4–1 Pursuit of Accurate Nuclear-Reaction Cross-Sections in the Resonant Region

— Synergy between Nuclear-Data Measurement and Theory —

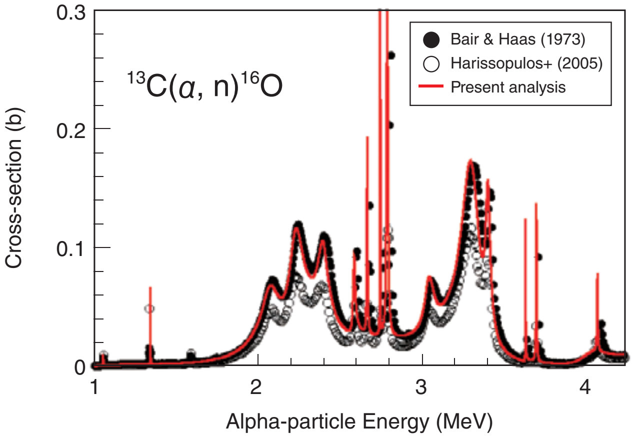

Fig.4-3 The systematic difference between the measurements together with the estimated values from the present analysis
We found that the systematic discrepancy among different experimental data could be resolved by a synergetic comparison between measurements and theory. In this example, an approximately 30% difference was observed between the old and recent measurements. Through shape analysis of the experimental data using R-matrix theory (which satisfies the quantum-mechanical conservation law), we obtained a result that supports the old measurement in this case.

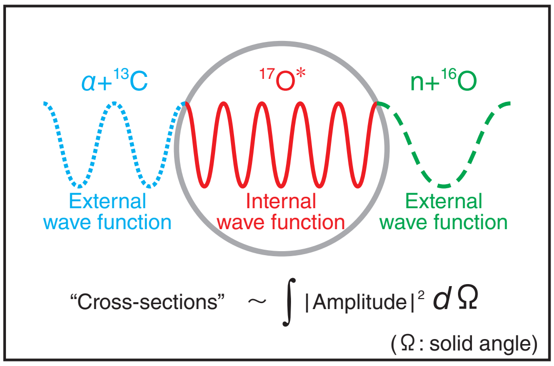

Fig.4-4 Concept of the resonant nuclear-reaction theory (R-matrix)
In the resonant nuclear-reaction theory adopted in this study, the matching condition of the internal and external wave functions is the parameter required for the calculation of the cross-sections. Note that the calculated cross-sections always satisfy the quantum-mechanical conservation law. In this study, we developed a computer code to obtain a value of the parameter from the shape of the experimental data.

Reactions occur in the nucleus with probabilities that depend on the energies of incident particles such as neutrons, protons, and alpha particles. Such probabilities, which are called nuclear-reaction cross-sections (or nuclear data), are fundamental values for nuclear engineering. With the recent progress of nuclear technology, cross-section data require ever-higher accuracy. Furthermore, the uncertainty values of these data must be fully accountable. To meet these demands, we are performing studies to enhance the general-purpose Japanese Evaluated Nuclear Data Library (JENDL; latest version is JENDL-4.0).

The cross-section shows resonant peaks in the low-energy particle reactions, reflecting the internal structure of the nucleus. Since those peaks are very difficult to predict only using nuclear theories, the most useful approach for determining the values is to conduct nuclear-data experiments at accelerator facilities with a combination of detectors. Here, let us indicate that we always see differences among measured data to a lesser or greater extent. An example is illustrated in Fig.4-3, in which an old measurement of the $^{13}C(\alpha, n)^{16}O$ reaction from 1970s and a recent one are systematically different by ~30%. Such a typical systematic difference is usually ascribable to uncertainty in the sample density.

In this study, we applied the R-matrix theory to the analysis of those experimental data (Fig.4-4). We adopted this theory essentially because it is strictly based on the quantum mechanics; hence, the theoretical calculation always obeys the quantum-mechanical conservation law (i.e., unitarity of the scattering matrix). The parameters in this theory are those for the matching condition of the internal and the external wave functions. We estimated those values from the shape of experimental data, assuming their absolute values to be unknown. The solid curve in Fig.4-3 shows the results of the present analysis, where the estimated values are consistent with the old experimental data. Moreover, the uncertainty of the present values is ~2.5% on average, which is significantly smaller than the difference in the measured data.

Uncertainty is always included in any measurement to a lesser or greater degree. However, we have presented a possibility for reducing the problem using a synergetic comparison between the measured nuclear data and the theory.

Reference

Kunieda, S. et al., Covariance of Neutron Cross Sections for ^{16}O through R-Matrix Analysis, Nuclear Data Sheets, vol.123, 2015, p.159-164.