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Feasibility guidelines for kaonic atom experiments with ultra-high-resolution X-ray spectrometry

E. Friedman [a,*], S. Okada [b]

[a] *Racah Institute of Physics, The Hebrew University, 91904 Jerusalem, Israel*
[b] *RIKEN Nishina Center, RIKEN, Wako 351-0198, Japan*

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Abstract

Recent studies of strong-interaction effects in kaonic atoms suggest that analysing so-called 'lower' and 'upper' levels in the same atom could separate one-nucleon absorption from multinucleon processes. The present work examines the feasibility of direct measurements of upper level widths in addition to lower level widths in future experiments, using superconducting microcalorimeter detectors. About ten elements are identified as possible candidates for such experiments, all of medium-weight and heavy nuclei. New experiments focused on achieving good accuracy for widths of such pairs of levels could contribute significantly to our knowledge of the K^-–nucleon interaction in the nuclear medium.

Keywords: Kaonic atoms; Antikaon–nucleon interaction; Microcalorimeter

1. Introduction

Results of the precision measurements of kaonic hydrogen atoms by the SIDDHARTA Collaboration [1,2] form already part of the data-base used by Ikeda, Hyodo and Weise (IHW) in constructing the antikaon–nucleon scattering amplitudes near threshold [3,4]. Studies of kaonic atoms using potentials built on sub-threshold in-medium antikaon–nucleon scattering amplitudes [5–7] clearly indicate that multinucleon processes contribute significantly to the observed

* Corresponding author.
E-mail address: elifried@cc.huji.ac.il (E. Friedman).

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Table 1
rms radii of various terms of the K^-–nucleus potential (in fm). r_m is the rms radius of the nucleus.

	r_m	Re(full)	Re(1N)	Re(mN)	Im(full)	Im(1N)	Im(mN)
Ni	3.72	3.34	3.82	2.86	3.73	4.46	3.12
Pb	5.56	5.21	5.71	4.78	5.46	6.23	5.00

strong-interaction level shifts and widths. In particular it was shown [8] using the IHW amplitudes that analysing so-called 'lower' and 'upper' levels in the same atom could separate one-nucleon (1N) absorption from multinucleon (mN) processes. This property is the result of the very different radial dependences of the 1N and 2N terms of the potential, as demonstrated for Ni and Pb in Table 1. It is seen that in both examples the rms radius of the 1N real term is larger than that for the mN real term by 0.95 fm and that for the imaginary part the difference is 1.2 to 1.3 fm.

With the one-nucleon amplitudes firmly based on the SIDDHARTA experiment and its subsequent analyses, there is now a possibility to gain information on multinucleon processes of antikaons in nuclei. This calls for reduced uncertainties in experimental results, particularly for the upper level widths.

Strong-interaction effects in exotic atoms have been studied in great detail for several decades, see [9] for a recent review. Regarding strengths of absorption, kaonic atoms are intermediate between weak absorption in pionic atoms and very strong absorption in antiprotonic atoms. Absorption is sufficiently strong to make it the dominant effect in kaonic atoms, where strong-interaction level widths are up to one order of magnitude larger than the corresponding strong-interaction level shifts. Furthermore, these shifts are almost universally repulsive, although the real potentials required to fit kaonic atom data are attractive. Hence the role of the real part is secondary to that of the imaginary part of the potential.

The level width which is usually obtained as the imaginary part of the complex eigenvalue when solving the Klein–Gordon equation with an optical potential [10] is also related to the imaginary part of the potential as follows

$$\Gamma_{\rm st} = -2\frac{\int \mathrm{Im}\, V_{\rm opt}|\psi|^2\, d\vec{r}}{\int[1-(B+V_{\rm C})/\mu]|\psi|^2\, d\vec{r}} \tag{1}$$

where B, $V_{\rm C}$ and μ are the K^- binding energy, Coulomb potential and reduced mass, respectively. (For a Schroedinger equation the denominator is just the normalizing integral.) The widths are therefore the quantities which are more directly connected to the potential.

All available experimental results regarding upper levels in kaonic atoms are in the form of relative yields, defined as

$$Y^{\rm rel} = \Gamma_{\rm rad}/(\Gamma_{\rm rad}+\Gamma_{\rm st}) \tag{2}$$

where $\Gamma_{\rm rad}$ and $\Gamma_{\rm st}$ are the radiation width of the upper to lower level transition and the strong-interaction width of the upper level, respectively. The relative error of the derived $\Gamma_{\rm st}$ which is the quantity of interest turns out to be the relative error of the measured yield divided by $(1-Y^{\rm rel})$, introducing conflicting demands between intensity and accuracy.

The available data for kaonic atoms are based on experiments of three to four decades ago [11]. Although the data cover the whole of the periodic table with reasonably good accuracy for the shifts and widths of the lower levels, the widths of the upper levels are determined from the measured relative yields of the upper to lower level transitions. This causes an increase of errors