Development of a gas target system for pionic atom spectroscopy with ^{136}Xe(p,^{2}He) reaction

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A spectroscopy of pionic atoms is one of the most established ways to investigate quantitatively partial restoration of chiral symmetry in medium. From experimental information on binding energies of pionic states, we can deduce in-medium parameters of the pion-nucleus optical potential, such as the b_1 parameter, which is connected to the quark condensate [1]. The quark condensate is an order parameter of chiral symmetry and its reduction corresponds to the partial restoration of chiral symmetry. Experiments at GSI verified that the quark condensate is reduced by about 33 % at the normal nuclear density by deducing an enhancement of the b_1 parameter [2]. For a better understanding of the in-medium QCD, it is essential to extract the experimental information on the density dependence of the quark condensate. This may be realized by a systematic study of pionic states in nuclei along isotope or isotone chains. Currently, a systematic study is ongoing at RIBF, focusing on the Sn isotopes. We are going to perform an experiment at RCNP with a ^{136}Xe gas target, which is difficult to use at GSI and RIBF. The study with a ^{136}Xe target will be a starting point of a systematic investigation along N=82 isotones and Z=54 isotopes.

In order to establish the experimental methods of the pionic atom spectroscopy at RCNP, we performed the E483 experiment using the ^{124}Sn(p,^{2}He) reaction at the WS course in 2017. We could observe peak structures corresponding to pionic states [3].

As a next step, we are now working on R&D of a gas target system. The optimum mass thickness of the gas target has been determined to be about 30 mg/cm^2. For example, it is fulfilled by setting the pressure and the temperature of the gas to be 2.0 atm and 250 K, respectively, with a cell thickness of 25 mm. For this purpose, we will construct a new cooling system and perform an endurance test of the window foil against differential pressure and beam irradiation.

The gas target we have developed is shown in Fig. 1. Since xenon will be frozen at the temperature of LN_2, the cooling system which is employed in usual experiments at the WS course [4] is not usable as it is. In order to realize the temperature around 250 K, we are developing new cooling system using a Peltier device. The target cell contacts with the cold side of a Peltier device and thus the inside gas is cooled. The hot side of the Peltier device is cooled with a heat sink. The heat sink is a plate made of copper with a pipe inside, so that coolant can flow through the pipe. We use diluted ethylene glycol as coolant.

A prototype of the gas cell is made of copper. The thickness is 20 mm in the beam direction and have a circular aperture on each end whose diameter is 18 mm. The window foil, 6 μm-thick aramid, is sealed to the cell body with epoxy adhesive and held by cover plates made of aluminum with a thickness of 2 mm. The target gas is transferred from the gas handler placed outside the scattering chamber; the gas is injected through a tube at the side of the cell body via a feedthrough on the lid of the scattering chamber.

In order to install these devices in the scattering chamber, they are attached under the LN_2 reservoir of the standard gas system. The target can be moved vertically by the pulse motor like the standard system.

For the sake of a measurement of background, an endurance test of the window foil and an operation test of the gas target system, we performed test experiments at WS course with a natural Xe gas target in November and December 2018 (E531).

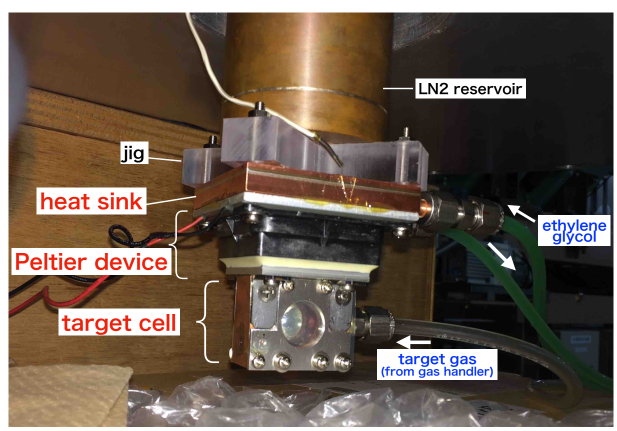

Figure 1: gas target used in the E531 experiment.

In November, the measurement of a background was performed with 392 MeV proton beam. The significant background in the main experiment is the accidental coincidence of the (p,p') reaction from the target. In the E531 experiment, we measured the counting rate of the (p,p') reaction in the momentum region of the production of pionic states. The trigger rate was 900 Hz/nA and 700 Hz/nA for the measurement with and without Xe gas, respectively. The counting rate due to the Xe gas ($\sim$200 Hz/nA) is as expected. Though the total trigger rate was large because of γ background from other than the target, it is expected to be reduced in the main experiment as we will use beam of lower energy, 350 MeV.

During the measurement, the temperature and the pressure were kept at -30 °C and 200 kPa, respectively. The temperature was stable; the change of the temperature was less than 1 °C throughout the beam time. On the other hand, the pressure decreased gradually by about 10% within 1 hour, although there was no abrupt change. The decrease may be attributed to a leak from the surface of the aramid foil, hence we need to prevent the leak by using a thicker foil or operating with a lower pressure.

In December, we checked endurance of the window foil against possible damage by the energy loss of the beam particle. 30 MeV proton beam with an average intensity of 140 nA impinged on the gas target for about 160 minutes. The total energy loss at the window is equivalent to that for irradiation of 350 MeV beam with an intensity of 30 nA for 3 days. Since we didn't observe a difference of the gas leakage compared to the previous experiment, we concluded that 6 μm aramid foil will be tolerable in the main experiment.

In addition, we also measured the net mass thickness of the gas target. The measurement is necessary because the effective thickness is not same as the thickness of the cell body due to the plasticity of aramid foil. The mass thickness along the beam direction was deduced from the energy loss of the beam particle, which was obtained by analyzing the momentum of a faint beam by Grand Raiden located at 0 degrees with and without the gas target. The measured energy-loss difference was consistent to the mass thickness with the expectation under the measured temperature and the pressure. We also found that the effective thickness has a weak position dependence, by changing the vertical position of the target, and this dependence may be attributed to expansion of the target cell. We will optimize the specification of the gas target, that is, the temperature, the pressure, and the size of the cell, as well as the material and thickness of the window, based on the result of the test experiments.

References

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