Elastic Proton Scattering from ^{4}He at 300 MeV

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Elastic scattering of polarized protons on nuclei at intermediate energies is an important probe providing useful information in the microscopic analysis of nucleon-nucleus interaction, wave function and reaction mechanism. In the medium energy range, NN interaction has been investigated in detail both experimentally and theoretically [1]. In this energy region, it is known that the NN total cross-section has a minimum and nuclear reaction is expected to be well described by a direct reaction picture. As a result, relativistic impulse approximation (RIA) calculations have succeeded in describing observables in elastic scatterings. Horowitz and Murdock reproduced observables for all heavier closed shell nuclei, requiring medium modification from Pauli blocking. However, they ruled out the calculation for ^{4}He target nuclei because of expected large center-of-mass corrections. From the small root-mean-square(rms) charge radius obtained by the electron scattering[2] or theoretical calculations for four-body system, it is suggested that the density at the central part of ^{4}He is higher than the saturation density. In order to obtain information from a higher density central region of ^{4}He nuclei, we measured three observables: $d\sigma/d\Omega$, A_y and Q for a wide range of angles (12 $^\circ_{lab}$ to 66 $^\circ_{lab}$) at 300 MeV.

The experiment was performed under the program E6 and E38 at RCNP. The beam accelerated up to 297 MeV by a ring cyclotron was transported to the liquid ^{4}He target at the scattering chamber. The scattered protons from ^{4}He were momentum-analyzed with the Grand Raiden. The LAS spectrometer was placed at a fixed angle, and was used as a monitor for the density of liquid target by counting elastic events from ^{4}He. Elastic scattering events were selected using a information of the VDC placed at the focal plane of Grand Raiden and DSR magnet. The $d\sigma/d\Omega$ and A_y were measured by using the vertically polarized beam with a intensity of 0.1 nA $\sim$ 2.0 nA, which value were measured using a Faraday cup in the scattering chamber. One of systematic errors of the $d\sigma/d\Omega$ is uncertainty of density of the liquid. The error bars of the $d\sigma/d\Omega$(Fig.2) contains this systematic error and statistical error. In Fig.3, the error bars of A_y show statistical errors only. Main part of systematic error is due to uncertainty of analyzing power of the beam-line polarimeters(BLP). It causes an 2.5% error of absolute value of A_y.

The Q and polarization were measured using a horizontal-polarized beam. The beam polarization was monitored by two sets of BLPs. Polarizations of scattered protons are measured using the FPP system with two DSR modes for each angle. A spin rotation angle β is defined as angle in the scattering plane of direction of polarization between initial and final state in the same coordinate system. In our analysis, the β is obtained without effective analyzing power (A_y^{eff}) of the FPP system. And, the A_y^{eff} values were deduced from the beam-polarization and obtained β. In Fig.3, data of A_y^{eff} are shown.

The Q observable can be written as $Q = \sqrt{1 - {A_y}^2} \sin\beta$. In Fig.4, the data of Q are shown, where the error bars show statistical errors only. Even at larger angles, those errors for Q are less than 0.03. As for systematic errors of the Q data, errors which comes from the uncertainty of absolute value of A_y above noted are at most ± 0.02 at 18°_{lab}. And, errors which comes from uncertainty in the precession angle in Grand Raiden is at most 0.02, where absolute value of Q are less than 0.25. Polarizations of scattered protons were obtained from left-right asymmetry measured with the FPP system and the obtained A_y^{eff}. In Fig. 3, data of polarization are also plotted.

Observables were calculated using the RIA code written by Horowitz et al [3]. In the calculation, we used three kinds of scalar and vector density distributions. The solid line is a calculation with a distribution from Dirac Hartree(DH) calculation [3], where the mass of scalar meson was changed from 520 MeV, a preferred value for heavier target nuclei, to 479 MeV in order to reproduce rms radius of charge distribution of ^{4}He. The dotted line shows calculation with the one-body distribution from Ref.[4]. The broken line shows the calculation with the distribution which was obtained from the electron scattering by naively unfolding the proton charge distribution[2]. Since the latter two distributions are not of relativistic nature, and there exists no scalar density distribution. Therefore, we made approximate scalar density distributions, assuming that the ratio of volume integral of scalar density to that of the vector density is equal to the ratio calculated from the DH distributions[5]. We assume that the shapes of scalar distributions are equal to those of vector density distributions, and that neutron densities are the same as proton densities.

The rms radius of density distributions of ^{4}He used in the RIA calculations are almost the same value, using with which the rms of charge radii[2] is reproduced. The observables calculated with these three density distributions are not varied at smaller angles. Changing the rms radius of the distribution, the observables calculated are drastically changed and much disagrees the data. As a free NN interaction, NN interaction parameters for 200 MeV is most preferable among the interaction parameters for three energies(200,300,400MeV). Considering the beam energy for NN interaction to be fold with, there are shift of energy causing transformation Breit-frame and c.m. frame. The beam energy for NN interaction is about at most 80 MeV lower than that for other heavier nuclei.

Then, we added recoil corrections which come from removing center of mass motion from Dirac equation. The Cooper and Jennings method [6] was used where both scalar and vector potentials are simply multiplied by constants. This corrections changes little and makes spin observables agreements rather bad. On the other hand, the corrections make the $d\sigma/d\Omega$ value smaller and agreement worse. Furthermore, we tried to add correction of medium modification from Pauli blocking using local density approximation. This correction is necessary for another heavier target nuclei[3]. But, this correction to ^{4}He makes the agreement of Q worse. This correction seems to be inadequate for ^{4}He. Using the realistic density distribution and NN interaction for 200MeV, the agreements between the data and the calculated observables are very good for smaller angles where ambiguity of the density distribution is small. However, calculation of second bump region of the $d\sigma/d\Omega$ is too small for the data. In earlier Dirac optical potential analysis[7] for experimental 500MeV data, this second bump and R-parameters was reproduced by using the fitted potential which had center minima. And, they discussed that this minima may reflect the central minimum in the ^{4}He point proton density[2]. In our calculation, the point proton density distribution which are made from unfolding the electron scattering data [2] have a center minima. But, in the process of the $t\rho$ approximation, minima of potential become to be very shallow. So, the calculated $d\sigma/d\Omega$ becomes to be rather large but it is still small for the data. In electron elastic scattering, the similar result is shown, where impulse approximation calculation for charge form factor of ^{4}He underestimated at second bump region. This discrepancy is explained to disappear with addition of meson exchange current(MEC). Because nucleon probe is thought to have different sensitivity for MEC of ground state of nuclei. As the comparison with data, nucleon probe is seen to be more sensitive to MEC or there are another physical background which isn't including in the RIA formalism.

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Figure 1: Measured A_y^{eff} of the FPP system. An x-axis is kinetic energy of incoming protons to the FPP system.

Figure 2: Comparison of differential cross section data to R.I.A. calculations.

Figure 3: Comparison of A_y data to R.I.A. calculations. Polarization data are also plotted.

Figure 4: Comparison of spin rotation parameter Q data to R.I.A. calculations.