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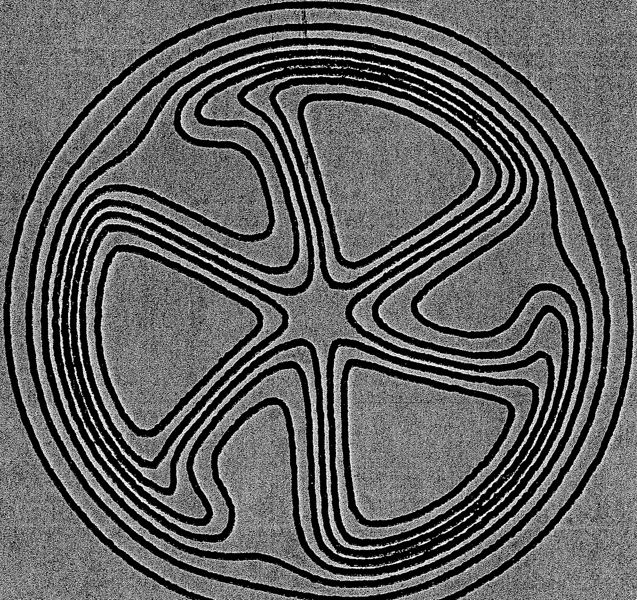

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Energy Levels of ^{25}Si from the ^{28}Si(^{3}He,^{6}He)^{25}Si Reaction at 70.4 MeV*

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ABSTRACT

The energy levels of ^{25}Si have been measured by detecting ^{6}He-particles from the ^{28}Si(^{3}He,^{6}He)^{25}Si reaction in photographic plates on the focal plane of a spectrometer. Twelve excited states were observed. The observation of weak state at 40 keV excitation leads to a new ^{25}Si ground-state mass-excess, 3.824±.010 MeV. The observed levels are discussed in terms of the isobaric multiplet mass equation and the shell model.

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The (^{3}He,^{6}He) reaction has been used previously to study the ground state masses of proton rich nuclei.[1,2,3] Six T=3/2 mass quartets have been completed this way and the results have been used to determine the coefficients of the isobaric multiplet mass equations (IMME). In principle this same equation should link the mass excesses of the excited T=3/2 states as well. The dependence of the various coefficients of the equation on excitation energy and spin can therefore be observed at a fixed value of A. The present experiment deals with the energy level scheme of ^{25}Si, which up to present was completely unknown.

Even the ground state transitions in the (^{3}He,^{6}He) reaction are difficult to observe because of the very small cross-sections (typically 1 ub/sr at the peak). Previous measurements employed a position-sensitive detector on the focal plane of a spectrometer[1,2] or a three-detector telescope.[3] When these methods are employed, the background due to neutrons and other charged particles obscures weakly populated states. In the case of the ^{28}Si(^{3}He,^{6}He)^{25}Si reaction, the resolution (70 keV) was not good enough to observe the ground state as a doublet (as predicted by the IMME), and hence the assumption was made that the peak observed was the ground state only.[2] In the present experiment relatively insensitive photographic plates were used on the focal plane of the spectrometer. The large solid angle, kinematic compensation and dispersion matching of the spectrometer, coupled with the insensitivity of the plates to neutrons, gammas and lower-mass charged-particles of the same magnetic rigidity, permitted the observation of the ground state and twelve excited states in ^{25}Si.

Ilford K(-1) plates were used with absorbers stepped in thickness to keep the ^{6}He-particles between 12 and 18 MeV at the surface of the emulsion. This puts the α-particles at 50- to 60-MeV typically. At this energy they leave barely observable tracks, which in the present experiment did not obscure any region of the plate in spite of the large number of α-particles compared to ^{6}He-particles. The elastic ^{3}He-particles, however, are so numerous at the forward angles used that they blacken the plate. Fortunately they fall at the same place as ^{6}He-particles corresponding to a fairly high excitation energy (about 6.7 MeV) in ^{25}Si. In general, the present method is limited to ^{6}He-particles of energy greater than about one-half the beam energy.

Data were taken at 9°, 12°, and 16° (LAB) with a 600 μg/cm^2 natural Si target and at 9° and 12° with a 200 μg/cm^2 SiO target. The beam energy was 70.4 MeV in all cases. The energy resolution was limited mainly by target thickness to 50 keV for the natural Si target and 28 keV for the SiO target. The spectrum taken on natural Si at 9° is shown in Fig. 1. The higher resolution SiO runs were used to attempt to resolve the first-excited-state ground-state doublet which is shown in Fig. 2.

These results show that mass measurement of ^{25}Si was predominately of the ground state, as was assumed by the authors,[2] but that the mass should be shifted downward by 8 keV which is within the error of their measurements. The new mass excess of ^{25}Si is 3.824±0.010 MeV.

The new mass of ^{25}Si changes the coefficients of the IMME only slightly. The form of the IMME used is

$$M = a+bT_z + cT_z^2 + dT_z^3.$$

The coefficients of the equation are sensitive to the choice of the mass of the lowest T=3/2 state of ^{25}Mg. In Ref. 2 the mass of ^{25}Mg was taken to be a weighted average of the measurements of Berman <u>et al.</u>[4] [7.7926±0.0040], Detraz and Richter[5] [7.782±.007] and Bohne <u>et al.</u>[6] [7.82±.01]. In the present paper the measurement of Bohne <u>et al.</u> was eliminated since it lies about three standard deviations from the weighted mean of the three measurements. This change alone reduces the cubic coefficient, d, from -7.9±3.9 to -6.3±3.9 keV. The new mass of ^{25}Si reduces d still further to -5.0±3.7.

The coefficients for the ground state and first excited state A=25 quartets are given in Table I. Since these states differ only slightly in spin ($5/2^+$ and $3/2^+$) and in energy, the agreement of the coefficients is not surprising. Also given in Table I are the predictions by Wildenthal and McGrory[7] of the coefficients of the IMME using shell-model wave functions.

These calculations include active $d_{5/2}$ and $s_{1/2}$ particles outside a closed ^{16}O core. The neutron single-particle energies used were the binding energies of a $d_{5/2}$ or a $s_{1/2}$ neutron in ^{17}O whereas the proton single particle energies came from ^{17}F. Two-body coulomb matrix elements were included. These were calculated using harmonic-oscillator wave functions. This simple method gives a good agreement with the magnitude of the coefficients but fails to predict correctly the shift of the $3/2^+$ state relative to the $5/2^+$ state as a function of T_z. The failure to predict the change of $3/2^+-5/2^+$ spacing as a function of T_z is probably due to the lack of $d_{3/2}$ particles in the calculation. Agreement between theory and experiment on the A=21 system is expected to be better. This analysis is presently under way.

The other known T=3/2, A=25 states are compared with the states found in the present experiment in Table II. The biggest gap in our present knowledge is the T=3/2 states in ^{25}Al. Since there are only two of these known, there are only two complete A=25 quartets. However, in all previously studied multiplets, the d-coefficients has been close to zero, and therefore the masses of the quartet have been predicted accurately by a quadratic relation. Hence, one can set d=0 and fit three members of the quartet to find the a, b, and c coefficients. Five multiplets can be analyzed this way. The coefficients are also given in Table II. An appreciable amplitude of $1s_{1/2}$ neutron in the neutron-rich member ^{25}Na, could account for the reduction in the magnitude of b and c, observed for the second and third excited state multiplets.

The present experiment does not indicate any strong dependence of the b and c terms of the IMME of spin or excitation energy. It would be of great interest to complete some of the remaining A=25 multiplets by finding the missing states in ^{25}Al. A more detailed discussion and the results of similar experiments on ^{21}Mg and ^{37}Ca will be presented in a future paper.

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TABLE I. Coefficients of the IMME ($M=a+bT_z+cT_z^2+dT_z^3$). The units are keV.

	Ground State (5/2$^+$)		1st Excited State (3/2$^+$)	
	Exp	Shell-Model	Exp	Shell-Model
b	-4382 ±6	-4382	-4371 ±11	-4417
c	221 ±4	221	216 ±4	214
d	-5.0 ±3.7	-2.7	-2.7 ±5.5	6.0

Table II. T=3/2 Energy Levels in the A=25 System.

J^π	Energy from Lowest T=3/2 State (MeV). ^{25}Na a)	^{25}Mg b)	^{25}Al c)	^{25}Si d)	Coefficients of IMME (keV) (d=0) b	c
$5/2^+$	0.0	0.0	0.0	0.0	-4389	220
$3/2^+$	0.090	0.080	0.072	0.040(5)	-4376	216
$1/2^+$	1.068	1.009	--	0.815(15)	-4311	207
$3/2^+$	2.201	2.206	--	1.963(15)	-4317	178
	2.417	--	--	2.373(10)		
	2.788	--	--	2.606(10)		
	2.914	2.836	--	--		
	--	--	--	[3.08(30)]		
	3.353	--	--	3.29(30)		
	3.455	--	--	[3.40(30)]		
	3.685	--	--	--		
$1/2^-$	3.928	3.943	--	3.82(20)		
$1/2^-$	3.950	3.965	--	--		
$1/2^-$	3.995	3.993	--	--		
$(1/2^-,3/2^-,5/2^-)$	5.190	5.116	--	4.99(25)	-4330	223
	--	--	--	5.42(40)		
	5.692			5.73(50)		

a) J.A. Becker, *et al.* Phys. Rev. **188**, 1783(1969); E. Kramer, *et al.* Nucl. Phys. **A165**, 353(1971).

b) From References 4 and 5.

c) G.C. Morrison *et al.* Phys. Rev. **174**, 1366(1968) and B. Teitelman and G.M. Temmer, Phys. Rev. 177, 1656(1969).

d) Present work; the square brackets indicate levels which were observed at only one angle. Errors in keV in parenthesis.

FIGURE CAPTIONS

Figure 1. Spectrum from $^{28}\mathrm{Si}(^{3}\mathrm{He},^{6}\mathrm{He})^{25}\mathrm{Si}$ at $_{\mathrm{LAB}}=9°$ and $E_{\mathrm{incident}}=70.4$ MeV.

Figure 2. Thin target runs on $^{28}\mathrm{Si}(^{3}\mathrm{He},^{6}\mathrm{He})^{25}\mathrm{Si}$ at 9° and 12°. The dotted curves are Gaussians 40 keV apart fitted to the data. The solid curve is the sum of the two Gaussians.

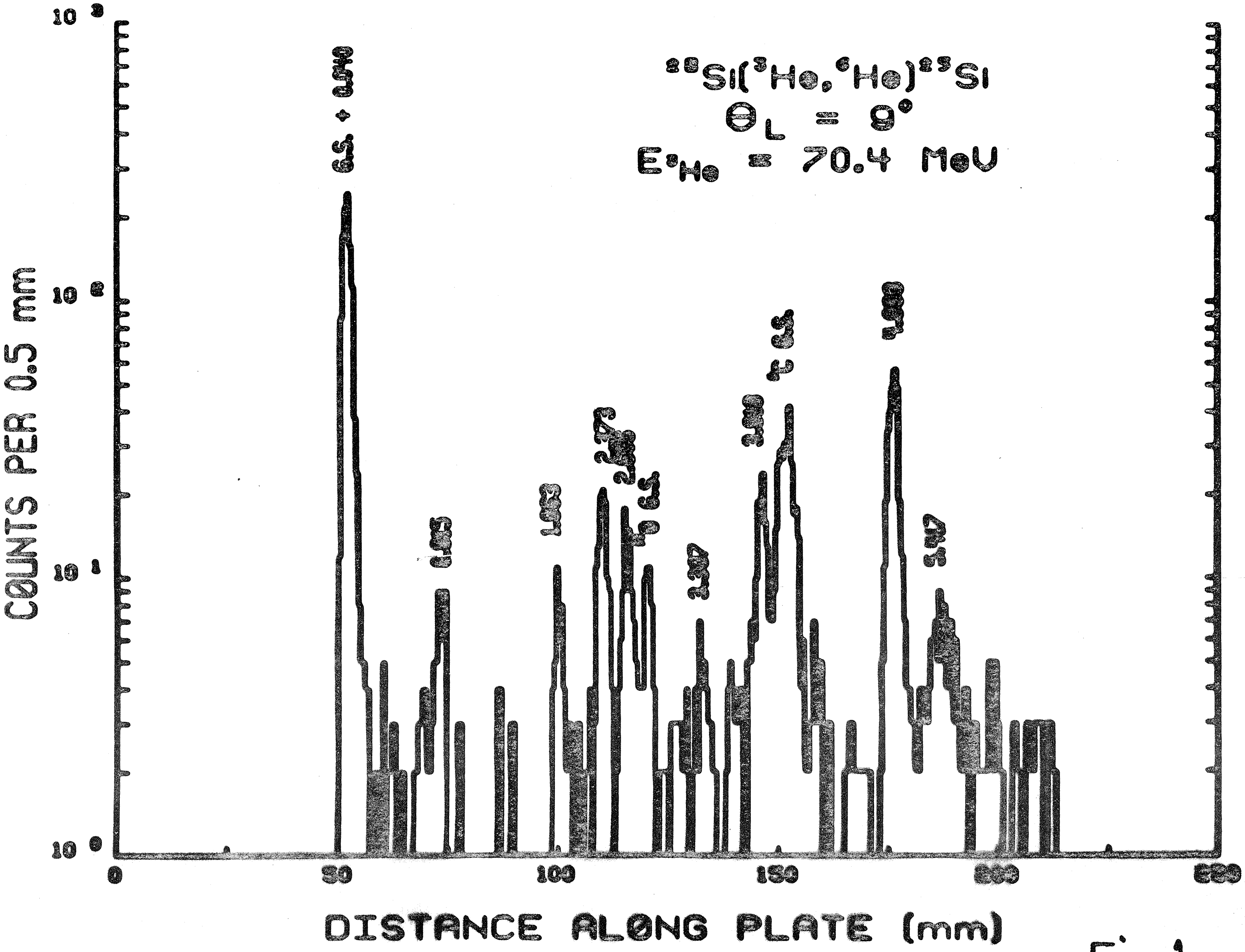
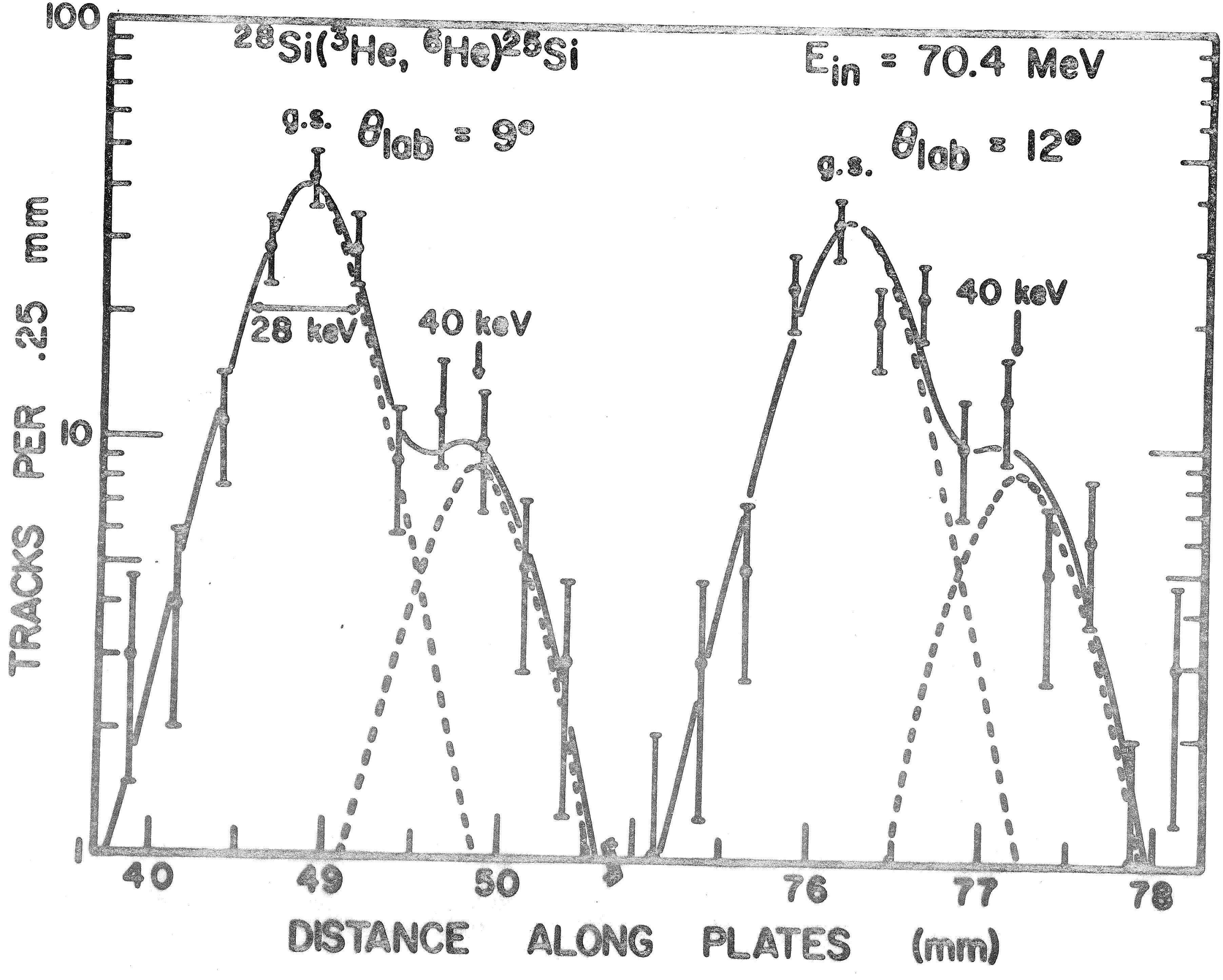

$^{28}Si(^{3}He,^{6}He)^{25}Si$
$\Theta_L = 9°$
$E_{^3He} = 70.4$ MeV
G.S. + 0.040
COUNTS PER 0.5 mm
DISTANCE ALONG PLATE (mm)
10^0
10^1
10^2
10^3
0
50
100
150
200
250

Fig 1



^{28}Si(^{3}He, ^{6}He)^{25}Si
E_{in} = 70.4 MeV
g.s.
θ_{lab} = 9°
g.s.
θ_{lab} = 12°
28 keV
40 keV
40 keV
100
10
1
TRACKS PER .25 mm
40
49
50
76
77
78
DISTANCE ALONG PLATES (mm)