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First measurement of X-rays from resonance states of muonic deuterium molecule using a cryogenic detector

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By using a superconducting transition-edge-sensor (TES) microcalorimeter with ultra-high resolution $\Delta E \sim 5$ eV (FWHM), a spectroscopic measurement of $dd\mu^*$ was successfully performed for the first time.

The $dd\mu^*$, in which μ^- is resonantly coupled with two deuterons, is predicted by the latest few-body calculations to emit dissociative X-rays with characteristic continuous distribution in the range of $1.60 - 1.97$ keV depending on its quantum state and to dissociate. These resonance states have attracted attentions in atomic physics and studied theoretically [1] because they can play an important role in muon catalyzed fusion (μCF). By introducing the reaction mechanism via the resonance states of muonic molecules ($dt\mu^*$, $dd\mu^*$) in the μCF process, the temperature dependence in the μCF cycle, which has not been understood before, was explained theoretically[2]. A muCF model that includes the formation and decay of these resonance states ($dt\mu^*$, $dd\mu^*$) can reproduce temperature dependence of μCF cycle rate at various deuterium-tritium mixing ratios.

Since the energy band of the dissociative X-rays ($1.60 - 1.97$ keV) is close to the $2p - 1s$ transition X-rays (1.97 keV) of $d\mu$ atoms, which are unavoidably mixed in the energy spectrum, a conventional semiconductor detector ($\Delta E \sim 100$ eV (FWHM)) hardly separates the origins of these X-rays. Thus, we performed an X-ray spectroscopy experiment on $dd\mu^*$ in February 2023 at the J-PARC MLF D2 beamline using the TES detector.

The energy resolution was sufficient not only to separate $d\mu$ atoms $2p - 1s$ X-rays and dissosiative X-rays of $dd\mu^*$ but also to separate the vibrational and rotational quantum states of $dd\mu^*$ from the obtained spectrum. Dissociative X-rays show an energy spectrum that strongly reflects the shape of the wavefunction, allowing spectroscopic measurement to investigate the quantum states of the resonance states.

References:
[1] I. Shimamura, Phys. Rev. A 40(1989)4863.; E. Lindroth et al., Phys. Rev. A 68(2003)032502.
[2] T. Yamashita et al., Sci. Rep. 12 (2022) 6393.

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