Title

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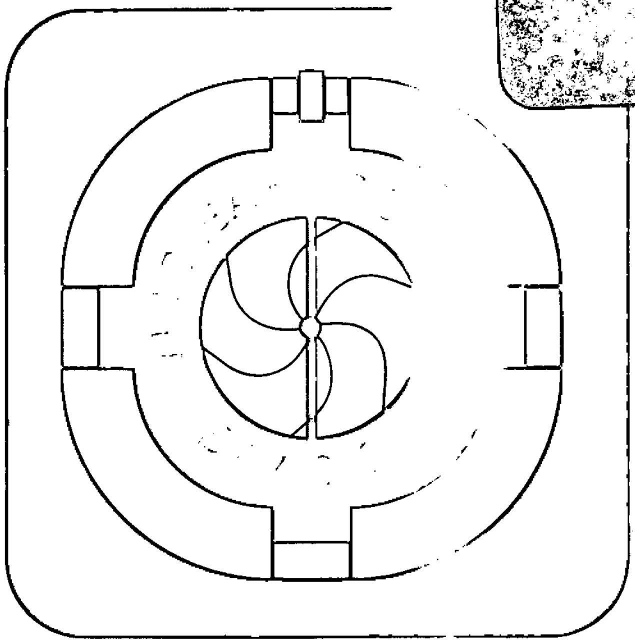

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Abstract:

Beta decay strengths from four $T_z = -3/2$ nuclei (^{21}Mg, ^{25}Si, ^{29}S and ^{41}Ti) to levels above the isobaric analog states have been measured by beta-delayed proton emission. At least seven new levels have been identified in the daughter nuclei. Log ft values indicate allowed beta decay strengths dominate and show good agreement in general with model comparisons.

RADIOACTIVITY: ^{20}Ne, ^{24}Mg, ^{28}Si, ^{40}Ca (^{3}He,2n)^{21}Mg, ^{25}Si, ^{29}S, ^{41}Ti; $T_z = -3/2$ nuclei; measured beta-delayed proton activity; deduced log ft; discussed daughter states and model comparison to Gamow-Teller decay strengths.

Beta-delayed proton emission has proven to be a useful tool for understanding nuclei far from stability. Most of the beta decay strength is concentrated at and below the isobaric analog state (IAS) of the parent nucleus (precursor) ground state. Identification of beta strength to states above the IAS is important not only because it provides additional tests of nuclear models of beta decay, but also because proton emission from such beta daughter nuclei frequently constitutes an important component of the background in searches for more exotic nuclei. (For example, production of ^{22}Al is frequently accompanied by copious amounts of ^{21}Mg.) Therefore, we have measured the beta-delayed proton spectra of four $T_z = -3/2$ nuclei (^{21}Mg, ^{25}Si, ^{29}S, ^{41}Ti) to establish log ft values for beta decay to states above the analog states. Fourteen previously unreported proton groups were observed and beta decay branching ratios were derived for each. References 1-4 refer to previous work on ^{21}Mg, ^{25}Si, ^{29}S and ^{41}Ti, respectively.

^{3}He beams from the Lawrence Berkeley Laboratory 88-Inch Cyclotron were used to produce the proton-rich nuclei of interest. A high speed helium jet system transported the activity to a region of low background shielded from the beam and target area. Reaction products recoiled out of the target and were thermalized in ~ 1.3 atm of helium gas. They were then carried to a low pressure counting chamber (~ 100 millitorr) through a 70 cm long, 1.37 mm i.d. capillary and deposited on an aluminum catcher wheel. Subsequent beta-delayed proton emission was observed using a high geometry, three-element semiconductor telescope with 38 μm ΔE1, 125 μm ΔE2 and 1000 μm E detector thicknesses. This telescope subtended a solid angle of 0.38 sr and was sensitive to protons ranging in energy from 4 to 10 MeV. Energy spectra were collected in event mode on a ModComp Classic computer. Particle identification was obtained using a semi-empirical energy loss formalism with varied detector combinations.

In all these experiments, beam energies and/or measurement conditions were selected to produce the isotope of interest via the (^{3}He,2n) reaction with little or no contamination from other beta-delayed particle emitters. The ^{20}Ne(^{3}He,2n) reaction at 41.5 MeV produced ^{21}Mg. Other beta-delayed particle emitters which could be formed at this energy include ^{20}Na and ^{17}Ne. ^{20}Na is a beta-delayed alpha precursor and the particle identification techniques described above were used to discriminate against this activity. Since ^{17}Ne is a noble gas, its transport and collection efficiency is quite small. ^{25}Si was produced via the ^{24}Mg(^{3}He,2n) reaction at 31.5 MeV which is well below the threshold for the (^{3}He,α2n) reaction leading to the formation of ^{21}Mg. Similarly, ^{29}S was made at 31.5 MeV using the ^{28}Si (^{3}He,2n) reaction. Again, this is below the threshold for the production of ^{25}Si via the α2n exit channel. Finally, ^{41}Ti was produced in the ^{40}Ca(^{3}He,2n) reaction at 32 MeV. A competing reaction, (^{3}He,α2n) leading to ^{37}Ca, has a very small cross section at this energy. Intensities from previous studies$^{4)}$ suggest that all of the protons observed above 4.5 MeV will originate from ^{41}Ti.

Figures 1 through 4 illustrate the beta-delayed proton spectra for each of the four measured isotopes. Energy calibrations were derived from the major proton groups of ^{21}Mg, ^{25}Si, ^{29}S, and ^{41}Ti. Energy uncertainties for the calibration groups originate primarily from measured peak widths and the energy resolution of the detector telescope. For each isotope the weak groups are at energies just above relatively intense proton peaks. These strong groups have been identified[1-4) as proton decay from the IAS of the beta parent.

The weak proton groups of interest lie on a high energy tail from the strong proton groups; the presence of this tailing is due in large part to our high geometry configuration which enhances coincidences between events in the strong proton groups and the preceding beta-particle. This "pile-up" background above the strong groups is assumed to have a shape illustrated by the solid curves of Figs. 1-4. Principal uncertainties in the extracted intensities of the weak proton groups arise from the uncertainty in this background subtraction as well as from the statistical uncertainty in the peak yield. Table I (Refs. 5-9) summarizes the states inferred to have been populated in the beta decay of these four isotopes. Tabulated intensities have been normalized relative to the yield of the most intense proton group of the beta-delayed proton emission from that isotope (again see Ref. 1-4). From the relative intensities, partial lifetimes and log ft values have been derived for each state. Log f values have been interpolated from the tables of Ref. 10.

In all cases the newly identified proton peaks correspond to the first observation of these levels through beta decay except for the state at 6945 keV in ^{41}Sc. The proton decay of this state to the 4823 (3^-) state in ^{40}Ca was measured by Sextro et al.[4)] and observed proton branches are in good agreement with reaction studies.[8,9)] (The relative intensity, as measured in these data, is well below the lower limit quoted in Ref. 4 and we would therefore not expect it to be present in those data.) Some of the beta decay daughter states shown in Table I have, however, been previously observed in reaction studies. States in ^{41}Sc close to E_x = 6825, 7202 and 7334 keV have been identified which have large partial widths to the ^{40}Ca (gs) proton channel. However there have been no available data until now on the states at 7630 and 7905 keV. For ^{29}P there are known levels[7)] close to 9715 and 9855 keV, however no previous evidence existed for the two observed levels above 10 MeV. The state at 10095 keV may be a good candidate for the analog of the ^{29}Al 1760 keV state (see Ref. 7). The 9280 keV state in ^{21}Na has been previously identified in proton elastic scattering experiments[6)], however its proton width has not been established.

The measured log ft values suggest that all the levels are populated by allowed beta decay. In most cases the established and tentative spin assignments of these levels also agree with the assumption of allowed beta decay. This restricts the spins of the new levels in ^{21}Na, ^{25}Al, and ^{29}P to $3/2^+$ - $7/2^+$ and ^{41}Sc to $1/2^+$ - $5/2^+$. For the case of our observed level in ^{29}P at E_x = 9715±50 keV, assignment to the known 9743 keV level of ^{29}P (which has been tentatively assigned$^{7)}$ a spin of $1/2^+$) would require a second forbidden beta decay. Since the state of ^{29}P at 9760 keV lies within our error bars and has been assigned a spin parity of $3/2^+$ or $5/2^+$, this may be the level to which the decay proceeds.

Wildenthal$^{11)}$ has calculated Gamow-Teller matrix elements for the s-d shell nuclei and some comparisons between theory and experiment can be made. A predicted $J^\pi = 5/2^+$ level at 9.42 MeV in ^{21}Na is calculated to have a log ft = 5.35 and, similarly, calculations for ^{29}P also predict a $J^\pi = 5/2^+$ state at 9.87 MeV with a log ft value of 5.18; both calculations agree quite well with the measured values. Unfortunately the number of levels predicted to be populated through Gamow-Teller beta decay is very large and a comparison to other states without experimental spin assignments would be specious at best.

In summary, 14 new beta-delayed proton groups from $T_z = -3/2$ isotopes have been identified and log ft's have been calculated. At least seven of these groups correspond to previously unknown levels in the beta daughter nuclei. As discussed, all log ft values observed are consistent with allowed beta decay as are the assigned spin values for known levels. Theoretical log ft values show good agreement to the newly measured values where comparison is possible.

Table I: Additional Proton Groups From $T_z = -3/2$ Nuclei

Spectrum Label	Daughter	E_p(keV)	E_x(keV)	Relative Intensity(%)[a]	log ft	Established E_x(keV)	Established J^π	Calculated E_x(keV)	Calculated J^π	Calculated log ft
Mg1	^{21}Na	6520±30	9280±30	0.12±.03	5.41±.10	9293±10[b]		9420	$5/2^+$	5.35
Si1	^{25}Al	6520±10	9065±10	0.72±.04	4.80±.03					
Si2		6720±25	9275±25	0.12±.02	5.41±.09					
Si3		6855±30	9415±30	0.12±.02	5.32±.07					
S1	^{29}P	6725±50	9715±50	0.10±.02	5.64±.10	9760[c]	$(3/2,5/2)^+$			
S2		6860±30	9855±30	0.21±.02	5.21±.04	9871[c]	$(3/2,5/2)^+$	9866	$5/2^+$	5.18
S3		7090±30	10095±30	0.12±.01	5.28±.05					
S4		7520±30	10535±30	0.18±.01	4.78±.04					
Ti1	^{41}Sc	5595±15	6825±15	0.26±.03	5.53±.05	6825[e]	$5/2^+$			
Ti2		5715±15	6945±15[d]	0.36±.03	4.32±.05	6948±10[e]				
Ti3		5950±20	7185±20	0.40±.03	5.25±.04	7202[f]				
Ti4		6125±20	7365±20	0.29±.02	5.39±.04	7334[f]				
Ti5		6380±50	7630±50	0.20±.03	5.41±.09					
Ti6		6650±50	7905±50	0.20±.02	5.25±.05					

a) Intensities quoted are relative to the strongest proton group in the beta-delayed proton spectrum for that nucleus. Mg (Ref. 1); Si (Ref. 2); S (Ref.3); and Ti (Ref. 4).

b) Ref. 5 and 6

c) Ref. 5 and 7

d) The beta decay to this state has been previously observed; however the subsequent proton decay to the ^{40}Ca ground state has not (See text and Ref. 4).

e) Ref. 8

f) Ref. 9

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Figure Captions

Fig. 1. Beta-delayed proton spectrum from ^{21}Mg. The structure at 7 MeV is not designated a new group because its width is much greater than that of the other proton groups and so could not be satisfactorily resolved. The solid curve is the assumed beta "pile-up" tail from the intense proton group at 6.2 MeV.

Fig. 2. Beta-delayed proton spectrum from ^{25}Si. For this isotope the beta "pile-up" tail (solid curve) arises from the state at 5.4 MeV.

Fig. 3. Beta-delayed proton spectrum from ^{29}S. The four new peaks appear on the beta "pile-up" tail from the peak at 5.6 MeV.

Fig. 4. Beta-delayed proton spectrum from ^{41}Ti. Six new proton groups have been identified. The beta "pile-up" tail from the peak at 4.7 MeV is represented by the solid curve.

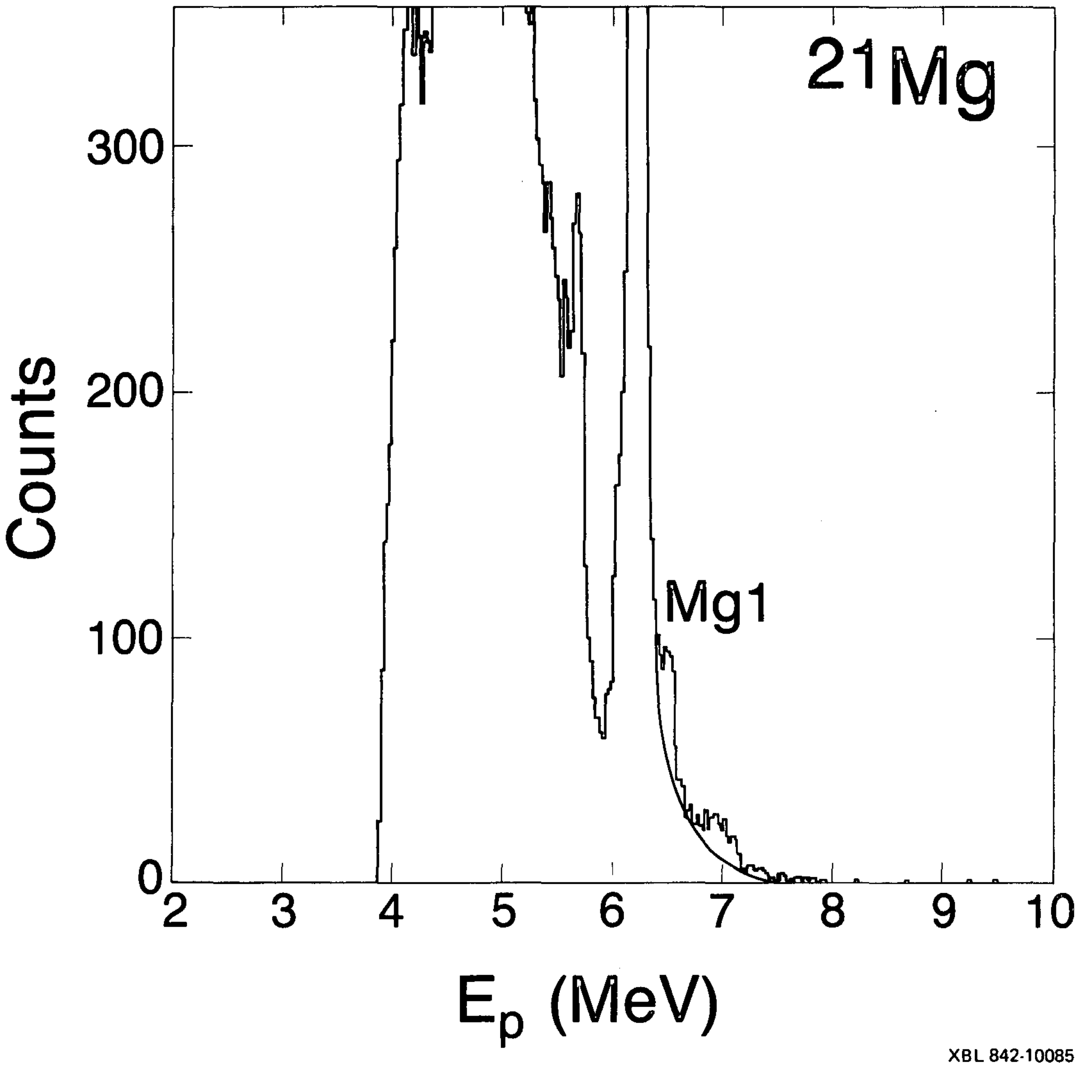
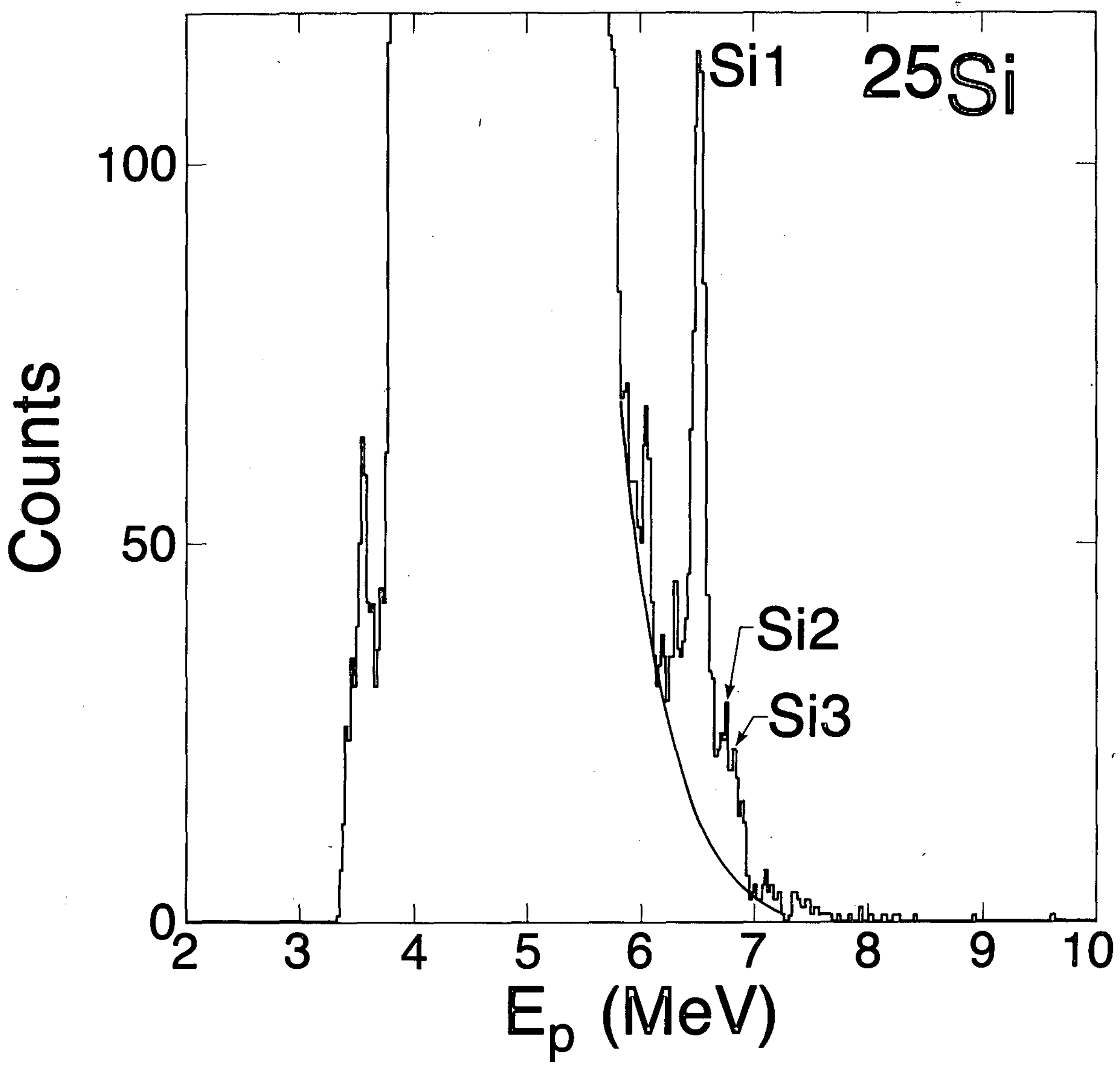


Fig. 1.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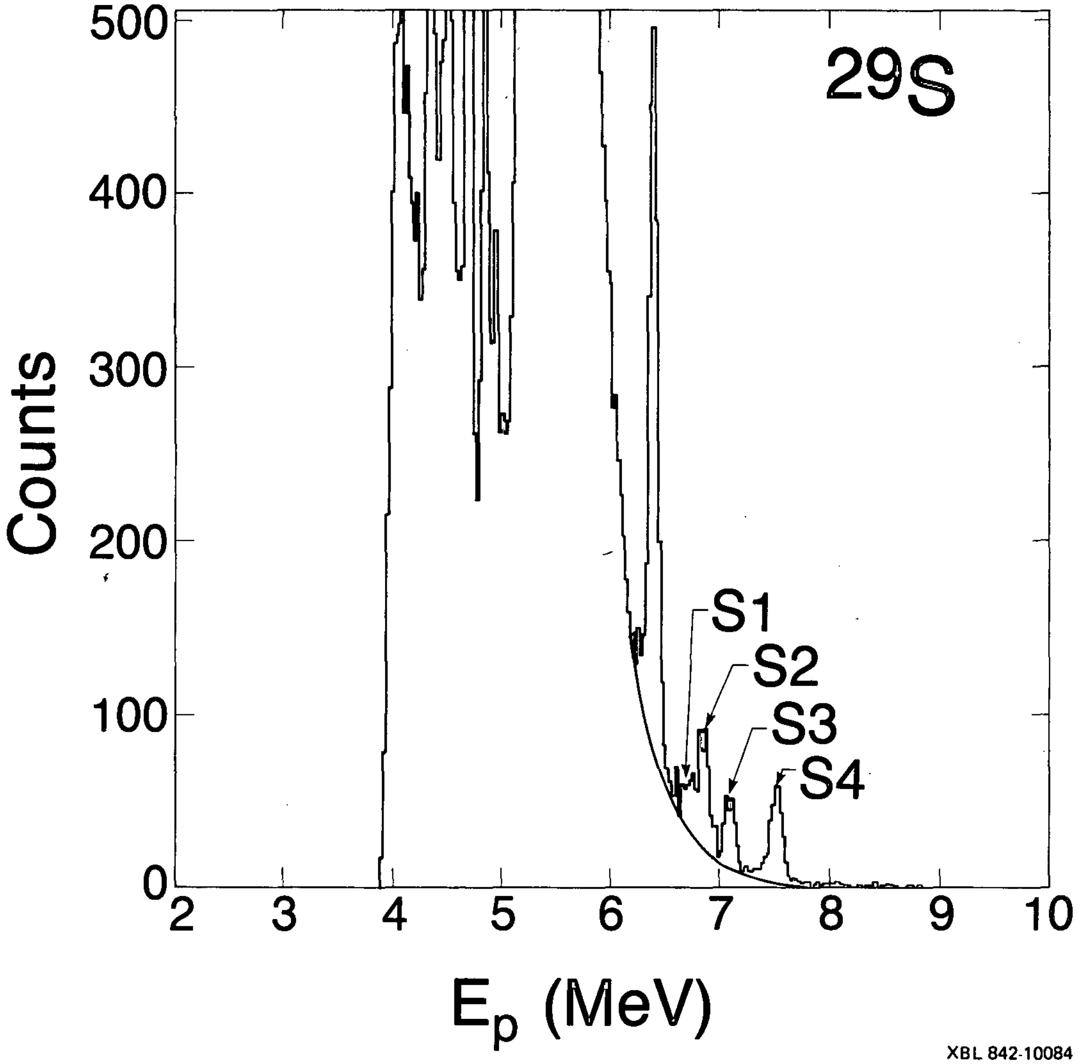
0
50
100
2
3
4
5
6
7
8
9
10
Ep (MeV)
Si1
Si2
Si3
25Si
XBL 842-10102

Fig. 2


29S
Counts
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400
300
200
100
0
2
3
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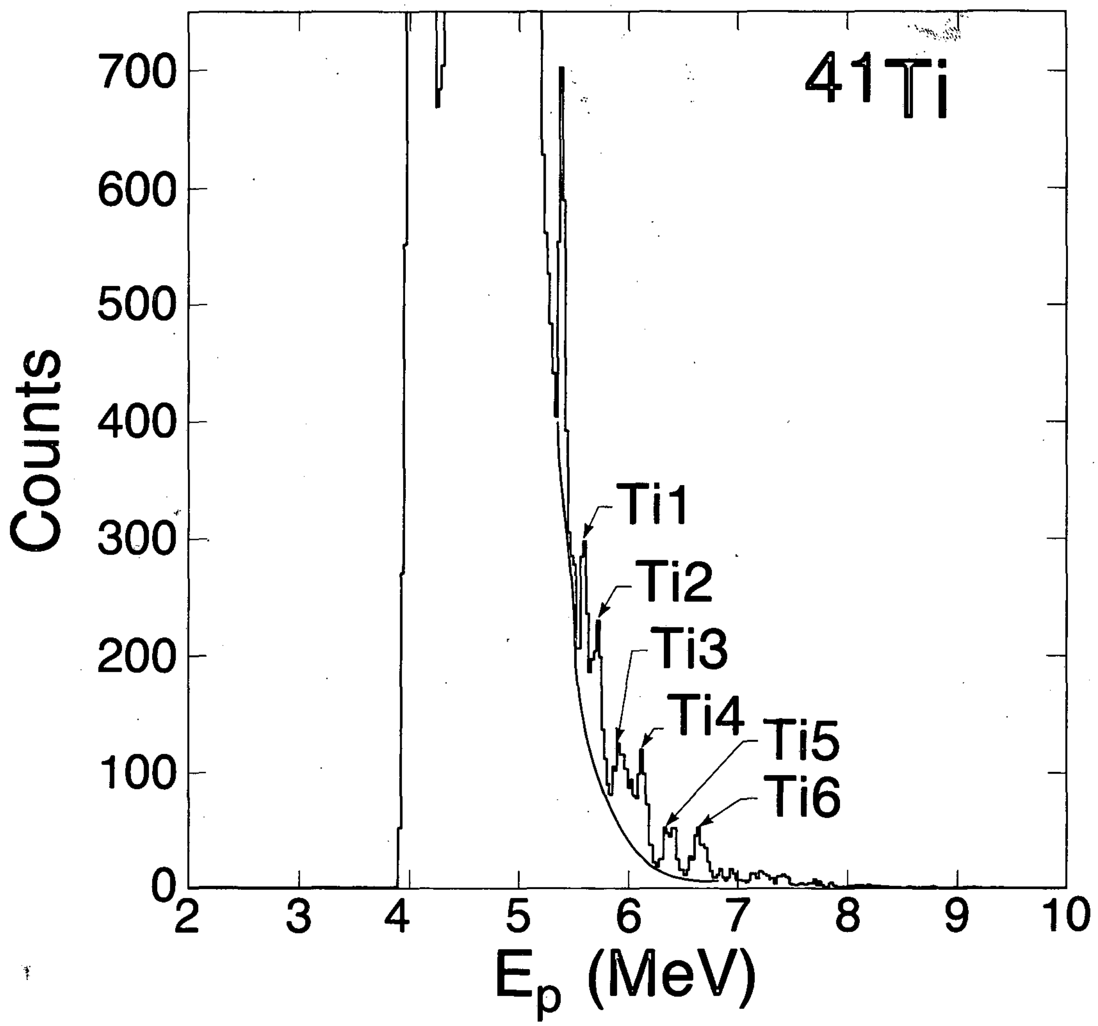
7
8
9
10
E_p (MeV)
S1
S2
S3
S4
XBL 842-10084

Fig. 3



XBL 842-10104Y

Fig. 4

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