Systematic analysis of inelastic alpha scattering off self-conjugate *A=4n* nuclei

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Summary

Strength distributions in excitation-energy spectra of atomic nuclei provide insights into the nuclear structure because they directly reflect nuclear wave functions. Excitation strength is fundamentally the overlap between wave functions of ground and excited states, and energy is an eigenvalue of a nuclear Hamiltonian associated with the wave function. The excitation strength and energy are experimental observables, and can be directly compared with theoretical calculations of the nuclear structures. Therefore, the determination of the strength distribution is important to study the nuclear structure, for example, the cluster structures in nuclei.

The inelastic alpha scattering has selectivity to isoscalar natural-parity transitions where transferred spin and isospin are $\Delta S = 0$ and $\Delta T = 0$ since both spin and isospin of the alpha particle are zero. Therefore, the inelastic alpha scattering is useful to determine the strength distribution in excitation-energy region where several states overlap each other. In addition, the multipole decomposition analysis (MDA) works well to separate the strength distributions of the different transferred angular momenta ΔL, and it enables us to obtain the strength distribution of the isoscalar natural-parity excitations even from continuous excitation-energy spectra where many states with large widths overlap each other.

The MDA is established on the assumption that the cross sections of the inelastic alpha scattering are reasonably well described by the distorted-wave Born-approximation (DWBA) calculation and are approximately proportional to the relevant transition strength. However, a result contradictory to this linear proportional relation was reported in the monopole excitation to the Hoyle state from the ground state in ^{12}C. It was claimed in Ref. [1] that this problem was due to the reaction mechanism of the inelastic alpha scattering, and the inelastic alpha scattering might strongly couple to the nuclear structure.

Therefore, it had been very urgent to confirm whether this puzzle of the

inelastic alpha scattering really exists or not. If it exists, the puzzle should be solved, otherwise the strength distribution determined by the MDA of the inelastic alpha scattering might not be reliable. Nevertheless, the systematic measurement of the inelastic alpha scattering had not been performed nor examined to check the reliability of the theoretical calculation used in the MDA until now. In the present work, we systematically measured the cross sections of the inelastic alpha scattering at E_α = 130 and 386 MeV exciting low-lying discrete states in ^{12}C, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si and ^{40}Ca for the first time. In addition, the comparison of the measured cross sections with the "parameter-free" DWBA calculation was carried out. All of the adjustable parameters in the DWBA calculation were determined by the electromagnetic transition strengths and the elastic alpha scattering, therefore there is no room for so-called "the puzzle of missing monopole strength" if the consistency between the measured cross sections and the present DWBA calculations is confirmed.

It was found that the DWBA calculation with the DI interaction at E_α = 386 MeV was better than with the DD interaction and the calculation with the DI interaction at E_α = 386 MeV was better than that at E_α = 130 MeV, and thus the inadequate density dependence in the effective αN interaction caused the "puzzle of missing monopole strength" by overestimating the cross sections for the $\Delta L = 0$ transitions. This puzzle was not specific to the Hoyle state in ^{12}C but universally observed in all of the $\Delta L = 0$ transitions.

We also studied ambiguities of the DWBA calculations from the distorting potentials, phenomenological interaction, transition densities, and coupled-channel effects. The ambiguities originating from these factors in the present calculations were negligibly small in most cases of the inelastic scattering, although the CC effects sometimes gave sizable modification to cross sections.

It was also shown that there were still some uncertainties even for the DWBA calculations with the DI interaction to determine the strength distribution. Therefore, a new effective αN interaction with a more sophisticated formula is necessary. The present results should provide the unique and important information for theoretical studies to develop a new reliable N interaction.

[1] Dao T. Khoa and Do Cong Cuong, Phys. Lett. B **660**, 331 (2008).