QUASI-FREE SCATTERING OF ^{4}He NUCLEUS

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A ^{4}He nucleus is a simple system composed of four nucleons but its central nuclear density is twice as high as other nuclei. On this special nuclei, Yoshimura et al. have studied elastic scattering of protons at 300 MeV and measured differential cross section, analyzing power Ay, and a spin rotation parameter.[1] They analyzed the data with the relativistic impulse approximation and found that the ratio of the volume integral of the scalar density to that of vector density was significantly smaller for the ^{4}He nucleus than other heavier nuclei, which is consistent with the fact that density of ^{4}He is high. On the other hand, for (*p*,2*p*) reactions with $1s_{1/2}$ nucleon knockout, observed analysing power values are drastically smaller than those for free p-p scattering. It has been suggested that this Ay reduction is a nuclear density effect. One of the purposes of this study is to examine a high density effect of ^{4}He nucleus by using (*p*,2*p*) reactions.

Another interest in this reaction is related to that a (*p*,2*p*) reaction gives a means to deduce momentum distribution of a bound nucleon experimentally. At RIKEN, constraction of a radioactive isotope beam facility is on going and study of unstable nuclei by using this reaction, in the inverse kinematics, is schemed. The unstable nuclei to be researched include light targets as He and Li isotopes and there are difficulties specific to studies of light nuclei with this reaction, such as a recoil effect. Thus it is valuable to study ^{4}He(*p*,2*p*) reaction precisely because the structure of ^{4}He, one of the lightest nuclei, is now well known. The second purpose of our study is to examine how accurately we can deduce the momentum distribution of the protons in this light nucleus.

We measured cross section and analyzing power for the (*p*,2*p*) reaction by using the ring cyclotron complex at RCNP, Osaka University. A polarized proton beam was accelerated up to 392 MeV and transported to the center of the scattering chamber. A cooled Helium-gas target[2] was placed at the center of a scattering chamber and used as a target. Momenta of two protons emitted from the target were analyzed by using a high-resolution magnetics spectrometer "Grand Raiden (GR)" and "Large Acceptance Spectrometer (LAS)".

Measurements were performed for three kinds of kinematic conditions. The first one is a condition where the kinetic energies of two outgoing protons and one of the detection angles θ_{gr} were kept fixed and another angle θ_{las} was changed. The second is a condition where the kinetic energies of two outgoing protons were fixed as the previous conditon, and both angles were changed keeping the momentum of residual nuclei parallel to the momentum of incident protons. As the third kinds of kinematics, both of the detection angles were fixed and the energies of two detected protons were changed. In all of these three kinds of conditions, a kinematical condition where θ_{gr}=38.5°, θ_{las}=48.5°, and E_{gr}=242 MeV, where E_{gr} is the energy of protons corresponding to the central orbit of GR, is included. This corresponds to a condition where the momentum of recoil nuclei, and therefore, the Fermi momentum of the proton to be knocked out in the plane wave limit, is zero.

Experimental data for Ay are shown in Fig. 1. The Ay values were compared with PWIA (Plane Wave Impulse Approximation) and DWIA (Distorted Wave Impulse Approximation) calculations. The measured value of Ay at 0 MeV/c was 0.19. This value is 30% lower than the value of Ay calculated by the PWIA calculation, which corresponds to the Ay value for a proton-proton elastic scattering in free space. On the other hand, it was known in a previous study that Ay for $1s_{1/2}$-proton knockout from a ^{12}C target is 55% lower than the calculated value. Therefore, we conclude that the effect of central high density of the ^4He nucleus is not observed clearly.

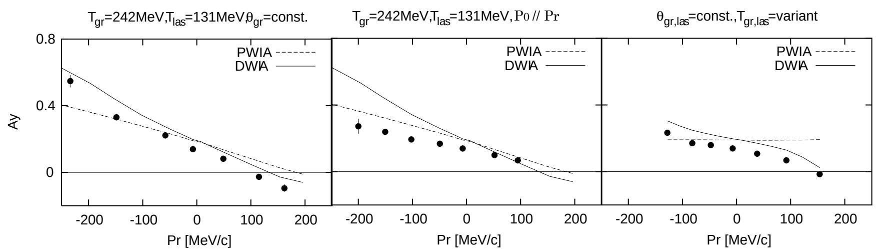

Figure 1: Experimental data of Ay with PWIA and DWIA calculations.

Data of the differential cross sections are compared with DWIA calculations. The experimental data for all kinds of kinematical conditions are consistent within 10% accuracy in FWHM (full width at half maximum). The width of the bound-state wave function is optimized in the DWIA calculations. Again, the discrepancies between the data and calculations are 10% level at most. The deduced S-factor, which is the ratio of the data and the calculation was 1.34, which is 67% of the shell model limit. Normally, S-factor is about 70%∼80% of shell model limit and the deduced value is lower than this range. However, S-factor was very sensitive to the width of wave function and, therefore, this discrepancy is not necessarily meaningful.

The data and the best-fit calculation is compared with various kinds of wave functions made in previous experimental and theoretical studies in Fig. 2. Even though one calculation is quite close to the best-fit calculation of the present study, and one gives significantly wider distribution, we need threoretical improvement before to give a concrete result because the deviation between the best-fit calculation and the experimental data are comparable with the differences between the best-fit calculation and the other calculation in Fig 2.

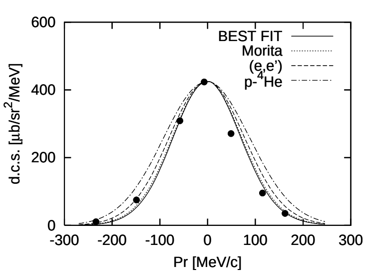

Figure 2: Several recoil momentum distributions for ^4He. The solid curve (BEST FIT) is the best-fit calculation in the present study. The dotted curve (Morita) is the distribution in a ATMS calculation.[3] The dashed curve ((e,e')) is the distribution obtained from the experimental charge distribution of ^4He by unfolding the charge form factor of a proton.[4] The dot-dashed curve (p-^4He) is the distribution obtained from the elastic scattering of protons and ^4He nucleus.[1] The root-mean-square (rms) radii of wave functions are 1.57 fm for BEST FIT, 1.54 fm for Morita, 1.45 fm for (e,e'), 1.34 fm for p-^4He respectively.

References

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