3–2 Probing the Strong Interaction with Superconducting Detectors

―Drastic Precision Improvement in the X-Ray Spectroscopy of Kaonic Atoms―

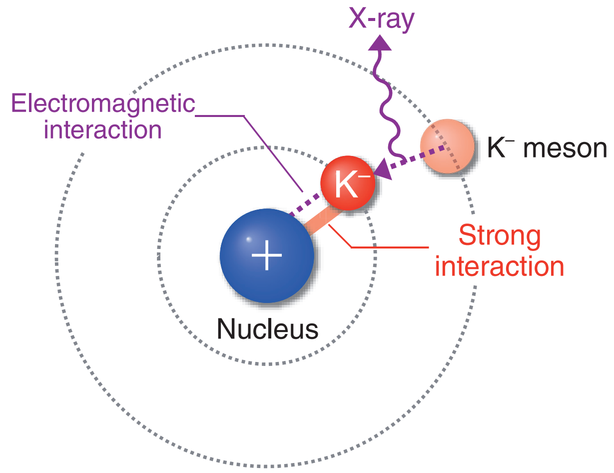

Fig.3-4 Diagram of a kaonic atom
K⁻ mesons, which have a negative charge like electrons, can replace an electron in ordinary atoms to form kaonic atoms via electromagnetic interaction. Additionally, the strong interaction slightly changes the orbital energies, and consequently, the X-ray energies.

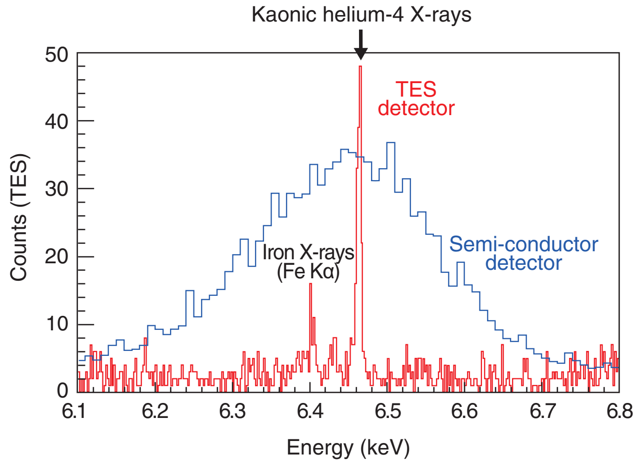

Fig.3-5 X-ray spectra of 3d→2p transitions in kaonic helium-4 atoms
We measured the X-ray spectra of kaonic helium atoms using a transition edge sensor (TES). The TES achieved excellent energy resolution compared to the conventional semiconductor detectors, and the peak energy was determined with high precision.

A kaonic atom is a system of a K^- meson and nucleus bound by electromagnetic interaction (Fig.3-4). We can study the strong interaction between a K^- meson and nucleus by measuring the X-rays emitted by kaonic atoms. Along with investigations of other particles with strange quarks, such as Λ particles, studies on K^- mesons will play an important role in elucidating the internal structure of neutron stars.

So far, the X-ray spectroscopy of kaonic atoms has suffered from the limited intensity of the K^- beam and the lack of X-ray detectors that can achieve both excellent energy resolution and good detection efficiency. We used the high-intensity K^- beam supplied by the J-PARC Hadron Experimental Facility to produce many kaonic atoms. The X-rays were then measured using superconducting transition-edge-sensor (TES) microcalorimeters.

The TES detector is a cryogenic detector with high energy resolution. It utilizes a rapid change in electrical resistance in a small temperature range at superconducting transition. Although a single pixel should be kept small for good resolution, a multipixel array realizes a reasonably large effective area. In this work, we used this detector at a charged-particle beamline for the first time. The K^- beamlines are particularly harsh environments for a high-sensitivity sensor as they contain many background particles such as π^- mesons. We successfully performed the X-ray measurement of kaonic atoms with excellent energy resolution by minimizing the background particles incident on the detector and removing their effects during signal analysis (Fig.3-5).

We determined the energy shift due to the strong interaction in the 2p orbitals of kaonic helium-3 and helium-4 atoms, with about 10 times better accuracy than the previous measurements. This result provides a strong constraint on how attractive the strong interaction between the K^- meson and the nucleus is. With further X-ray measurements of other kaonic atoms and studies of recently discovered nuclear systems containing a K^- meson, we wish to reveal more details about the strong interaction of K^- mesons and how K^- mesons affect the properties of neutron stars.

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Reference

Hashimoto, T. et al., Measurements of Strong-Interaction Effects in Kaonic-Helium Isotopes at Sub-eV Precision with X-Ray Microcalorimeters, Physical Review Letters, vol.128, issue 11, 2022, 112503, 6p.