ENAM98, Shanty Creek Resort, Bellaire, Michigan, June 23-27, 1998

Study of the High-j States in ^{249}Cm

I. Ahmad,* B. B. Back,* A. Bacher, G. P. A. Berg,† R. R. Chasman,* C. C. Foster,† J. P. Greene,* T. Ishii,*,‡ W. R. Lozowski,† L. R. Morss,* W. Schmitt,†,§ E. J. Stephenson† and T. Yamanaka†,¶

**Argonne National Laboratory, Argonne, IL 60439*
†Indiana University Cyclotron Facility, Bloomington, IN 47405

Abstract: We have performed the reaction ^{248}Cm(^{4}He,^{3}He) using 98.5-MeV alpha particles from the IUCF cyclotron to populate high-j states in ^{249}Cm. A tentative assignment of the $k_{17/2}$ component of the 1/2$^+$[880] Nilsson state has been made.

INTRODUCTION

The position of the $k_{17/2}$ (ℓ=8) orbital plays an important role in determining the stability of superheavy elements. Because of its large degeneracy, it has a significant influence on the magnitude of shell corrections in this region. The lowest component of the $k_{17/2}$ orbital, in a deformed prolate potential, is the 1/2$^+$[880] Nilsson state [1] which is expected to lie below 2 MeV in nuclei with N≥152. As yet, this orbital has not been observed. In an earlier high resolution (d,p) study [2] of ^{251}Cf, we identified all of the neutron single-particle states between the deformed gaps at N=152 and N=164. Using a momentum-dependent single particle potential, which reproduces the observed level energies in ^{251}Cf, we calculate the energy of the 1/2$^+$[880] orbital at ~1400 keV in ^{251}Cf. An angular momentum decomposition of this orbital indicates that it is 74% $k_{17/2}$. Such orbitals are expected to be strongly populated in (^{4}He,^{3}He) reactions [3,4] due to the angular momentum mismatch. Because of the intense radioactivity associated with ^{250}Cf, it is not possible to study ^{251}Cf levels in the reaction ^{250}Cf(^{4}He,^{3}He). For this reason, we have carried out a study of the (^{4}He,^{3}He) reaction with the longer-lived isotone ^{248}Cm. The nuclide ^{249}Cm is an isotone of ^{251}Cf and hence the ^{249}Cm level ordering is expected to be similar to that of ^{251}Cf. A detailed article has been submitted for publication [5].

EXPERIMENTAL RESULTS

The ^{248}Cm(^{4}He,^{3}He) measurement was performed at the Indiana University Cyclotron Facility. A beam of 98.5-MeV α-particles with currents up to 25 pnA was incident on a 110-μg/cm^2 ^{248}Cm target on a 75-μg/cm^2 carbon backing. The emerging ^{3}He ions were momentum analyzed by the K600 high-resolution magnetic spectrometer. For this experiment, the spectrometer was equipped with a magnetic septum at the entrance to allow operation at small scattering angles close to the beam. A brass collimator at the front of the septum set the solid angle to 0.47 msr. Measurements were made at θ_{cm}=4.1°, 6.1°, 10.2°, 12.2°, and 16.2°. ^{3}He ions that passed through the spectrometer were detected by a series of wire chambers and scintillators located parallel to the spectrometer focal plane. Tuning of the beam line and spectrometer magnetic elements for dispersion matching and focus yielded a minimum resolution of about 45 keV (FWHM). Momentum, as measured by position along the K600 focal plane, was calibrated by observing the excited state spectrum from the ^{208}Pb(^{4}He,^{3}He)^{209}Pb reaction without changing the spectrometer magnetic field settings. Transitions to the ground and first two excited states at 779 and 1423 keV in ^{209}Pb were used to produce a quadratic relationship between focal plane position and ^{3}He momentum that was then applied to the ^{249}Cm spectra.

DISCLAIMER

DISCUSSION

The assignments of levels in ^{249}Cm, which are strongly populated in the ^{248}Cm(^{4}He,^{3}He) reaction, are based on a comparison of the cross sections measured for this reaction with those measured for known high-j states in ^{209}Pb and ^{233}Th. The cross sections were also calculated with the DWUCK4 code [6]. The magnitude of the cross section and the angular distribution are tracked by the calculation but the agreement is only qualitative. Thus it is not possible to firmly distinguish ℓ-transfer or parity from a comparison of measured and calculated cross sections alone.

The ^{232}Th(^{4}He,^{3}He) reaction (Fig. 1) shows only two strong peaks, which are associated with the $j_{15/2}$ orbital. Because of the large gap at N=152 [1], only states above N=152 gap are populated with substantial intensities in ^{249}Cm. In the ^{248}Cm(^{4}He,^{3}He) spectrum, shown in Fig. 2, a strong peak at 593 keV was observed at all angles. This peak is identified as the 15/2 member of the 11/2$^-$[725] band. The same level has been identified at 570 keV in the isotone ^{251}Cf [3]. The peak at 664 keV has been assigned to the 11/2 member of the 9/2$^+$[615] orbital because this state is expected to have a large cross section and it has been identified in ^{251}Cf at 680 keV. For the 1898 keV level, the observed cross section is about one half the calculated value as is the case for the 988 keV level in ^{233}Th. The measured cross section for the 1560 keV level agrees well with the value calculated for the j=17/2 component of the 1/2$^+$[880] band. It is possible that for the higher $j_{15/2}$ states the cross section is reduced because the state is mixed with many other states. On this basis it is plausible that the 1898 keV state would be the 15/2 member of the 13/2$^-$[716] band and the 1560 keV level would be the 17/2 member of the 1/2$^+$[880] band.

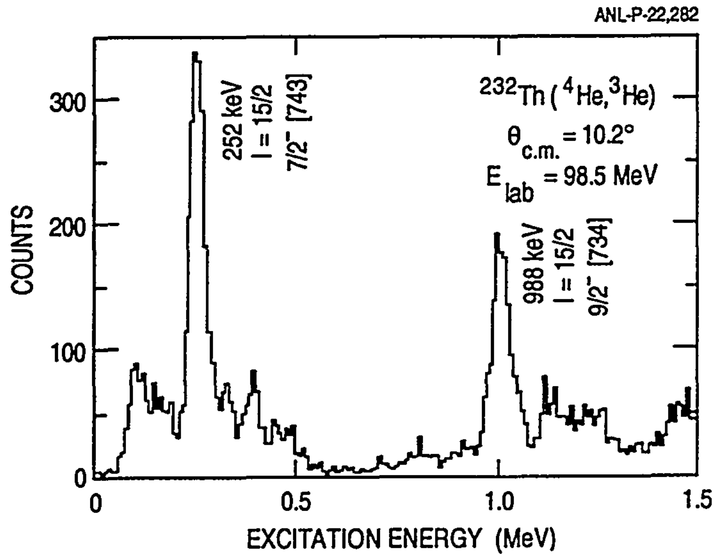

Figure 1. A portion of the ^{3}He excitation energy spectrum from the reaction ^{232}Th(^{4}He,^{3}He) measured with the K600 magnetic spectrometer.

To get some idea of the uncertainties involved in theoretical assignments, we have made calculations of level orderings and spacings using a momentum-independent (m.i.) Woods-Saxon potential, in addition to the calculations carried out with the momentum-dependent (m.d.) potential discussed in [2]. Using the m.i. potential, we are able to carry out Strutinsky method calculations to determine the deformation. We have done such calculations in a three dimensional deformation space and find that the

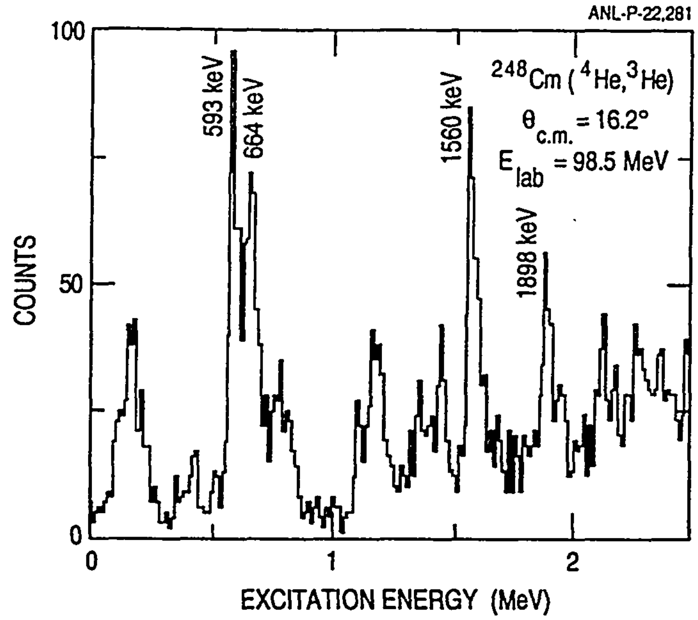

Figure 2. A portion of the ^{3}He spectrum from the reaction ^{248}Cm(^{4}He,^{3}He) measured with the K600 magnetic spectrometer.

minimum in the energy surface is at ν_2=0.24, ν_4=-.01 and ν_6=0.02; in rather good agreement with the deformation inferred [2] from the observed low-lying levels (ν_2=0.25, ν_4=-.01 and ν_6=+.02). In Fig. 3, we show the single-particle spectra calculated with the two potentials and compare them with the experimentally known levels in ^{251}Cf [2] and ^{249}Cm [7,8]. The level orderings and spacings obtained from the momentum independent and momentum dependent potentials are in fairly good agreement with each other, as well as with the experimental assignments below 800 keV. Both potentials give a large gap at N=164. Above the gap, the levels calculated with the m.i. potential are typically 100-200 keV higher than those obtained with the m.d. potential. The notable exception to the agreement in level positions obtained from the two potentials is the position of the 1/2$^+$[880] orbital, which is about 600 keV higher in the m.i. calculation. We note that the 1/2$^+$[880] configuration is at a slightly larger deformation than the other configurations because of its very strong deformation driving character. With these differences in the theoretical estimates, we feel that either of the large peaks at 1560 and 1898 keV could be associated with the 1/2$^+$[880] orbital. Assuming that the level assignments are consistent with the m.i. potential, we feel that we can calculate [9] the properties of the superheavy elements with a considerable degree of confidence using the Strutinsky prescription.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy, Nuclear Physics Division, contract No. W-31-109-ENG-38 and by the National Science Foundation Grant PHY 48-308-44. The calculations reported here were carried out on the SP computer of the MCS Division of the Argonne National Laboratory and the NERSC facility at Livermore and Berkeley. The authors are also indebted for the use of ^{248}Cm to the Office of Basic Energy Sciences, U.S. Department of Energy, through the transplutonium element production facilities at Oak Ridge National Laboratory.

ANL-P-21,965a

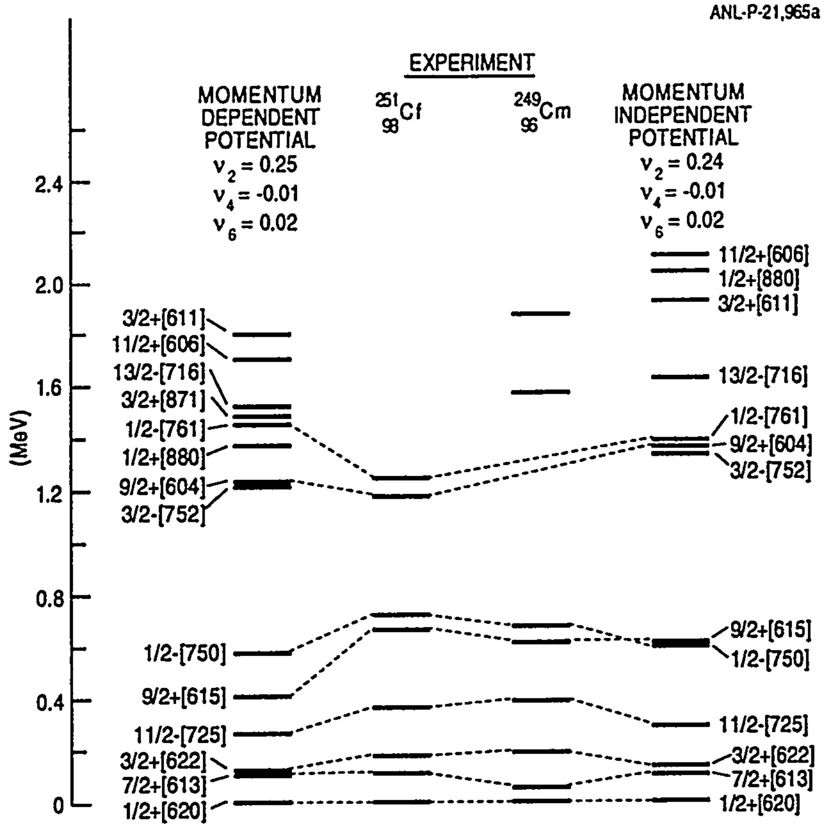

Figure 3. Experimental bandhead energies of neutron orbitals in ^{249}Cm [7,8] and ^{251}Cf [2] along with theoretical values.

REFERENCES

‡Permanent address: JAERI, Tokai, Ibaraki, Japan
§Present address: Massachusetts Institute of Technology, Cambridge, MA 02139
¶Exchange student from the Research Center for Nuclear Physics, Mihogaoka 10-1, Ibaraki, Osaka 567, Japan

1. Chasman, R. R., Ahmad, I., Friedman, A. M., and Erskine, J. R., Rev. Mod. Phys. **49**, 833-891 (1977).
2. Ahmad, I., Chasman, R. R., Friedman, A. M., and Yates, S. W., Phys. Lett. **251**, 338-342 (1990).
3. Massolo, C. P. et al., Phys. Rev. **C34**, 1256-1261 (1986).
4. Tickle, R., and Gray, W. S., Nucl. Phys. **A247**, 187-194 (1975).
5. Ahmad, I., submitted to Nucl. Phys. A.
6. Kunz, P. D. and Rost, E., University of Colorado, code DWUCK4.
7. Braid, T. H., Chasman, R. R., Erskine, J. R., and Friedman, A. M., Phys. Rev. **C4**, 247-262 (1971).
8. Hoff, R. W. et al., Phys. Rev. **C25**, 2232-2253 (1982).
9. Chasman, R. R., and Ahmad, I., Phys. Lett. **B392**, 255-261 (1997).