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Measurement of the beta decay half-life of ^{17}B

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The beta decay half-lives of seven neutron-rich isotopes, ^{9}Li, ^{12}B, ^{13}B, ^{15}B, ^{17}B, ^{17}C, and ^{19}N, have been measured. The isotopes were produced by bombarding a tantalum target with a ^{22}Ne beam with 35 MeV/nucleon. The isotopes were separated and identified using a reaction product mass separator. The half-life measurement of ^{17}B, 5.3(6) ms, is the first for this isotope.

The properties of nuclei far from stability provide a stringent test of the validity of shell model Hamiltonians derived from data for nuclei near the valley of stability. Failure of shell model calculations to extrapolate to nuclei far from stability may indicate a breakdown of symmetries assumed in the model. Such a breakdown may provide evidence for new regions of deformation as were found for neutron-rich sodium and magnesium isotopes.[1]

In the present experiment, the Michigan State University (MSU) reaction product mass separator (RPMS) (Ref. 2) was used to measure the beta decay half-lives of seven neutron-rich isotopes produced by the fragmentation of an $E/A=35$ MeV ^{22}Ne beam incident on a tantalum stopping target. The MSU RPMS is designed to separate exotic nuclei produced in intermediate energy heavy ion reactions so that their decay properties can be studied. The RPMS is a "triply focusing" device—focusing in horizontal and vertical position as well as in velocity. It then disperses ions in the vertical direction according to their mass-to-charge ratio m/q. Ions of the mass to charge ratio of interest are focused onto a silicon detector telescope where they can be identified and their decay properties studied. The long target-to-focal-plane distance (14 m) assists in providing the relatively clean environment necessary for decay studies. The cyclotron beam was turned off following the detection of an ion of interest to allow detection of the beta decay of the ion without background from the reaction products.

Using a 770 MeV ^{22}Ne beam from the K500 cyclotron at the National Superconducting Cyclotron Laboratory, we made the first measurement of the half-life of ^{17}B along with measurements of the half-lives of ^{19}N, ^{17}C, ^{15}B, ^{13}B, ^{12}B, and ^{9}Li. The neutron-rich isotope ^{18}C was also observed in sufficient quantity for a lifetime measurement, but would have required a separate run for its measurement, since its half-life is significantly longer than the other isotopes of interest at the same mass to charge ratio. The isotope ^{19}C was also observed, but not in sufficient quantities to make a half-life measurement. Beta decay half-lives were determined by event-by-event measurements of the absolute time of detection for an ion of interest and all subsequent events during the beam-off period. The technique, first used by Murphy *et al.*,[3] is capable of measuring lifetimes as short as a few milliseconds. The beta decay time spectra measured in this experiment are shown in Fig. 1.

The tantalum target thickness was chosen to stop the primary neon beam but allow light "projectilelike" fragments to escape. This allowed the RPMS to be operated at zero degrees. Reaction products were separated according to their mass-to-charge ratio, m/q, and detected in a focal plane detector consisting of a position sensitive single wire gas counter followed by a silicon detector telescope. The single wire gas proportional counter provided the horizontal position by resistive wire charge division and the vertical position by electron drift time. The silicon telescope was made up of three element, ΔE, E, and veto, with thicknesses of 100 μm, 1 mm, and 100 μm, respectively. Aluminum foil degraders were placed in front of the telescope and adjusted in thickness such that isotopes of interest were stopped in the Si E detector. The third element of the telescope was used as a veto to reject ^{6}He and ^{9}Li isotopes that punched through the E detector. These isotopes had count rates which were much higher than those of the isotopes of interest.

When an ion with $Z \geq 2$ was detected that did not fire the veto, the beam was turned off in approximately 40 μs by switching the rf phase on one of the dees of the K500 cyclotron. The beam remained off for a preset time of either 125 ms or 1 s chosen to be several half-lives of the longest-lived isotope of interest present at the focal plane. At this time the silicon detector preamplifier gains were increased by a factor of 10 (in about 2 ms) in order to facilitate the detection of beta decay. The data acquisition electronics were inhibited during the gain-switching period. During the beam-off period, all counts in the E detector above a threshold of approximately 0.3 MeV were recorded. A scalar was used to count pulses from a prescaled 262.144 kHz quartz-crystal oscillator, which gave the absolute time for the detection of the incident ion and for all events in the subsequent beam-off period. The data associated with the particle identification and beam-off events were then written to magnetic tape for off-line analysis.

The analysis of the data for the cases of the short-lived isotopes ^{12}B, ^{13}B, ^{15}B, and ^{17}B was complicated by the presence of a short-lived background attributed to reactions induced by thermal neutrons in the vault. In addition, the background also contained a constant component due to long-lived isotopes implanted in the silicon and long-lived daughters, as well as cosmic rays. The background was conveniently parametrized as an exponential plus a constant using data, shown in Fig. 2, from long-lived or stable isotopes which were accumulated along with the isotopes of interest. For the longer-lived isotopes ^{9}Li, ^{17}C, and ^{19}N, the effect of the short-lived component of the background was eliminated by discarding the first 31.2 ms of the beam-off period. Thus, only the constant component of the background had to be considered. Both the short-lived and the constant components of the background were found to vary from run to run, since they depended on the average beam current, and the length of the beam-off period. For the short-lived isotopes, the rate of detection of a short-lived background event was 0.1 per beam-off period, while the efficiencies for detecting a beta decay ranged from 0.3 to 0.6, depending on the isotope. The maximum constant background rates were 3.35 counts/s during the runs with a 125 ms beam-off period and 0.66 counts/s during the runs with a 1 s beam-off period.

The beta decay time spectra, shown in Fig. 1, were fit with a newly developed computer code using the method of maximum likelihood for Poisson statistics.[4,5] The maximum likelihood technique was used instead of the χ^2 method because of the low statistics data. Each decay spectrum was analyzed with an exponential form which had two free parameters, the normalization and the decay rate. The fitting function also included an appropriate background with fixed parameters normalized to the number of incident ions for the spectrum. The results of these fits are shown in Table I.

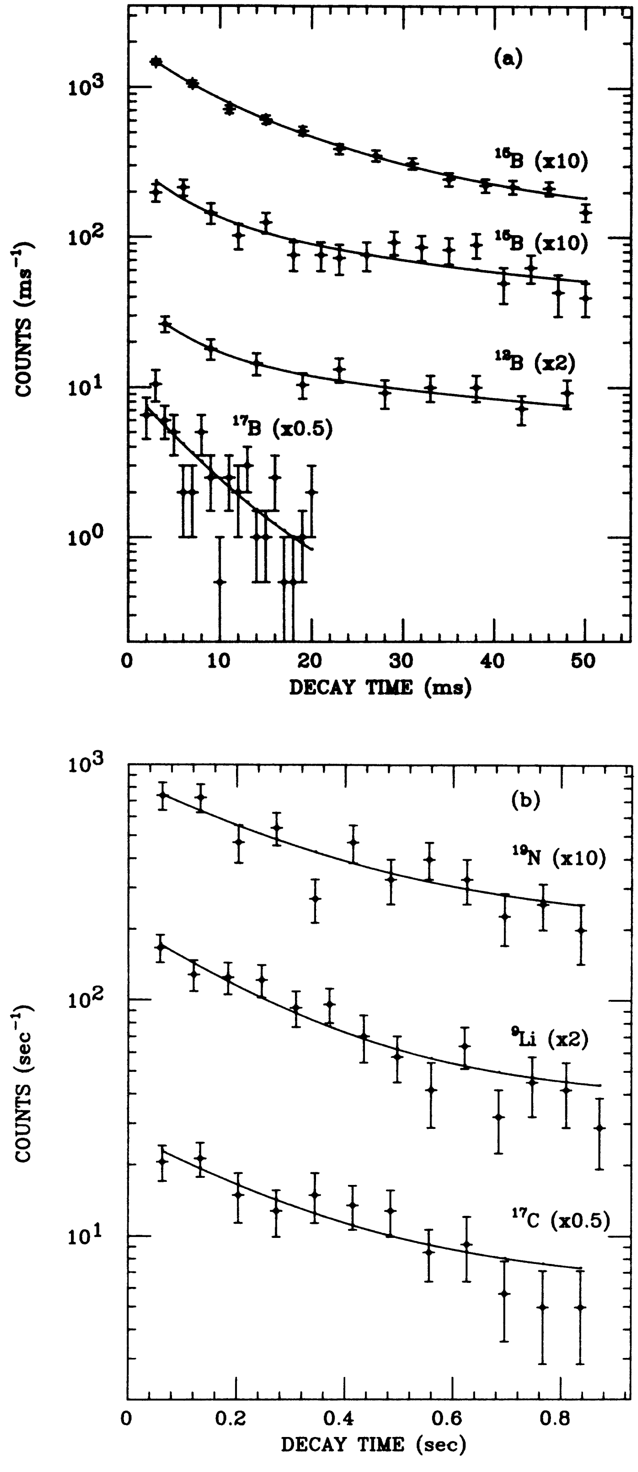

FIG. 1. Beta decay half-life data. Curves shown are fits to an exponential plus an appropriate background. For the short-lived isotopes (a), the background is an exponential plus a constant. For the longer-lived isotopes (b), the background is a constant only.

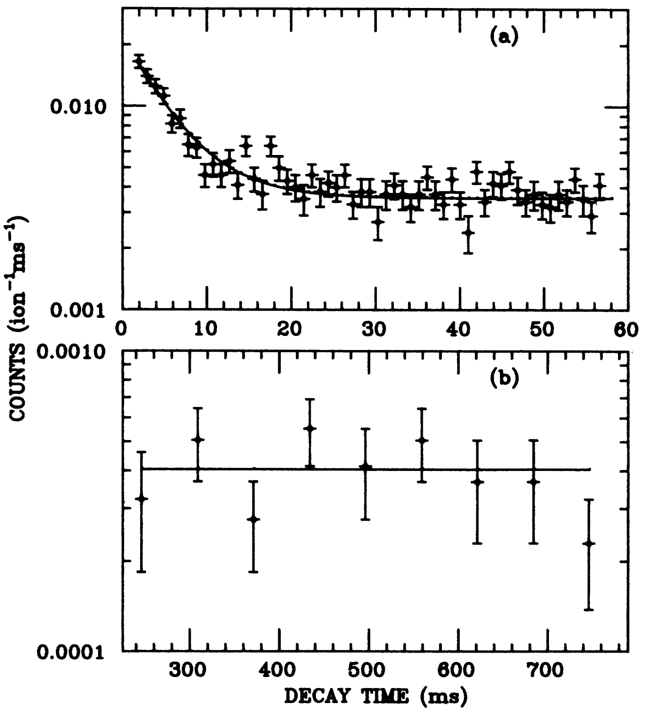

FIG. 2. Background per ion. (a) The sum of spectra acquired for ^{6}He, ^{4}He, and ^{10}Be. ^{6}He is long-lived relative to the beam-off period used. (b) The sum of spectra acquired for ^{14}B, ^{12}B, and ^{11}B. ^{14}B and ^{12}B are short-lived relative to the beam-off period used, and the first 200 ms (ten half-lives of ^{14}B) were discarded in determining the constant background.

TABLE I. Half-life values (ms). Beta decay half-lives from this experiment compared to previous experimental results and shell-model predictions. The three theoretical predictions given for ^{17}C are for ground state J^{π} values of $\frac{5}{2}^{+}$, $\frac{3}{2}^{+}$, and $\frac{1}{2}^{+}$, respectively. The Q values shown are calculated using the mass excesses given in Ref. 6 unless otherwise noted.

Isotope	This measurement	Previous measurements	Prediction	Q value (MeV)
^{19}N	235(32)	320(100)[a] $210^{(200)}_{(100)}$[b]	620	12.5
^{17}C	180(31)	202(17)[c] 220(80)[a]	402,493 702	13.2
^{17}B	5.3(6)		8.6	21.8[h]
^{15}B	10.8(5)	8.8(6)[c] 11.0(10)[d] 10.3(4)[b]	12.3	19.1
^{13}B	17.6(12)	17.37(16)[e]	19.0	13.4
^{12}B	20.9(18)	20.20(2)[f]	22.7	13.4
^{9}Li	167(20)	178.3(4)[g]	127	13.6

[a] Reference 7.
[b] Reference 8.
[c] Reference 9.
[d] Reference 10.
[e] Reference 11.
[f] Reference 12.
[g] Reference 13.
[h] Reference 14.

The error bars shown include both statistical uncertainties and systematic errors in the fitting routine. The systematic error is due to uncertainty in the parameters which describe the background events. We determined the effect of errors in the parametrization of the background by extensive Monte Carlo simulation of the experimental data for each isotope.

The simulation for the long-lived isotopes was relatively straightforward since we could assume that the uncertainty in the constant background was purely statistical. For each isotope we generated a set of 200 decay spectra and made a fit to the simulated data using values for the constant background that varied over a range of one standard deviation. A Gaussian fit to the resulting half-life distribution gave the standard deviation of the half-life measurement. A similar method was used to assign the uncertainties to the normalization and decay rate of the short-lived background.

The decay of the short-lived isotopes could be simulated after the uncertainties in all three background parameters were determined. Simulated decay spectra were generated based on the experimental data as before. We then made fits to the spectra with different sets of parameter values, varying each parameter independently over one standard deviation. Again, the distribution of the half-lives resulting from these fits was used to determine the standard deviation of the half-life measurement.

The value found in this experiment for the half-life of ^{15}B disagrees by more than one standard deviation with the previous measurement done at MSU by Curtin *et al.* (see Ref. 9). While we are uncertain as to the cause of the discrepancy, it is possible that the previous experimental analysis did not fully take into account the effect of the short-lived background. The ^{15}B half-life measurement is in good agreement with two more recent measurements by Mueller *et al.* (Ref. 8) and Dufour *et al.* (Ref. 10). The agreement with previous measurements is good for the other isotopes, with the measurement of ^{19}N increasing the precision to which the half-life is known by a factor of 2.

The theoretical predictions shown in Table I are the results of shell-model calculations carried out in the *spsd* model space in which the $0s_{1/2}$, $0p_{3/2}$, $0p_{1/2}$, $1s_{1/2}$, and $0d_{5/2}$ orbitals are active. The residual-interaction matrix elements connecting the 0*p*-shell orbitals were taken from the results of a fit to 0*p*-shell energy levels in the $A=10-15$ mass region obtained by Millener.[15] The matrix elements connecting the 1*s*0*d*-shell orbitals were taken from the fit to 1*s*0*d*-shell energy levels in the $A=18-38$ mass region obtained by Wildenthal.[16] All other matrix elements, including the cross-shell matrix elements connecting the 0*s*, 0*p*, and 1*s*0*d* orbitals, were calculated with the residual interaction of Millener and Kurath.[17] Within this model space a "$0\hbar\omega$" truncation was made for the initial state and for the final states allowed "$0\hbar\omega$" ($A<14$) and "$1\hbar\omega$" ($A>14$) relative to the ground state configuration of the daughter nucleus. The calculated half-lives include a quenching factor of 0.6 in the B(GT) value. The calculations for the phase-space factor are based on the experimental Q value for the lowest final state and theoretical excitation energies for the final states.

The overall agreement between experiment and theory is good. The theoretical half-life predictions for ^{17}B, ^{17}C, and ^{19}N are two to three times longer than experiment, which indicates some defect in the model wave functions for these nuclei. (See also the discussion in Ref. 9.) The theoretical prediction for the half-life of ^{18}C is 110 ms assuming a Q value of 12.1 MeV. This prediction is again about two times longer than the recent measurement of

66 ms of Mueller *et al.* (Ref. 8).

In summary, we have made the first measurement of the half-life of ^{17}B. Simultaneously, we have measured the half-lives of ^{9}Li, ^{12}B, ^{13}B, ^{15}B, ^{17}C, and ^{19}N. Shell model calculations in the *spsd* model space give reasonable predictions of the half-lives for these neutron-rich nuclei.

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