Probing the Low-lying Level Structure of $^{94}\text{Zr}$ Using $\beta^-$ decay


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Introduction

The structural evolution along the chain of even-$A$ Zr isotopes is shown in Fig. 1. It is evident from the figure that there is a major shape transition with increasing neutron number from spherical $^{90}\text{Zr}$ to strongly deformed $^{102}\text{Zr}$. The lightest stable isotope, $^{90}\text{Zr}$, lies at the $N = 50$ shell closure, whereas the heaviest stable isotope, $^{96}\text{Zr}$, lies at the $N = 56$ subshell closure. Lying between these two closures, $^{92,94}\text{Zr}$ appear to have spherical ground states. It is also observed that there is an onset of mild collectivity in $^{94}\text{Zr}$ at the excitation regime of $\sim 1.3 - 1.7$ MeV. The excitation of protons across the $Z = 40$ subshell closure appears to play a dominant role in stabilising the collective structure in $^{94}\text{Zr}$ in this low-energy regime [1]. We are reporting here a part of our findings for $^{94}\text{Zr}$ obtained from an experiment following $\beta^-$ decay of $^{94}\text{Y}$.

Experimental Procedures and Results

The low-lying excited states of $^{94}\text{Zr}$ were populated through $\beta^-$ decay of radioactive $^{94}\text{Y}$ ($T_{1/2} = 18.7$ min, $J^\pi = 2^-$, $Q_{\beta^-} = 4.918$ MeV and 100% $\beta^-$ branch). The experiment was carried out at the TRIUMF Isotope Separator and Accelerator radioactive beam facility. The accelerated 500 MeV proton beams impinged upon a $^{238}\text{U}$X target...
get and the radioactive $^{94}$Y sources were produced as fission fragments. Following mass separation of the fission products, $A = 94$ mass activities were deposited on the moving tape collector at the center of the $8\pi$ spectrometer. This spectrometer was comprised of an array of 20 Compton-suppressed HPGe detectors along with other detection devices for charged particles. The details of the experimental setup can be found in Ref. [1]. For off-line analysis, standard $\gamma$-ray spectroscopic techniques were used. The random-background-subtracted $\gamma - \gamma$ coincidence matrix contained about $2 \times 10^8$ events. Representative singles spectra showing the high-energy region are depicted in Fig. 2. Combining the singles and coincidence data, a comprehensive level scheme of $^{94}$Zr has been constructed up to $E_x = 4.8$ MeV, which is very close to the $Q_{\beta^-}$ value. A total of 64 new levels and 161 new transitions has been placed in the decay scheme of $^{94}$Zr. Several weak and low-energy decay branches have been newly placed from previously known levels, and the corresponding $B(E2)$ values could be obtained using the lifetimes of the levels from Ref. [2]. It appears that none of these transitions carry significant $E2$ strength, except for the 371 keV ($2^+_1 \rightarrow 0^+_1$)-transition, thereby suggesting the dominance of single-particle excitations. For theoretical interpretation of the observed structure in $^{94}$Zr, shell model calculations were carried out using the NuShellX code [3]. $^{88}$Sr was used as the inert core and the valence space was comprised of $\pi(2p_{1/2}, 1g_{9/2})$ and $\nu(3s_{1/2}, 2d_{5/2})$ configurations. The two-body interaction matrix file "gl" was used for the calculation. Reasonable agreement between the experimental and theoretical level energies was obtained (see Fig. 3). It is observed that the wave function structure of the first and second $0^+$ states is quite different. A neutron pair excitation from $3s_{1/2} \rightarrow 2d_{5/2}$ is the dominant contribution to the wave function of the $0^+_1$ state. On the other hand, for the $0^+_2$ state, a proton pair excitation from $2p_{1/2} \rightarrow 1g_{9/2}$ dominates the wave function.

FIG. 2: Representative $\gamma$-ray singles spectra for $^{94}$Zr showing the higher-energy regions. The ground state transitions are labelled with their energies. The unmarked $\gamma$ rays are the ones feeding the first three excited states of $^{94}$Zr.

FIG. 3: Difference between experimentally observed and shell model predicted level energies for a few of the low-lying states of $^{94}$Zr.

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