Pionic atoms spectroscopy at RCNP with the ^{124}Sn(p,^{2}He) reaction

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A spectroscopy of pionic atoms is one of the most established way 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 about 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 as a target at GSI and RIBF [3]. The study with ^{136}Xe target will be a starting point of a systematic investigation along N=82 isotones and Z=54 isotopes and may extract information about the density dependence of the quark condensate.

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. The reasons to choose ^{124}Sn as the target as the first step is as follows: Experiments at GSI or RIBF with solid Sn targets are performed intensively with using the (d,^{3}He) reaction. We will be able to compare the experimental results with those of the past experiments. ^{124}Sn was selected because the neutron number is largest in the stable Sn isotopes, hence large formation cross sections are expected.

The E483 experiment was performed from October 22nd to November 4th, 2017. We measured the ^{124}Sn(p,^{2}He) reaction using a 350 MeV proton with the average intensity of 30 nA. The proton beam was bombarded on a 30 mg/cm^{2}-thick ^{124}Sn target and two outgoing protons were momentum-analyzed by Grand Raiden located at 4.5 degrees.

We measured the ^{124}Sn(p,^{2}He) reaction for 170 hours during the 2 weeks of the beam time, and a sufficient number of the (p,^{2}He) events were recorded. The trigger rate was about 3 kHz and the background due to an accidental coincidence of particles which are inelastically scattered on the target was not so serious. The DAQ accept rate was about 75 %.

In addition to the measurement of the production of pionic atoms, some calibration measurements were performed:

- Beam energy measurement
  The reaction Q-value is calculated as $Q = T_{^2\mathrm{He}} - T_\mathrm{p} = B_{\pi^-} - 146.8$ MeV, where $T_{^2\mathrm{He}}$ is a sum of kinetic energies of 2 protons, T_p is a kinetic energy of projectile proton and B_{π^-} is a binding energy of pionic atom. We have to evaluate explicitly T_p for the determination of B_{π^-}, as the energy region of the detected protons ($\sim$100 MeV for each) is far different from that of the beam. Therefore, we performed the measurement of the absolute value of the beam energy, by using the p(p,p)p, ^{12}C(p,p)^{12}C, ^{12}C(p,d)^{11}C and p(p,π^{+})d reactions.

- Monitoring of the beam energy fluctuation
  Since there is no calibration peak available in the measurement of the ^{124}Sn(p,^{2}He) reaction, we checked the fluctuation of the beam energy by measuring the ^{197}Au(p,p) elastic scattering once every 3 hours and the ^{12}C(p,^{2}He)^{11}B reaction once every 6 hours. We found that the drift of the beam energy was as small as a few hundred keV, owing to careful operation and tuning of the cyclotrons. The change of the beam energy during the production measurement can be corrected by interpolating the results of the calibration measurement.

- Acceptance measurement
  The acceptance of Grand Raiden for two protons is evaluated from the yields of the ^{12}C(p,^{2}He)^{11}B$_{\mathrm{g.s.}}$ reaction with changing the magnetic rigidity of Grand Raiden.

The analysis, such as the correction for the ion-optical aberration and the shift of the beam energy during the beamtime, is in progress. After taking these effects into account with great care, we will be able to sum up all the data and obtain the excitation-energy spectrum of the ^{124}Sn(p,^{2}He) reaction.

References

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