Probe dependence of the nuclear deformation length of ^{120}Sn

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Introduction

Inelastic transitions in a nucleus are caused by electromagnetic and/or nuclear interactions with a second nucleus. The transition amplitudes reveal dynamic deformation parameters of nuclei. Excitation in heavy ion collisions is often induced by energetic ions not too far above the barrier; contributions from Coulomb and nuclear processes thus become comparable. The cross section is characterized by a Coulomb-nuclear interference (CNI) pattern, which allows simultaneous determination of electromagnetic (charge) and isoscalar (mass) deformation lengths, δ^{ch} and δ^{m}. These are sensitive to charge (proton) and mass (neutron + proton) distributions, respectively. In the collective model of nuclear vibrations, one thinks of a homogeneous neutron-proton fluid undergoing shape oscillations about equilibrium, with respective densitities in the ratio N/Z. However, these structural parameters of a nucleus are often found to be probe-dependent [1]. The main objective of this paper is to utilize the CNI effects for quantitative assessments of these structural parameters for $0^+_{g.s} \rightarrow 2^+_1$ (1.17 MeV) and $0^+_{g.s} \rightarrow 3^-_1$ (2.40 MeV) transitions in ^{120}Sn nucleus with ^{12}C as probe at $E_{lab} = 60$ MeV and compare the results with those obtained with a weakly bound probe at similar E/V_B [2].

Experimental details

The angular distributions were measured at BARC-TIFR Pelletron facility, Mumbai. A self-supporting enriched ($\sim$ 99%) target of ^{120}Sn (thickness $\sim$ 280 μg/cm^2) was used. Ten telescopes ($\Delta E - E$) of Si-surface barrier detectors, placed 10^o apart at a distance of $\sim$20 cm from centre, were used to detect projectile-like fragments in the angular range of 20^o to 110^o. Two Si detectors, fixed at $\pm$ 20^o w.r.t. the beam were used for flux normalization. Along with the elastic peak, the yields of inelastic states corresponding to 2^+_1 quadrupole (λ=2) and 3^-_1 octupole (λ=3) vibrational states of ^{120}Sn as well as 2^+_1 quadrupole state of ^{12}C (4.44 MeV) were detected. In addition, few states corresponding to 1-neutron pickup (^{12}C,^{13}C) with subsequent excitation of residual nucleus, were present. All these states were included in the theoretical model for constraining the calculations to lead to realistic potential and coupling parameters.

Analysis and Results

The inelastic scattering angular distributions were analyzed by Coupled Channels Born Approximation (CCBA) calculation using the code FRESCO. The strongly coupled elastic and inelastic scattering channels were solved exactly and blocked together to be treated as a single unit during iterations. The weaker transfer couplings were treated as successive perturbations iteratively. The wave functions were generated from an optical potential of Woods-Saxon volume type, whose parameters were determined by fitting the elastic scattering data. A calculation of the inelastic scattering angular distribution required an independent adjustment of δ^m_λ and δ^{ch}_λ. For $0^+_{g.s} \rightarrow 2^+_1$ transition, the value of $B(E2)$ or δ^{ch}_2 is consistent with existing Coulomb excitation measurements, and $\delta^m_2 > \delta^{ch}_2$. For $0^+_{g.s} \rightarrow 3^-_1$, available $B(E3)$ value deduced from Coulomb excitation was used for calculations, with $\delta^m_3 < \delta^{ch}_3$. These results are compared with those of a recent measurement on ^{120}Sn nucleus with ^{7}Li as probe at similar E/V_B [2]. The calculation for the ^{7}Li+^{120}Sn system was performed by taking into account the effect of projectile breakup. The target excitations have been coupled to the bound and unbound inelastic excitations

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(above breakup threshold 2.47 MeV) up to an excitation energy of about 8 MeV of ^{7}Li, where it has been assumed to have a two-body cluster structure of α + t. The experimental data and calulations are shown in Fig. 1. The deformation lengths are indicated in the figure. As the nature of the electromagnetic force is well understood, the observed probe-dependence of the mass deformation length may be attributed to the nuclear interaction governing the excitation.

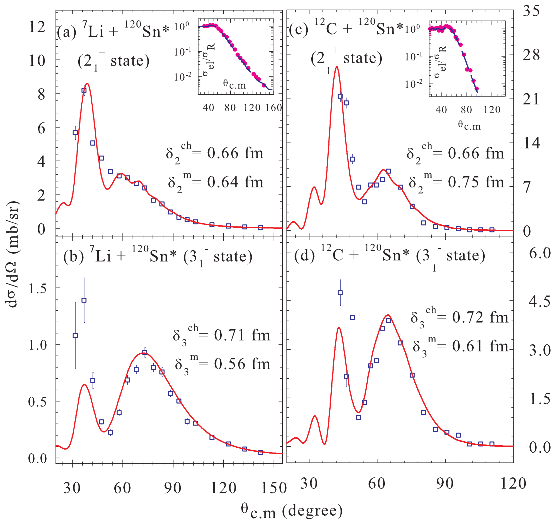

FIG. 1: Experimental cross sections (open squares) and CRC calculations (solid lines) for λ=2 and λ=3 inelastic scattering in ^{120}Sn in (a,b) ^{7}Li+^{120}Sn (using data from Ref.[2]) and (c,d) ^{12}C+^{120}Sn (present work) systems. Inset: Experimental elastic scattering angular distribution (circles) with calculation (dashed lines).

Discussion

Neutron-excess nuclei with high N/Z ratios may exhibit the unusual feature of decoupled neutron and proton density distributions. In such scenarios, the question of the relative participation of neutron and proton distributions in low lying collective surface vibrations is of considerable interest. The ratio of the neutron and proton transition matrix elements, M_n/M_p, has often been used to identify any inhomogeneity between their respective transition strengths, in comparison with the isoscalar value of $M_n/M_p \sim N/Z$ [1]. From the experimental information of δ_λ^m and δ_λ^{ch}, the exclusive contributions of neutrons and protons can be decoupled to investigate isospin dependence, if any. Following the prescription of Ref.[3], the ratio of the matrix elements M_n/M_p was deduced, as given in Table I. The results have been compared with microscopic calculation employing quasiparticle random phase approximation (QRPA) within the quasiparticle-phonon model that accounts for the fact that the proton system in ^{120}Sn is closed (magic) and the neutron one is not (non-magic) and collectivity is largely caused by neutrons.

TABLE I: M_n/M_p ratios for low-lying excitations in ^{120}Sn.

Probe	λ	M_n/M_p	$(M_n/M_p)/(N/Z)$
^{12}C	2	1.81(12)	1.29
	3	1.09(8)	0.77
^{7}Li	2	1.38(11)	0.98
	3	0.91(15)	0.66
†QRPA	2	1.89	1.35
	3	1.86	1.33

†V. Yu. Ponomarev, private communication.

The M_n/M_p ratio acts as a realistic tool for identifying the relative participation of neutrons and protons in a collective mass vibration. Here, the underlying assumption is that proton and neutron densities are proportional to each other with Z and N factors. The variation observed in Table I indicates a qualitative probe dependence (static and dynamic effects) of the collective nature of such transitions. To summarize, simultaneous measurement and description of elastic and inelastic scattering channels has been made for ^{12}C+^{120}Sn system and deformation lengths for collective excitation of ^{120}Sn to its low-lying vibrational states have been determined. The M_n/M_p ratio for the λ=2 transition is larger than the isoscalar value of N/Z and in reasonable agreement with QRPA. For the λ=3 transition, M_n/M_p ratio is lower than the expected isoscalar value, as also observed with ^{7}Li probe.

References

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