Kaonic ^3He and ^4He X-ray measurements in SIDDHARTA

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Abstract The SIDDHARTA experiment measured the kaonic ^3He and ^4He $3d \rightarrow 2p$ X-ray transitions using gaseous targets for the first time. The strong-interaction shift both of the kaonic ^3He and ^4He $2p$ states was determined with a precision of

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a few eV. The shift of kaonic ${}^4\text{He}$ is much smaller than the values obtained in the experiments performed in 70's and 80's, while it is consistent with the recent result of the KEK E570 experiment, as well as the theoretical calculated values. Therefore, the problem on kaonic helium (the “kaonic helium puzzle”) was definitely solved. The first observation of the kaonic ${}^3\text{He}$ X-rays was also achieved in the SIDDHARTA experiment. The shift both of kaonic ${}^3\text{He}$ and ${}^4\text{He}$ was found to be as small as a few eV.

Keywords Kaonic helium • Silicon drift detectors • X-ray spectroscopy

1 Introduction

There was a serious problem in the strong-interaction shift of the kaonic ${}^4\text{He}$ $2p$ state (the “kaonic helium puzzle”). The shift determined by the X-ray spectroscopy of kaonic ${}^4\text{He}$ was large (about -40 eV) [1], while a value deduced from the kaonic atom data of $Z \geq 3$ was about 0 eV [2, 3]. This discrepancy remained for more than 20 years.

This abnormal $2p$ level shift was focused in recent theoretical studies related to kaonic nuclear states. The largest shift of 10 eV was estimated in either the kaonic ${}^3\text{He}$ or ${}^4\text{He}$ $2p$ states [4]. However, the abnormal shift could not be explained even using the new theories. More precise and accurate measurements both of kaonic ${}^3\text{He}$ and ${}^4\text{He}$ were needed to understand this unclear situation.

The KEK E570 collaboration measured the kaonic ${}^4\text{He}$ $3d \rightarrow 2p$ transition with better detector resolution and a precise calibration method. The shift was determined to be $+2 \pm 2$ (stat.) ± 2 (syst.) eV [5], which disagreed with the previously found average value of -43 ± 8 eV [1]. The new result is consistent with the values according to theory [2, 3], but further confirmations by experiment were needed.

To confirm the result obtained by the E570 experiment, the SIDDHARTA experiment measured the kaonic ${}^4\text{He}$ X-rays for the first time using a gaseous target [6]. In addition, the kaonic ${}^3\text{He}$ X-rays were measured using the same setup, by replacing the target gas [7]. It is note that the world first's observation of the kaonic ${}^3\text{He}$ X-rays was achieved by the SIDDHARTA experiment. This article gives a summary of the kaonic He X-ray measurement in SIDDHARTA.

2 Experiment

The kaonic He X-rays were measured in the framework of the SIDDHARTA experiment in the DAΦNE e^+e^- collider at LNF (Italy). Figure 1 shows the schematic view of the experimental setup. Charged kaon pairs produced by the annihilation of e^+e^- beams were detected by two scintillators mounted in the interaction point (kaon detector). A cryogenic gas target was installed above the interaction point. Large area silicon drift detectors (SDDs) with a total area of 144 cm^2 [8] were installed to surround the target cell. The advantage of the gas target is a negligible effect of Compton scattering in helium. A contribution of the Compton tail was one of the difficulties in the analysis of the previous experiments [1, 5].

Fig. 1 Schematic view of the SIDDHARTA experimental setup

The data of kaonic helium were taken in the SIDDHARTA beam time, together with the kaonic hydrogen/deuterium X-ray measurement [9, 10]. The measurement of kaonic helium is important not only for the determination of the shift, but also for the performance check of the experimental apparatus. Because the X-ray yields of the kaonic helium $3d \rightarrow 2p$ transition are about 10 times higher than the yield of the kaonic hydrogen $2p \rightarrow 1s$ transition, the kaonic helium X-rays can be observed with excellent statistics in a short period of time.

The energy scale of each SDD was calibrated using the fluorescence X-rays from the Ti and Cu foils. An energy resolution of about 150 eV (FWHM) at 6 keV was obtained. Background events associated with the accelerator were rejected using the timing resolution of the SDDs. The main contribution of the background in DAΦNE is charged particles scattered from the beams. These background events are uncorrelated to the timing of the kaon production. The selection of the events correlated to the timing of K^+K^- pairs reduced background by several order of magnitudes.

Figure 2a shows the X-ray energy spectrum of kaonic ^4He [6]. The X-ray peak at 6.4 keV corresponds to the kaonic ^4He $3d \rightarrow 2p$ transition. Together with the kaonic helium X-rays, the Mn $K\alpha$ (5.9 keV) and $K\beta$ (6.4 keV) lines were observed because of the installation of an ^{55}Fe source intended for calibration and stability check of the SDDs [6, 8]. The shift of kaonic ^4He was determined to be

$$\Delta E_{2p}^{^4\text{He}} = 0 \pm 6 \text{ (stat.)} \pm 2 \text{ (syst.) eV.} \quad (1)$$

After the successful measurement of kaonic ^4He with the ^{55}Fe calibration source, kaonic ^4He and ^3He X-rays were measured without the source. Figure 2b shows the X-ray energy spectrum of kaonic ^3He [7]. The X-ray peak at 6.2 keV corresponds to the kaonic ^3He $3d \rightarrow 2p$ transition. In addition to the kaonic helium X-rays, other kaonic atom X-ray peaks (kaonic carbon, oxygen, and nitrogen) were observed, which were originated from the material of the target window (Kapton Polyimide).

Fig. 2 X-ray energy spectra of the $3d \rightarrow 2p$ transition of kaonic ^4He (a) and ^3He (b). The energy of these transitions were determined within a precision of a few eV

The shift of kaonic ^3He was determined to be

$$\Delta E_{2p}^{^3\text{He}} = -2 \pm 2 \text{ (stat.)} \pm 4 \text{ (syst.) eV.} \quad (2)$$

By replacing the target gas, the kaonic ^4He X-rays were remeasured. The fit result gave a shift of

$$\Delta E_{2p}^{^4\text{He}} = +5 \pm 3 \text{ (stat.)} \pm 4 \text{ (syst.) eV.} \quad (3)$$

3 Conclusions

The SIDDHARTA experiment measured the strong-interaction shift both of the kaonic ^3He and ^4He $2p$ levels with a precision of a few eV. They were measured using the gaseous targets for the first time, and the world first's observation of kaonic ^3He X-rays was achieved.

The determined values are summarized in Fig. 3, together with the results of the previous experiments. A large shift of the order of -40 eV determined by the experiments performed in 70's and 80's was not observed neither in kaonic ^3He nor kaonic ^4He . Both shifts of kaonic ^3He and ^4He are consistent with 0 eV within the errors. These results agree with theoretical values determined from other kaonic atoms with $Z \geq 3$ using optical model approaches [2, 3]. However, the theoretical prediction of a possible shift of more than 1 eV [4] cannot be ruled out within our precision.

A small isotope difference between kaonic ^3He and kaonic ^4He might exist. A much precise measurement, such as the J-PARC E17 experiment [11], will help for better understanding of the kaon-helium interaction.

The determination of the strong-interaction width of the kaonic helium $2p$ state is also important for the study of the kaon-helium interaction. However, the width

Fig. 3 Comparison of experimental results. *Open circle*: $\text{K-}^4\text{He } 2p$ state, *Closed circle*: $\text{K-}^3\text{He } 2p$ state. A negative (positive) value of the shift shows a repulsive (attractive) shift

is much smaller than the detector resolution. The upper limit of the $2p$ level width both of kaonic ^3He and ^4He will be reported in future.

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References

1. Baird, S., et al.: Nucl. Phys. A **392**, 297 (1983)
2. Batty, C.J.: Nucl. Phys. A **508**, 89c (1990)
3. Friedman, E.: Hyperfine Interact (2011). doi:[10.1007/s10751-011-0515-1](https://doi.org/10.1007/s10751-011-0515-1), [arXiv:1111.7194v1](https://arxiv.org/abs/1111.7194v1) [nucl-th]
4. Akaishi, Y.: In: Proc. Inter. Conf. on Exotic Atoms (EXA05), Austrian Academy of Sciences Press, Vienna, p. 45 (2005). doi:[10.1553/EXA05a45](https://doi.org/10.1553/EXA05a45)
5. Okada, S., et al.: Phys. Lett. B **653**, 387 (2007)
6. SIDDHARTA Collaboration: Phys. Lett. B **681**, 310 (2009)
7. SIDDHARTA Collaboration: Phys. Lett. B **697**, 199 (2011)
8. Bazzi, M., et al.: Nucl. Instrum. Methods A **628**, 264 (2011)
9. SIDDHARTA Collaboration: Phys. Lett. B **704**, 113 (2011)
10. Cargnelli, M., et al.: Hyperfine Interact (2011). doi:[10.1007/s10751-011-0541-z](https://doi.org/10.1007/s10751-011-0541-z)
11. Hayano, R.S., et al.: Proposal of J-PARC 50-GeV PS. Precision spectroscopy of Kaonic Helium $3\ 3d \rightarrow 2p$ X-rays (2006)