}C, ^{14}C, ^{14}N, ^{15}N, ^{16}O, ^{19}F measured atomic mass. ^{3}H, ^{14}C deduced Q^{-}. ^{2}H(n,γ), ^{3}He(n,γ), ^{12}C(n,γ), ^{13}C(n,γ), ^{14}N(n,γ) deduced Q.]

INTRODUCTION

A mass spectrometer comparing, in essence, high harmonics of cyclotron frequencies of isobaric or nearly isobaric atomic or molecular ions in a homogeneous magnetic field has been developed by the first author.[1,2] The instrument is capable of thus measuring their mass difference with a precision of about one part in 10^{9} of the mass number of these ions, corresponding to a few eV's for light ions. The papers mentioned report measurements on atomic masses of fundamental nuclides like ^{1}H, ^{2}H, ^{14}N, and ^{16}O. The present paper gives more data on these masses, unfortunately not all in good agreement with the earlier work which now seems not to have been completely free from systematic errors. We describe several instrumental changes which resulted in a considerable improvement in this respect.

In addition, new measurements have been made for a number of nuclides selected in such a way that comparison is possible with (potentially) very accurate nuclear reaction and decay energy measurements. A preliminary report on some of these measurements has already appeared elsewhere.[3] Such a comparison allows to raise both the accuracy and the dependability of measurements in the fields of nuclear mass and reaction energy measurements to higher standards.

INSTRUMENTAL

The following modifications have been made:

(1) Insulators supporting the jaws of the phase defining slit have been thoroughly screened from the ion beam by double cylindrical shields which, like all other parts near the beam, are gold plated. These have reduced but not eliminated the slow drop-off to an asymptotic value of the radially outward field at the phase defining slit (PD slit) which is required to be applied in order to match peaks of a wide calibration doublet for known values of the two applied frequencies. This drop-off, of magnitude proportional to the current striking the PD slit jaws, still requires that measurements be made only after the beam has been present for about 30 min and that approximately the same current be used for a close doublet as for a wide calibration doublet. Again, the effect is less for larger masses (and magnetic fields). It is believed that, for the more recent measurements, because of more frequent and careful calibration runs, errors due to electric field effects are no greater than the setting errors.

(2) Other insulators of leads to deflecting plates at the edge of the magnet gap have also been more carefully screened from the beam by gold-plated shields.

(3) It has been found that, after a peak has been swept, the electrometer amplifier does not return immediately exactly to zero so that, for a sweep repetition rate of 30 sweeps per sec, a very small tailing of the previous peak underlies the peak being swept. This problem is not serious if the two peaks have roughly the same intensity, but if the intensities are widely different, so that a large setting of the differential gain control is required, a small error can result, the measured spacing being too small or too large depending on whether the larger mass peak is much more or much less

intense.

This effect could explain a discrepancy between some present results and corresponding ones reported earlier. This effect is enhanced by the sharp peak of ions to the detector on each fly-back of the sweep. To eliminate this fly-back peak, a gate pulse which lasts from the end of one sweep until the start of the next (at least 5 msec) is applied to one of the two parallel plates that cause axial (vertical) bending of the beam just before it enters the upper slit of the modulator. Thus, the beam during this time is deflected vertically sufficiently so that no ions can get through the 1.2 mm horizontal slot in front of the lower modulator slit. Hence, none can reach the detector during the gate period. In all work reported here, the intensities of the two peaks being matched were set about equal.

(4) A small but observable amount of signal from the rf power amplifier that was turned off was found to be present at the modulator, along with that from the one that was turned on. This caused a weak side band to accompany one or both frequencies which could cause errors. The unwanted signal was reduced from about −60 db relative to the wanted one to a value well below −100 db and made undetectable by arranging to have all three stages of each power amplifier turned off on alternate sweeps rather than only the last two, as was previously done. Some increase in the desired suppression was also achieved by arranging to have the cathode biases of the turned-off stages switched to more favorable values.

(5) A number of other changes in the electronics have resulted in elimination of some instabilities and greater ease, if not precision, of measurement. Thus a solid state circuit has been added for locking the independent positive and negative supplies feeding the curved electrostatic and other deflector plates together so that their positive and negative outputs remain much more nearly equal. This is done in such a way that the sweep voltage may be added either to the output of the positive supply only or equally and oppositely to the outputs of both supplies. Thus the beam may be swept either essentially across the slit at the input to the magnet and simultaneously across the detector slit, or essentially across the modulator slit only. (The high voltage is locked to and swept with the negative supply.)

Such sweep displays are necessary to check the exact congruence of the two ion orbits throughout the machine. Another innovation is an automatic gain control circuit for regulating the gains of the two rf power amplifiers so that the two rf voltages of the modulator remain much more nearly equal and free of small modulations during the sweeps than previously. An annoying source of instability of relative peak heights thereby has been eliminated. Other improvements include much better filtering in the two phase lock circuits to eliminate unwanted spurious signals (e.g. rf signals returning to the phase detector output via the lead that conducts this output to the voltage variable capacitance diodes). The power supplies of the two rf oscillators have been rebuilt to provide much better regulation of the anode supply voltages and lower hum levels. Also numerous small changes of the solid state switching circuitry have been incorporated to reduce potential interactions thereof.

Measurements of masses 3 and 4

In Table I are given experimental measurements of the doublet $^1H^2H$-^3He at mass 3 and of the three spacings between the three ions of the triplet $^1H^3H^+$, $^2H_2^+$, $^4He^+$ at mass 4. Also given for the latter triplet are values (underlined) obtained by a least squares adjustment. All values include corrections for differences of kinetic energy, chemical binding energy, and ionization potential as were given for results in Ref. 2.

Table II shows values of the mass excesses of ^3He, ^3H, and ^4He derived from the values of Table I and those of ^1H-1, ^2H-2, and $^1H_2$-^2H of Ref. 2.

Measurements at mass 28 and the mass of ^{13}C

Table I shows experimental values of the three spacings of the triplet $^{13}C_2{}^1H_2^+$, $C_2{}^2H_2^+$, and $C_2{}^1H_4^+$ at mass 28, as well as adjusted values (underlined). All three doublets have been matched about 25 times; the averaged results are given in Table I.

It is somewhat discouraging[4] to note that the three values (the last ones, but for the ^{15}N doublets mentioned below, that Smith measured before his untimely death) do not agree very well: the least squares adjustment on these three doublets yields a consistency factor as high as $R_e/R_i = 3.15$. Yet, even accepting the external errors (as done here), they determine the mass of ^{13}C with higher accuracy than was obtained in any earlier mass determination except Smith's own earlier ^1H and ^2H measurements. The (unadjusted) values for the $^1H_2$-^2H doublet as well as another one, measured again about 25 times at mass number 17 (see Table I) are somewhat higher than Smith's earlier value[2]; the adjusted value, though, agrees quite well with it. The resulting mass of ^{13}C is given in Table II.

GENERAL ERROR DISCUSSION

As before,[2] several error estimates are given in Table I. The empirical setting errors σ_m are

TABLE I. Measured and adjusted (underlined) values in nu of doublets measured in the present work.

Mass No.	Doublet	Adjusted and measured values (nu)	Error estimates (nu) σ_m	σ_{sm}	σ_e	σ_r
3	$^1H^2H$-^3He	5 897 512± 5	3.96	1.68	3.29	5.14
4	$^2H_2$-^4He	<u>25 600 328</u>				<u>7.84</u>
		25 600 315± 14	2.30	1.68	14.26	14.44
4	$^1H^3H$-^4He	<u>21 271 070</u>				<u>7.76</u>
		21 271 075± 12	2.17	1.82	11.85	12.05
4	$^2H_2$-$^1H^3H$	<u>4 329 257</u>				<u>2.73</u>
		4 329 257± 3	2.32	1.68	2.41	3.35
(2)	$^1H_2$-^2H	<u>1 548 286</u>				<u>8.49</u>
	a	(1 548 287± 4)				
28	$\frac{1}{2}(C_2{}^1H_4$-$C_2{}^2H_2)$	1 548 298± 8	3.16	5.31	0.86	3.27
17	N^1H_3-N^1H^2H	1 548 301± 5[b]	5.12	6.38	0.86	5.19
(14)	C^2H-$^{13}C^1H$	<u>2 921 911</u>				<u>8.49</u>
28	$\frac{1}{2}(C_2{}^2H_2$-$^{13}C_2{}^1H_2)$	2 921 923± 8	2.77	5.08	1.62	3.20
(13)	C^1H-^{13}C	<u>4 470 197</u>				<u>8.49</u>
28	$\frac{1}{2}(C_2{}^1H_4$-$^{13}C_2{}^1H_2)$	4 470 185± 8	2.53	5.59	2.49	3.55
(16)	N^2H-O	<u>22 261 156</u>				<u>8.62</u>
18	$N^2H^1H_2$-O^1H_2	22 261 160± 13	3.38	7.00	12.40	12.85
(16)	$^{14}C^1H_2$-N^2H	<u>1 716 269</u>				<u>3.04</u>
18	$^{14}C^1H_4$-$N^2H^1H_2$	1 716 269± 3	3.16	9.90	0.96	3.30
16	C^2H_2-$^{14}C^1H_2$	<u>9 311 501</u>				<u>4.40</u>
18	$C^2H_2{}^1H_2$-$^{14}C^1H_4$	9 311 498± 6	2.19	7.18	5.19	5.63
(16)	$^{14}C^1H_2$-O	<u>23 977 425</u>				<u>8.63</u>
18	$^{14}C^1H_4$-O^1H_2	23 977 413± 14	4.04	6.83	13.35	13.95
(14)	C^2H-N	<u>11 027 770</u>				<u>4.39</u>
	a	11 027 799± 9				
18	$C^2H_2{}^1H_2$-$N^2H^1H_2$	11 027 773± 7	2.43	7.18	6.14	6.60
(16)	C^2H_2-O	<u>33 288 926</u>				<u>9.51</u>
	a	33 289 109± 16				
18	$C^2H_2{}^1H_2$-O^1H_2	33 288 940± 19	4.71	6.68	18.54	19.13
16	$C^1H_2{}^2H$-O	<u>34 837 212</u>				<u>12.75</u>
32	$\frac{1}{2}(C_2{}^1H_4{}^2H_2$-$O_2)$	34 837 202± 20[b]	3.17	6.46	19.40	19.66
(16)	$^{15}N^1H$-N^2H					
18	$^{15}N^1H_3$-$N^1H_2{}^2H$	9 241 780± 8	6.61	12.9	5.14	8.38
(20)	C^2H_4-^1HF					
34	$C_2{}^1H_2{}^2H_4$-C^1H_3F	50 178 885± 43	32.2	18.9	27.9	42.6

[a] Previous rf spectrometer value, see Ref. 2.
[b] Not used in adjustment.

defined as $[\sum(Q_i - \bar{Q})^2/(N-1)]$, Q_i being the values obtained in N separate matchings. Estimates σ_{sm} for the same quantity have been derived from the earlier result[2] that the average error in a matching is 1/2500 of the peak width. Excluding the older of these measurements (mass numbers 3, 4, 17, and the fluorine ones), σ_m is a factor between 2 and 3 smaller than σ_{sm}. This can be considered as proving the success of the changes, described above, made for improving the setting accuracy. The final error σ_r is the square root of the sums of the squares of σ_m and of the error estimate σ_e representing the uncertainty in the PD setting. The last quantity has been assumed to be proportional to the doublet width with the same constant factor as the one used in Ref. 3 (occasionally, Ref. 2 uses a somewhat larger constant).

Quite probably, this is unduly pessimistic. It is noted, indeed, that for the mass 28 doublets the consistency factor R_e/R_i is indeed as large as 3.15. In this case, though, the PD errors σ_e are only small compared with the setting error, except for the last of the three doublets where they are about equal. On the other hand, the consistency factor in the least squares adjustment of the mass 18 doublets is uncommonly low, $R_e/R_i = 0.40$ as found below. In this case, the estimated PD errors are dominant; the low consistency factor therefore strongly points to rather lower values for σ_e than have been used here. Again, this proves that the last changes made by Smith have resulted in a decided improvement.

Measurements at mass 18 and the masses of ^{14}C, ^{14}N, and ^{16}O

Table I shows experimental values of the six spacings of the quartet $C^1H_2^+$, $N^2H^1H_2^+$, $^{14}C^1H_4^+$, and $C^2H_2{}^1H_2^+$, as well as adjusted values (underlined). The values given are those of the last one of three series of measurements. The results in the three series agree within about 10 nu with as the only noticeable exception, the value of C^2H_2-$^{14}C^1H_2$, which is about 50 nu higher in both earlier series.

In Table I, the adjustment shows that only the latest result agrees well with the other data. The least squares adjustment of these six doublets yields a consistency factor 0.40, as already discussed above.

A comparison with earlier reported results obtained with the same rf mass spectrometer (see Table I) shows a difference with the earlier C^2H-N doublet which is disappointing but not upsetting. The present oxygen results, though, are decidedly lower than the earlier ones. The occurrence of lower values for the O doublets did not arise gradually. All values obtained before making the changes discussed in the first part of this paper were (rather) consistent. Already the first measurement made thereafter showed the lower value. Since then, three complete sets of measurements have been made at mass 18, and another one at mass 32 (see Table I; this result is again the average of about two dozen matchings), which all agreed with the new value, with only small variations. Since several substantial changes in the apparatus were made between these series of measurements, this agreement may be taken as an indication that these new values should definitely be preferred over the older ones. Other reasons for this belief are given in the general error discussion above. The resulting masses of ^{14}C, ^{14}N, and ^{16}O are given in Table II.

TABLE II. Masses derived from the present measurements (in nu).

^{1}H-1	7 825 029± 5 [a]
^{2}H-2	14 101 771± 10 [a]
^{3}H-3	16 049 256± 12
^{3}He-3	16 029 288± 12
^{4}He-4	2 603 214± 15
^{13}C-13	3 354 831± 10
^{14}C-14	3 241 983± 12
^{14}N-14	3 074 001± 11
	(3 073 973± 14) [a]
^{15}N-15	108 963± 14
^{16}O-16	−5 085 384± 22
	(−5 085 567± 26) [a]
^{19}F-19	−1 596 830± 58

[a] Previous rf spectrometer value, see Ref. 2. The values in parentheses are considered obsolete.

The mass of ^{15}N

Table I shows the result of a measurement on the doublet $^{15}N^1H_3$-$^{14}N^2H^1H_2$. This is the average of only seven matchings made in Smith's last few active days, and not worked out by him. The result has been corrected in the usual way for relativistic kinematic effects. In this special case, evidently, no correction is necessary for atomic binding energy and ionization energy differences. The error assigned in Table I is not especially low. The limited number of measurements may, though, be considered a reason to use this error with some caution. Even if the error would be multiplied by, say, a factor 3, the resulting mass of ^{15}N given in Table II is an order of magnitude more precise than that given in earlier work.

The mass of ^{19}F

Table I gives a value for the doublet C^2H_4-^1HF which is the average of 11 carefully selected matchings. About two dozen more matchings resulted in an average value almost exactly 100 nu higher. They have been disregarded since the two peaks were of slightly different shape. It should be mentioned that Smith may have had some reservations about the result adopted here: not only did he not mention it at the Teddington conference where he presented the mass 3 and 4 results measured even slightly later, but deviating from his normal habit he did not (himself) correct the given average for relativistic kinematics, atoming binding energies, and ionization energies. Thus, it is not excluded that the adopted error is somewhat optimistic. Yet, without much doubt the mass of ^{19}F derived from this doublet and given in Table II is considerably more precise than earlier values.

Comparison with earlier values

Table II gives mass values for the nuclides measured in this work, obtained from the masses of ^1H and ^2H as measured earlier with the same instrument,[2] and from the adjusted values given in Table I. The earlier ^1H and ^2H values have not been changed to take account of the new $^1H_2$-^2H results, since the new average value agrees almost numerically with the old one. For convenience, the mass values of ^1H and ^2H referred to have been added to the table, and for comparison, the values for N and O obtained in the same earlier rf mass spectrometer work have been added also.

Figures 1 and 2 show a comparison with earlier results. We note poor agreement with the Brookhaven mass synchrometer values (S 58, FS 58) of the two wide doublets $^2H_2$-^4He and $^1H^3H$-^4He. This indicates the presence of electric field effects in the older results obtained at much lower ion ener-

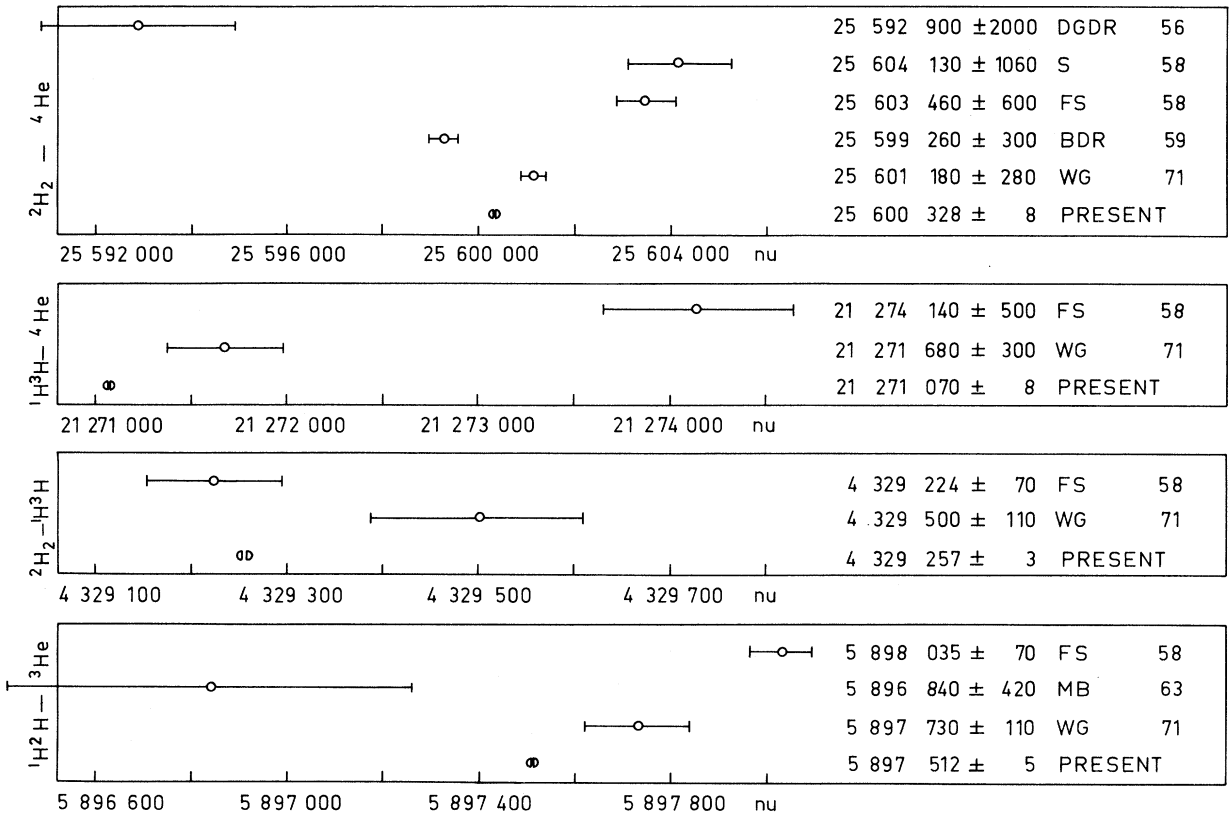

FIG. 1. Present adjusted and previously measured values of four doublets in nu. DGDR 56 R. A. Demirkhanov *et al.*, At. Energ. 2, 21 (1956); S 58 L. G. Smith, Phys. Rev. 111, 1606 (1958); FS 58 L. Friedman and L. G. Smith, Phys. Rev. 109, 2214 (1958); BDR 59 J. L. Benson, R. A. Damerov, and R. R. Ries, Phys. Rev. 113, 1105 (1959); WG 71 see Ref. 6; MB 63 P. E. Moreland and K. T. Bainbridge, in *Nuclide Masses*, edited by W. H. Johnson, Jr. (Springer Verlag, Vienna, 1964), p. 425.

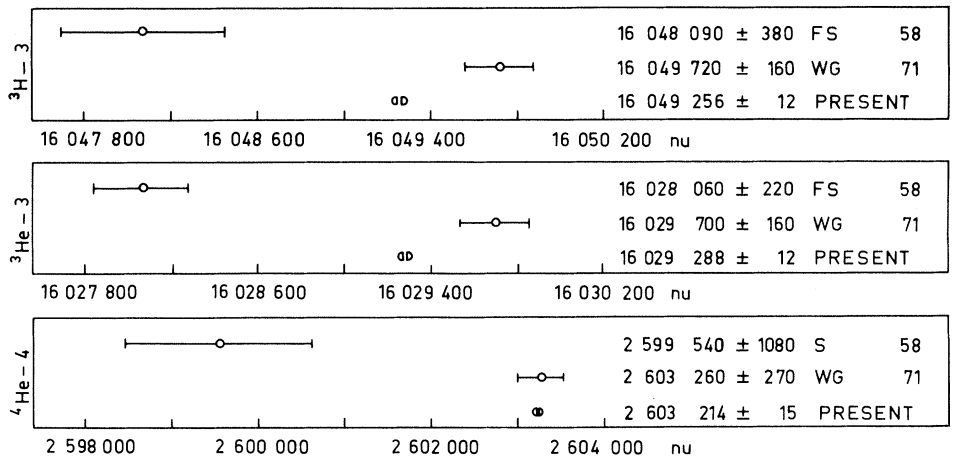

FIG. 2. Mass excesses of ^{3}H, ^{3}He, and ^{4}He compared with earlier values, in nu. FS 58 L. Friedman and L. G. Smith, Phys. Rev. 109, 2214 (1958); WG 71 see Ref. 6; S 58 L. G. Smith, Phys. Rev. 111, 1606 (1958).

gies. For the small difference ^{3}H-^{3}He (Fig. 4), the Brookhaven results are in good agreement with the present one.

For comparison between the new ^{14}N and ^{16}O values and earlier ones, the preceding paper[2] should be consulted. The new mass value for ^{16}O tends to disagree somewhat more with earlier mass spectroscopic values than the first published rf mass spectrometer value. It agrees now substantially better with the value found in mass adjustments[5,6] using both nuclear reaction results and mass spectroscopic ones. No earlier mass spectrometer measurements have been made on ^{14}C; a comparison with nuclear reaction results will be discussed in a following paragraph.

For ^{13}C, ^{15}N, and ^{19}F, the new results are compared with earlier values in Fig. 3 which again demonstrates the very considerable improvement obtained by Smith. The comparison with the earlier Minnesota values SQN 56 is somewhat complicated (as Smith found already[2] in constructing Figs. 3 and 4 of the paper mentioned) due to com-

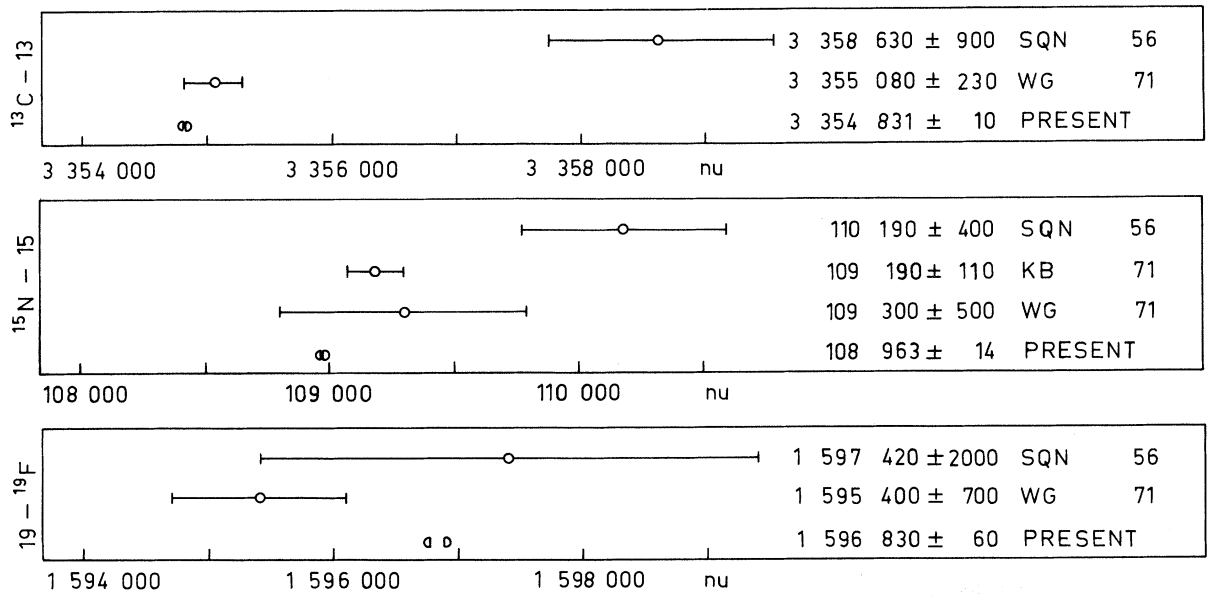

FIG. 3. Present adjusted and previously measured values in nu. All errors given are external standard errors. SQN 55 T. T. Scolman, K. S. Quisenberry, and A. O. Nier, Phys. Rev. 102, 1076 (1956); WG 71 see Ref. 6; KB 71 D. P. Kerr and K. T. Bainbridge, Can. J. Phys. 49, 756 (1971).

bination of their giving the result in the ^{16}O mass scale and somewhat deviating ^{1}H-C-N mass ratios. The masses given in Fig. 3 are obtained by multiplying those given in SQN 56 with the factor 16/15.994 914 62, which is the conversion factor between the ^{16}O and ^{12}C scales as found in the present work.

As in all previous comparisons, it should be noted that the WG 71 values are not based on mass spectrometry alone. The substantial agreement with these values therefore demonstrates a satisfactory agreement of the present result with nuclear reaction data, worked out in more detail in the next paragraphs.

Comparison with nuclear reaction and decay energies

The mass difference between two neighboring isobars equals the β decay energy of the heaviest of them, which is the end point of the β spectrum but for a small correction in atomic electron binding energies. Two such differences have been determined in the present work with very high precision. They are compared in Fig. 4 with earlier mass spectroscopic data and with nuclear decay measurements. The earlier Brookhaven result for this difference agrees reasonably well with the present one, though obtained from doublet measurements deviating much as mentioned above. The agreement with the best available measurement of the β decay end point could be better, though the absolute magnitude of the difference would formerly have been considered very small indeed. Yet, in the discussions at the Teddington conference[2] Bergquist rather emphatically denied the possibility that his value could be high by even as little as 51 eV. Instead, he proposed the possibility that a considerable fraction of the ^{3}He ions measured in the doublets discussed here could have been in the metastable 2*S* electron state instead of in the 1*S* one, as assumed in making the correction for electron binding energies. This suggestion has not been checked by Smith. It might be considered somewhat unlikely since the electron energy in the ion source is only of the order of 100 V.

TABLE III. Neutron binding energies derived from the present measurements (eV).

$^{1}H^{1}H$-^{2}H	1 422 232 ± 4	S_n (^{2}H)	2 224 662 ± 30
$^{2}H^{1}H$-^{3}H	5 474 942 ± 5	(^{3}H)	6 257 372 ± 30
C ^{1}H-^{13}C	4 163 996 ± 7	(^{13}C)	4 946 426 ± 30
^{13}C ^{1}H-^{14}C	7 394 145 ± 14	(^{14}C)	8 176 575 ± 30
^{14}N ^{1}H-^{15}N	10 050 965 ± 17	(^{15}N)	10 833 395 ± 30

In the case of ^{14}C, no really accurate determination of the β ray end point exists. The value given in the figure, an average[6] of many determinations, is somewhat lower than the present one. The agreement with the value of the mass adjustment[6] is much better.

The mass difference between two neighboring isotopes is closely connected to the energy liberated when a neutron is captured in the lightest one

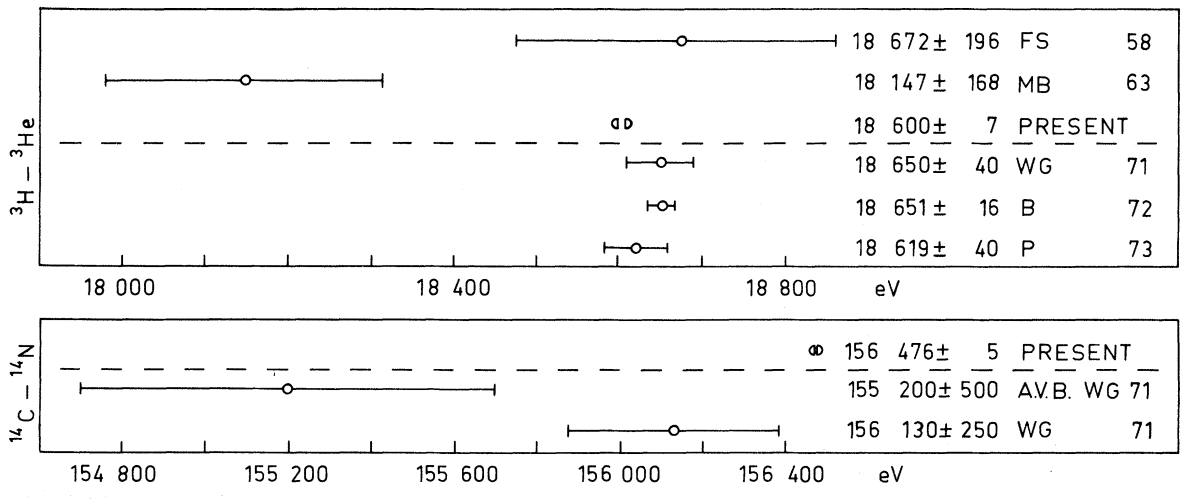

FIG. 4. Present adjusted and previously measured values of the mass differences ^{3}H-^{3}He and ^{14}C-^{14}N, i.e. the β decay energies of ^{3}H and ^{14}C plus the ionization energy of their daughters. FS 58 L. Friedman and L. G. Smith, Phys. Rev. 109, 2214 (1958); MB 63 P. E. Moreland and K. T. Bainbridge, in *Nuclide Masses*, edited by W. H. Johnson, Jr. (Springer Verlag, Vienna, 1964), p. 425; WG 71 see Ref. 6; B 72 K. E. Bergquist, Nucl. Phys. B39, 371 (1972); P 73 H. W. F. Piel, Jr., Nucl. Phys. A203, 369 (1973).

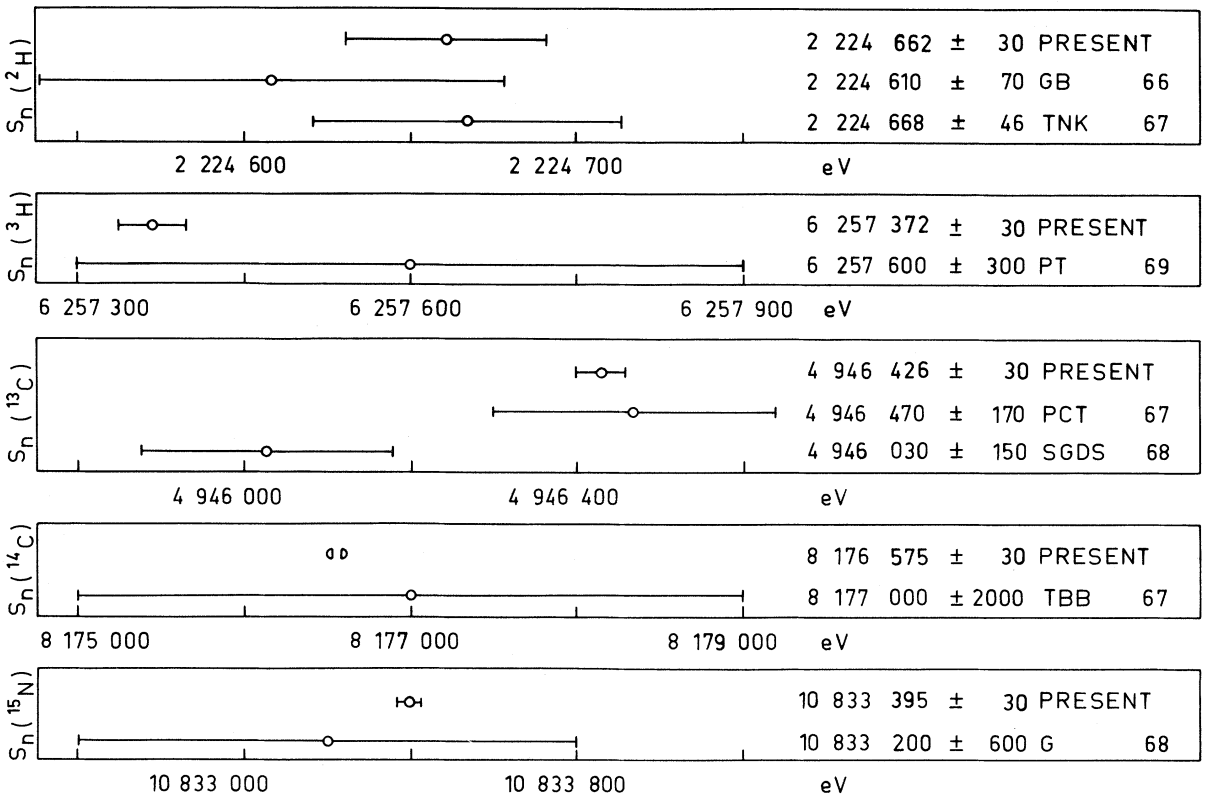

FIG. 5. Neutron separation energies in ^{2}H, ^{3}H, ^{13}C, ^{14}C, and ^{15}N derived from the present adjusted values, compared with direct measurement. The error given for the present result is mainly that in the adopted mass of the neutron, see Table III. GB 66 R. C. Greenwood and W. W. Black, Phys. Lett. 21, 702 (1966); TNK 67 H. W. Taylor, N. Neff, and J. D. King, Phys. Lett. 24B, 659 (1967); PT 69 W. V. Prestwich and G. E. Thomas, Phys. Rev. 180, 945 (1969); PCT 67 W. V. Prestwich, R. E. Cote, and G. E. Thomas, Phys. Rev. 161, 1080 (1967); SGDS 68 R. Spilling, H. Gruppelaar, H. F. de Vries, and A. M. J. Spits, Nucl. Phys. A113, 395 (1968); TBB 67 G. E. Thomas, D. Blatchley, and L. M. Bollinger, Nucl. Instrum. Methods 56, 325 (1967); G 68 R. C. Greenwood, Phys. Lett. 27B, 274 (1968).

of the two. In the relation, though, enters the mass of the neutron, or, more conveniently, the mass difference[6] between the neutron and the hydrogen atom, n-^{1}H = 782 430 ± 30 eV. The error in this quantity is considerably larger than that in the masses determined in the present work. Therefore, Table III gives both S_n and the mass differences ^AZ-^{A+1}Z, recalculated to energy units using the conversion factor 1 u = 931 501 600 ± 2600 eV[7] (the systematic error due to the uncertainty in this factor has not been taken into account).

The desired reaction energies are obtained by adding (n-^{1}H) to this quantity. The resulting values are compared to directly measured values in Fig. 5. The agreement is seen to be quite good. This is not significant for the most precise one, the ^{1}H$(n,\gamma)^2$H reaction, since this Q value had a great weight in determining[6] the mass difference value n-^{1}H mentioned above. The other cases could, in principle, be used to get corroborating information on the neutron mass. At the present state of the art, though, calibrations for γ ray energy determinations at higher energies are considerably less precise than would be useful for this purpose. In fact, the present results can be used to improve considerably the precision of γ ray energy calibrations.

ACKNOWLEDGMENTS

Dr. J. A. Hipple drew our attention to the possibility that valuable unpublished material might be available in L. G. Smith's notebooks. These notebooks were made available by Princeton University, with help of Mrs. L. G. Smith. Ir. E. Koets gave much valued help in finding the relevant material in the 6000 written notebook pages and in reading them.

APPENDIX

In view of the change in the oxygen doublets, resulting in a difference in the ^{16}O mass value of

seven times the error assigned to the earlier results[2] measured with the same instrument, the question may well be asked whether the not-remeasured doublets might show a similar shift. These doublets are the ones determining the masses of ^{1}H, ^{2}H, ^{35}Cl, and ^{37}Cl.

We have no real answer to this question. It is noted that combination of two of the earlier doublets, $C_3{}^2H_8$-$C^1H_3{}^{37}Cl$ and $C_4{}^1H_8O_2$-$C^1H_2{}^{37}Cl_2$, yields an oxygen doublet deviating by nearly the same amount from the present values, which would suggest that the error is only typical for O-containing doublets. The reported errors in these two doublets, though, are quite comparable to the shift mentioned, so that no really significant inference can be drawn.

In view of this unfortunate situation one may perhaps welcome the news that it has been decided to put the rf spectrometer to work again after moving it to the University of Technology in Delft. Certainly remeasuring the above-mentioned isotopes will be one of the first new tasks.

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†Deceased December 1972.

[1]L. G. Smith, in *Proceedings of the Third International Conference on Nuclidic Masses,* edited by R. C. Barber (Univ. of Manitoba Press, Winnipeg, Manitoba, 1967), p. 811.

[2]L. G. Smith, Phys. Rev. C 4, 22 (1971).

[3]L. G. Smith, in *Proceedings of the Fourth International Conference on Atomic Masses and Fundamental Constants,* edited by J. H. Sanders and A. H. Wapstra (Plenum, New York, 1972), p. 164.

[4]This is the point where the manuscript of Dr. Smith breaks off.

[5]J. H. E. Mattauch, W. Thiele, and A. H. Wapstra, Nucl. Phys. 67, 1 (1965).

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