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Mass and excited states of the nucleus ^{89}Mo

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The mass excess of ^{89}Mo has been measured using the ^{92}Mo(^{3}He,^{6}He) reaction at 70-MeV bombarding energy. The mass excess was determined to be -75.008 ± 0.015 MeV. The excited states observed are also reported.

[NUCLEAR REACTIONS ^{92}Mo(^{3}He, ^{6}He)^{89}Mo; $E = 70$ MeV, measured reaction Q values, deduced mass excess, excitation energies.]

The (^{3}He, ^{6}He) reaction has been used extensively for studying the properties of proton-rich nuclei, especially in the lighter mass region. Recently we have used it to measure the masses of a number of medium mass nuclei.[1] These measurements not only test the accuracy of mass relations in the proton-rich region but also provide important outposts for future β-decay mass determinations. In this communication we report the mass and excited states of the isotope ^{89}Mo.

The β^+ decay of ^{89}Mo was first reported by Butement and Qaim.[2] They reported an activity of 7 min half-life based on the observation of positrons with energies greater than 3.6 MeV. The β^+ endpoints observed were 4.05 and 4.95 MeV. No γ rays were observed in the decay. The results of our work show that the maximum β^+ decay energy available in the decay of ^{89}Mo is 4.59 MeV. Therefore, the 4.95-MeV activity observed could not have been ^{89}Mo. Much later, Hagenour *et al.*[3] attempted to study ^{89}Mo. Using three different targets, two projectiles, and seven energies they reported no activities which could be identified as ^{89}Mo. Systematics in this region predict a half-life of 1–2 minutes for ^{89}Mo. Based on these considerations, we doubt that the activity observed in Ref. 2 was really ^{89}Mo.

The Michigan State University cyclotron provided 70-MeV ^{3}He beams with intensities of approximately 700 nA on target. Reaction products were identified in the focal plane of an Enge split-pole spectrograph with a two wire, charge-division proportional counter in a manner described in Ref. 1. The resolution obtained was approximately 60 keV. A target of 260 μg/cm^2 thickness was produced by electron sputtering 98.3% enriched ^{92}Mo onto a 20 μg/cm^2 carbon foil reinforced by 2 μg/cm^2 Formvar. The principal calibration reaction chosen was ^{26}Mg(^{3}He, ^{6}He). The ^{26}Mg target used was a 251 μg/cm^2 self-supporting foil. Target thickness was determined by α-gauge measurements using 8.784-MeV α particles from ^{228}Th decay products.

Calibration of the spectrograph was accomplished in a two stage manner. First, the ^{27}Al(^{3}He, α) reaction was used to calibrate the detector in mm/channel. The ^{26}Mg(^{3}He, ^{6}He) reaction then served as the reference reaction. This reaction was chosen because its Q value of -13.407 ± 0.002 MeV allows the entire experiment to be performed at the same spectrograph field setting. The mass excesses used for the relevant nuclei involved in the calibration are those of Wapstra and Bos.[4]

The results reported here are based on data taken at 7° and 10° laboratory angles. In an effort

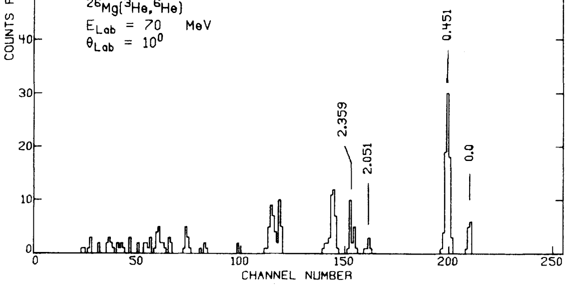

FIG. 1. Spectrum of all events from the ^{92}Mo(^{3}He, ^{6}He) reaction ($Q_{\mathrm{total}} = 37\,000$ μC) and the calibration reaction ^{26}Mg(^{3}He, ^{6}He). Both spectra were taken at the same spectrograph field strength.

TABLE I. Comparison of ^{89}Mo mass excess to predictions (see Ref. 5).

Experimental	−75.008 ± 0.015 MeV
Myers	−75.72
Groofey, Hilf, Takahashi	−75.41
Seeger and Howard	−75.2
Liran and Zeldes	−74.65
Beiner, Lombard, Mos	−74.5
Janecke, Garvey, Kelson	−74.68
Comay and Kelson	−74.90
Janecke and Cynou	−74.48
Wapstra and Bos (Ref. 4)	−75.220

TABLE II. Identified excited states of ^{89}Mo. Results of ^{92}Mo(^{3}He, ^{6}He) reaction.

Excitation energy	J^π [a]
0.0	$\frac{9}{2}^+$
0.124 ± 0.010	$\frac{7}{2}^+$
(0.40 ± 0.04)	$\frac{1}{2}^-$
1.25 ± 0.015	
1.74 ± 0.015	
2.11 ± 0.015	
5.34 ± 0.025	
5.48 ± 0.025	

[a] Assignments of J^π are based only on nuclear systematics.

to minimize systematic errors, data were taken in a total of five separate runs during two independent experiments.

A spectrum of all events observed at 10° laboratory angle ($Q = 37\,000\ \mu C$) is shown in Fig. 1, along with a spectrum of the calibration reaction. The Q value of the ^{92}Mo(^{3}He, ^{6}He) was determined to be $-14.465 \pm .015$ MeV. This results in a mass excess of -75.008 ± 0.015 MeV for ^{89}Mo. A careful analysis of the possible sources of experimental uncertainties predicts $\sigma = 0.015$ MeV. The observed rms deviation for five runs was 0.011 MeV. The larger of these uncertainties was chosen to represent the error of the experiment. Table I compares our results to the predictions of various mass relations.

The foregoing discussion assumes that the ground state of ^{89}Mo has been properly identified. To do this requires an understanding of the level scheme of ^{89}Mo, but no information on excited states in ^{89}Mo exists. Therefore it is necessary to rely on information from nuclear systematics to guide our understanding of ^{89}Mo.

The systematics of the nearby odd-A, $N = 47$ nuclei indicate that the ground state of ^{89}Mo should be $\frac{9}{2}^+$. The first excited state in ^{83}Kr, ^{85}Sr, and ^{87}Zr is a $\frac{7}{2}^+$ state and occurs at 0.0094, 0.232, and 0.201 MeV,[6] respectively. The second excited states in these nuclei have $J^\pi = \frac{1}{2}^-$ and are located at 0.0416, 0.239, and 0.336 MeV.[6] As can be seen in Table II and Fig. 1, the first excited state of ^{89}Mo is identified at 0.124 MeV excitation energy. Although very weakly populated, a second excited state at approximately 0.40 MeV is indicated. Other excited states observed in this study are reported in Table II.

These systematic trends imply that the 0.124 MeV level has $J^\pi = \frac{7}{2}^+$ and the tentative level at 0.40 MeV would be the $J^\pi = \frac{1}{2}^-$ state. Since there are no other low-lying states in nearby $N = 47$ nuclei, we are confident of the proper identification of the ground state.

The cross section for populating the ^{89}Mo ground state was observed to be 51 nb/sr. The maximum observed cross section to any state was 83 nb/sr to the 1.74-MeV state. This agrees well with the cross sections observed in the ^{90}Zr(^{3}He, ^{6}He)^{87}Zr reaction in Ref. 1.

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