Experimental study on the ΞN interaction using Ξ^- atoms

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A particle which contains three quarks such as nucleon is called as baryon. The nuclear force, the strong interaction between nucleons had been studied well. On the other hand, for the interaction between a nucleus and a hyperon which is baryon with one or more strange quarks, the experimental data are very limited due to some experimental difficulties. Especially for Ξ^-(dss), there are almost no data. Investigation of the ΞN interaction is necessary for general understanding of the baryon-baryon interaction.

I performed a first pioneering experiment of the Ξ^- atomic X-ray spectroscopy to obtain information on the ΞN interaction. The atomic levels are shifted due to the ΞN interaction from that of only the Coulomb interaction is considered. The shift of the X-ray energy (ΔE) and the X-ray peak width give information of the real and imaginary parts of the Ξ^--nuclear potential, respectively. The measurement of Ξ^-C, Ξ^-Ag, and Ξ^-Br atomic X rays was performed at J-PARC. In the experiment, Ξ^-s were produced in a diamond target via the $p(K^-, K^+)\Xi^-$ reaction. Some of them were stopped in the target, or in the nuclear emulsion placed downstream of the target, and then formed Ξ^-C, Ξ^-Ag, and Ξ^-Br atoms. Most of produced Ξ^-s decay before stopping and cause a huge background. The key of experiment to measure X rays with good significance is to select Ξ^--stop events cleanly. Two methods were developed, one was using the nuclear emulsion (Method 1) and the other was using information of the Ξ^- momentum (Method 2). The Ξ^- atomic X rays were measured using the Germanium(Ge) detectors array called Hyperball-X. According to a theoretical calculation, the energy shift is as small as a few keV. In order to measure the energy shift with high precision, I developed a new in-beam calibration method using LSO scintillators and ^{22}Na sources. Because of this method, the systematic error for calibration was improved from a few hundreds eV to less than 100 eV for one Ge detector.

In Method 1, the Ξ^- track was searched for in the image of the developed emulsion and the Ξ^-Ag or Ξ^-Br atom production events were identified. The Ξ^- stop events were able to be selected with high accuracy by this emulsion image method. This analysis is on going. At the present analysis, the Ξ^-Ag and Ξ^-Br atomic X-ray spectrum was obtained with 20% statistics of the estimated total yield. When the image analysis is completed, an expected X-ray yield of the Ag($8J\rightarrow 7I$) transition will be 7.75 counts and a peak significance ($S/\sqrt{N}$) would be 4.56 in the $\pm 2\sigma$ peak region. The statistical error will be 290 eV and the systematic error is 100 eV. Thus, the energy shift is expected to be measured with 300 eV accuracy with the completed analysis.

In Method 2, Ξ^- momentum was reconstructed by analysis of magnetic spectrometers, and the events in which Ξ^- was stopped in the target with a large probability and captured by a ^{12}C atom were selected. From the Ξ^-C atomic X-ray spectrum, the upper limit of the branching ratio for the electromagnetic transition was experimentally evaluated. This limit was compared to the theoretical calculation using the Woods-Saxon-type Ξ^--nuclear potential. It was found that the experimental sensitivity was not sufficient to constrain the imaginary part of the Ξ^--nuclear potential. More improvements, for example optimization of the target thickness and detector developments to reject contamination of the background process, are required in the future experiment.

The Ξ atomic X-ray spectroscopic experiment, one of the powerful ways to investigate the strong Ξ^--nuclear potential, was established at J-PARC E07. From the obtained atomic X-ray spectrum, the sensitivity of the present experiment with both of two methods was evaluated and improvements necessary for future experiments were discussed.