LOW ENERGY STRUCTURE OF ^{73}Zn

M. Huhta, P.F. Mantica, D.W. Anthony, P.A. Lofy, J.I. Prisciandaro, R.M. Ronnigen, M. Steiner, W.B. Walters[a]

The experimental study of β unstable nuclei in the region Z ~ 28, N > 40 is important for the testing and further development of theoretical models to better describe the properties of exotic neutron-rich nuclei important to the astrophysical r-process and the progression of shell structure towards the neutron drip-line. The recent improvements in the intensity of metal primary beams at the NSCL has allowed access to regions of the chart of the nuclides previously unavailable for nuclear structure measurements. By fragmenting a ^{76}Ge beam, we were able to produce secondary beams of several A ~ 70 nuclides with sufficient intensities to perform β-γ and γ-γ spectroscopic studies on these species. We report here on the low-energy level structure of ^{73}Zn populated following the β decay of ^{73}Cu. With only 5 particles outside the Z = 28, N = 40 semi-magic shell closure, one would expect this nuclide to exhibit modest collective features. However, a transition from spherical to deformed structure has been observed [1] in both the Ge and Ga isotopes with the addition of two neutrons, from N = 40 to 42. The low energy levels of ^{73,74}Zn determined from two-proton pickup experiments [2] and the systematics of the first 2^+ states in the even-even Zn isotopes hint at a similar transition in these nuclides. This may suggest that the N = 40 subshell is weakened within close approach to the Z = 28 proton shell closure.

Radioactive nuclei having Z ~ 28, N ~ 40 were produced by fragmentation of $^{76}Ge^{19+}$ projectiles having energies of 70 MeV/nucleon in a 202 mg/cm^2 thick ^{9}Be target. The A1200 fragment separator with a 70 mg/cm^2 Al wedge at its second dispersive image was used to separate the fragments. The momentum acceptance was set to 1% of the central Bρ using a slit at the first momentum dispersed image of the A1200. Further M/q separation was achieved using the Reaction Product Mass Separator (RPMS). The A1200 was tuned to the peak of the momentum yield curve for ^{73}Cu secondary fragments. Other activities identified by ΔE-TOF at the RPMS tail for this setting of the A1200 included ^{70,71}Ni, ^{72}Cu and ^{74,75}Zn. The desired ^{73}Cu beam was implanted into a collection wheel consisting of nine aluminium collection foils equally spaced around the circumference. For these measurements, implantation and decay times of 6 s and 12 s, respectively, were chosen. β– and γ-ray detectors were arranged as scintillator-Ge pairs in close geometry on both sides of the implantation point of the collection wheel, with the plastic beta detectors placed immediately in front of the Ge detectors. β– and γ-ray singles and β-γ and γ-γ coincidence data were collected event-by-event and written to 8 mm magnetic tape.

Transitions belonging to the β decay of ^{73}Cu were first identified [3] at 199, 307, 450, 502, and 674 keV, and a half-life of 3.9(3) s was determined for ^{73}Cu from the decay characteristics of the 450-keV transition. The decay curves for transitions assigned to the β-decay of ^{73}Cu and the 228-keV transition from the β decay of ^{75}Zn, the most abundant contaminant mass, are shown in Fig. 1. A weighted mean of the measured half-lives for the five transitions shown in this figure results in $T_{1/2}$ = 4.4(3) s, which is consistent with the previous measurement [3]. The proposed level scheme for ^{73}Zn shown in Fig. 2 is based on γ–γ coincidence data, intensity balances, and sum-energy considerations. A ground-state β branch of 42(12)% was deduced from the difference between the total number of β particles, determined from the growth curve of 218-keV transition associated with ^{73}Ga, and β feeding to excited states. Systematics of the neutron-rich odd-A Cu isotopes suggest spin and parity $I^\pi = 3/2^-$ for the ground state of ^{73}Cu. The ground state spin and parity of ^{73}Zn is most likely $I^\pi = 1/2^-$. This assignment is supported by the fact that the β decay of the ground state of ^{73}Zn to the $5/2^-$ state in ^{73}Ga has a log*ft* value greater than 7. A strong β branch is observed to the 450 keV state in ^{73}Zn, which deexcites via γ emission only to the ground state. The log*ft* value of 5.2 to this state suggests an allowed β transition and we have tentatively assigned $I^\pi = 3/2^-$ to this state. The levels at 307, 502, 1124, and 2009 keV are all fed weakly in β decay and the deduced log*ft* values of ~6 suggest that these are all negative parity states with spin values of 1/2, 3/2, or 5/2.

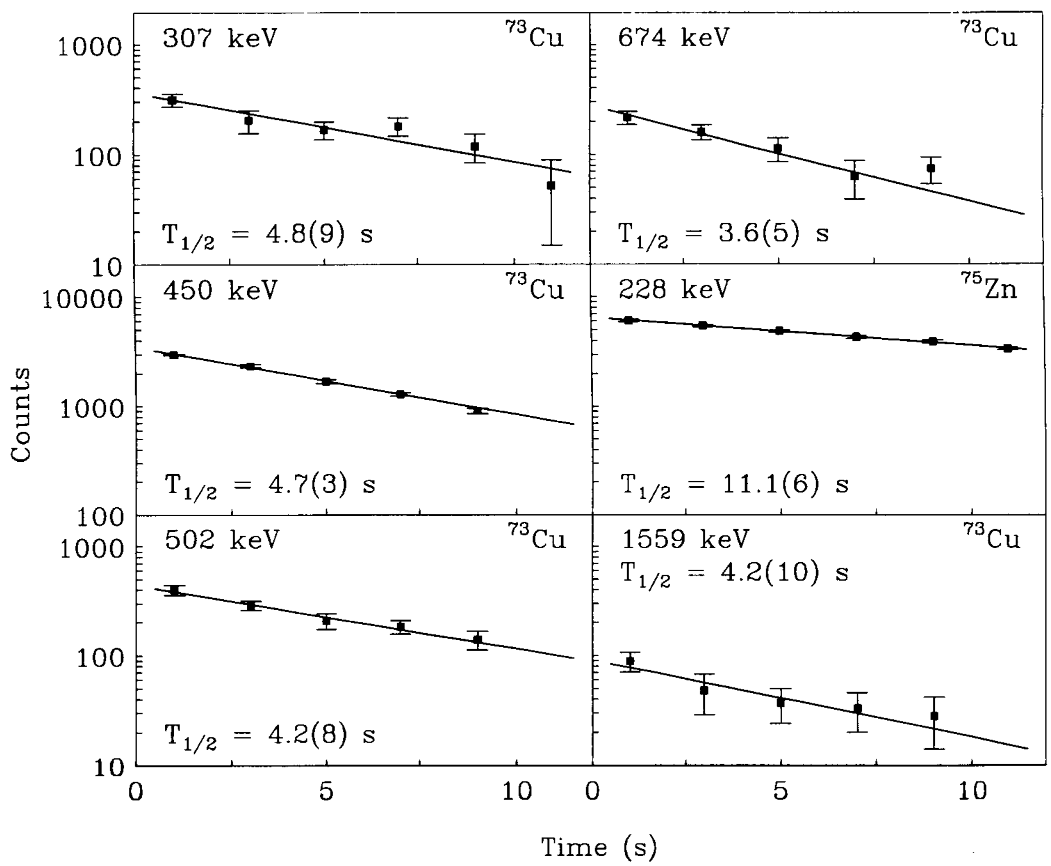

Fig. 1. Decay curves for proposed β-delayed γ ray transitions from ^{73}Cu. A representative curve for the 228-keV β-delayed γ ray transition from ^{75}Zn, the major isotopic contaminant, is also shown.

The collection of γ-ray singles data during the growth and decay periods made it possible to detect short-living (millisecond) isomers. With the A1200 tuned for the peak production of ^{73}Zn, we identified a short-lived 195-keV transition in the γ ray singles spectrum, whose decay curve is shown in Fig. 3. These data were obtained using a 30 ms growth period and a 100 ms decay period, and the deduced half-life of 13.0(2) ms is several orders of magnitude faster than the $T_{1/2}$ = 5.8(8) s 195-keV isomeric transition assigned to ^{73}Zn in Ref. [4]. Our new measured half-life for the 195-keV transition in ^{73}Zn restricts the multipolarity of this transition to M2, when using the Weisskopf estimates, which establishes the spin and parity of the 195-keV state in ^{73}Zn to be $I^\pi = 5/2^+$. Since all transitions below 100-keV were too low in energy to penetrate the endcaps of our p-type Ge detectors, we could neither confirm nor refute the existence of a $T_{1/2}$ = 5.8 s isomeric transition at 42 keV as reported in Ref. [4]. Such an isomeric transition would be reasonable to consider in ^{73}Zn, where a low-energy $9/2^+$ level may be present a few tens of keV above the $5/2^+$ isomeric state. The expected E2 transition rate between such closely-positioned states would be slow.

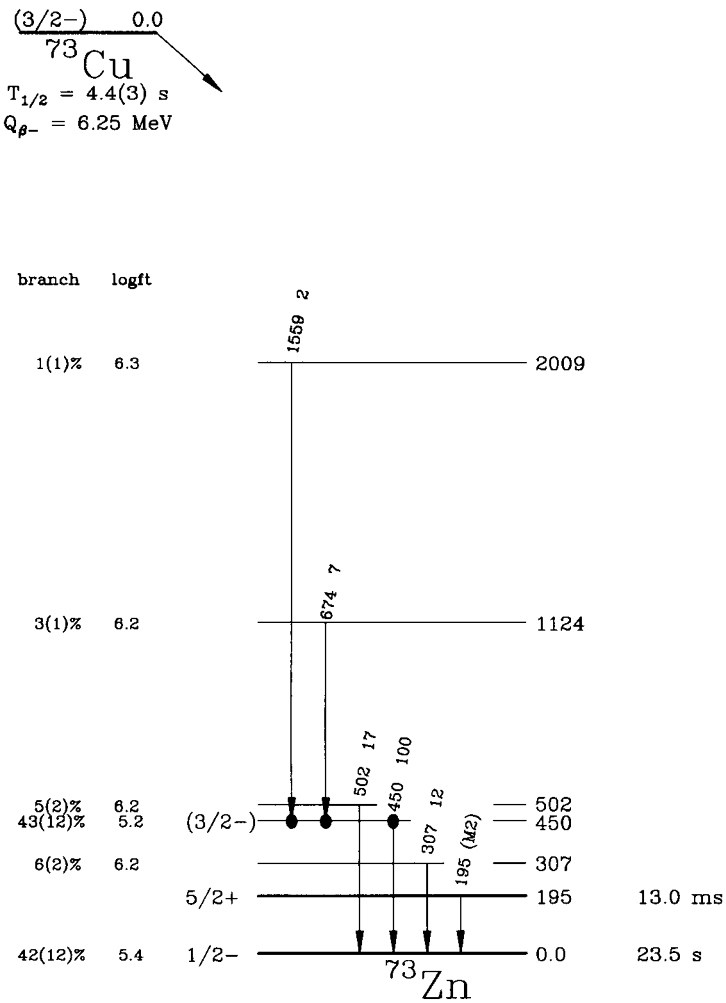

Fig. 2. Proposed decay scheme for ^{73}Zn → populated via the β decay of ^{73}Cu.

We have performed particle-triaxial rotor model (PTRM) calculations [5,6] in an attempt to reproduce the low-energy level structure of $^{73}Zn_{43}$ and $^{75}Ge_{43}$. Although ^{73}Zn lies only two protons off the Z = 28 shell closure and the microscopic-macroscopic calculations of Möller *et al.* [7] predict an ε_2 value of only 0.06, results of other global calculations, for instance the Extended Thomas-Fermi Strutinsky Integral(ETFSI) approach [8], predict moderate prolate ground state deformation ($\beta_2 = 0.24$) for ^{73}Zn and ^{75}Ge. Our new measurement offers an opportunity to explore which prediction is more accurate in this region of the chart of the nuclides. The PTRM calculations involved the diagonalization of the deformed shell-model hamiltonian to compute single-particle energies and wave functions of a nonaxially symmetric deformed Woods-Saxon potential [9,10]. The quadrupole deformation parameters were initially taken from Ref. [8] and β_4 and γ were both taken as zero. Positive and negative parity states were calculated separately (no octupole deformation) considering all Nilsson orbitals within ± 7 MeV of the Fermi surface. The relative positions of the positive parity states to the negative parity states were determined from available experimental data. The residual pairing interaction was treated within the BCS approximation, where a standard value of the pairing strength parameter G was adopted for each isotope using the prescription given in Ref. [11]. The core 2^+ energies were taken from the neighboring even-even nuclides. The recoil terms in the hamiltonian were treated as one-body operators. Attenuation of the Coriolis matrix elements by a factor 0.7 was used to reduce the mixing between intrinsic states and to lower the energy of non-spin aligned members of the band build upon the intruder $\nu[422]5/2^+$ orbital. The results of the PTRM calculations for ^{75}Ge agreed well with experimental level energies, magnetic moments, and γ-ray branching ratios.

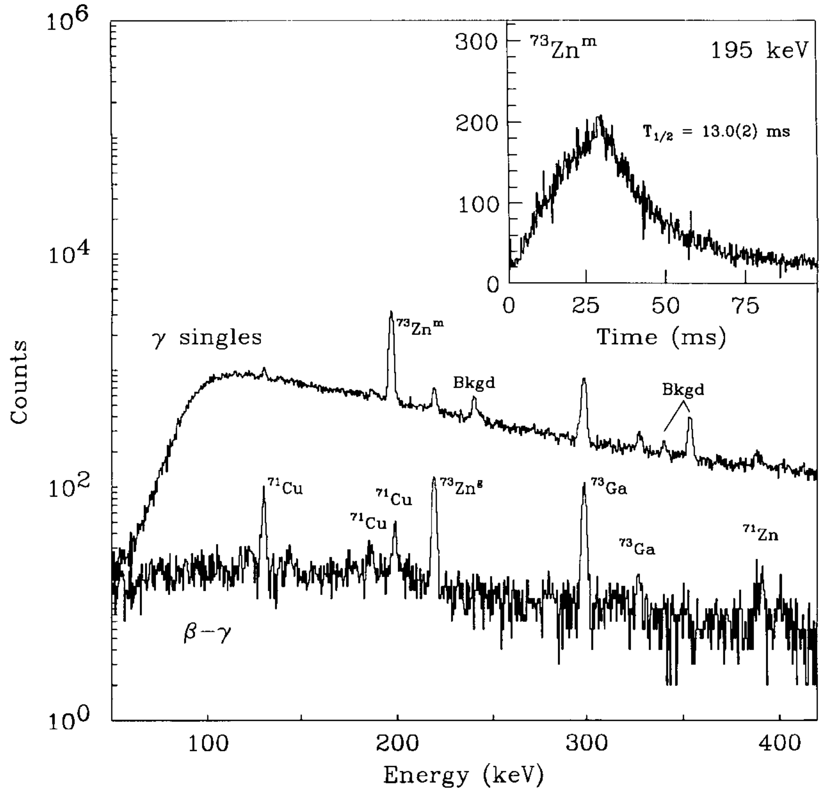

Fig.3. Portions of the γ ray singles and β−γ coincidence spectra collected during implantation when the A1200 was tuned for peak production of ^{73}Zn. The growth and decay curve for the 195-keV isomeric transition assigned to ^{73}Zn is shown in the inset.

Although only limited experimental information is available for ^{73}Zn, the results of the PTRM calculations were encouraging. The calculations using a ground state quadrupole deformation of β_2 = 0.20 predict the lowest positive-parity state to be $5/2^+$, with a wavefunction that is highly mixed between the $\nu[422]5/2^+$, $\nu[431]3/2^+$, and $\nu[440]1/2^+$ deformed single-particle states. Two other positive parity states having $I^\pi = 7/2^+, 9/2^+$ are also predicted at low energy, where the $9/2^+$ state may be responsible for the $T_{1/2}$ = 5.8 s isomeric state in ^{73}Zn identified by Runte *et al.* [4]. The next set of positive parity levels are predicted to lie around 1 MeV. The experimental states observed in ^{73}Zn fed in the β decay of ^{73}Cu are most likely negative parity states, and map well with those calculated within the PTRM. The lowest negative parity state is predicted to be $1/2^-$ and is predominately $\nu[301]1/2^-$. The first excited state is the bandhead of the $\nu[303]5/2^-$ deformed single particle orbital. Both the $3/2^-_1$ and $5/2^-_2$ states are members of the ground state and and are predicted to decay primarily to the $1/2^-$ ground state, as is observed experimentally. The $3/2^- \rightarrow 1/2^-_1$ transition is calculated to be mostly M1 ($\delta(E2/M1)$ = +0.245) and the theoretical B(E2; $5/2^-_2 \rightarrow 1/2^-_1$) value of 0.029 e^2b^2 is at least three times larger than that calculated for the other transitions depopulating the $5/2^-_2$ state.

a. University of Maryland, College Park, MD 20742

References

1. M.N. Vergnes et al., Phys. Lett. 72B, 447 (1978).
2. M. Bernas *et al*., Nucl. Phys. A413, 363 (1984).
3. E. Runte *et al*., Nucl. Phys. A399, 163 (1983).
4. E. Runte *et al*., Nucl. Phys. A441, 237 (1985).
5. S.E. Larsson, G.A. Leander, and I. Ragnarsson, Nucl. Phys. A307, 189 (1978).
6. I. Ragnarsson and P.B. Semmes, Hyperfine Interactions 43, 425 (1988).
7. P. Möller, J.R. Nix, W.D. Myers, and W.J. Swiatecki, At. Data Nucl. Data Tables 59, 185 (1995).
8. Y. Aboussir, J.M. Pearson, A.K. Dutta, and F. Tondeur, At. Data Nucl. Data Tables 61, 127 (1995).
9. W. Nazarewicz, J. Dudek, R. Bengtsson, T. Bengtsson, and I. Ragnarsson, Nucl. Phys. A435, 397 (1985).
10. S. Cwiok, J. Dudek, W. Nazarewicz, J. Skalski, and T. Werner, Comput. Phys. Commun. 46, 379 (1987).
11. J. Dudek, A. Majhofer, and J. Skalski, J. Phys. G 6, 447 (1980).