Lawrence Berkeley National Laboratory
Recent Work

Title
BETA-DELAYED PROTON DECAY OF AN ODD-ODD Tz=-2 ISOTOPE, 22al

Permalink
https://escholarship.org/uc/item/9q4448b3

Author
Cable, M.D.

Publication Date
1982-05-01

eScholarship.org Powered by the California Digital Library
University of California

LBL-14419
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

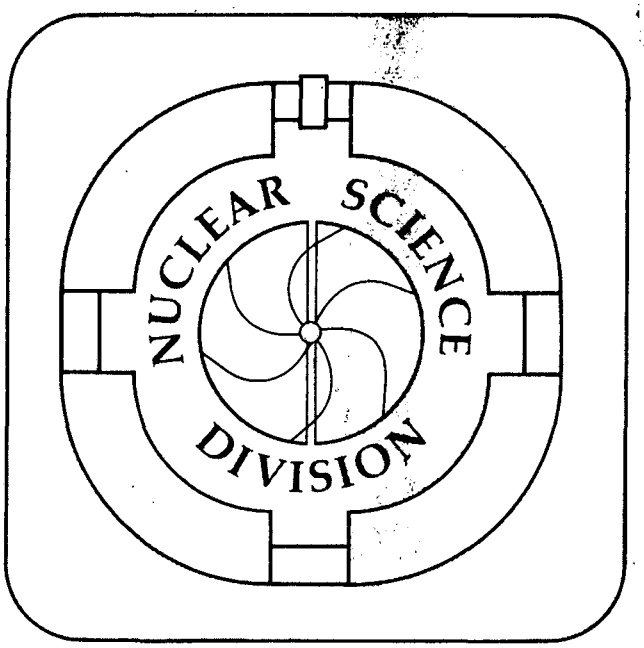
RECEIVED
LAWRENCE
BERKELEY LABORATORY
JUN 2 1982
LIBRARY AND
DOCUMENTS SECTION

Submitted to Physical Review Letters

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

May 1982



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-14419

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

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

Nuclear Science Division,
Department of Chemistry and
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

May 1982

Abstract:

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.

*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.

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 beta 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=-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 3 target 12 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 3 element semiconductor particle telescope (110μm ΔE1, 60μm ΔE2, 1000μm E) to reduce expected problems from β^+ and neutron induced background. A system of collimators and a 4kG 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 (FWHM). Energy and TAC spectra were recorded event by event on a Mod Comp IV computer using the data 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,α2n)^{21}Mg and ^{24}Mg(^{3}He,2n)^{25}Si reactions. At 110 MeV, 2 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. 2b, 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 2 proton groups is 325±15 keV which agrees very well with the known mass difference of 331.9 keV[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.

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. 2a 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,α2n) reactions. All known proton emitters (other than ^{21}Mg or ^{25}Si) with $Z \leqslant 14$ that could produce protons of $\sim$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 $T_z = -5/2$ 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 = 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 $\sim$7.8 MeV, and also because of the similarity in the ^{22}Al and ^{23}Si reaction thresholds (64 and 61 MeV, respectively), we believe its presence in our spectrum is negligible. First, ^{23}Si would be expected to have additional, relatively intense β^+-delayed proton decays to either one or both of the first excited and ground states of ^{22}Mg (at 9.8 and 11.0 MeV, respectively), which are not observed (see Fig. 2b). Second, as mentioned above, the spacing of the two observed groups is characteristic of the known mass difference in ^{21}Na. Third, the expected shorter half-life of ^{23}Si ($\sim$30ms) and its expected 5 times lower cross-section than that of ^{22}Al (based on the evaporation code ALICE[10]) make the observaton 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[3,11] 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 70ms 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 of 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=-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.

Footnotes and References

†On leave from: Dept. of Physics, University of Jyväskylä, Finland.

‡Present address: Dept. of Physics, University of Ghent, Belgium.

‡‡Present address: CNC Division, Los Alamos National Laboratory.

‡‡On leave from: Dept. of Physics, Nanking University, 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. C23 , 897 (1981).

3. A. H. Wapstra and K. Bos, At. Data and 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.

C9, 216 (1974).

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

10. M. Blann, ERDA Rep. No. COO-3494-29 (1976).

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

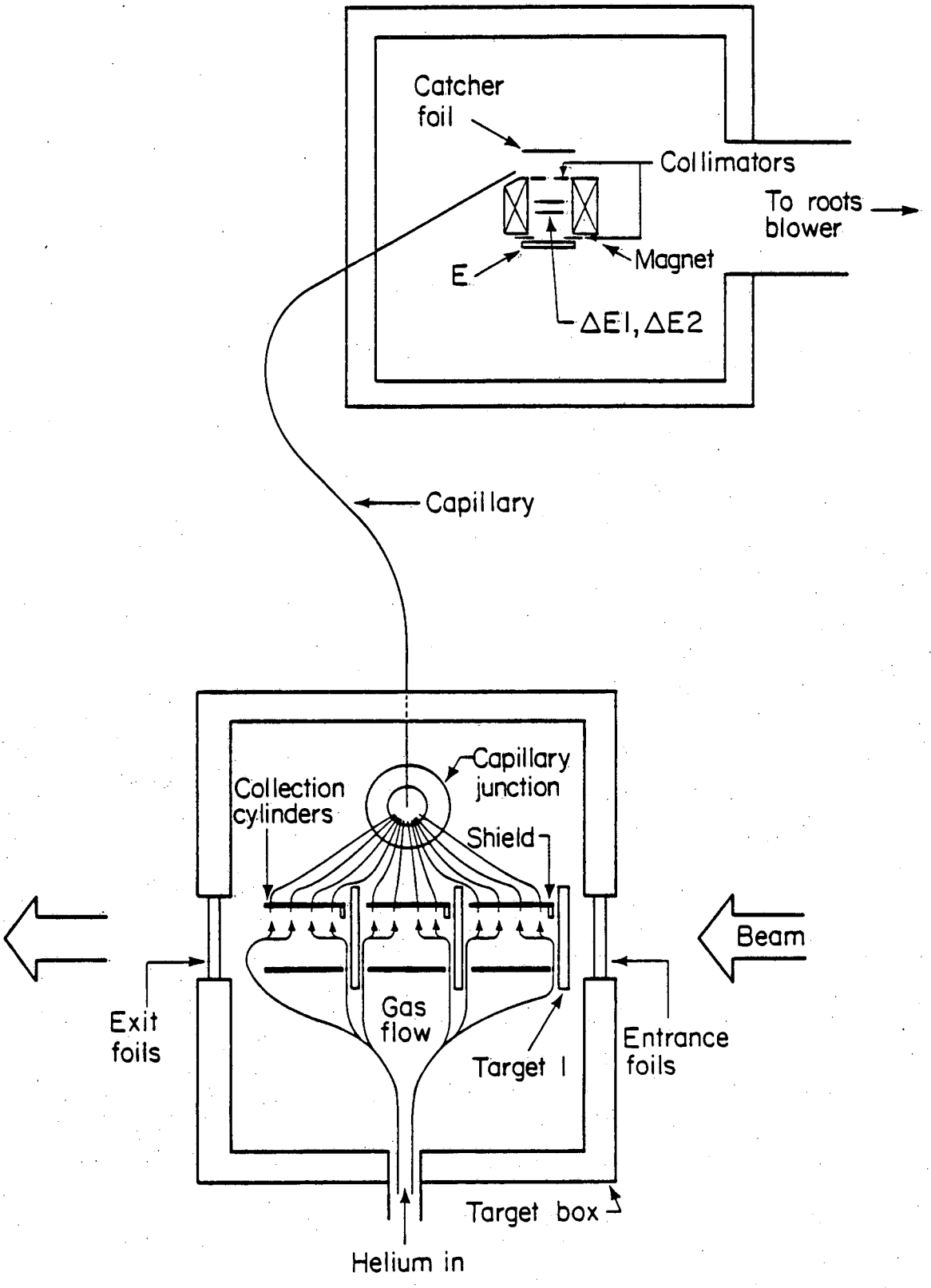
12. B. H. Wildenthal, private comm.

Figure Captions

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

Fig. 2. Beta-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.



XBL 823-3708

Fig. 1

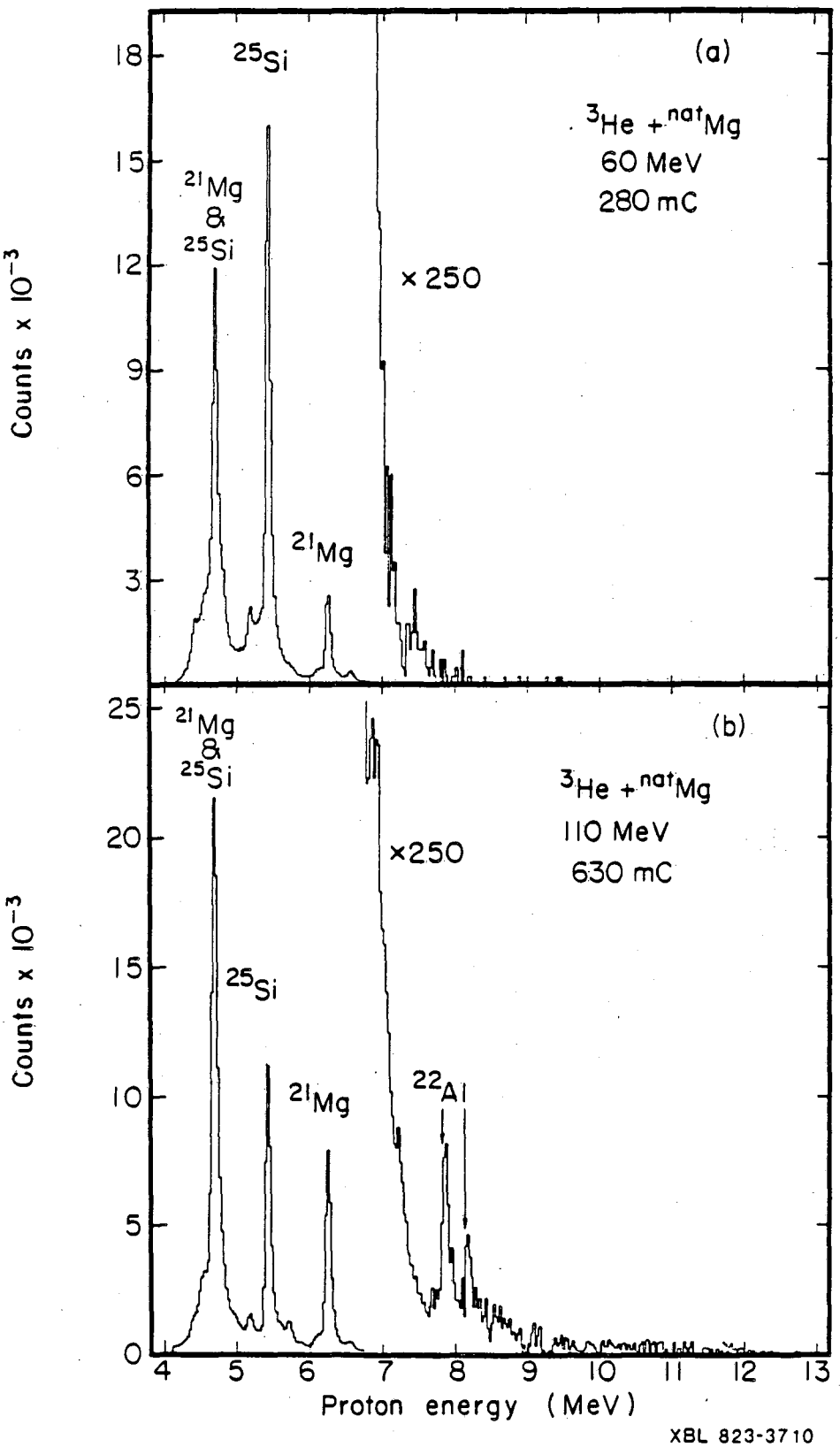

(a)
^{25}Si
^{21}Mg & ^{25}Si
^{21}Mg
×250
^{3}He + ^{nat}Mg
60 MeV
280 mC
Counts x 10^{-3}
(b)
^{21}Mg & ^{25}Si
^{25}Si
^{21}Mg
^{22}Al
×250
^{3}He + ^{nat}Mg
110 MeV
630 mC
Counts x 10^{-3}
Proton energy (MeV)
XBL 823-3710

Fig. 2

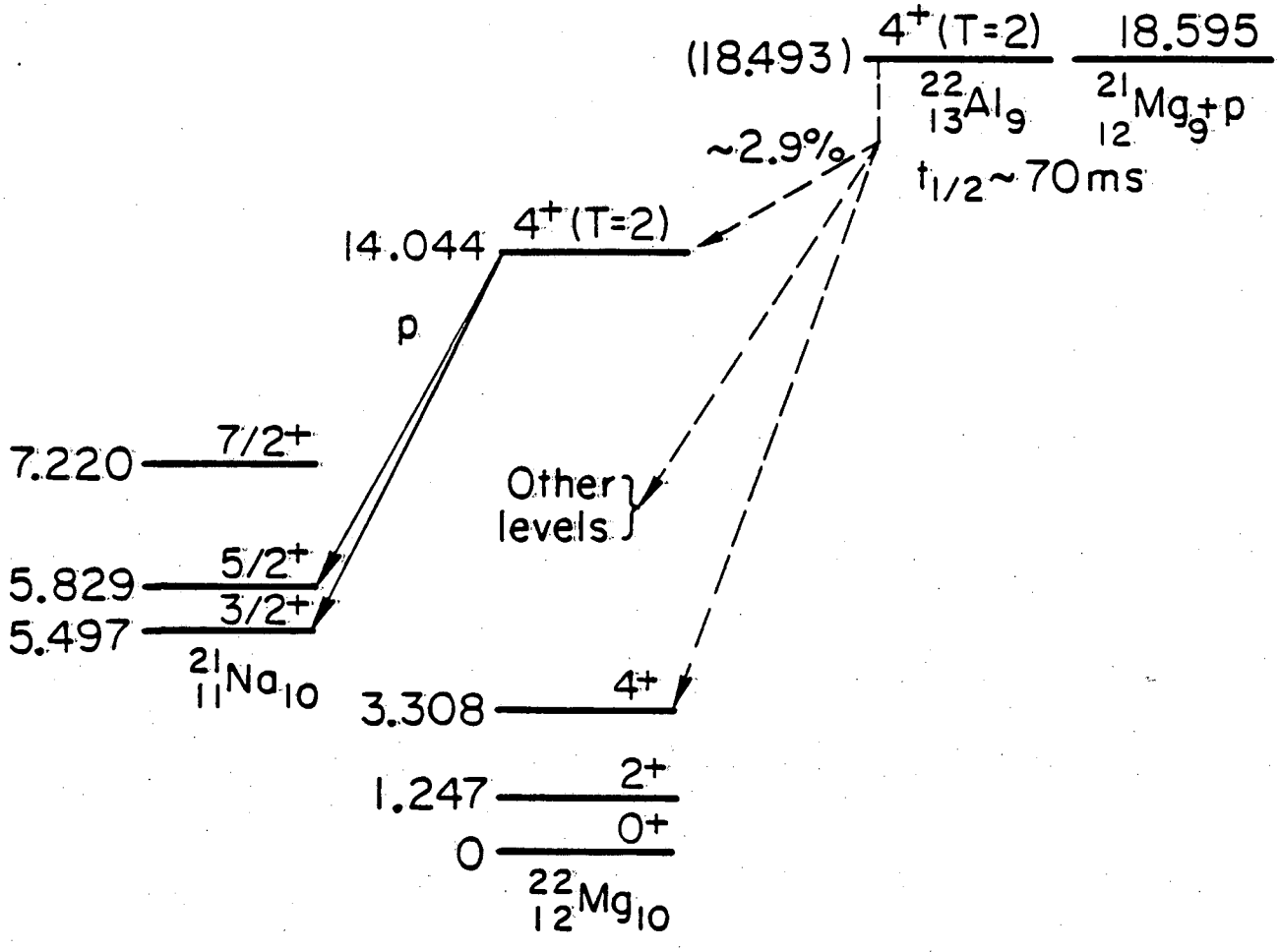

(18.493)
4+(T=2)
22 13Al9
18.595
21 12Mg9+p
~2.9%
t1/2~70ms
14.044
4+(T=2)
p
7.220
7/2+
Other levels
5.829
5/2+
5.497
3/2+
21 11Na10
3.308
4+
1.247
2+
0
0+
22 12Mg10
XBL823-3709

Fig. 3

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720