氏名・(本籍)	三好敏喜（みよしとしのぶ）
学位の種類	博　士（理　学）
学位記番号	理博第１９９４号
学位授与年月日	平成15年３月24日
学位授与の要件	学位規則第４条第１項該当
研究科，専攻	東北大学大学院理学研究科（博士課程）物理学専攻
学位論文題目	Spectroscopic study of Λ hypernuclei by the (e,e', K$^+$) reaction ((e,e' K$^+$) 反応によるラムダハイパー核の分光学的研究)
論文審査委員	（主査）教授 橋本　治 教授 滝川　昇，山口　晃，織原　彦之丞 助教授 中村　哲

論　文　目　次

論　文　内　容　要　旨

A Λ hypernucleus is a baryon many-body system with strangeness degree of freedom. The study of Λ hypernuclei provide us with opportunities to investigate new forms of baryonic matter, and strong and weak baryon-baryon interaction. In previous Λ hypernuclear study, most of the counter experiments have been performed by the (K$^-$, π^-) and (π^+, K$^+$) reactions. In the spectroscopic study, it is particularly important to have good energy resolution in hypernuclear mass spectra. For example, the core-excited states of the $^{12}_{\Lambda}$C were observed in the ^{12}C(π^+, K$^+$)$^{12}_{\Lambda}$C reaction for the first time, because an energy resolution of 2.0 MeV (FWHM) was achieved by using the SKS spectrometer at KEK. Therefore, it is expected that spectroscopy with much improved energy resolution will yield significant information on hypernuclear structure, and the ΛN spin-dependent interactions. In this regard, the study of Λ hypernuclei produced via reactions other than the (K$^-$, π^-) and (π^+, K$^+$) reactions is required for further spectroscopic investigation of Λ hypernuclei.

Spectroscopic study of Λ hypernuclei by the (e,e' K$^+$) reaction has advantages over those by the meson induced reactions. The reaction has unique characteristics that transfers large momentum to a recoil Λ hypernucleus and populate both spin-flip and spin-non-flip states. Being more important from the experimental point of view, the reaction also makes it possible to achieve sub-MeV energy resolution, which is essential for further investigation of

hypernuclei.

In the present study, the Λ hypernuclear spectroscopy via the (e,e' K^+) reaction has been successfully carried out for the first time. Continuous Electron Beam Accelerator Facility (CEBAF) of Jefferson Lab (JLab) delivers high-quality CW electron beam which is indispensable for hypernuclear spectroscopy. Energy precision of the beam is less than 10^{-4} and the beam emittance is small, 2×10^{-9} m-rad. The hypernuclear spectrum with sub-MeV energy resolution can be obtained using the high-quality beam.

The present experiment adopted a unique kinematics to make full use of virtual photon flux which sharply peaks near 0 degrees. Thus, scattered electrons were detected including 0 degrees. Positive kaons were also detected at forward angles (0−4 degrees) because they also have forward angular distribution. To detect negatively and positively charged particles at forward angles, a dipole magnet (called the splitter magnet) was installed immediately downstream the target.

Scattered kaons were detected by the Short-Orbit Spectrometer (SOS) which was designed for detection of short-lives particles. Two drift chambers were used for particle tracking. Four hodoscopes were used for measurement of particle time-of-flight and for triggers. Shower and Cherenkov (gas, aerogel, and lucite) counters were used to distinguish kaons from other particles such as positrons, protons, and pions.

Scattered electrons were detected by the Enge split-pole spectrometer (ESPS) which has good focusing at the focal plane. A silicon strip detector (SSD) for momentum measurement and a scintillator hodoscope for timing measurement were installed near the focal plane of the ESPS. In the present experiment, the detectors must be operated with high-rate scattered electrons due to bremsstrahlung (10^8 Hz/74-cm focal plane). Especially, the SSD must be operated under high radiation dose. Thus, the radiation hard SSD and fast readout system was designed.

The ${}^{12}_{\Lambda}B$ spectrum was measured in the ${}^{12}C(e,e'\ K^+){}^{12}_{\Lambda}B$ reaction with 0.9 MeV (FWHM) energy resolution, which is better than the best one (1.5 MeV) obtained in SKS hypernuclear experiments. The spectrum showed two prominent peaks, which can be interpreted as having the configurations with the outermost proton-hole and a Λ hyperon in the s_Λ-orbits, $[(p_{3/2})^{-1}_{p},(s_{1/2})_{\Lambda}]$, and in the p_Λ-orbits, $[(p_{3/2})^{-1}_{p},(p_{1/2},p_{3/2})_{\Lambda}]$. Additionally, some small peaks are seen between the prominent peaks.

Absolute scale of missing mass was calibrated using the $p(e,e'\ K^+)\Lambda/\Sigma^0$ reaction on a CH_2 target. Therefore, the binding energy of the ground state of ${}^{12}_{\Lambda}B$ was determined within the present data. The binding energy of the ${}^{12}_{\Lambda}B$ ground state was obtained to be 12.19 $\pm$0.05 (statistic)$\pm$0.25 (systematic) MeV, which was close to the emulsion data, 11.37 $\pm$0.06 MeV. The difference between the present result and the emulsion value is unknown.

The global structure of the ${}^{12}_{\Lambda}B$ spectrum was similar to that of the mirror hypernucleus, ${}^{12}_{\Lambda}C$, which was measured with the (π^+, K^+) reaction. A ${}^{12}_{\Lambda}B$ spectrum with higher statistics and higher resolution is expected to give information on hypernuclear structure and ΛN interaction in the future.

The cross section of the ${}^{12}_{\Lambda}B$ ground state was derived to be 117 $\pm$13 (statistic) $\pm$14 (systematic) nb/sr. The theoretical prediction of the cross section (138 nb/sr) was consistent with the present result and therefore it was found that a DWIA calculation for the (e,e' K^+) reaction adopting a phenomenological potential for ΛN interaction described reasonably well the hypernuclear production process as in the case of the (π^+, K^+) reaction.

In summary, the present experiment proved the effectiveness of Λ hypernuclear spectroscopy via the (e,e' K^+) reaction for the first time, and paved the way to the precision spectroscopy of hypernuclei.

論文審査の結果の要旨

核子（陽子，中性子）を構成粒子とする原子核に対して“奇妙さ（ストレンジネス）”量子数を持つハイペロンをも含むハドロン多体系をハイパー核と呼ぶ。新しい自由度であるストレンジネスを持つラムダハイパー核は分光学的研究を通じてハドロン多体系の構造やラムダ核子相互作用についての貴重な情報を提供する。これまでのハイパー核研究は，主としてKEK 12GeV陽子シンクロトロンや米国ブルックヘブン国立研究所のAGS加速器で得られるπ，K中間子ビームを用いる反応によって行われてきた。これに対して高エネルギー電子線を用いた(e,e’ K^+)反応は，（１）スピン反転振幅が大きくスピン反転，非反転状態をともに励起する。（２）陽子をΛ粒子に転換し，中性子過剰Λハイパー核を生成する，という(π^+, K^+)反応等とは対照的な特徴を持つ。さらに，（３）大強度で質の高い一次ビームによる反応であるため１ＭｅＶ以下の高分解能分光実験が可能となる点は特に実験的に重要である。これらの特徴を持つ(e,e’ K^+)反応はハイパー核分光実験に最も適した反応の一つであり，その実験的研究が長く期待されていた。しかしながら，電磁相互作用によるハイパー核生成断面積は小さく，また，散乱電子とＫ中間子の同時測定を必要とすることから，実験が難しく，その実現には至っていなかった。

本論文は，米国ジェファーソン国立研究所の高エネルギー連続電子線ビームを用い^{12}C(e,e’ K^+)$^{12}_{\Lambda}B$反応により，初めて$^{12}_{\Lambda}B$ラムダハイパー核のスペクトルを分解能0.9 MeV(FWHM)で観測することに成功した研究に関するものである。得られた$^{12}_{\Lambda}B$ラムダハイパー核スペクトルから，$^{12}_{\Lambda}B$ハイパー核の基底状態の束縛エネルギーを導出し，これまで原子核乾板実験で得られている値と一致することを示した。また，(π^+, K^+)反応によって研究されている$^{12}_{\Lambda}B$の鏡映核である$^{12}_{\Lambda}C$のスペクトルとの対応がよいことを示し，さらに，その起源とラムダ核子相互作用との関係が注目を浴びている芯核励起状態に対応すると考えられるピークを観測した。本実験の成功は，(e,e’ K^+)反応によるラムダハイパー核分光研究の端緒を開いたものであり，電子線によるハイパー核生成反応の有効性を，実験的に明らかにし，(e,e’ K^+)反応が，この分野の今後の発展にとって重要であることを示した。また，今後の，電子線によるハイパー核研究の進むべき道を明らかにした点でも，ハイパー核分研究分野の基礎を築く研究である。

審査論文は著者が主要な役割を果たすことによって完成したものであり，本人が自立して研究を行うための優れた学識，研究能力をもつことを示している。したがって，三好　敏喜提出の論文は，博士（理学）の学位論文として合格と認める。