Title
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Publication Date
1972-11-01

Submitted to Physics Letters B

LBL-1292
Preprint c.1

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November 1972

AEC Contract No. W-7405-eng-48

LBL-1292
c.1

DISCLAIMER

ON THE LOWEST T = 3/2 STATE† IN ^{41}Sc

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Precise energies of β^+-delayed protons emitted from the lowest T = 3/2 analogue states in several T_z = -1/2 nuclei have been measured. The lowest T = 3/2 level in ^{41}Sc was found to lie at 5.935 ± 0.008 MeV, in substantial disagreement with the previously accepted value.

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Precise energies have been reported for the lowest T = 3/2 states in all mass 4n+1, T_z = 1/2(N-Z) = -1/2 nuclei with 9 ⩽ A ⩽ 41 [1-10]. Such measurements provide one component in testing the model-independent isobaric multiplet mass equation (IMME) [1]. Using a technique which provides a simple method of cross checking one such measurement against another, we have observed the β^+-delayed proton decay of ^{21}Mg, ^{25}Si, ^{29}S, ^{37}Ca, and ^{41}Ti. These results lead to a value of 5.935 ± 0.008 MeV for the excitation energy of the lowest T = 3/2 state in ^{41}Sc, which disagrees with the previously accepted value of 5.863 ± 0.006 MeV [2,6]* reported from ^{40}Ca (p,p) resonance measurements.

Experimental masses for only three members of the A = 41, T = 3/2 multiplet are known: the ^{41}K ground state [11], its analogue in

†Work performed under the auspices of the U. S. Atomic Energy Commission.

*Throughout this report, the 1971 Atomic Mass Table [11] is used in all calculations requiring masses for which explicit references are not cited.

^{41}Ca [12] and this new result for ^{41}Sc. The IMME can now be used to predict a value of -15.78 ± 0.03 MeV for the ground state mass excess of ^{41}Ti. This agrees favorably with a value of -15.72 MeV predicted by Kelson and Garvey [13]. Although the lowest T = 3/2 level in ^{41}Sc has been previously studied in lower-resolution, β^{+}-delayed proton work [14], a precise measurement of its excitation energy was not reported [15].

In the present experiment, a He-jet transport system [16] and standard particle-identification techniques were used to detect β^{+}-delayed protons emitted from the lowest T = 3/2 level in each of the following T_z = -1/2 nuclei: ^{21}Na, ^{25}Al, ^{29}P, ^{37}K, and ^{41}Sc. Their precursors, with half-lives ranging from 88 to 220 msec [14,17-19], were produced by (^{3}He,2n) reactions on target nuclei of ^{20}Ne, ^{24}Mg, ^{28}Si, ^{36}Ar, and ^{40}Ca using ∿ 3.5 μA of ^{3}He beam from the Berkeley 88-inch cyclotron. A beam energy of 29.5 MeV was used for all but the ^{36}Ar (^{3}He,2n) reaction for which the energy was increased to 40 MeV to improve the yield. The He jet rapidly transported activity, recoiling from the target, away from the bombardment area. This activity was deposited as a thin sample on a foil located ∿ 35 cm away in a low-background region maintained at a pressure of ∿ 0.05 Torr. Delayed protons from the activity on the foil were detected in a counter-telescope consisting of a 48-μm ΔE followed by a 500-μm E detector. An additional reject detector was used to aid in background reduction. These silicon counters were cooled to -25°C. Signals from the ΔE and E detectors were fed into a Goulding-Landis particle identifier.

An experimental energy resolution of 30 keV (FWHM) was achieved, permitting centroid determinations reproducible to within one or two keV.

Each of the targets could be selected without disturbing the detectors or their associated electronics in any way. Self-supporting targets of ^{24}Mg, ^{28}Si, and ^{40}Ca with a thickness of 1.5 mg/cm^2 were used. In the ^{21}Mg experiment, a mixture of 90% Ne and 10% He, at a pressure of 1300 Torr, served as both target and carrier gas. The isotopically-enriched ^{36}Ar gas was contained in a 3-cm^3 cylindrical target cell having a diameter of 1.9 cm, and an orientation coaxial with the beam. Pinhole-free Ni isolation foils were used on the cell; the entrance foil was 1.67 mg/cm^2 and the exit foil, through which the reaction recoils escaped into the He, was 200 μg/cm^2. Both the ^{36}Ar and the He were at a pressure of 1100 Torr. An absolute pressure differential of $\leqslant 5$ Torr was maintained to prevent the exit foil from rupturing.

The delayed-proton spectra were all substantially background free; even in the bombardment of ^{36}Ar, the Ni containment foils did not contribute any significant background. Typical identified-proton energy spectra resulting from the decay of ^{25}Si and ^{41}Ti are shown in fig. 1. Proton groups arising from the decays of the T = 3/2 levels under study are prominent in each spectrum because these narrow states are strongly populated by superallowed β^+ decay of the precursor ground state. The low log _ft_ values (typically ∿ 3.3 [20]) associated with these β^+ transitions provide an unambiguous identification of the observed T = 3/2 decays. In fig. 1(a) the T = 3/2 level in ^{25}Al is seen to decay both to the ground state of ^{24}Mg (peak 1) and to its first excited state (peak 2). Since the energies of the ground and first excited states are precisely known [2,11], as is the energy of the T = 3/2 level in ^{25}Al [5,7,10], peaks 1 and 2 were chosen as two of the three points used in the calibration (see Table 1). Electronic gain stability was monitored during each run by a precision pulser. As a further precaution, a ^{25}Si spectrum was recorded between runs on each of the reactions being studied.

In fig. 1(b), peak 3 represents proton decays from the lowest T = 3/2 level in ^{41}Sc to the ground state of ^{40}Ca. As discussed below, this ground state branch accounts for $\gtrsim$ 86% of all the proton decays from the analogue state. Using thinner ΔE counters, a search was made for decays from the T = 3/2 level to the first three excited states in ^{40}Ca. A 4±2 % branch to the 3.35-MeV level was observed, while no decays corresponding to the transition to the 3.90-MeV level in ^{40}Ca were detected. Unfortunately, protons from the decay to the second excited state in ^{40}Ca at 3.73 MeV have similar energies to protons from an observed state at 6.105 MeV in ^{41}Sc which possibly decays to the third excited state in ^{40}Ca. In addition, these protons have similar energies to the major proton decay branch from the β^+-delayed proton precursor ^{40}Sc [21], produced in the ^{40}Ca(^{3}He,p2n) reaction, which consititutes a background problem at low proton energies. From our analysis of data taken at several bombarding energies, the decay branch from the T = 3/2 level in ^{41}Sc to the ^{40}Ca second-excited state appears to be $\lesssim$ 10%.

The results of our energy measurements, corrected for detector dead layers and very slight gain drifts, appear in Table 1, where center-of-mass (c.m.) proton decay energies are shown for the lowest T = 3/2 level in each of the T_z = -1/2 nuclides investigated. Each entry in the first column is a weighted average of values deduced from previous experimental measurements. Since the decay energies for ^{37}K and ^{25}Al are the most precisely known, they were used as calibrants. Our results are presented in the second column of the table. Excepting the 72-keV discrepancy in the ^{41}Sc result, the present values agree very well with the results of earlier experiments. This agreement establishes, in a unique way, a self-consistency among the many independent measurements. The final column of Table 1 lists what we consider to be best values for the c.m.

proton decay energies. In the case of ^{21}Na and ^{29}P, this is a weighted average of the results in the first two columns.

Information on the locations, widths and (isospin-forbidden) decay modes of high-isospin states is important to an understanding of the charge independence of nuclear forces. The lowest T = 3/2 level in ^{41}Sc at 5.935 ± 0.008 MeV proton decays primarily to the ^{40}Ca ground state with a c.m. decay energy of 4.851 ± 0.006 MeV. This corresponds to a laboratory proton resonance energy of 4.973 ± 0.006 MeV in the ^{40}Ca (p,p) or ^{40}Ca (p,γ) reaction. Our IMME prediction of -15.78 ± 0.03 MeV for the ground state mass excess of ^{41}Ti is of interest because no simple technique exists for its precise experimental measurement.

We would like to thank Mr. John Dwyer for his considerable assistance in the collection and analysis of these data.

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Table 1. Center-of-mass proton decay energies of the lowest T = 3/2 analogue states.

Precursor ($T = 3/2$, $T_z = -3/2$)	$\xrightarrow{\beta^+}$	Emitter ($T = 3/2$, $T_z = -1/2$)	$\xrightarrow{p}$	Residual Nucleus ($T_z = 0$)	Proton Decay Energies (c.m.): Deduced from Previous work (MeV ± keV)	Proton Decay Energies (c.m.): Present Results (MeV ± keV)	Proton Decay Energies (c.m.): Best Value (MeV ± keV)
^{37}Ca	$\xrightarrow{\beta^+}$	^{37}K	$\xrightarrow{p}$	^{36}Ar (g.s.)	3.1898 ± 2.4[a]	calibrant	
^{25}Si		^{25}Al		^{24}Mg (1.37)	4.2623 ± 2.8[b,c,d]	calibrant	
^{41}Ti		^{41}Sc		^{40}Ca (g.s.)	4.779 ± 4[d]	4.851 ± 6	4.851 ± 6
^{21}Mg		^{21}Na		^{20}Ne (1.63)	4.908 ± 5[e,f]	4.898 ± 6	4.904 ± 4
^{25}Si		^{25}Al		^{24}Mg (g.s.)	5.6309 ± 2.8[b,c]	calibrant	
^{29}S		^{29}P		^{28}Si (g.s.)	5.633 ± 4[c,g]	5.633 ± 6[h]	5.633 ± 3
^{21}Mg		^{21}Na		^{20}Ne (g.s.)	6.542 ± 5[e]	6.533 ± 6	6.538 ± 4

[a] References 4 and 10.

[b] References 5, 7, and 10.

[c] Proton resonance energies in ref. 7 were measured with probable errors of 6 keV [22].

[d] Reference 2.

[e] Reference 8.

[f] Reference 23.

[g] References 3, 5, 7, and 9.

[h] By combining this result with the resonance energy measurements from refs. 3, 7, and 9, and with the direct excitation energy measurements from refs. 5 and 9, an improved value for the ^{29}P ground state mass excess of -16.949 ± 0.004 MeV can be calculated.

FIGURE CAPTION

Fig. 1. Beta-delayed proton spectra of (a) ^{25}Si and (b) ^{41}Ti. The numbered peaks correspond to proton emission from the lowest T = 3/2 analogue states in ^{25}Al and ^{41}Sc via the decays:

(1) $^{25}Si \xrightarrow{\beta^+} {}^{25}Al\ (T = 3/2) \xrightarrow{p} {}^{24}Mg\ (g.s.)$

(2) $^{25}Si \xrightarrow{\beta^+} {}^{25}Al\ (T = 3/2) \xrightarrow{p} {}^{24}Mg^*\ (1.37\ MeV)$

(3) $^{41}Ti \xrightarrow{\beta^+} {}^{41}Sc\ (T = 3/2) \xrightarrow{p} {}^{40}Ca\ (g.s.)$

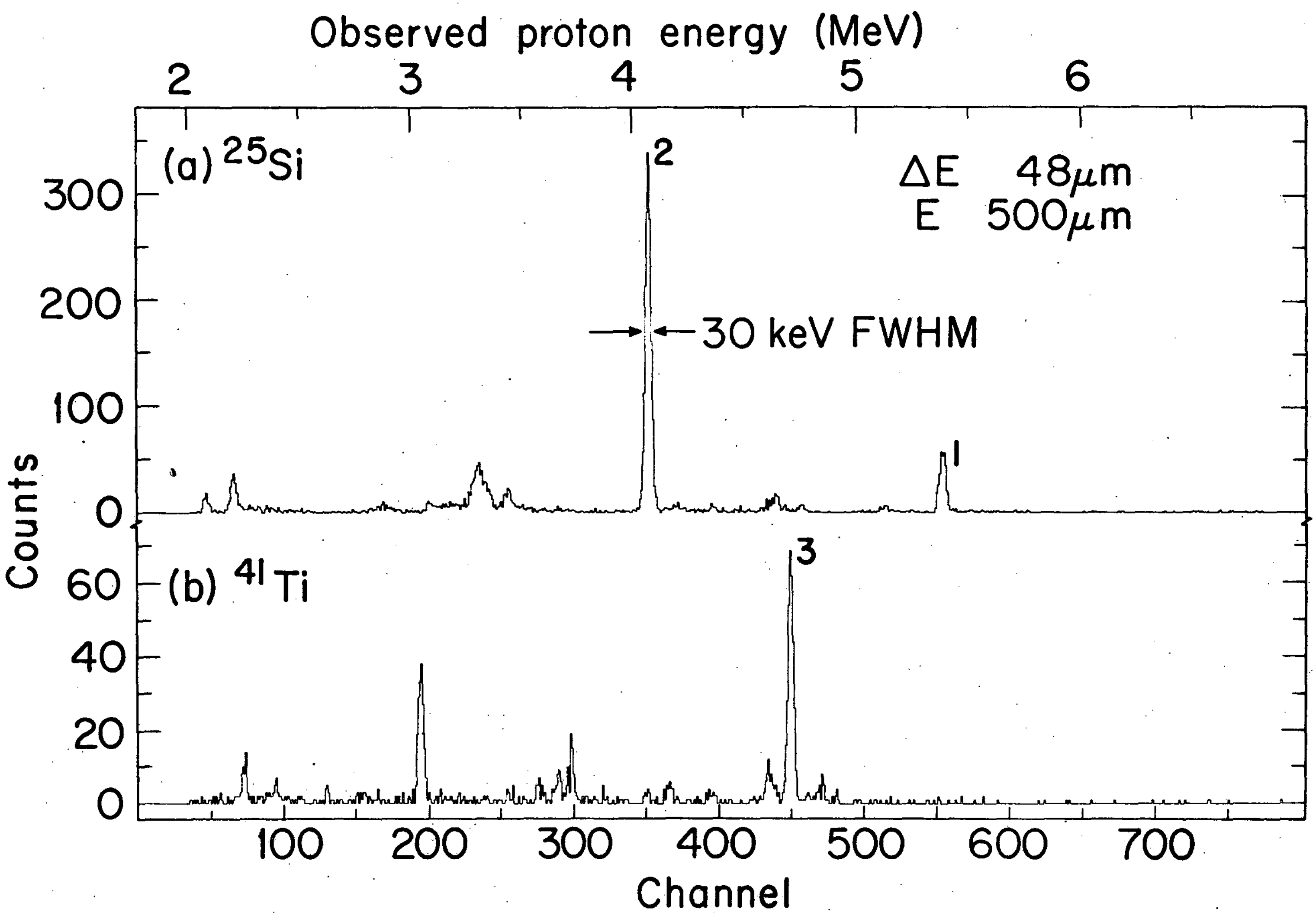

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Fig. 1

Table III. Percent ^{38}K Activity Produced from K, Cl, and Ca.

^{3}He Beam Energy (MeV)	From Elements[a]		
	K	Cl	Ca
8	90	9	1
10	51	16	33
15	10	10	80
20	7	5	88

[a]Equal weight of natural elements in a thin sample.

Table IV. Percent ^{34m}Cl Activity Produced from Cl, S, and K.

^{3}He Beam Energy (MeV)	From Elements[a]		
	Cl	S	K
8	16	84	0
10	19	81	0
15	24	73	3
20	30	36	34

[a]Equal weight of natural elements in a thin sample.

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