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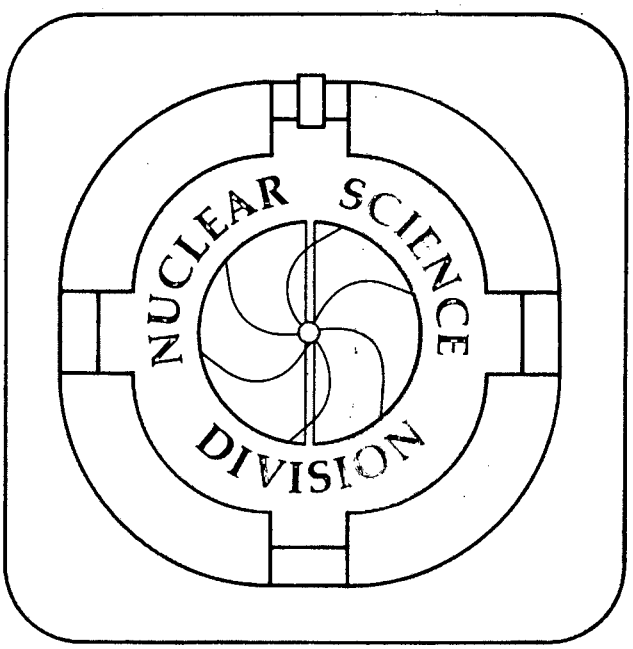

DISCLAIMER

Beta-Decay Half-lives of Isotopes Produced in Projectile Fragmentation

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ABSTRACT

Beta-decay half-lives have been measured for eight neutron-rich isotopes produced in the fragmentation of 11.4 GeV ^{40}Ar on ^{9}Be. The experiment used a new measurement technique designed to observe very short half-lives. The previously unknown half-lives of ^{22}O (910 $\pm$ 350 ms) and ^{32}Al (35 $\pm$ 5) have been obtained, as well as six known half-lives to provide a check of the procedure.

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This letter reports the first application of a significant new technique to measure the beta-decay half-lives of large numbers of short-lived exotic nuclei. The method utilizes high energy projectile fragmentation to produce the nuclei, and suffers none of the limitations of chemical or mass separation techniques for the study of beta decay. Moreover, it is the only method at present which can observe many of the most neutron-rich isotopes. With it we have measured for the first time the half-lives of ^{22}O and ^{32}Al, and also obtained the previously known half-lives of ^{25}Ne, ^{27}Na, ^{28}Na, ^{29}Mg, ^{30}Mg, and ^{31}Al.

The properties of such exotic nuclei are fundamental to many problems in nuclear physics and astrophysics. Their beta-decay lifetimes control the progress of stellar evolution and nucleosynthesis;[1] the decay rates of nuclei of mass 20 - 60 in particular are important during the early stages of a star's gravitational collapse.[2] The combination of nuclear lifetimes and masses allows the matrix elements for beta decay to be systematically studied, and when mass and lifetime measurements have been made for many isotopes of a given element, new regions of nuclear deformation have been discovered[3] in which the predictions of the spherical shell model are no longer valid.[4]

It was discovered a few years ago that heavy-ion projectile fragmentation at several hundred MeV/nucleon produces a broad spectrum of exotic isotopes ranging far from stability.[5,6,7] The

fragments emerge from the reaction with beam velocity and are strongly peaked at 0^{o} , which allows very high detection efficiency. For example, in the fragmentation of 9.6 GeV ^{48}Ca on ^{9}Be, twenty-seven neutron-rich isotopes of unknown lifetime were observed.[5] Most of these isotopes are expected to have half-lives of much less than one second.

In order to measure the half-lives of these projectile fragments, it is necessary to

a) stop the fragments,
b) identify the parent isotopes by charged particle spectroscopy,
c) observe their beta decay without transporting the products,
d) interrupt the beam while observing betas,
e) correlate the delayed betas with the parent nuclei, and
f) minimize the background from more abundantly produced isotopes.

All of these conditions are satisfied by the following technique: The forward-peaked projectile fragments are deflected through a magnetic spectrometer to select isotopes of a particular rigidity. Their uniform velocity and charge state allows the spectrometer to cleanly separate the rare neutron-rich isotopes from the more

abundantly produced isotopes nearer to stability. The fragments are then stopped in a multi-element solid state telescope; their range and energy loss provide charge and mass identification. Within 2 ms of seeing a specified isotope stop the beam is interrupted, the detector electronics are switched to the higher gain necessary to detect low energy electrons, and a period of 2 seconds is allowed to observe the delayed beta from the embedded fragment. The stopping detectors are position-sensitive in one dimension, so that we may determine that the observed beta originated near the position of the fragment.

The solid state telescope used to stop the fragments consisted of two 5 cm diameter x 800 μm thick Si(Li) detectors (for a particle trigger) backed by six 7 cm diameter x 5 mm thick position- sensitive Si(Li) detectors. The telescope was surrounded by scintillators and an active collimator to suppress background. Aluminum degraders fixed the stopping point of the chosen fragments in the center of the telescope.

The experiment was controlled by a Microprogrammable Branch Driver (MBD) linked to a PDP 11/34 data acquisition computer. The MBD examined a hardware particle identification signal for each fragment event in the telescope; if specified identification gates were satisfied the MBD signalled the beam interruption and the change to the high gain beta detection mode.

For the measurements reported here, an 11.4 GeV ^{40}Ar beam of $\sim 10^6$ particles/sec from the LBL Bevalac was used to produce neutron-rich isotopes by fragmentation on a ^{9}Be target. Oxygen through argon were observed in the charge identification spectrum from the particle telescope. By accurately calibrating the gains of the detectors and averaging the multiple ΔE-E measurements which a six-element telescope provides, isotopes were clearly resolved for oxygen through silicon. A cut of 30% on the tail of the χ^2 for the averaged ΔE-E measurements eliminated much of the dispersion in particle identification due to straggling and reactions in the detectors. An example of the resulting particle identification spectrum for the aluminum isotopes is shown in Fig. 1.

The isotope masses were unambiguously determined by two independent identifications. The particle spectra at the spectrometer position corresponding to A=2Z were obtained as an initial mass identification. This was extrapolated to spectra from other points on the focal plane through the empirical relation

$$(E+\Delta E)^{1.78} - E^{1.78} \propto Z^2 A^{0.78}$$

A later comparison of measured lifetimes with those already known provided an independent verification of the mass identification.

To obtain the half-lives of the isotopes, gates were set around each isotope peak and the delay times for electrons originating in the stopping detector were histogrammed (Figure 2). Using the position information, cuts were made on the trajectories of both the stopping isotope and the delayed electron to insure that the electron originated in the vicinity of the identified isotope.

In this first measurement it was possible to obtain half-lives for ^{22}O, ^{25}Ne, ^{27}Na, ^{28}Na, ^{29}Mg, ^{30}Mg, ^{31}Al, and ^{32}Al. Their decay curves and least squares fits are shown in Fig. 2 and compared to previous measurements in Table I. With the exception of ^{27}Na, all of the curves had essentially flat background contributions, which were subtracted. The spectrum for ^{27}Na has two components with decay times of less than 1 second, and was fit to a composite decay curve.

This is the first reported measurement of the half-lives of ^{22}O (910 ± 350 ms) and ^{32}Al (35 ± 5 ms). The known half-lives of the other isotopes provide a check on the accuracy of the technique. In all cases but ^{27}Na our measurement agrees to within one standard deviation with the previously reported value. The time spectrum for ^{27}Na was observed to have a fast component superimposed on a

substantial, slowly decaying background. A two-component fit of this curve yielded half-lives of 105 $\pm$ 85 ms and 910 $\pm$ 260 ms, with a χ^2 at the 95% confidence level. The fast component of 105 $\pm$ 85 ms was identified with ^{27}Na, and disagrees with the best previous value of 304 $\pm$ 7 ms. An alternative attempt to fit the entire spectrum to a curve with a 300 ms halflife yielded a χ^2 well below the 1% confidence level. We offer no explanation for the disagreement, but suggest that previous measurements for ^{27}Na might conceal a similar background which significantly lengthens its apparent lifetime.

This measurement technique has been developed to make a rapid, comprehensive survey of beta decay lifetimes for very-neutron-rich nuclei. One of the important applications of such a systematic measurement will be to the test of nuclear structure models for the parent and daughter nuclei. Spherical shell model calculations are often used to predict half-lives, because nuclear beta decay nearer to the valley of stability typically involves the ground states and low-level excitations of nearly spherical nuclei. Such a shell model calculation has recently been made[12] for several of the isotopes which we have observed. The half-lives which this calculation predicts are included in Table I, and compare favorably with our measurements. While these isolated comparisons provide useful checks for specific calculations, we foresee more

fundamental tests of nuclear structure. For instance, other fragmentation reactions[7] should yield the half-lives of ^{45}Cl and ^{46}Ar, which are the furthest known N=28 nuclei from stability. Whether major spherical shell closures such as N=28 occur in such very neutron-rich nuclei is a subject of considerable interest.[3]

The first measurement of beta half-lives using this new method has provided eight known and new half-lives in two days of data-taking. The technique limits accurate measurements to half-lives of less than 1 second. However, it is intended for short half-lives; 1 sec activities are accessible in other methods. The lower limit for half-lives is approximately 5 ms, which makes this method nearly unique in its ability to reach a broad range of very neutron-rich isotopes. With the heavier, more intense beams soon to be available from the Bevalac, we anticipate a significant contribution to the systematics of nuclear beta decay.

We wish to thank Jack Walton for the fabrication and continued maintenance of the large position-sensitive Si(li) detectors, P.J.Lindstrom for valuable discussions, and the Bevalac operations staff for their efforts during the data acquisition. 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.

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Table I. Beta-decay half-lives measured for fragments from 11.4 GeV $^{40}Ar + {}^{9}Be$. Previously measured values and recent theoretical predictions are included for comparison.

ISOTOPE	THIS MEASUREMENT	PREVIOUS VALUE	PREDICTION[e]
^{22}O	910±350 ms	-	1800
^{25}Ne	780±180	610 ms[a]	549
^{27}Na	105±85	304±7[b]	254
^{28}Na	62±33	31±0.4[b]	23.3
^{29}Mg	1790±565	1470±90[b] 1090±120[c]	525
^{30}Mg	270±135	325±30[c]	320
^{31}Al	945±425	644±25[d]	-
^{32}Al	35±5	-	28.8

[a]Ref. 8
[b]Ref. 9
[c]Ref. 10
[d]Ref. 11
[e]Ref. 12

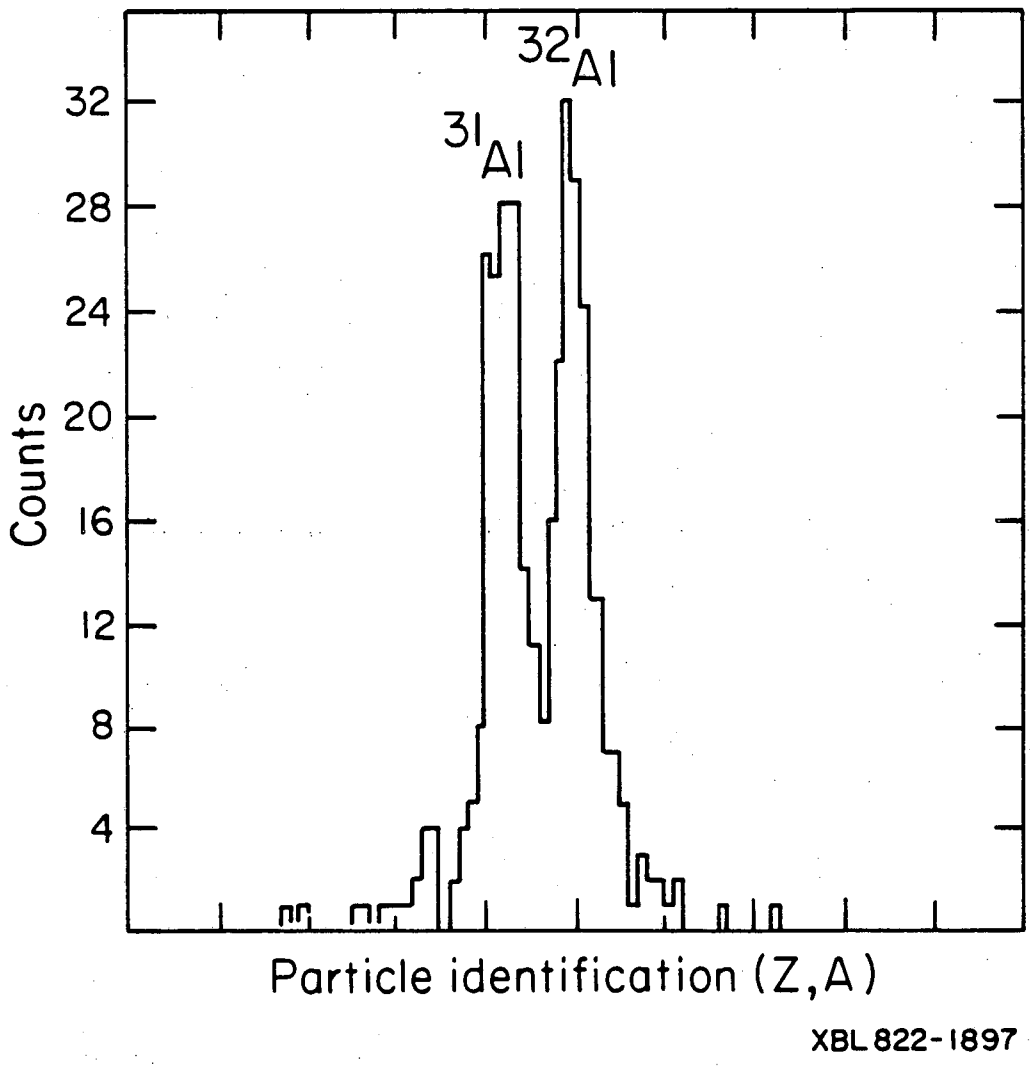
32Al
31Al
32
28
24
20
16
12
8
4
Counts
Particle identification (Z,A)
XBL 822-1897

Fig. 1.

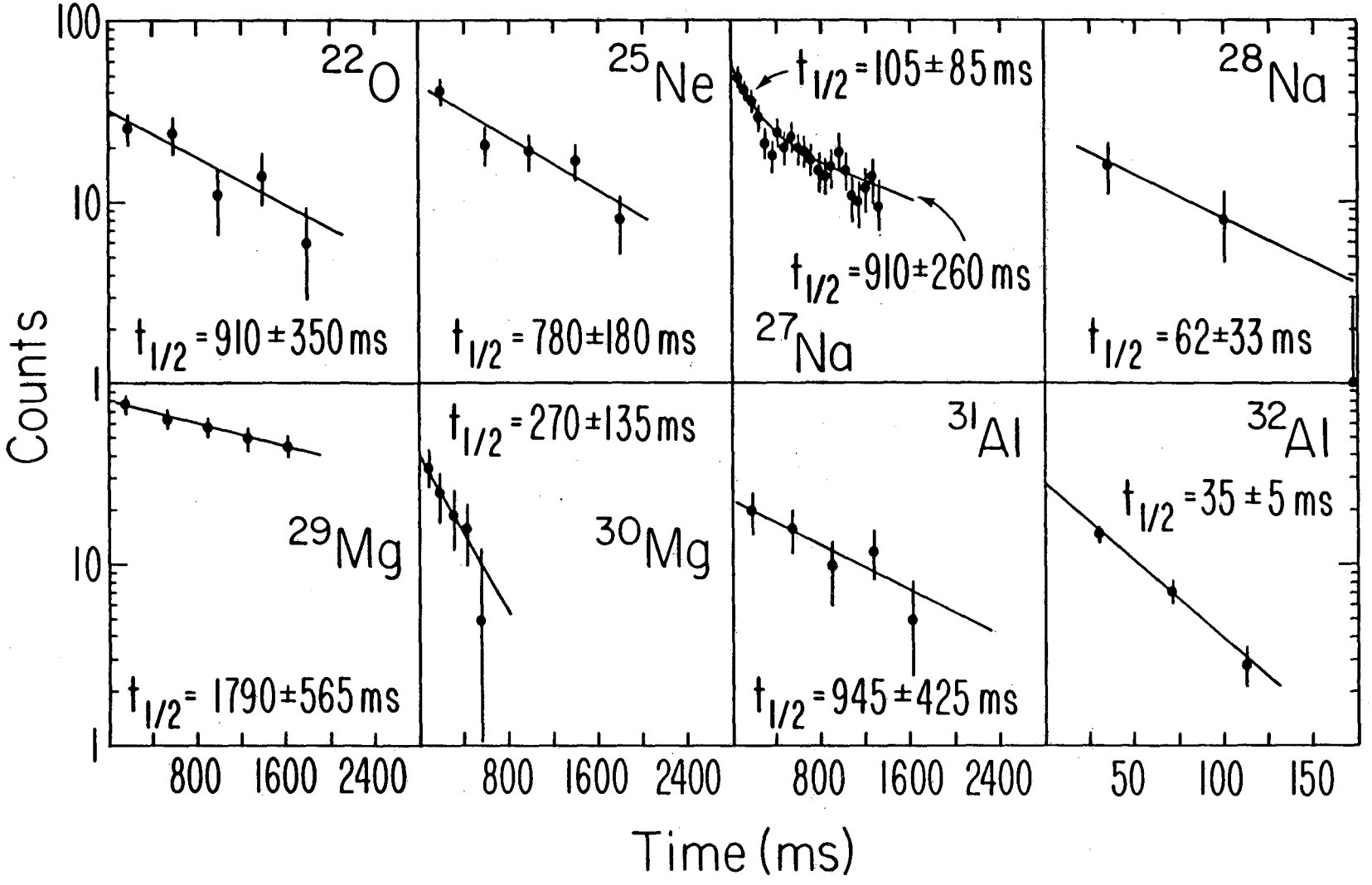

Fig. 2.

XBL822-1899

LBL-14272

FIGURE CAPTIONS

1. The particle identification spectrum for Z=13, showing the clear resolution of ^{31}Al and ^{32}Al.

2. The beta decay half-life curves observed in this experiment. In all cases except ^{27}Na the background components have been subtracted. The curves are least-squares fits to the data.

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