Letters to the Editor

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The Atomic Masses of H^1, C^{12}, and S^{32}

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THE masses of H^1, C^{12}, and S^{32} have been determined relative to O^{16} by the doublet method with the double-focusing mass spectrometer developed in this laboratory.[1] Table I lists the doublets studied together with the number of runs on each and the results obtained. As in previous work, each run consists of ten determinations. Mass differences involving hydrocarbon ions of the form $(C^{12})_n(H^1)_m$ are corrected for the presence of unresolved $(C^{12})_{n-1}C^{13}(H^1)_{m-1}$ ions. The probable error given indicates the consistency between runs. From the data in Table I, one finds:[2]

TABLE I. Mass doublets from which masses of H^1, C^{12}, and S^{32} are calculated.

Doublet	Source of ions	No. of runs	$\Delta M \times 10^4$amu
a. $(C^{12})_4-S^{32}O^{16}$	C_4H_6 SO_2	4	331.82±0.07
b. $C^{12}(O^{16})_2-C^{12}S^{32}$	CO_2 CS_2	6	177.82±0.25
c. $(C^{12})_3(H^1)_8-C^{12}(O^{16})_2$	C_3H_8 CO_2	6	729.67±0.41
d. $(C^{12})_6(H^1)_4-C^{12}(S^{32})_2$	C_6H_6 CS_2	4	873.26±0.58

$$S^{32}=32-b=31.982218\pm25$$
$$C^{12}=12+(a-b)/4=12.003850\pm6$$
$$H^1=1+(a+7b+8c-4d)/48=1.0081685\pm90$$

or

$$H^1=1+(5c+4b-2d)/32=1.008166\pm8$$

or

$$H^1=1+(2d+3c-4a)/32=1.008151\pm6.$$

The result for S^{32} substantiates the value 31.9823±3 given by Aston[3] rather than that of Okuda and Ogata,[4] 31.98089±7. The new value is consistent with 31.98199±21 computed by Penfold[5] from disintegration and some mass spectrographic data, and the number 31.9823±10 found by Smith[6] in his new "synchrometer" mass spectrometer.

The weighted average of the three values for H^1 is 1.008159±4. An examination of the computations which lead to the three individual values shows that all three depend rather strongly upon the value of the doublet c, the first two more so than the last. If one arbitrarily weights the three in the ratio 1:1:2, respectively, in computing the average, one again obtains 1.008159. Because of the strong dependence of the three separate errors upon the error in the common doublet c it may be safer to assume 6, the lowest probable error of the three separate values, as the probable error in the final answer. This has been done in the computations which follow.

The present values for H^1 and C^{12} are in good agreement with the values 1.0081686±52 and 12.003803±13, respectively, found by Roberts while considering an entirely different cycle. His results are given separately.[7] The weighted averages of his and the present results for H^1 and C^{12} are given in Table II. Also given in Table II are masses for other isotopes based upon doublet measurements reported in the present two letters and in the paper referred to under reference 1.

TABLE II. Summary of atomic masses determined by mass spectrometry.

H^1	1.008165±4
H^2	2.014778±8[a]
He^4	4.003944±19[b]
C^{12}	12.003842±6
N^{14}	14.007564±7[c]
Ne^{20}	19.998835±43[d]
S^{32}	31.982218±25
A^{36}	35.97926 ±8[e]
A^{40}	39.97524 ±3[f]

[a] From $H_2-D=(15.519\pm0.017)\times10^{-4}$amu.
[b] From $D_2-He^4=256.12\pm0.09$.
[c] Weighted average from $C^{12}H_2-N^{14}=125.86\pm0.13$; $(N^{14})_2-C^{12}O^{16}=112.80\pm0.13$; $(C^{12})_3H_8-(N^{14})_2O^{16}=617.6\pm0.9$.
[d] From $D_2O^{16}-Ne^{20}=307.21\pm0.39$.
[e] From $H_2O^{16}-A^{36}/2=267.02\pm0.40$.
[f] Weighted average from $Ne^{20}-A^{40}/2=112.80\pm0.18$; $(C^{12})_3H^4-A^{40}=688.77\pm0.35$; $D_2O-A^{40}/2=419.67\pm0.18$.

The assistance of Walter H. Johnson and Ruth C. Boe in making the determinations is gratefully acknowledged. The construction of the apparatus used in this research was aided by grants from the Graduate School and the Minnesota Technical Research Fund subscribed to by General Mills, Inc., *Minneapolis Star* and *Tribune*, Minnesota Mining and Manufacturing Company, Northern States Power Company, and Minneapolis Honeywell Regulator Company.

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[1] Preliminary reports on the apparatus and some results already have been given: Phys. Rev. **75**, 346 (1949); **77**, 746 (1950). A more complete report on the apparatus and measurements on 13 mass doublets will be found in a paper appearing elsewhere in this issue, Phys. Rev. **81**, 507 (1951).
[2] Except in Table I, probable errors given in this letter apply to the last significant figures in the values to which the probable errors are attached.
[3] F. W. Aston, Nature **138**, 1094 (1936); Proc. Roy. Soc. (London) **A163**, 391 (1937).
[4] T. Okuda and K. Ogata, Phys. Rev. **60**, 690 (1941).
[5] A. S. Penfold, Phys. Rev. **80**, 116 (1950).
[6] L. G. Smith, Phys. Rev. **81**, 295 (1951).
[7] T. R. Roberts, Phys. Rev. **81**, 624 (1951).

The H_2-D Mass Difference and the Determination of Secondary Atomic Mass Standards*

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THE physical table of isotopic weights is determined relative to O^{16}. As summarized by Tollestrup, Fowler, and Lauritsen[1] key light elements H, C^{12}, and N^{14} have not yet been compared directly with O^{16} by nuclear reactions and are dependent only upon mass doublet measurements. The low probable errors of Mattauch's and Jordan's fundamental doublets H_2-D, $C^{12}H_4-O^{16}$, and $D_3-C^{12}/2$ have weighted their data predominantly in the mass values recommended by Bainbridge,[2] and are shown in Table I.

TABLE I. Secondary atomic mass standards.

Isotope	Bainbridge report[a]	Present results
H	1.0081283 ±0.0000026	1.0081686 ±0.0000052
D	2.0147186 ±0.0000055	2.014785 ±0.000010
C^{12}	12.003856 ±0.000019	12.003803 ±0.000013
N^{14}	14.007536 ±0.000022	14.007544 ±0.000010
n	1.0089383 ±0.0000057	1.0090087 ±0.0000056

[a] See reference 2.

The H_2-D doublet can be combined with the deuteron binding energy to give the neutron-proton mass difference. Recently Bell and Elliott[3] have reported a new and considerably different value for the deuteron binding energy. In addition the $T(p, n)$ threshold of Taschek, *et al.*[4] combined with the tritium beta-decay end point gives the $n-H$ difference directly. The nuclear data thus indicates a H_2-D difference of 15.55 ± 0.08 (expressed in units of 10^{-4} atomic mass units in this paper). This figure differs from Mattauch's mass spectrographic value[5] of 15.380 ± 0.021 by eight times the latter's probable error.

In an attempt to resolve this discrepancy and also to recheck the secondary atomic mass standards, H, D, and C^{12}, various doublets have been measured with the double-focusing spectrometer described elsewhere.[6] For H_2-D measurements, D ions were obtained from D_2O vapor admitted through an adjustable leak. A preliminary value[7] for this doublet was based on data with the D peaks about 10 percent broader than those of H_2 at the half-height. Subsequent studies have shown this shape difference to be caused by the initial lateral kinetic energy spread of the D ions. This effect has been minimized and the average of runs obtained on fourteen different days over an eight-month period is 15.519 ± 0.017.

To obtain the secondary mass standards the following doublets are used:[6]

$$a=H_2-D$$
$$b=C^{12}H_4-O^{16}=364.78\pm0.22$$
$$c=2(D_2O^{16}-A^{40}/2)-(C_3H_4-A^{40})=150.57\pm0.50.$$

Solution for the masses yields the results in Table I:

$$H=1+(4a+3b+c)/16$$
$$D=2-(4a-3b-c)/8$$
$$C=12-(4a-b+c)/4.$$

The N^{14} mass is obtained using the $N_2{}^{14}-C^{12}O$ and $C^{12}H_2-N^{14}$ doublets previously reported. The values in the table for H, D, and n differ by about ten times the probable errors assigned.

Recent mass spectrographic studies by Ewald[8] have shown that the spacing of doublets containing fragment ions such as O^+ could be changed by very slight instrument misalignments. Results of Dempster and Shaw[9] indicate that inaccuracies may arise in instruments at pressures greater than 10^{-5} mm. With the exception of doublet a, the present results are based primarily on doublets involving only molecular ions. All data are taken at pressures below 5×10^{-6} mm. Measurement of the $(C^{12})_3H_8-(C^{12})_3H_7$ mass difference indicates that systematic errors in a doublet measurement are not likely to exceed 0.1 percent.

The construction of the apparatus used in this research was aided by grants from the Graduate School and the Minnesota Technical Research Fund subscribed to by General Mills, Inc., *Minneapolis Star* and *Tribune*, Minnesota Mining and Manufacturing Company, Northern States Power Company, and Minneapolis Honeywell Regulator Company.

* Assisted by the joint program of the ONR and AEC.

[1] Tollestrup, Fowler, and Lauritsen, Phys. Rev. **78**, 372 (1950).
[2] K. T. Bainbridge, National Research Council Preliminary Report No. 1, Nuclear Science Series (1948).
[3] R. E. Bell and L. G. Elliott, Phys. Rev. **79**, 282 (1950).
[4] Taschek, Argo, Hemmendinger, and Jarvis, Phys. Rev. **76**, 325 (1949).
[5] J. Mattauch and A. Flammersfeld, (*Isotopic*) *Report—1948* (Verlag d. Zeits. f. Natur., Tubingen, Germany, 1949).
[6] A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).
[7] T. R. Roberts and A. O. Nier, Phys. Rev. **77**, 746 (1950).
[8] H. Ewald, Z. Naturforsch. **2a**, 384 (1947); **3a**, 114 (1948).
[9] A. J. Dempster and A. E. Shaw, Phys. Rev. **77**, 746 (1950).

Beta-Decay and Meson Decay

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THE question has been raised recently[1,2] of whether it is possible to re-establish Yukawa's scheme of β-decay by assuming the decay to occur through the creation of a virtual pseudoscalar π-meson, which subsequently gives rise to an electron-neutrino pair. This would be of great interest, since the experimental data on the π-meson (induced disintegration of deuterium[3] and considerations of parity and selection rules[4]) rule out a scalar and a vector π-meson. The results quoted in reference 1 tend to favor this possibility, while an earlier study by Nelson[5] rejects it, so that it has seemed to be appropriate to investigate the question further. Our calculation confirms Nelson's result completely, the conclusion being that only a virtual vector meson (τ-meson?) can fit the Yukawa scheme.

We have considered the decay of a free neutron, since uncertainties arising from our lack of knowledge of the true nuclear wave functions are thereby eliminated. Let r_μ be the ratio m_μ/m_π, M be the nucleon mass, $g_1, f_1, g_2, f_2, g_2', f_2'$ be pseudoscalar (g) and pseudovector (f) constants coupling a pseudoscalar π-meson respectively with nucleons, electron-neutrino, and μ-meson, and neutrino. We assume the neutrino mass to be zero and define

$$G_1=g_1+2Mf_1/m_\pi,\quad G_2=g_2+m_ef_2/m_\pi,\quad G_2'=g_2'+m_\mu f_2'/m_\pi.$$

Then a standard quantization procedure for the π-meson field yields the following relations among the lifetimes τ_e, τ_μ, τ_β for the processes ($\tilde{\nu}$ represents the antineutrino):

$$\begin{array}{ccc} & \pi\to e+\nu,\quad \pi\to\mu+\nu, & \\ & P+\pi^-+\tilde{\nu} & \\ N+\tilde{\nu} & & P+e, \\ & N+\pi^++e & \end{array}$$

$$1/\tau_\mu=(1-r_\mu{}^2)^2(G_2'/G_2)^2/\tau_e,$$
$$1/\tau_\beta=(13.84/\pi)(m_e/m_\pi)^5(m_e/M)^2(G_1{}^2/\hbar c)\cdot(1/\tau_e),$$

to the first significant power of m_e/M, where

$$1/\tau_e=(m_\pi c^2/2\hbar)(G_2{}^2/\hbar c).$$

Normalization of the interaction Hamiltonian as in reference 5 would double the value of $1/\tau_e$.

As pointed out by d'Espagnat, the assumptions $g_2=g_2'=0$, $f_2=f_2'$ lead to $\tau_e\gg\tau_\mu$, in agreement with experiment; but evaluation of τ_e, using the values $m_\pi=280m_e$, $\tau_\beta=$(10 to 20 min)/0.693 and $(G_1{}^2/\hbar c)\cong1$, gives $\tau_e\cong10^{-15}$ sec, a value which is completely unacceptable. This is largely due to the fact, overlooked in reference 2, that the γ_5 appearing in the pseudoscalar interaction Hamiltonian brings an additional momentum into the expression for the transition probability. A similar momentum factor appears also if one considers the β-decay of complex nuclei; this effect would itself rule out the Yukawa scheme for a pseudoscalar meson because it leads to a $W_0{}^7$ (W_0 is the maximum β-ray energy) dependence of the lifetime rather than the experimentally established $W_0{}^5$.

We may then ask whether a Yukawa scheme for β-decay is possible at all, foregoing identification of the virtual meson with the π-meson, if we require only that we should obtain a $W_0{}^5$ law, together with Gamow-Teller selection rules. It turns out, as is well known, that only a virtual vector meson can satisfy the Yukawa scheme. If we use the lifetime expression for a vector meson given by Bethe and Nordheim,[6] a lifetime of 10 minutes for the neutron decay, a meson mass $\mu=1000m_e$, and a value $F_1{}^2/\hbar c\cong1$ for the constant coupling the meson with nucleons (retaining only the part of the interaction that gives Gamow-Teller selection rules), we find $\tau_e\cong2.5\times10^{-11}$. Such a vector τ-meson may still be found and validate the Yukawa scheme.

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[1] B. d'Espagnat, Compt. rend. **228**, 744 (1949).
[2] H. Yukawa, Revs. Modern Phys. **21**, 474 (1949).
[3] Panofsky, Aamodt, Hadley, and Phillips, Phys. Rev. **80**, 94 (1950).
[4] Brueckner, Tamor, and Marshak (to be published).
[5] E. C. Nelson, Phys. Rev. **60**, 830 (1941).
[6] H. A. Bethe and L. W. Nordheim, Phys. Rev. **57**, 998 (1940).