Neutron and proton transition matrix elements for low-lying collective excitations in Sn isotopes

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Introduction

Neutron-rich nuclei with large N/Z ratios may exhibit the unusual feature of decoupled neutron and proton density distributions. In such nuclei, the question of relative amount of neutron and proton transition strengths in low-lying collective excitations (surface oscillations) is of considerable interest. Along with the isoscalar (mass) transition density (neutrons and protons oscillating in phase), the isovector (out of phase) component, may be mixed in such transitions, which is not reflected in the pure collective picture. The ratio of the neutron and proton transition matrix elements, M_n/M_p, has often been used to indicate inhomogeneity between their transition densities, in comparison with the homogeneous isoscalar value of $M_n/M_p \sim$ N/Z. While proton (or charge) transition matrix elements, M_p, can be obtained from electron scattering or Coulomb excitation, the determination of M_n requires scattering of hadronic/heavy-ion probes. Comparing Coulomb scattering and heavy-ion data is considered as one of the most transparent approaches to determine M_n/M_p ratios [1]. However, to avoid large experimental uncertainties of M_n/M_p due to normalization errors of heavy-ion cross sections, a simultaneous determination of electromagnetic (charge) and isoscalar (mass) transition rates may be achieved by heavy-ion scattering in the Coulomb-nuclear-interference (CNI) region.

The main objective of this paper is to utilize the CNI effects in inelastic scattering for quantitative assessments of charge and mass transition rates, and thereby deduce the M_n/M_p ratios for ^{118,120,122,124}Sn isotopes for the $(0^+_{g.s} \rightarrow 2^+_1; \lambda = 2)$ and $(0^+_{g.s} \rightarrow 3^-_1; \lambda = 3)$ transitions using ^{7}Li beam as a probe at E$_{lab}$ = 28 MeV.

Measurement & Results

The angular distributions for ^{7}Li+^{118,120,122,124}Sn were measured at BARC-TIFR Pelletron facility, Mumbai. Six telescopes $(\Delta E - E)$ of Si-surface barrier detectors, placed 10° apart, were used to detect projectile-like fragments from 30° to 140°. Another Si detector, fixed at 30° w.r.t. the beam was used for flux normalization. Along with the elastic peak, yields of inelastic states corresponding to first rotational state of ^{7}Li (0.478 MeV), and 2^+_1 and 3^-_1 vibrational states of Sn were detected. In addition, several states corresponding to 1-n stripping (^{7}Li,^{6}Li) and 1-p stripping (^{7}Li,^{6}He), and subsequent excitation of respective residual nuclei, were identified. For constraining the model calculations, all these states were included (with available spectroscopic factors), to lead to realistic potential and coupling parameters.

The measured inelastic angular distributions were reproduced by collective DWBA calculations using FRESCO. It required independent adjustment of mass and charge deformation lengths, δ^m_λ and δ^{ch}_λ. The optical potential was of Woods-Saxon volume type, determined by fitting elastic scattering data (see inset of Fig. 1). For λ=2 transition, δ^{ch}_2 is consistent with already existing measurements, while for λ=3, existing δ^{ch}_3 values measured with different probes, could not reproduce the data throughout the angular range. For all Sn isotopes, $\delta^m_\lambda < \delta^{ch}_\lambda$ (see Table I). The experimental cross section and model calculation for λ=3 transitions are shown in Fig. 1.

From the information of δ^m_λ and δ^{ch}_λ for each transition, the contributions of neutrons and protons can be decoupled by extracting $\delta^{(n,p)}_\lambda$. Empirically, it is often assumed [1] that $\delta^p_\lambda \approx \delta^{ch}_\lambda$ and $\delta^m_\lambda \approx \frac{Zb_p\delta^p_\lambda + Nb_n\delta^n_\lambda}{Zb_p + Nb_n}$, where $b_{n(p)}$ are microscopic interactions of the external field (^{7}Li) with the neutrons (protons) of the Sn isotopes, evaluated by means of double folding calcula-

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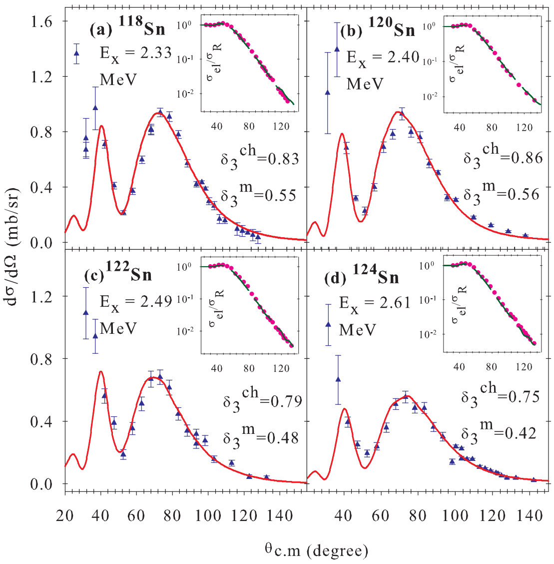

FIG. 1: Experimental cross section (points) and calculation (lines) for λ=3 inelastic scattering process in ^{7}Li+^{118,120,122,124}Sn system. (δ_3^{ch} values from existing Coulomb excitation measurement)

tions for the isoscalar and isovector parts of the density-dependent nucleus-nucleus potential. This leads to the ratio of corresponding matrix elements $M_n/M_p = \frac{N<r^{\lambda-1}>_n\delta_\lambda^n}{Z<r^{\lambda-1}>_p\delta_\lambda^p}$. The radial momenta $< r^{\lambda-1} >_{n,p}$ are taken over the g.s. densities. If the transitions are pure isoscalar, neutron and proton densities are expected to have the same radial shape and one would obtain $\delta_\lambda^n = \delta_\lambda^p$. For the present work, the results are summarized in Table I. A large and unusual deviation of the M_n/M_p ratios from N/Z is observed for the transition to the (3_1^-) states, as shown in Fig. 2.

TABLE I: Point proton and neutron transition parameters (experimental)

Nucleus	N/Z	$\lambda = 2$			$\lambda = 3$		
		δ_2^{ch}	δ_2^m	M_n/M_p	δ_3^{ch}	δ_3^m	M_n/M_p
^{118}Sn	1.36	0.651	0.612	1.22	0.831	0.552	0.57
^{120}Sn	1.40	0.662	0.624	1.26	0.865	0.556	0.54
^{122}Sn	1.44	0.615	0.591	1.34	0.792	0.480	0.47
^{124}Sn	1.48	0.575	0.513	1.23	0.751	0.425	0.39

The corresponding isoscalar (IS) and isovector (IV) transition densities are determined following the prescription of Ref. [2] and shown in Fig. 3. Unlike the $\lambda = 2$, a significant isovector mixing is present for $\lambda = 3$ transitions in Sn, which could be giving rise to damped isoscalar (mass) vibrations for these transitions ($\delta_3^m << \delta_3^{ch}$), leading to lower M_n/M_p ratios. Some uncertainty arises due to ambiguity in the available choices for δ_3^{ch} from Coulomb excitation, electron scattering, etc. However, the net conclusion of Fig. 3 is found to remain unchanged.

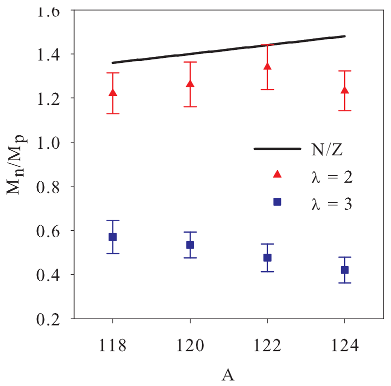

FIG. 2: M_n/M_p ratios for Sn isotopes, compared with the isoscalar value of N/Z.

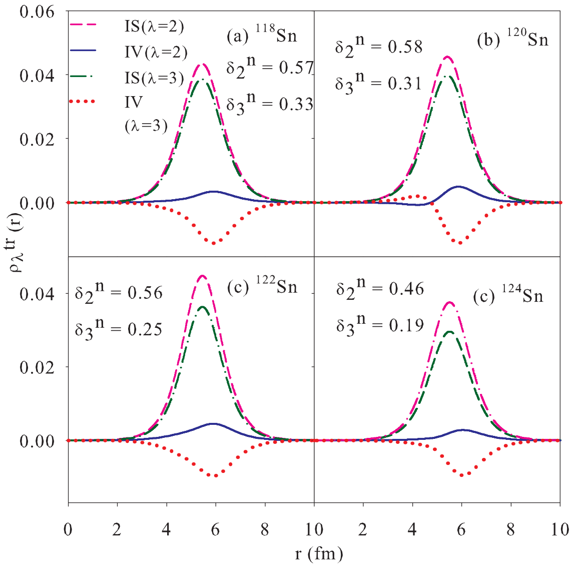

FIG. 3: IS and IV transition densities for the first quadrupolar ($\lambda = 2$) and octupolar ($\lambda = 3$) excitations in Sn isotopes.

References

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