PHYSICAL REVIEW C VOLUME 26, NUMBER 4 OCTOBER 1982

Beta-delayed proton decay of an odd-odd $T_z = -2$ isotope, ^{22}Al

M. D. Cable, J. Honkanen,[*] R. F. Parry, H. M. Thierens,[†] J. M. Wouters,[‡] Z. Y. Zhou,[§] and Joseph Cerny
Department of Chemistry and Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

(Received 17 May 1982)

A helium jet system and the ^{24}Mg(^{3}He,$p4n$)^{22}Al reaction at 110 MeV have been used to discover the first odd-odd $T_z = -2$ nuclide ^{22}Al ($t_{1/2} \sim 70$ ms), which has been predicted to lie on the edge of stability. Beta-delayed protons from its decay establish the mass excess of the lowest $T = 2$ state in ^{22}Mg as 13.650 ± 0.015 MeV corresponding to an excitation energy of 14.044 MeV.

[RADIOACTIVITY ^{22}Al from ^{24}Mg(^{3}He,$p4n$); measured β-delayed protons, $T_{1/2}$; deduced branching and σ; derived mass excess of lowest $T = 2$ state in ^{22}Mg.]

While the decays of several even-even $T_z = -2$ nuclei have been studied,[1,2] to date no odd-odd $T_z = -2$ nucleus has been characterized. We wish to report the observation of the β^+-delayed proton decay of the first such nucleus, ^{22}Al. In addition to isobaric analog state masses and β-decay information gained in this type of work, the particle stability of ^{22}Al has been a question of interest for many years[3] since the first of the Kelson-Garvey type calculations.[4] Most mass models predict ^{22}Al to be at the very limit of particle stability, with some models indicating stability and others not. Wapstra and Bos[3] summarized the situation by predicting a proton separation energy of zero. Production of $T_z = -2$ nuclides is always accompanied by production of other strong β^+-delayed proton emitters (in particular, the $A = 4n + 1$, $T_z = -\frac{3}{2}$ series). This "background" obscured the protons following the superallowed β^+ decay of the even-even $T_z = -2$ series ($E_p < 4.5$ MeV) and necessitated the use of on-line mass separation; however, the expected high proton energy ($E_p \sim 8$ MeV) of odd-odd ^{22}Al made it reasonable to attempt to study this decay by direct helium jet methods.

^{22}Al was produced via the ^{24}Mg(^{3}He,$p4n$)^{22}Al reaction with 110 MeV ^{3}He^{+2} beams of 3–7 μA intensities from the 88-Inch Cyclotron at the Lawrence Berkeley Laboratory. A three-target, twelve-capillary helium jet system described in detail elsewhere[5] was used to collect nuclear reaction recoils and transport them via a 1.1 m stainless steel main capillary (i.d. 1.6 mm) to a counting chamber (see Fig. 1). Ethylene glycol or NaCl was used as an additive to form an aerosol transport medium. Recoil products were collected on an Al catcher and their subsequent β^+-delayed proton decay was observed with a three-element semiconductor particle telescope (110 μm $\Delta E1$, 60 μm $\Delta E2$, 1000 μm E) to reduce expected problems from β^+ and neutron induced background. A system of collimators and a 4 kG magnetic field was used to reduce the number of β particles reaching the E detector. The telescope subtended a solid angle of 1.3% of 4π sr and could detect protons between 4.3 and 13 MeV. A standard slow coincidence network was used together with fast coincidences measured by time-to-amplitude converters (TAC). The timing resolution achievable was typically better than 10 ns (full width at half maximum). Energy and TAC spectra were recorded event by event on a Mod Comp IV computer using the data

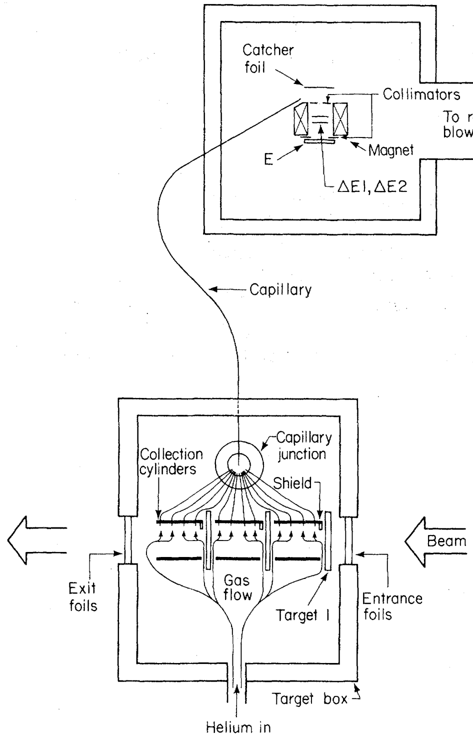

FIG. 1. Schematic view of the target and counting chambers.

acquistion and analysis program, CHAOS,[6] enabling use of several software particle identification techniques.

Proton spectra observed at 110 and 60 MeV ^{3}He energies are shown in Fig. 2. The dominant features of each spectrum are due to β^+-delayed protons from the decays of ^{21}Mg and ^{25}Si produced via the ^{24}Mg(^{3}He,$\alpha 2n$)^{21}Mg and ^{24}Mg(^{3}He,$2n$)^{25}Si reactions. At 110 MeV, two new proton groups are observed at laboratory energies of 7.839 ± 0.015 MeV and 8.149 ± 0.021 MeV. As noted below and as indicated in Fig. 2(b), these groups lie very near the predicted absolute proton energies for the decay of ^{22}Al based on Coulomb displacement energy calculations.[7]

As shown in Fig. 3, these two groups can be attributed to the isospin forbidden proton decay of the lowest $T = 2$ state in ^{22}Mg fed by the superallowed β^+ decay of the $T = 2$ ground state of ^{22}Al. Allowed decay to other states near this excitation energy would lead to considerably lower intensities in the proton spectrum. The J^π assignment of 4^+ to the levels in this isospin multiplet is based on the measurement by Davids *et al.*[8] of the $T_z = +2$ member, ^{22}F. The relative center-of-mass energy difference between the two proton groups is 325 ± 15 keV which agrees very well with the known mass difference of 331.9 keV (Ref. 9) between the ground state and first excited state of ^{21}Na. A rough half-life (70^{+50}_{-35} ms) for the 7.839 group was determined by observing the relative yields of ^{25}Si, ^{21}Mg, and ^{22}Al with different helium jet operating conditions resulting in different transit times from target to catcher. If a helium jet had a discrete transit time for each nucleus transported, this method could, in principle, yield an exact measurement of the ^{22}Al half-life using the ^{25}Si/^{21}Mg ratio as a "clock" to monitor changes. In practice, a helium jet has a distribution of transit times, and uncertainties about this distribution together with the low ^{22}Al counting rate yield a measurement with the large error bars quoted.

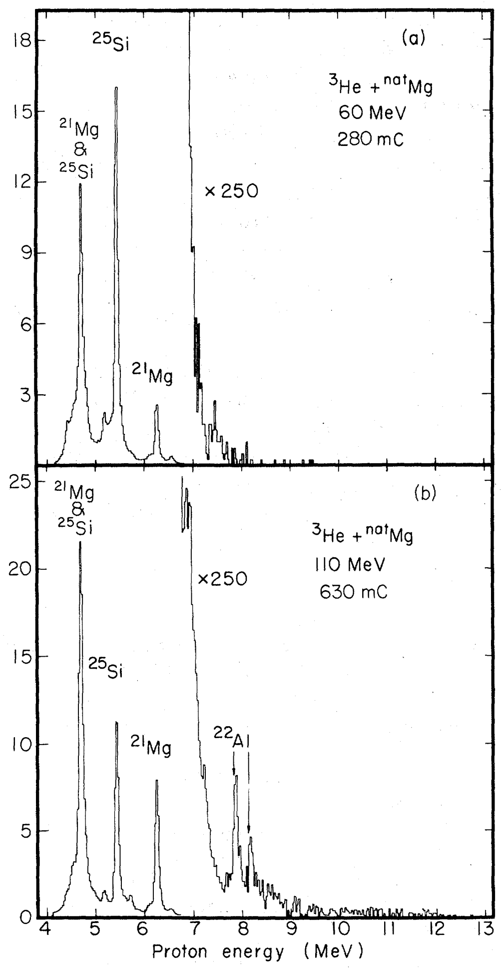

FIG. 2. β-delayed proton spectra. The positions of the arrows labeled ^{22}Al are the predicted energies obtained by using the method of Hardy *et al.* (Ref. 7).

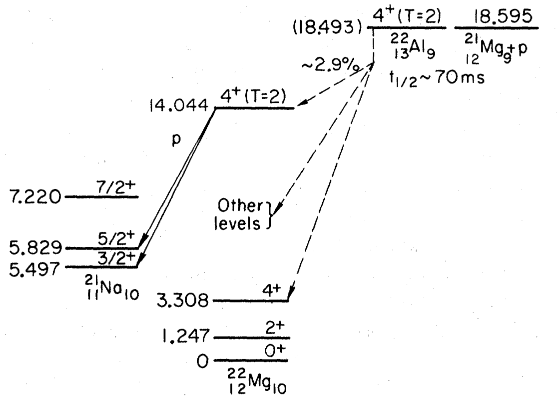

FIG. 3. Proposed decay scheme for ^{22}Al.

In order to confirm the assignment to ^{22}Al, a spectrum was also obtained at 60 MeV (below the ^{22}Al threshold). The spectrum shown in Fig. 2(a) does not exhibit these proton groups after a bombardment of sufficient duration to produce ^{21}Mg and ^{25}Si in quantities comparable to those obtained at 110 MeV. This eliminates ^{21}Mg and ^{25}Si as sources of this activity and also eliminates all nuclei that could have been produced from possible target impurities by high yield (^{3}He, $2n$) or (^{3}He,$\alpha 2n$) reactions. All known proton emitters (other than ^{21}Mg or ^{25}Si) with $Z \leq 14$ that could produce protons of ~ 8 MeV energy would have been identified by known groups not present in the observed spectra. These arguments leave only ^{22}Al and the unknown $T_z = -\frac{5}{2}$ isotope, ^{23}Si, as possible candidates for the source of the new groups. While some contribution from ^{23}Si cannot be conclusively eliminated, primarily because the predicted mass[7] of the $T = \frac{5}{2}$ analog state in ^{23}Al is such that proton decay to the *second* excited state of ^{22}Mg would give an observed proton group at ~ 7.8

MeV, and also because of the similarity in the ^{22}Al and ^{23}Si reaction thresholds (64 and 61 MeV, respectively), we believe its presence in our spectrum is negligible. First, ^{23}Si would be expected to have additional, relatively intense β^+-delayed proton decays to either one or both of the first excited and ground states of ^{22}Mg (at 9.8 and 11.0 MeV, respectively), which are not observed [see Fig. 2(b)]. Second, as mentioned above, the spacing of the two observed groups is characteristic of the known mass difference in ^{21}Na. Third, the expected shorter half-life of ^{23}Si (~ 30 ms) and its expected five times lower cross section than that of ^{22}Al (based on the evaporation code ALICE[10]) make the observation of ^{22}Al the more likely of the two. We attribute both of the new proton groups to the decay of ^{22}Al.

The center-of-mass proton energy of the group decaying to the first excited state of ^{21}Na taken together with the ^{21}Na* mass[3,9] gives a mass excess of 13.650 ± 0.015 MeV for the lowest $T = 2$ state in ^{22}Mg. A theoretical value of 13.587 MeV was obtained by the method of Hardy *et al.*[7] based on Coulomb displacement energy calculations in the $1d_{5/2}$ shell and the ^{22}F ground state mass excess of 2.826 MeV (Refs. 3 and 11) which has a quoted error of ± 0.030 MeV. This very good agreement with experiment seems to be typical of this calculative approach when employed in the $1d_{5/2}$ shell.

Using the experimental ^{22}Mg* mass excess and the Hardy *et al.*[7] value for the ^{22}Al-^{22}Mg* mass difference, a new value of 18.099 MeV for the ^{22}Al ground state mass excess can be predicted, which would make ^{22}Al bound to direct proton emission by only 102 keV. Stokes and Young[11] have measured the excited states of the ^{22}Al mirror, ^{22}F, and have determined that its first excited state has an excitation energy of 660 keV, indicating that the ground state of ^{22}Al should be its only bound level. In the same work, Stokes and Young tentatively identified the lowest $T = 2$ state in ^{22}Ne at an excitation energy of 14.07 ± 0.04 MeV. If this assignment is correct, ^{22}F, ^{22}Ne*, and ^{22}Mg* constitute three known members of the mass 22, $T = 2$ isobaric quintet and can be used to obtain the coefficients of the quadratic form of the isobaric multiplet mass equation (IMME). The IMME can in turn be used as another method to predict the ^{22}Al ground state mass excess and gives a value of 18.046 MeV indicating that ^{22}Al is bound by 155 keV. Measurements of the mass excesses of the remaining mass 22 analog states (^{22}Na* and ^{22}Al) would be useful to check the IMME for deviations in this $A = 4n + 2$ quintet.

A shell model calculation by Wildenthal[12] for the decay of ^{22}Al using allowed branches up to 11 MeV excitation in ^{22}Mg and the superallowed branch yields a predicted half-life of 90 ms. (This should be considered an upper limit on the expected half-life since there will be some contributions from decays to levels at 11–18 MeV). Assuming a pure Fermi log*ft* of 3.19 (the Gamow-Teller contribution should be negligible[12]) and using the observed half-life of 70 ms gives a superallowed branch of $2.9^{+2.1}_{-1.5}\%$. Comparison of the ^{22}Al yield to that of ^{25}Si and ^{21}Mg indicates an effective cross section for the observed proton groups of 1.2 nb (within a factor 3) which corresponds to a total production cross section of 40 nb.

These results also show that for nuclei decaying by high energy proton emission a direct helium jet experiment, with proper particle identification techniques, can be very sensitive, detecting decays of nuclei with half-lives less than 100 ms and effective cross sections on the order of nanobarns. Such conditions will exist for other light nuclei very far from stability (in particular, the $T_z = -\frac{5}{2}$ series), making this technique a reasonable approach for observing those decays.

We wish to thank C. E. Ellsworth for his invaluable assistance on these experiments. This work was supported by the Director, U. S. Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics, and by Nuclear Sciences of the Basic Energy Sciences Program of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098.

---

[*] On leave from Department of Physics, University of Jyväskylä, Jyväskylä, Finland.

[†] Present address: Department of Physics, University of Ghent, Ghent, Belgium.

[‡] Present address: CNC Division, Los Alamos National Laboratory, Los Alamos, N.M.

[§] On leave from Department of Physics, Nanking University, Nanking, China.

[1] E. Hagberg, P. G. Hansen, J. C. Hardy, A. Huck, B. Jonson, S. Mattson, H. L. Ravn, P. Tidemand-Petersson, and G. Walter, Phys. Rev. Lett. 39, 792 (1977).

[2] J. Äystö, M. D. Cable, R. F. Parry, J. M. Wouters, D. M. Moltz, and J. Cerny, Phys. Rev. C 23, 879 (1981).

[3] A. H. Wapstra and K. Bos, At. Data Nucl. Data Tables 19, 175 (1977).

[4] I. Kelson and G. T. Garvey, Phys. Lett. 23, 689 (1966).

[5] D. M. Moltz, J. M. Wouters, J. Äystö, M. D. Cable, R. F. Parry, R. D. Von Dincklage, and J. Cerny, Nucl. Instrum. Methods 172, 519 (1980).

[6] C. Maples and J. Sivak, IEEE Trans. Nucl. Sci. NS-26, 4409 (1979).

[7] J. C. Hardy, H. Brunnader, J. Cerny, and J. Janecke, Phys. Rev. 183, 854 (1969).

[8] C. N. Davids, D. R. Goosman, D. E. Alburger, A. Gallmann, G. Guillaume, D. H. Wilkinson, and W. A. Lanford, Phys. Rev. C 9, 216 (1974).

[9] P. M. Endt and C. van der Leun, Nucl. Phys. A310, 1 (1978).

[10] M. Blann, Energy Research and Development Administration Report No. COO-3494-29, 1976 (unpublished).

[11] R. H. Stokes and P. G. Young, Phys. Rev. 178, 1789 (1969).

[12] B. H. Wildenthal (private communication).