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K-series X-ray yield measurement of kaonic hydrogen atoms in a gaseous target

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Abstract

We measured the K-series X-rays of the K^-p exotic atom in the SIDDHARTA experiment with a gaseous hydrogen target of 1.3 g/l, which is about 15 times the ρ_{STP} of hydrogen gas. At this density, the absolute yields of kaonic X-rays, when a negatively charged kaon stopped inside the target, were determined to be $0.012^{+0.004}_{-0.003}$ for K_α and $0.043^{+0.012}_{-0.011}$ for all the K-series transitions K_{tot}. These results, together with the KEK E228 experiment results, confirm for the first time a target density dependence of the yield predicted by the cascade models, and provide valuable information to refine the parameters used in the cascade models for the kaonic atoms.

Keywords: Kaonic atom; Kaonic hydrogen; Atomic cascade; X-ray spectroscopy

1. Introduction

The measurements of the K-series X-rays of kaonic hydrogen K^-p and kaonic deuterium K^-d atoms give uniquely the isospin dependent antikaon–nucleon s-wave scattering lengths a_0 ($I = 0$) and a_1 ($I = 1$). Extracted from the energy spectra, the strong interaction induced energy shifts ϵ_{1s} and widths Γ_{1s} of the ground states of these kaonic atoms are connected to the s-wave scattering lengths via Deser-type formulae [1,2]. The SIDDHARTA collaboration succeeded in giving a precise evaluation of a_{K^-p} ($= \frac{1}{2}[a_0 + a_1]$) [3,4], and is preparing to perform the first precision measurement of the K^-d X-rays, to determine the isospin components a_0 and a_1 by extracting a_{K^-d}.

Moreover, a new result on the yield of K^-p K-series X-rays is essential to improve the cascade model calculation of the kaonic hydrogen, which is the most poorly understood among all the hydrogen-like exotic x^-p atoms, where x^- represents $\bar{p}, \mu^-, \pi^-$, or K^-. Up to now only the KEK-PS E228 (KpX) experiment obtained $Y_{K_\alpha} = 0.015 \pm 0.005$ and a K_α to K_{tot} ratio of 0.27 for a 10 ρ_{STP} hydrogen gas target [5,6]. The spectra from three earlier experiments [7–9] where a liquid target was used, were ambiguous and did not allow a reliable subtraction of the number of X-ray events. The K^-p and K^-d K-series X-rays are difficult to measure, firstly due to their small yields, mainly as a result of the Stark mixing of the high-lying atomic states, that causes the K^- to be absorbed by the nucleus from excited states, reducing the rate of the transitions to the ground state. A second reason is the large natural width of the $1s$ states, which makes a high signal to background ratio hard to achieve. For K^-p, results of experiments indicate a $1s$ width of ∼500 eV [3–6,10]; for K^-d, only theoretical predictions exist, which range from 650 eV to 1000 eV [11–13].

In this paper, we present the SIDDHARTA experimental result on the kaonic hydrogen K-series X-ray yield, which together with the KpX result, confirms a density dependence as predicted by multiple cascade calculations [14–17]. The new data will contribute to tuning the parameters including the $2p$ strong-interaction induced width, which is used in the latest kaonic hydrogen cascade models as the only free input parameter [16–18].

2. The SIDDHARTA experiment

The SIDDHARTA experiment was performed at the DAΦNE electron–positron collider, where the energies of the beams were tuned to 510 MeV to produce the $\phi(1020)$ meson al-