Experimental studies of spin-dependent interactions in unstable nuclei with polarized proton target

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Abstract. A new polarized proton solid target has been constructed at Center for Nuclear Study, University of Tokyo. The target is designed specifically for use in radioactive nuclear beam experiments. We have measured the analyzing power for the p-^6^He elastic scattering by using the polarized proton target. The results are incompatible with any microscopic calculations presented before the measurement. Planned experiments at RIBF with the polarized target are also described.

Spin-dependent interactions are the origin of fundamental properties of nuclei, such as saturation, shell and cluster structures. One of direct manifestations of the spin-dependent interactions is the spin-orbit coupling in nuclei, which plays an essential role in nuclear shell model as first claimed by Mayer and Jensen[1, 2]. The spin-orbit coupling is phenomenologically modelled by a spin-orbit potential. The spin-orbit potential is localized at the nuclear surface and has a shape of $V_{LS} \sim \frac{1}{r} \frac{d}{dr} \rho(r)$. Here $\rho(r)$ is a density distribution.

From this surface nature of the spin-orbit potential, one can readily expect that the spin-orbit potential will be modified in neutron rich nuclei. If protons and neutron have different distributions, the spin-orbit potential should be composed of two parts localized at different positions. In addition, if neutrons has an extended distribution as is typical in skin or halo nuclei, the spin-orbit potential would have an extended shape correspondingly.

For the purpose to investigate the possible modifications of the spin-orbit potential in neutron-rich nuclei, measurement of spin-dependent asymmetry, vector analyzing power, can be a direct approach. One example is determination of a spin-orbit term in phenomenological optical potential from vector analyzing power for the proton elastic scattering from a nucleus. Another example is an energy difference between $j = \ell \pm \frac{1}{2}$ single particle states, spin-orbit splitting, which can be unambiguously determined from vector analyzing power for transfer or proton induced nucleon-knockout reactions. Those measurements for unstable nuclear beams require a polarized proton target.

A new polarized proton solid target (see Fig. 1) which is applicable to radioactive nuclear beam experiments[3, 4] has been constructed at Center for Nuclear Study, University of Tokyo. Here the proton polarization is produced at high temperature of 100 K and in low magnetic field of 0.1 T by use of an electron alignment in the photo-excited triplet state of aromatic molecules. The condition of high temperature and low magnetic field is essential in use of the target for radioactive nuclear beam experiments, allowing a detection of low-energy recoiled protons. The target material is a single crystal of naphthalene (C_{10}H_{8}) doped with a small amount of pentacene (C_{22}H_{14}). It is formed in a disk with a thickness of 1 mm and a diameter of 14 mm for use as a target. A pulsed laser light with a wavelength of 532 nm from Ar-ion
lasers are used to induce an electron alignment in the triplet state of pentacene. The population difference in Zeeman sublevels of the triplet state is transferred to proton polarization by means of a cross polarization method. Proton polarization of $\sim 20\%$ has been achieved with the system.

Figure 1. Overview of the polarized proton solid target.

By use of the polarized target, vector analyzing power $A_y$ for the proton-$^6$He elastic scattering was measured at 71 MeV/A. The experiment was carried out at RIPS, RIKEN. A $^6$He beam with an intensity of $\sim 2.5 \times 10^5$ s$^{-1}$ was produced via the projectile fragment reaction of a primary $^{12}$C beam of 92 MeV/A from a $^9$Be target. Detectors for recoiled protons and scattered $^6$He particles were placed to cover an angular range of $\theta = 35^\circ - 90^\circ$ in the center of mass system. Data were collected for two polarization states, “UP” and “DOWN”, for ease of cancellation of geometrical asymmetries. The magnitude of the proton polarization was measured every two hours by means of a weak-pulse NMR method throughout the experiment. The absolute value of the polarization is calibrated by comparing the NMR signal amplitude to the asymmetry of the proton-$^4$He elastic scattering at 80 MeV/A, the analyzing power for which is known[5].

The data of vector analyzing power is found to be incompatible with results of any microscopic calculations presented before our measurement. The theories predict positive values of analyzing power in the region of measurement, especially large positive values of 0.7–1.0 at $\theta > 50^\circ$. On the other hand, the measured data have negative values in the region of 40$^\circ$–50$^\circ$ and have small values in the backward angles. Analyses based on an optical potential model indicate that this behavior of the analyzing power can be understood if one uses a large radius parameter of $\sim 1.5$ fm for a spin-orbit part of the potential. Although this may a signature of an extended shape of the spin-orbit potential, its microscopic origin is still unclear. Further theoretical investigations, for example to evaluate contributions from coupling to breakup channels, are needed to extract information on the spin-orbit potential in neutron-rich nuclei from the data.

Experimentally, the spin-orbit splitting in nuclei can be determined by measuring an energy difference of $j = \ell + 1/2$ and $j = \ell - 1/2$ single particle/hole states. Nucleon transfer reactions such as $(d, p)$ and $(p, d)$ reactions, measured extensively at low energies, have been a powerful tool to determine the total angular momentum $j$ of single particle/hole states. At the energies of $E/A > 200$ MeV, proton induced knockout $(p, pN)$ reactions should take the place of transfer reactions. This is because small distortion effects and reasonable momentum transfer in the reactions at the energies will enable clear interpretation based on an impulse approximation. Combination of the polarized proton solid target and radioactive nuclear beams from RI beam factory at RIKEN will greatly widen the experimental opportunities along this line.

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