frequencies, most likely because of a shift or distortion of the resonance. In an attempt to support this conclusion, the doublet measurements were repeated using a 3-in.-long version of the same hairpin; the result [$g_I = 2.9367(2) \times 10^{-4}$] from this shorter hairpin still gave an inconsistent least-squares fit, but was in much closer agreement with our triple-loop results.

It is difficult to understand why the result for g_I quoted in Ref. 2 differs from our results and those of Ref. 1. The data listed by Penselin *et al.* in Ref. 2 are very consistent, and a recalculation based on their data has given essentially the same result as quoted in their article. Furthermore, their results are internally self-consistent in that the mean value of their doublet frequency agrees with their zero-field measurement of the hyperfine-structure separation. An explanation of the disparity remains an open question at this time.

We express our appreciation to Professor Richard Marrus for bringing this discrepancy to our attention and for urging us to remeasure this ratio.

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Atomic Masses of Fe^{56} and Fe^{57}†

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The 16-in. double-focusing mass spectrometer has been employed to remeasure the atomic masses of Fe^{56} and Fe^{57} in order to study a disagreement between earlier mass-spectroscopic results and nuclear reaction Q values. We find that the present results agree well with the nuclear reaction Q values. A test of the Einstein mass-energy relationship was made using the measured Fe^{57}–Fe^{56} isotopic difference and the $Fe^{56}(d,p)Fe^{57}$ reaction Q value. The mass-energy relationship was substantiated to an accuracy of 0.12%.

INTRODUCTION

THE University of Minnesota's 16-in. double-focusing mass spectrometer has been employed in a wide variety of atomic-mass measurements.[1–8] Improvements made in the instrument during the time of these measurements have caused significant increases in the precision of the measurements. A reduction of systematic errors, measured by improvements in the internal consistency of the data, has also occurred.[8]

Discrepancies between doublet measurements and Q-value mass differences have occurred at a number of isolated masses. It is for this reason that we have undertaken a program of remeasurement of a number of mass doublets. This paper reports a series of measurements which resolve a discrepancy in the Fe^{57}-Fe^{56} mass difference.

MEASUREMENT

An instrument description and a discussion of the technique of measurement have been recently reported by Benson and Johnson.[8] No change in the instrument has been made for these measurements except that a higher resolution, about 170 000, was employed. The section of the mass spectrum employed for the measurements is shown in Fig. 1. Fragment ions containing iron atoms were obtained from ferrous chloride. Doublets yielding the Fe^{57}-Fe^{56} mass difference could be measured at three different positions in this spectrum. The results of these measurements are listed in Table I. In addition, the mass of Fe^{57} was measured using the C_7H_8-$Fe^{57}Cl^{35}$ doublet. This result is also listed in Table I. In Fig. 2, the consistency of the three different methods of determining the Fe^{57}-Fe^{56} mass difference is shown.

RESULTS

In order to calculate the resultant Fe^{57}-Fe^{56} mass difference, each run of the various doublets which determine this mass difference was given equal weight. This final result together with the associated error is listed in Table II. The mass of Fe^{57} was calculated from the hydrocarbon doublet result using the following two known masses:

$$C^{12} = 12.000\,000\,00 \text{ u},$$

$$H^1 = 1.007\,825\,22 \pm 3 \text{ u}.^8$$

This mass was combined with the measured Fe^{57}-Fe^{56}

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TABLE I. Doublet results.

Doublet	No. of runs	Result (u)	Fe^{57}-Fe^{56} (u)
$Fe^{57}Cl^{35}$-$Fe^{56}Cl^{35}$	5	1.000 453 2±21	1.000 453 2±21
$Fe^{56}Cl^{37}$-$Fe^{57}Cl^{35}$	1	0.996 586 3±43	1.000 461 1±43[a]
$Fe^{57}Cl^{37}$-$Fe^{56}Cl^{37}$	3	1.000 456 6±14	1.000 456 6±14
C_7H_8-$Fe^{57}Cl^{35}$	8	0.158 378 5±35	

[a] In order to calculate this mass difference, a Cl^{37}-Cl^{35} difference of 1.997 049 7±6 u (Ref. 8) was employed.

mass difference in order to calculate the mass of Fe^{56}. These results are also listed in Table II.

We have compared in Table II the present mass results with the previous Minnesota results[3] and also the results from the 1964 mass table.[9] The difference between the present results and the previous Minnesota results appears to be consistent with the findings of Konig, Mattauch, and Wapstra,[10] i.e., that the ratio of external error to internal error was 2.65 for early doublets measured on this instrument. The disagreement between the 1964 mass table and the present results may indicate the dependence of the 1964 table on the previous Minnesota measurements.

The Fe^{57}-Fe^{56} result is also compared with a similar mass difference calculated by using Q values from the (d,p) reaction measurement of Sperduto and Buechner[11] and Bjerregaard *et al.*[12] and from the (n,γ) reaction by Kinsey and Bartholomew[13] and by Adyasevich, Groshev, and Demidov.[14] Excellent agreement exists between the present result and the (d,p) reaction results. The consistently higher results for the (n,γ) reaction Q values may indicate that these do not represent ground-state transitions.

TABLE II. Mass results.

Mass	Present results u	Other results u
Fe^{56}	55.934 917 2±37	55.934 935±4[a] 55.934 936 3±43[b]
Fe^{57}	56.935 372 4±35	56.935 403±7[a] 56.935 397 8±45[b]
Fe^{57}-Fe^{56}	1.000 455 2±18	1.000 468±8[a] 1.000 461 5±62[b] 1.000 453±8[c] 1.000 458±8[d] 1.000 464±4[e] 1.000 468±11[f]

[a] Reference 3. [b] Reference 9. [c] Reference 11. [d] Reference 12. [e] Reference 13. [f] Reference 14.

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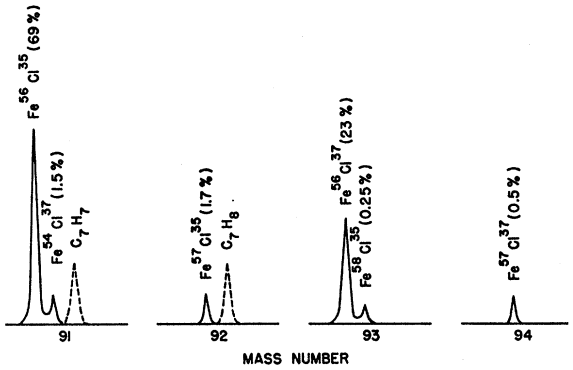

FIG. 1. The mass spectrum employed to determine the Fe^{57}-Fe^{56} isotopic mass difference.

MASS-ENERGY RELATIONSHIP

A number of tests of the Einstein mass-energy relationship have been conducted by comparing a reaction energy with a mass difference. The first test[15] and several subsequent tests[16,17] were made by Bainbridge and associates. The most accurate of these comparisons tested the relationship to an accuracy of 0.3–0.5%.

A more recent test by Wapstra[18] follows the construction of a mass table using all available reaction energies and mass doublets. By performing a least-squares fit with these data and allowing the mass-energy conversion factor to be one of the adjustable parameters, a comparison was made between the mass-energy conversion factor derived from the mass-energy relationship using fundamental constants and the conversion factor which resulted from the least-squares fit. The mass-energy relationsip was substantiated by this test to about one

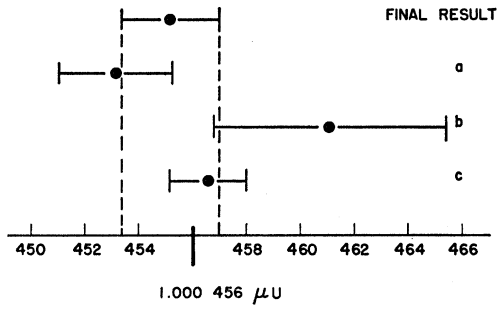

FIG. 2. The Fe^{57}-Fe^{56} mass difference as derived from the three different doublets. Results labeled a, b, and c are for the doublets $Fe^{57}Cl^{35}$-$Fe^{56}Cl^{35}$, $Fe^{56}Cl^{37}$-$Fe^{57}Cl^{35}$, and $Fe^{57}Cl^{37}$-$Fe^{56}Cl^{37}$, respectively. The final result is that listed in Table II. Errors are the standard deviation of the mean of the runs for each doublet except in the case of b, where only one run was made. In this case, the error was estimated.

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part in 5000. Wapstra,[19] however, has suggested that a more direct tests should be undertaken because of the possibility of systematic errors in a large least-squares fit.

A direct test of the mass-energy relationship may be made with the present results. In order to perform the test, one assumes that the energy-mass relationship is written as

$$\Delta E = K\Delta M c^2, \quad (1)$$

where K is proportionality constant which should be equal to unity. The left side of Eq. (1) can be estimated from the (d,p) Q-value results of Sperduto and Buechner[11] and those of Bjerregaard *et al.*[12] By combining these two results, the Q value for the $Fe^{56}(d,p)Fe^{57}$ reaction is found to be 5.422 ± 0.006 MeV. This result can be converted to joules using fundamental constants given by Cohen and DuMond.[20] The result is $\Delta E = 8.686 \pm 0.010\times10^{-13}$ J.

The available mass which is converted to energy in this relation is $\Delta M = M(d) - M(p) - M(Fe^{57}) + M(Fe^{56})$. Using the deuteron-proton mass difference in the 1964 mass table[9] and the measured Fe^{57}-Fe^{56} mass difference, ΔM is equal to 5812.8 ± 1.8 μu. Again using values of fundamental constants from Cohen and DuMond,[20] $\Delta M c^2 = 8.6880\pm0.0027\times10^{-13}$ J.

By comparing the two results, one finds that $K = \Delta E/\Delta M c^2 = 0.9998\pm0.0012$. Thus, the value of K differs from unity by two parts in 10 000, with an experimental accuracy of 12 parts in 10 000.

It is clear from a consideration of the experimental uncertainties for ΔE and $\Delta M c^2$ that the larger contributor to the final uncertainty is the reaction Q value. An improvement in this measurement would result in some improvement in this test.

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1.528- and 0.891-MeV States of Na^{22}

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The 1.528- and 0.891-MeV states of Na^{22} were studied using the $F^{19}(p,n\gamma)Na^{22}$ reaction at a beam energy of $E_\alpha = 5.1$ MeV. γ-ray angular correlations with the neutrons detected at 0° yielded spin assignments of $J=5$ (or 3) and $J=4$, respectively. Through the use of Doppler-shift attenuation measurements, the lifetimes of these states were found to be $\tau_{1.528} = 3.9_{-1.0}^{+2.2}$ psec and $\tau_{0.891} = 11.1_{-3.7}^{+11.2}$ psec.

I. INTRODUCTION

SOME recent studies[1,2] have made available new information concerning spins of a number of states in Na^{22}. From these studies the spins of the 1.528- and 0.891-MeV states were found to be $J=5$ or 3 and $J=4$, respectively. Another study[3] using $Ne^{20}(\alpha,d)Na^{22}$ reaction favored a spin of $J=5$ for the former state. This spin sequence of $J=5$, 4, 3 for the 1.528-, 0.891-MeV, and ground states provided the possibility of a rotational-band interpretation.[4,5] At the time the following experiment was contemplated, the 1.528-MeV state had not been studied using the $F^{19}(\alpha,n\gamma)Na^{22}$ reaction and there existed no lifetime information for these two states; thus n-γ angular correlations and Doppler-shift attenuation measurements were attempted in order to provide more information for testing the rotational-band interpretation. Since this time, however, new information[6–8] concerning these states has been published.

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