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The Mass of ^{25}Si and the Isobaric Multiplet Mass Equation[*]

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ABSTRACT

The mass excess of ^{25}Si has been measured via determination of the Q-value for the $^{28}Si(^3He,^6He)^{25}Si$ reaction. The results are used to test the isobaric multiplet mass equation for A=25.

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Precise measurements of the masses of neutron deficient $T_z=-3/2$ nuclei are essential to test the isobaric multiplet mass equation,[1] since these nuclei have generally been the least accurately measured members of $T=3/2$ isobaric quartets. The isobaric multiplet mass equation (IMME),

$$M=a+bT_z+cT_z^2,$$

(where $T_z=\frac{N-Z}{2}$) relates the masses of isobars under the assumptions that the specifically nuclear properties of all multiplet members are identical, and that all charge dependent forces are two-body in character.

Recent measurements of the ^{9}C mass,[2] and the ^{13}O and ^{21}Mg masses[3,4] have allowed the IMME to be tested for the A=9, 13, and 21 isobaric quartets. These measurements indicate that an additional term dT_z^3 ($d=8.0\pm3.7$ keV)[2] is required for the IMME for A=9, while for A=13, and 21 the value of such a term is consistent with zero. This letter presents a new measurement of the mass of ^{25}Si and subsequent application of the IMME to the A=25 isobars.

The value of the mass of ^{25}Si presented here was determined from the average of five individual measurements of the Q-value of the $^{28}Si(^{3}He,^{6}He)^{25}Si$ reaction. This reaction was induced by 70 MeV ^{3}He ions from the Michigan State University sector-focused Cyclotron, and the ^{6}He particles were momentum analyzed in a split-pole magnetic spectrograph.

Determination of the Q-value required measurement of the ^{6}He energies, the ^{3}He beam energies, and the laboratory scattering angle. The ^{6}He energies from ^{28}Si(^{3}He,^{6}He)^{25}Si were measured by comparing their magnetic rigidity to that of ^{6}He particles from the ^{12}C(^{3}He,^{6}He)^{9}C (g.s.) reaction. The Q-value for the latter reaction is now well established[2]. A comparison was established by measuring the spectrograph magnetic fields necessary to position the ^{6}He particles from each reaction at the same position on the focal plane. The spectrograph magnetic field was monitored by a nuclear magnetic resonance probe located between the large pole tips. The actual spectrograph field behavior relative to the flat field value given by the NMR has been carefully calibrated for previous (^{3}He,^{6}He) work[5] using a momentum matching technique[6].

The scattering angle for each run was determined by measuring the magnetic rigidity of ^{3}He from ^{1}H(^{3}He,^{3}He)^{1}H scattering from a very thin formvar target. Since the laboratory energy of the scattered ^{3}He is extremely sensitive to the scattering angle, the angle could be measured to $\pm 0.03°$ at $\theta_L \approx 10°$. The sensitivity of the measured Q-value to scattering angle was $dQ/d\theta_L \approx 100$ keV/deg at $\theta_L \approx 10°$, and is due to the difference in kinematic recoil energies of ^{9}C and ^{25}Si.

Preliminary values of the ^{3}He beam energies were determined to accuracies of ± 70 keV using the beam transport-analysis system. The final precise measurements of beam energy were then made by comparing the magnetic rigidities of ^{6}He from the $^{12}C(^{3}He,^{6}He)^{9}C$ (g.s.) reaction to that of elastic scattering of ^{3}He from ^{12}C. Since the charge to mass ratio of these particles is different, the ratio of their magnetic rigidities is sensitive to changes in beam energy. The $^{28}Si(^{3}He,^{6}He)^{25}Si$ Q-value is comparatively insensitive to uncertainty in beam energy (dQ/dE_{Beam}=9 keV/100 keV at $\theta_L \approx 10°$) due to the relative nature of the measurement.

Particle detection and identification at the spectrograph focal plane were accomplished using a 300 micron silicon surface barrier position-sensitive detector operating in the dE/dx mode for all particles of interest[7]. Serious background problems due to particle induced reactions in the position-sensitive detector were nearly eliminated by mounting an ordinary silicon surface barrier detector behind the position detector and operating these two detectors in coincidence. Figures 1a and 1b show ^{6}He spectra from $^{28}Si(^{3}He,^{6}He)^{25}Si$ with and without this coincidence requirement. Typical ^{6}He resolution was target-thickness limited at ∿70 keV FWHM.

Table 1 lists the individual measurements of the $^{28}Si(^{3}He,^{6}He)^{25}Si$ Q-value, the resulting mass excesses for ^{25}Si, and the various uncertainties. The dominant uncertainty in the Q-value determination was due to uncertainty in target thickness, and since one target was used for all measurements but one, this uncertainty is applied to the average Q-value. The correction to the Q-value due to target energy loss was 102±10 keV. Similarly, the ±4 keV and ±3 keV uncertainties associated with the ^{6}He mass[8] and ^{9}C mass,[2] respectively, were applied to the average of the ^{25}Si mass-excess values. The fluctuations of the values of the individual measurements are believed to be caused by slight changes in beam energy between runs on carbon and on silicon, and by small changes in scattering angle caused by instabilities in the various transport bending magnets. These uncertainties and uncertainties in the centroid positions are added in quadrature and given with the associated Q-value. Further details of the experimental procedure, spectrograph calibration, and target thickness measurements may be found in reference 5.

Table 2 lists the values for the IMME coefficients a, b, and c from at least squares fit of the form $M=a+bT_z+cT_z^2$ to the lowest lying ($j^{\pi}=5/2^{+}$) T=3/2 levels of the mass 25 isobars. (We assume that the (^{3}He,^{6}He) reaction populates the lowest $5/2^{+}$ level of ^{25}Si predominately.) The d term is from a determination of the coefficients of $M=a+bT_z+cT_z^2+dT_z^3$ using the same data. The mass excess of ^{25}Na ground state and of the $5/2^{+}$, T=3/2 state in ^{25}Al are taken from reference 1. Several recent investigations of the T=3/2 levels of ^{25}Mg have given different excitation energies for the $5/2^{+}$ level[1,9,10]. A weighted average of these values is used.

Since the lowest lying T=3/2 states in ^{25}Na, ^{25}Al, and ^{25}Mg are $5/2^+$, $3/2^+$ doublets,[10] the quadratic form of the IMME was applied to the $3/2^+$, T=3/2 levels of these nuclei to predict the excitation energy of the first excited state of ^{25}Si. Using excitation energies of .090 MeV, 7.863 MeV, and 7.987 MeV for ^{25}Na, ^{25}Mg, and ^{25}Al yields a predicted excitation energy E_x≈50 keV for a $3/2^+$ state in ^{25}Si. No evidence of this state was observed in the longest run (70 keV resolution) shown in figure 1b. The differential cross-section for the observed ^{6}He peak from ^{25}Si at $\Theta_L=10°$ was measured as $d\sigma/d\Omega \approx 0.9$ μb/sr.

As indicated in Table 2 there may be evidence for the addition of a small cubic term d≈6 keV to the IMME for the A=25 isobaric quartet. However, the sensitivity of the IMME to fluctuations in the measurements of excitation energies of the T=3/2 levels of the $T_z=\pm 1/2$ members indicates that conclusions as to the existence and magnitude of such a cubic term must be viewed with caution. This sensitivity to experimental data must also be taken into account when the IMME is used to predict the masses of nuclei yet to be determined experimentally.

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Table 1. Experimentally Measured Q-values for $^{28}Si(^{3}He,^{6}He)^{25}Si$ and Mass Excess Values for ^{25}Si[a].

E(Beam) MeV	Θ_L Degrees	Q-value MeV	^{25}Si Mass Excess MeV
70.330±.030	10.01±.03	-28.008±.014	3.851±.014
70.325±.025	9.97±.03	-27.985±.008	3.828±.008
70.325±.025	9.97±.03	-27.980±.007	3.823±.007
68.090±.060	9.78±.03	-27.998±.010	3.841±.010
70.000±.020	10.48±.03	-27.993±.008	3.836±.008
Weighted Average[b]		———	3.832±.012

[a] ^{25}Si mass excess based on a ^{9}C mass excess of 28.910±.003 MeV See Ref. 2.

[b] Uncertainties of ±.003 MeV for ^{9}C mass excess, ±.004 MeV for ^{6}He mass excess and ±.010 MeV for target thickness uncertainty are added in quadrature to the uncertainty of the weighted average.

Table 2. Coefficients of the Isobaric Multiplet Mass Equation of the forms $M=a+bT_z+cT_z^2$ and $M=a+bT_z+bT_z^2+cT_z^3$ as applied to the A=25 quartet. Mass excess values used are: -9.356±.009 for $^{25}Na^a$, -5.4003±.0034 for $^{25}Mg^b$ -1.017±.005 for $^{25}Al^a$ and the ^{25}Si mass excess of the present work.

a (MeV)	b (MeV)	c (MeV)	x^2	d (MeV)	^{25}Si Predicted	^{25}Si Experimental
-3.263±.003	-4.391±.004	0.222±.004	2.6	---	---	3.832±.012
-3.264±.004	-4.382±.007	0.223±.004	---	-.0063±.0039	---	3.832±.012
-3.262±.003	-4.383±.006	0.214±.006	---	---	3.794[c]	3.832±.012

[a] See reference 1.

[b] Weighted Average of references 1, 9, and 10.

[c] The predicted ^{25}Si mass excess is from a fit of the IMME to the masses of the lowest T=3/2 levels of ^{25}Na, ^{25}Mg, and ^{25}Al.

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FIGURE CAPTIONS

Figure 1a: ^{6}He spectrum from position sensitive detector at spectrograph focal plane. Background is primarily due to reactions in the detector.

Figure 1b: ^{6}He position spectrum with ordinary detector mounted behind position sensitive detector. Both detectors are operated in coincidence to reduce background.

FIGURE 1a

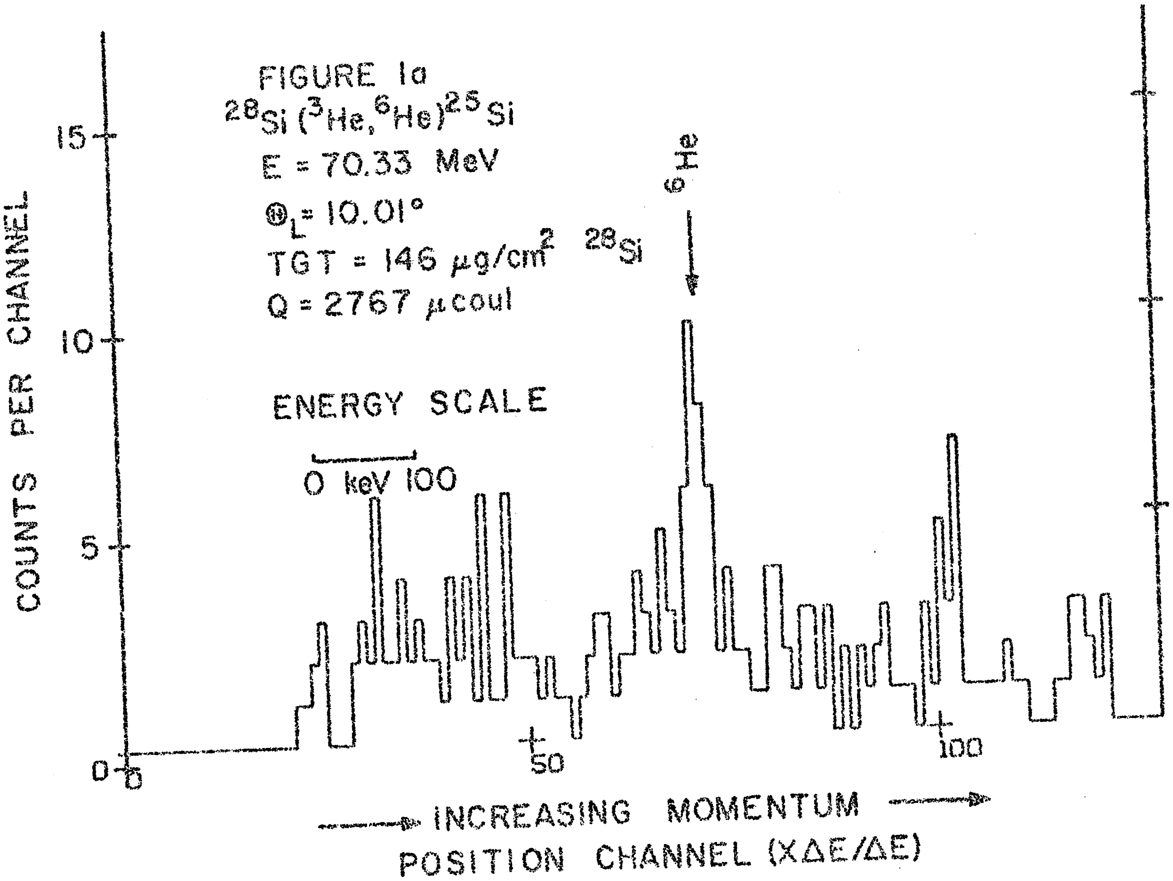

FIGURE 1b