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Mass of $^{35}K^*$

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ABSTRACT

The $^{40}Ca(^3He,^8Li)^{35}K$ reaction at 73.7 and 75.8 MeV was employed to make the first observation of ^{35}K and to measure its mass. The Q-value for the reaction was found to be -29.693±0.020 MeV and the mass excess to be -11.170±0.020 MeV. Excited states of ^{35}K were found at 1.56 and 2.89 MeV.

Nuclear Reactions: $^{40}Ca(^3He,^8Li)^{35}K$, E=75.8, 73.7 MeV, measured $\sigma(8°)$ Q-value

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I. INTRODUCTION

In this paper we discuss the first observation of ^{35}K and a measurement of its mass excess. This nucleus is one for which an accurate measurement of the mass is required to complete the ground state isobaric mass quartets in the sd shell. ^{35}K and the other $T_z=-3/2$, A=4n+3 nuclei can be reached with either the $(p,^6He)$ or $(^3He,^8Li)$ reaction on A=4n, $T_z=0$ targets. In a recent experiment[1] the $(^3He,^8Li)$ reaction was employed for the first time and shown to have some advantages over $(p,^6He)$. The main source of these advantages results from the somewhat less negative Q-values and the capability of modern sector focused cyclotrons to produce ^3He beam energies 50% higher than proton beam energies.

II. EXPERIMENTAL

The $^{40}Ca(^3He,^8Li)^{35}K$ reaction was induced with 73.7 and 75.8 MeV ^3He-particles from the Michigan State University Cyclotron. The ^8Li-particles were detected on the focal plane of the Enge split pole spectrograph in the manner described previously.[2] One addition to the scintillator-proportional counter detector system was a second proportional counter which provided redundant energy-loss information. This has proven to be very valuable in reducing background due to occasional events from lighter particles which have energy losses considerably larger than the mean value. Time-of-flight measurements eliminate the vast majority of these events, but the random arrival of the γ-ray in the scintillator at the required time for a ^8Li could then simulate a ^8Li ion.

The targets consisted of 370 μg/cm^2 and 190 μg/cm^2 of enriched ^{40}Ca on a 20 μg/cm^2 natural carbon backings. The 1% ^{13}C in the backing proved to be the major source of background in this experiment since the (^{3}He,^{8}Li) reaction on ^{13}C and ^{40}Ca have similar Q-values. The energy loss in the ^{40}Ca targets, about 150 and 80 keV, was the determining factor in the resolution and also added to the error of the Q-value determination. Even with the thick target, long runs (≈1 day) were required, but the ^{13}C peak present in the spectrum provided a check on drifts. Calibration runs made before and after the data runs showed only a few kilovolts of drift. The final error (20 keV) of the mass includes contributions mainly from centroid determination but also from beam energy and angle determination.

The spectrum of ^{40}Ca(^{3}He,^{8}Li)^{35}K shown in Fig. 1 was taken at 8° and 73.8 MeV. The cross section for ^{13}C(^{3}He,^{8}Li) reaction leading to the ground state of ^{8}B about 60 times greater than that for the ^{35}K ground state. An enriched ^{12}C backing would have improved the appearance of the data substantially, because much of the background between peaks is due to the ^{13}C(^{3}He,^{8}Li) reaction to unbound states, but it would not have affected the error of the Q-value measurement. One can also see in Fig. 1 excited states of ^{35}K at 1.56±0.04 and 2.69±0.05 MeV, which corresponds to the $1/2^+$ and ($5/2^+$) levels in the mirror nucleus ^{35}S at almost the same energies.[3] The resolution of the spectrum is about 90 keV which permits an observation of the approximately 200 keV broadening of the ^{35}K(g.s.) + ^{8}Li(0.98 MeV) peak due to the recoil after γ-emission by the ^{8}Li. The equivalent companion peak for the 1.56 MeV state is apparently too weak to be observed.

The Q-value for the ^{40}Ca(^{3}He,^{8}He)^{35}K reaction was determined by means of a comparison to the ^{40}Ca(^{3}He,^{6}Li)^{37}K, ^{40}Ca(^{3}He,^{7}Li)^{36}K, ^{24}Mg(^{3}He,^{8}Li)^{19}Na and ^{13}C(^{3}He,^{8}Li) reactions. A list of the cross sections at 8° and 73.8 MeV for these reactions is given in Table I. An average value of these calibrations was used, and a contribution to the error due to their lack of perfect internal agreement (approximately 5 keV) was included. The final Q-value for the ^{40}Ca(^{3}He,^{8}Li)^{35}K reaction obtained was -29.693±0.020 MeV. This corresponds to a mass excess of -11.170±0.020 MeV for ^{35}K.

III. DISCUSSION

Although the ^{35}K mass is needed to complete the A=4n+3 ground state isobaric mass quartets in the sd shell, it does not complete the A=35 quartet satisfactorily because the corresponding T=3/2, $J^\pi=3/2^+$ level in ^{35}Ar is not accurately known. It has only been observed once in a difficult (^{3}He,n) experiment.[4] The value obtained for the excitation energy is 5.537±0.025 MeV, but the peak is weak and it rides on top of a strong sloping background which made accurate energy measurements difficult. Using the quartic form isobaric multiplet mass equation (IMME) and the present ^{35}K mass excess one can predict the level to lie at 5.579±0.014 MeV excitation energy, and therefore the above experimental value gives a significant d-coefficient, -21±13 keV. This d-coefficient would represent the largest deviation from the IMME ever found. Both (p,d)[5] and (^{3}He,^{4}He)[6] reactions have shown a strong T=1/2, $J^\pi=3/2^+$ or $5/2^+$ level at close to the energy predicted by the IMME. The most accurate measurement of this level, by Betts, Fortune and Middleton[6] using (^{3}He,^{4}He) gives an excitation energy of 5.591±0.01 MeV. This reaction is of course expected to populate only T=1/2 states. Thus the situation in ^{35}Ar may be very similar to ^{35}Cl, its mirror, in which the spacing between T=1/2 and 3/2 levels is 6 keV. If the T=1/2 states in the two nuclei prove to be $3/2^+$, they could have a marked effect on the T=3/2 level positions and therefore on the IMME.

In an attempt to observe the T=3/2 state in ^{35}Ar, the (^{3}He,t) reaction was studied at 35 MeV and forward angles with an energy resolution of 40 keV. The data shown in Fig. 2 were observed at 6° with a 200 μg/cm^2 Li-^{35}Cl target. The peaks are labelled according to Table III of Ref. 6, and there is no evidence for a peak at the energy observed in the (^{3}He,n) experiment, which would lie abou half way between peaks 18 and 19. Since the ^{36}Ar(^{3}He,^{4}He) reaction can excite only T=1/2 states, one might therefore conclude that the T=1/2 and T=3/2 levels do indeed lie close in energy. Isolating the two levels will require much better resolution, and an equally important experiment would be to measure the J^π of the T=1/2 state observed in the neutron pickup experiments. There also is the possibility that the (^{3}He,n) value is correct, but that the state is weakly excited in (^{3}He,t) at forward angles.

In Table II a comparison is made of the present mass excess measurement to several predictions. The prediction labelled Kelson and Garvey was made using the equations given by those authors[7] but with the most recent mass data available. The prediction of Wapstra and Gove[9] is based on the systematics of

nuclear masses. A very interesting prediction was made by Sherr and Talmi.[8] They showed that a difference between the neutron-neutron and proton-neutron interaction in the T=1 state is indicated by existing multiplet data in the $d_{3/2}$ shell. This difference is consistent with nucleon-nucleon scattering data and has a marked effect which adds to Coulomb energy differences between members of the multiplet. The measured ^{35}K mass, unfortunately, does not distinguish very strongly between the various theoretical models.

Table I.--Laboratory cross sections at 8° for various multiparticle transfer reactions induced by 73.8 MeV ^{3}He-particles.

Reactions	Final states (MeV)	$d\sigma/d\Omega$ μb/sr
^{40}Ca(^{3}He,^{8}Li)	g.s.	0.027 ± 0.004
^{40}Ca(^{3}He,^{7}Li)	g.s.	0.491 ± 0.11
^{40}Ca(^{3}He,^{6}Li)	g.s.	10.2 ± 1.2
^{13}C(^{3}He,^{8}Li)	g.s.	1.9 ± 0.3

Table II.--Comparison of the measured ^{35}K mass to various Theoretical predictions

Mass Excess (MeV)	Reference
-11.170±0.020	Present Result
-11.149	Kelson and Garvey[7]
-11.24	de Meijer, *et al.*[8]
-11.25	Wapstra and Gove[9]
-11.148	Sherr and Talmi[10]

FIGURE CAPTIONS

Figure 1.--Spectrum from the $^{40}Ca(^{3}He,^{8}Li)^{35}K$ reaction at 73.8 MeV and 8°. The scale corresponds to approximately 33 keV per channel.

Figure 2.--Spectrum from the $^{35}Cl(^{3}He,t)^{35}Ar$ reaction at 6° and 35 MeV. The large background is due to the $(^{3}He,t)$ reaction on the ^{6}Li and ^{7}Li in the 200 μg/cm^{2} Li-^{35}Cl target. The peak numbers are from the $(^{3}He,^{4}He)$ paper of Betts, Middleton and Fortune.[6] Peak 19 is at an excitation energy of 5.591±0.010 MeV, which is very close to the expected T=3/2 state. Each channel corresponds to approximately 11.4 keV.

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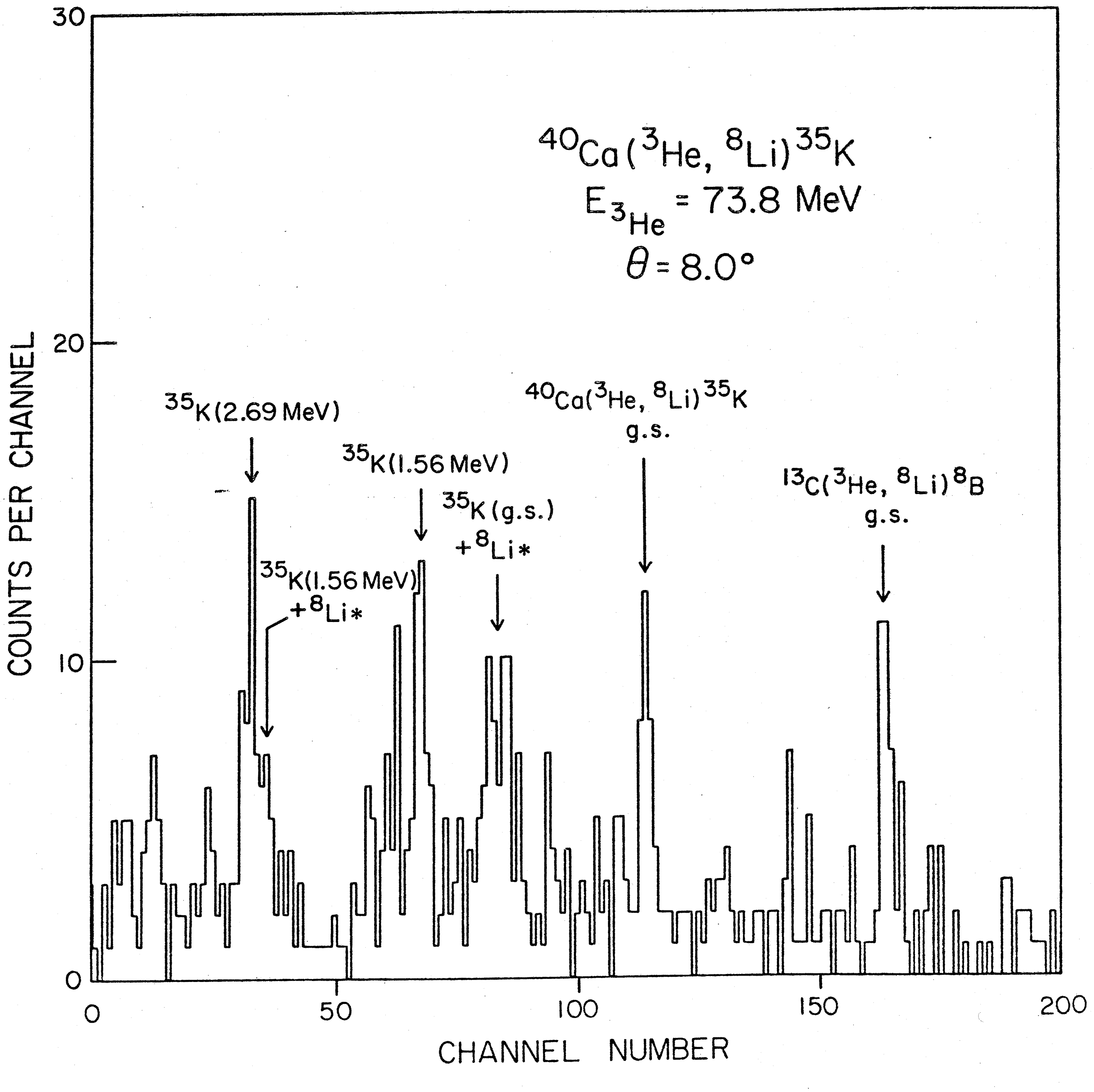
$^{40}Ca(^{3}He, ^{8}Li)^{35}K$
$E_{^{3}He} = 73.8$ MeV
$\theta = 8.0°$
$^{35}K(2.69$ MeV)
$^{35}K(1.56$ MeV)
$^{35}K(1.56$ MeV) $+ ^{8}Li*$
^{35}K(g.s.) $+ ^{8}Li*$
$^{40}Ca(^{3}He, ^{8}Li)^{35}K$ g.s.
$^{13}C(^{3}He, ^{8}Li)^{8}B$ g.s.
COUNTS PER CHANNEL
CHANNEL NUMBER
0
10
20
30
0
50
100
150
200

Fig. 1

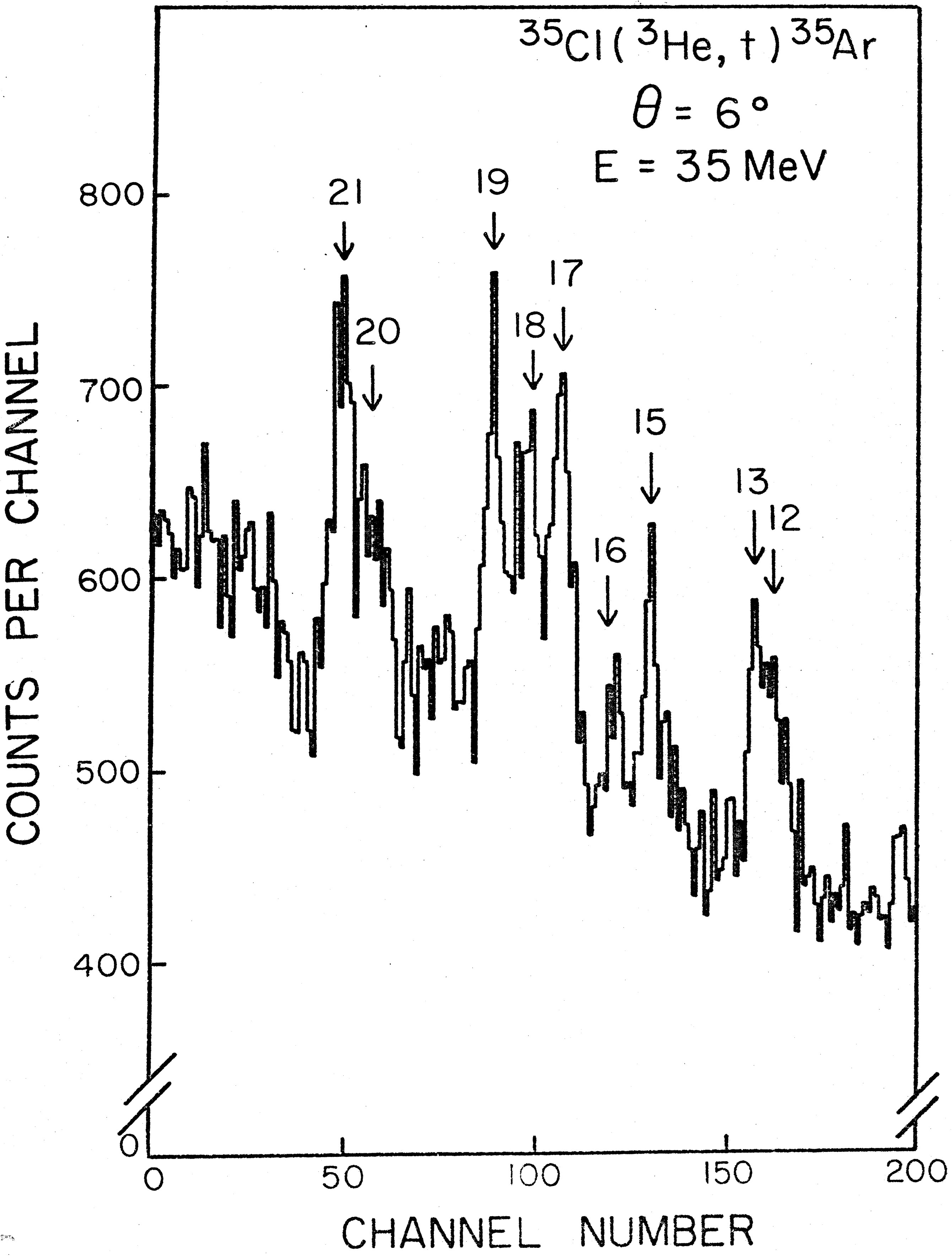
$^{35}Cl(^{3}He,t)^{35}Ar$
θ = 6°
E = 35 MeV
21
20
19
18
17
16
15
13
12
COUNTS PER CHANNEL
800
700
600
500
400
0
CHANNEL NUMBER
0
50
100
150
200

Fig. 2