論文の内容の要旨

論文題目　Search for η' mesic nuclei by missing-mass spectroscopy of the ^{12}C(*p,d*) reaction

（ ^{12}C(*p,d*) 反応の分光による η' 中間子原子核の探索 ）

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In this thesis, we describe a first experimental search for η' meson-nucleus bound states (η' mesic nuclei). An η' meson is one of the pseudoscalar mesons with a mass of 958 MeV/c^2, which is especially large compared with the other pseudoscalar mesons. This is theoretically considered as a consequence of $U_A(1)$ anomaly, which contributes to the η' mass only with spontaneous and/or explicit breaking of chiral symmetry in the low-energy region of QCD. In the nuclear medium, chiral symmetry is partially restored, and the quark condensate $\langle\bar{q}q\rangle$, which is an order parameter of chiral symmetry, is expected to be reduced by about 30%. Then, the mass of the η' meson can be reduced at normal nuclear density; about 150 MeV/c^2 reduction is expected, for example, in the Nambu-Jona-Nasinio model calculation. Such a mass reduction induces an attraction between an η' meson and a nucleus, and existence of η' mesic nuclei is theoretically suggested.

For production of the η' mesic nuclei, we employed the ^{12}C$(p,d)^{11}$C$\otimes\eta'$ reaction at an incident proton energy of 2.5 GeV. In this reaction, one neutron in the target is picked up, and a deuteron is emitted in a forward direction. At the same time, an η' meson is created in the residual ^{11}C nucleus and forms a nuclear bound state coupling with a neutron hole state.

In 2014, we performed, for the first time, the missing-mass spectroscopy experiment of the ^{12}C(p,d) reaction at GSI Helmholtz Center for Heavy Ion Research, in Germany. A 2.5 GeV proton beam accelerated by the SIS-18 synchrotron impinged onto a ^{12}C target to produce the η' mesic states via the ^{12}C(p,d)^{11}C$\otimes\eta'$ reaction. The ejected deuteron was analyzed by the Fragment Separator (FRS) used as a high-resolution spectrometer. The momentum of the deuteron was measured at a dispersive focal plane of the FRS, and a missing mass in the reaction was obtained by the energy and momentum conservation law.

The calibration of the spectrometer was carried out by measuring the $d(p,d)p$ backward elastic scattering using a 1.6 GeV proton beam and a CD_2 target. In this reaction, monochromatic deuterons with the momentum of 2.8 GeV/c are emitted, which is at the middle of the momentum range in the main measurements. By measuring these deuterons at the dispersive focal plane of the FRS, the proper functionality of the whole system was confirmed. We performed these measurements with various central momenta of the FRS, and calibrated the ion-optical properties of the spectrometer.

The particle identification was provided by a time-of-flight measurement between two focal planes of the FRS. In this experiment, an experimental background was mainly protons produced by the inelastic (p,p') reaction in the same momentum range. Since the velocity of these background protons ($\beta_p \sim 0.95$) were different from that of the signal deuterons ($\beta_p \sim 0.84$), they were clearly distinguished by the time-of-flight measurement. Furthermore, accidental multi-proton events were also rejected by analyzing recorded waveforms of the signals from scintillation counters. As a result, a contamination of the background protons in the spectrum was reduced to be a negligible level.

We successfully obtained an excitation-energy spectrum of ^{11}C from -90 MeV to $+30$ MeV with respect to the η' emission threshold. A high statistical sensitivity of a level better than 1% was achieved owing to a high-intensity primary beam and a thick carbon target. At the same time, an experimental resolution in the obtained spectrum was evaluated to be 2.5 MeV, which is sufficiently small compared with the expected widths of the η' mesic nuclei.

Since no peak structure was observed in the excitation-energy spectrum, we determined upper limits for the formation cross sections of the η' mesic nuclei. We statistically tested a Voigtian peak, which is a Lorentzian peak folded by a Gaussian resolution, at each fixed energy and width. The obtained upper limits around the η' emission threshold are about 0.1–0.2 μb/sr for the assumed peak width of $\Gamma = 5$ MeV, 0.2–0.4 μb/sr for $\Gamma = 10$ MeV, and 0.3–0.6 μb/sr for $\Gamma = 15$ MeV at 95% confidence level. These upper limits are as small as theoretically-expected cross sections for cases of deep η'-nucleus potential of the order of 100 MeV. Furthermore, the obtained spectrum was also directly compared with the theoretically-calculated spectra to discuss a limitation for the η'-nucleus potential parameters.