SECTION I

RESEARCH IN PROGRESS

Sub-keV Mass Measurements

P.H. Barker,* J.A. Nolen, and R.G.H. Robertson

Masses of ^{10}C and ^{14}O

Precise measurements of end-point energies in 0^+ to 0^+ super-allowed beta decay are very important for the determination of the vector coupling constant of nuclear beta decay, as well as in testing the various calculations of charge dependent corrections to the beta decay matrix elements. In particular, the importance of the ^{14}O-^{14}N decay energy has recently been emphasized by Wilkinson.[1] The present measurement of the mass of ^{14}O was carried out in an attempt to clarify the disagreement between two recent measurements[2,3] and previous determinations of this mass.[4,5,6] The results of these five previous measurements and the present preliminary result are compared in Table I. We also give in the table the preliminary result of our measurement of the mass of ^{10}C, together with the only previously reported sub-keV measurement[7] of this nucleus.

The present measurements utilized the MSU cyclotron-magnetic spectrograph system and the momentum-matching calibration procedure described previously.[8] The ^{14}O and ^{10}C masses were determined by comparing the triton momenta from the $^{16}O(p,t)$ and $^{12}C(p,t)$ reactions with deuteron and proton momenta from the $^{15}N(p,d)^{14}N$ and various (p,p') reactions. The recently reported precise value of the ^{15}N-^{14}N mass difference[9] served as the primary energy standard for this work. The decay energies are derived from the Q-values using the stable isotope mass differences (^{16}O-^{14}N and ^{12}C-^{10}B) from refs. 9 and 10.

The discrepancies seen in Table I are disquieting since the present result implies an f^Rt-value for the ^{14}O-^{14}N case of 3098±5 as compared with a value of 3079±6 sec. based on the Munich Q-value measurement.[2] Because of the significance of these discrepancies, the present data are being reexamined for systematic errors as well as to reassess the reliability of the presently quoted uncertainties.

In addition, we have recently made additional exposures on nuclear emulsions with a beam energy chosen to give a direct measure of the Q-value difference between $^{12}C(p,t)$ and $^{16}O(p,t)$. These data, which are currently being scanned, will provide an internal consistency check of the results reported here.

Mass of ^6Li

A precise knowledge of the mass of ^6Li is important to increase the sensitivity of the α+d nuclear parity violation experiment currently in progress at MSU (this experiment is described in this Annual Report under the title "Search for weak neutral currents in nuclei). In the 1977 Mass Table of Wapstra and Bos the weighted average of four previous $^6Li(p,\alpha)^3He$ Q-value determinations is 1022.9±1.8 keV, whereas the "adjusted" Q-value based on all available reaction data is 1020.0±0.8 keV. Using a thin ^6LiF target we have recorded data on nuclear emulsions to determine the $^6Li(p,\alpha)^3He$ Q-value relative to that of $^{19}F(p,\alpha)^{16}O$. These data are currently being scanned with the hope of obtaining a new independent mass of ^6Li with an uncertainty of 1 keV or less.

* On leave from University of Auckland, Auckland, New Zealand.

1. D.H. Wilkinson, Phys. Lett. 67B (1977) 13.
2. H. Vonach et al., Nucl. Phys. A278 (1977) 189.
3. R.E. White and H. Naylor, Nucl. Phys. A276 (1977) 333.
4. M.L. Roush, L.A. West, and J.B. Mation, Nucl. Phys. A147 (1970) 235.
5. R.K. Bardin, C.A. Barnes, w.A. Fowler, and P.A. Seeger, Phys. Rev. 127 (1962) 583.
6. J.W. Butler and r.O. Bndelid, Phys. Rev. 121 (1961) 1770.
7. D.C. Robinson and P.H. Barker, Nucl. Phys. A225 (1974) 109.
8. G.F. Trentelman and E. Kashy, Nucl. Instr. and Meth. 82 (1970) 304 and J.A. Nolen, G. Hamilton, E. Kashy, and I. Proctor, Nucl. Instr. and Meth. 115 (1974) 189.
9. L.G. Smith and A.H. Wapstra, Phys. Rev. C 11 (1975) 1392.
10. A.H. Wapstra and K. Bos, Atomic Data and Nuclear Data Tables 19 (1977) 175.

Table I. Summary of sub-keV measurements of the ^{14}O and ^{10}C decay energies.

	$Q_\beta(0^+-0^+)$ [1]	Difference	Method	Calibration	Reference
^{14}O	1809.34 ± 0.7	-1.03 ± 0.9	(^{3}He,n) thres.	electrostatic anal.	6
	1810.24 ± 0.5	-0.13 ± 0.8	(^{3}He,n) thres.	^{7}Li(p,n) thres.	5
	1810.54 ± 0.5	+0.17 ± 0.8	(^{3}He,n) thres.	time of flight (rf)	4
	1808.78 ± 0.4	-1.59 ± 0.7	(p,n) thres.	alpha source	4
	1807.88 ± 0.8	-2.49 ± 1.0	(^{3}He,t) Q-value	time of flight (rf)	2
	1810.37 ± 0.6	-----	(p,t) Q-value	^{15}N-^{14}N mass diff.	present
^{10}C	888.27 ± 0.6	+2.68 ± 0.9	(p,n) thres.	alpha source	7
	885.59 ± 0.7	-----	(p,t) Q-value	^{15}N-^{14}N mass diff.	present

1. All values in keV. All values calculated using masses from references 9 and 10.

$T_z = -3/2$ Nuclei in the s-d Shell

L. Robinson, W. Benenson, E. Kashy, and R. Pardo

We are continuing our studies of the $T_z = -3/2$ nuclei in the s-d shell which are accessable with the (^{3}He,^{6}He) reaction. We are using the new focusing and dispersion matching technique described by E. Kashy et. al. elsewhere in this report and also a new counter consisting of:

(1) a thin (0.10 in.) wire counter with good position resolution

(2) a thick (.85 in.) wire counter with good ΔE resolution

(3) a thin (.039 in.) scintillator (Pilot B) backed by an adiabatic light pipe for efficient light collection.

We have obtained better resolution and particle discrimination than previously. The counter is described in more detail elsewhere in this report.

Figure 1 shows a spectrum of ^{21}Mg taken at $\theta_{lab} = 6^o$, on a target consisting of 116μg/cm^2 of ^{24}Mg on a 20μg/cm^2 carbon + 2μg/cm^2 formvar backing. The full width at half maximum for these peaks is about 25 keV. The 60 keV doublet at 2 MeV is well resolved, however the peak at 1.6 MeV is an unresolved doublet, as was evidenced by an apparent energy shift with angle and suggested by the corresponding 25 keV doublet at 1.74 MeV in the mirror nucleus ^{21}F. Angular distributions for the resolved states below 2 MeV have been taken between 6^o and 34^o.

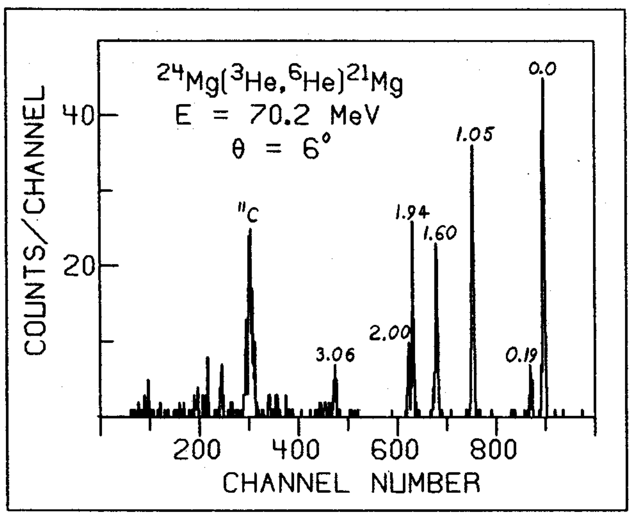

Fig. 1

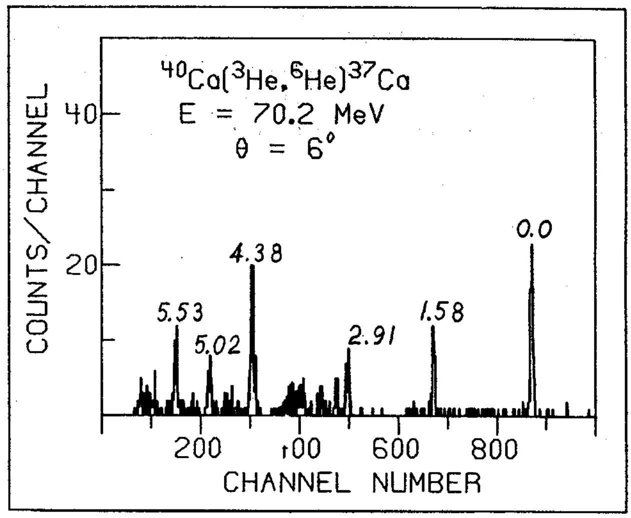

Fig. 2

The two previous measurements of the mass of ^{37}Ca are in poor agreement,[1] we have therefore remeasured this mass by comparing the rigidity of the ^{6}He particles produced by the ^{40}Ca(^{3}He,^{6}He) reaction to that of those produced by the ^{24}Mg (^{3}He,^{6}He) and the ^{58}Ni(^{3}He,^{6}He) reactions, as was described previously.[1] Preliminary analysis indicates an uncertainty of <15 keV, which should resolve the disagreement.

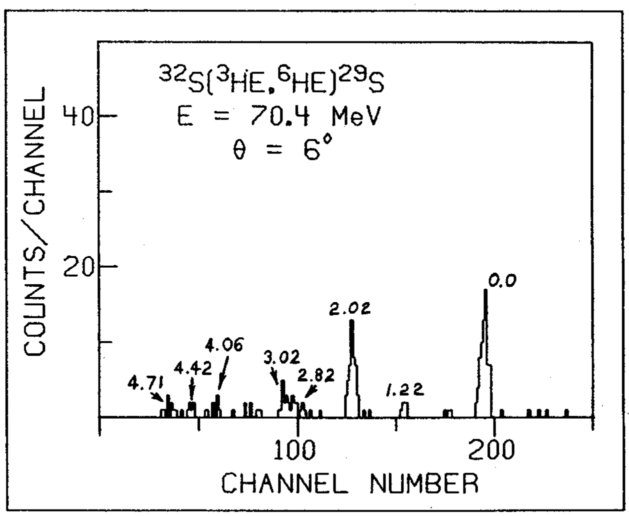

Fig. 3

Figure 2 shows a spectrum of ^{37}Ca also taken at $\theta_{lab} = 6^o$. The target was 284μg/cm^2 of ^{40}Ca on a backing of 20μg/cm^2 carbon +1 layer formvar. The cross-section to the ground state is 158 ± 13 nb/sr, so that a large amount of charge, 57 mCoul., was required to obtain this spectrum. Target thickness was the major factor in the peak widths. In addition to those labeled in figure 2, states are apparent at 3.09, 3.31, 3.63, 3.81, 4.33, and 4.74 MeV.

Figure 3 shows a spectrum of ^{29}S taken at $\theta_{lab} = 6^o$. The width of the peaks is due almost entirely to target difficulties. The beam spot had to be defocused to prevent destruction of the target, and migration of the sulfur caused large thickness variations. The mass of ^{29}S is the least well known of these $T_z = -3/2$ nuclei, due entirely to the target difficulties mentioned above. We have recently resolved this problem by making a target of alternate layers of calcium and sulfur, about 30μg/cm^2 per layer. The calcium carries the heat away while providing a calibration peak. Several spectra were taken with the target rotated 180° between spectra to reduce thickness errors. The uncertainty was dominated by the uncertainty in ^{37}Ca, which has now been reduced and the new ^{29}S mass will have an error of ∿20 keV.

---

1. W. Benenson, et. al. Phys. Rev. C8, 210 (1973)

A=9 Isobaric quartet and Mass of ^{9}C

E. Kashy, W. Benenson, J.A. Nolen Jr., and R. G. H. Robertson

We have recently made photographic plate exposures for the reactions (^{3}He,^{3}He), (^{3}He, ^{4}He) and (^{3}He, ^{6}He) with 72 MeV ^{3}He beam on a target containing a 60/40 mixture of ^{12}C and ^{13}C. The reaction particles were magnetically analyzed in the split pole spectrograph and were separated according to their mass with an electric field perpendicular to the orbit plane. The peaks on the plate correspond to well known levels of ^{10}C, ^{11}C, ^{12}C, and ^{13}C and will be used in a global fit to obtain a new measure of the ^{9}C mass. Scanning of the plates is underway and is complicated by the large variation in cross section of the various reactions. Exposures were made with beam incident on both surfaces of the target to minimize problems associated with location of the isotopes within the target. It is expected that a mass of ^{9}C with an accuracy ∿3 keV will result from this data. It will further check the value of the d-coefficient of the isobaric mass multiplet equation which was previously determined for the A=9 ground state quartet to be 5.8 ± 1.5 keV[1]. The mass 9 T=3/2 quartet is currently the only one which indicates a significant departure from a purely quadratic equation.

---

1. E. Kashy, W. Benenson, D. Mueller, R.G.H. Robertson and D.R. Goosman, Phys. Rev. C11, 1959 (1975)

Mass-Measurement of Proton-Rich, Medium-Weight Nuclei by the (^{3}He,^{6}He) Reaction

R.C. Pardo, E. Kashy, W. Benenson, and L.W. Robinson

We have used the (^{3}He,^{6}He) reaction at 70 MeV on targets of ^{70}Ge, ^{90}Zr, ^{106}Cd, ^{112}Sn, and ^{144}Sm to study the proton-rich nuclei ^{67}Ge, ^{87}Zr, ^{103}Cd, ^{109}Sn, and ^{141}Sm. This study was to provide additional tests of mass formulae in the medium-weight region of the periodic table and to provide well-determined masses of proton-rich nuclei which could serve as standards in future beta decay studies in this region. Previous use of the (^{3}He,^{6}He) reaction has been limited to studies of nuclei lighter than zinc.

The data in this study were taken with the MSU Enge split-pole magnetic spectrograph using a two-wire charge-division gas proportional counter backed by a plastic scintillator for light output and timing information. The time-of-flight, light output, and dE information allowed unique identification of the ^{6}He nuclei. Measurements were made mainly at 7^o and 10^o laboratory angles, though some data were taken at 5^o, 8^o, and 13^o as well. Each reported measurement is the result of at least two independent runs.

The targets used were isotopically enriched with thicknesses ranging from 239 to 1100 μg/cm^2. All targets were self-supporting except ^{70}Ge and ^{144}Sm, which has approximately 20 μg/cm^2 and 25 μg/cm^2 ^{12}C backings. Either the ^{60}Ni(^{3}He,^{6}He)^{57}Ni (Q=−11.0541±.004 MeV) or the ^{62}Ni(^{3}He,^{6}He)^{59}Ni (Q=−8.255±.002 MeV) reactions were chosen as the calibration reactions because they have almost the same Q-value as the reactions of interest. This made it unnecessary to change the magnetic field of the spectrograph, and eliminated a major source of error in the Q-value determinations.

The results of this experiment are shown in Tables I and II. Figs. 1 and 2 show examples of spectra obtained. The resolution was approximately 60 keV FWHM except when limited by the thickness of the targets. The errors shown for the mass excesses correspond to the standard deviation of the mean of the various determinations. These internal errors were compared to a careful analysis of various sources of random error. In general, agreement between the observed uncertainty and the expected random error was good; occasionally the expected random error was greater than that observed. The larger of the two results has been used in all cases. The observed differential cross section for population of the ground state in each reaction is included in Table I. The value quoted is the average over all data taken regardless of angle.

More discussion of the results of this work can be found in a paper accepted for publication in Phys. Rev. C.

This project is continuing and early results on the ^{92}Mo(^{3}He,^{6}He)^{89}Mo reaction have yielded the first determination of the mass excess of ^{89}Mo. In addition, the (^{3}He,^{8}Li) reaction on many of these targets reaches nuclei whose masses are either not known or poorly known. A test run for the reaction using the ^{144}Sm reaction showed the (^{3}He,^{8}Li) cross-section to be approximately 18 nb/sr in a 5 MeV energy interval, which indicates that the series of (^{3}He,^{8}Li) experiments on the same targets as above will be feasible but difficult.

TABLE I. Mass Excesses and Q-values.

Nucleus	Number of Measurements	Measured Q-value (MeV)	Inferred Mass Excess (MeV)	Previous Mass Excess Ref. 2 (MeV)	$\frac{d\sigma}{d\Omega}$ (nb/sr)
^{67}Ge [a]	2	−10.572±0.03	−62.65 ±0.03	−62.450±0.050	270
^{87}Zr	6	−12.083±0.008	−79.344±0.009	−79.430±0.080	100
^{103}Cd	3	−9.173±0.017	−80.620±0.018	−80.600±0.140	170
^{109}Sn	4	−8.686±0.009	−82.634±0.011		70
^{141}Sm	5	−8.693±0.012	−75.933±0.016	−75.910±0.060	90

[a] Lowest energy state observed is assumed to be 18 keV state. See text.

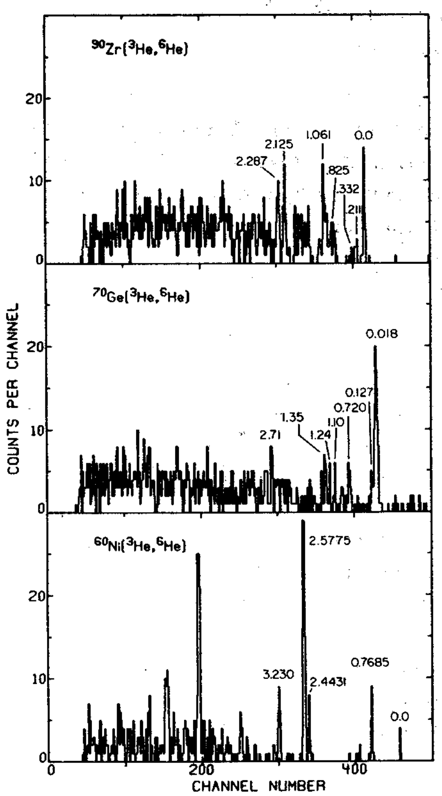

Fig. 1. Spectra of ^{6}He particles observed from various targets in the (^{3}He,^{6}He) reaction. All spectra were taken at θ_L=7° and $E_{^3He}$ 70 MeV. The states labeled by their excitation energy in the ^{60}Ni(^{3}He) spectrum served as calibration points for the other reactions.

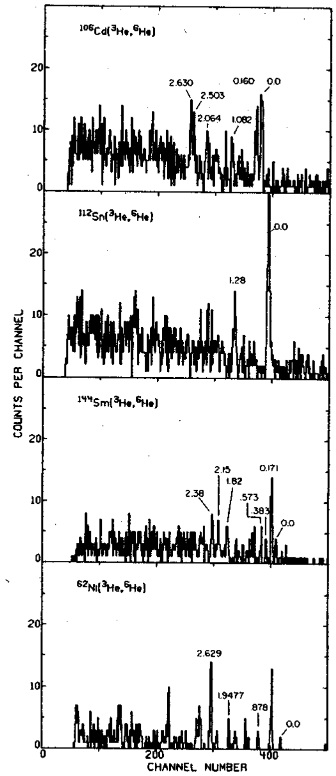

Fig. 2. Spectra of ^{6}He particles observed from additional targets in the (^{3}He,^{6}He) reaction. All spectra were taken at θ_L=7° and $E_{^3He}$ 70 MeV. The states labeled by their excitation energy in the ^{62}Ni(^{3}He,^{6}He) spectrum served as calibration points for the other reactions.

TABLE II. Excited States observed.

^{67}Ge E_x (MeV)	^{87}Zr E_x (MeV)	^{103}Cd E_x (MeV)	^{109}Sn E_x (MeV)	^{141}Sm E_x (MeV)
0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
0.119 (33)	0.211 (10)	0.180 (12)	1.277 (15)	0.171 (16)
0.702 (33)	0.332 (10)	1.082 (12)		0.383 (16)
0.905 (33)	0.825 (13)	2.064 (22)		0.573 (17)
1.084 (33)	1.061 (15)	2.503 (18)		1.820 (22)
1.223 (33)	2.125 (15)	2.630 (18)		2.150 (22)
1.328 (33)	2.287 (15)			2.380 (22)
2.694 (33)				