Ministry of Education
Department of Higher Education
University of Monywa

Monywa University Research Journal

Vol. 6, No. 1

December, 2015.

Contents

Theoretical Investigation of Differential Cross Section for $d(p, K^0p)ppK^-$ Reaction

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Abstract

We have studied theoretically kaonic nucleus formation in $d(p, K^0p)ppK^-$ reaction. We calculated differential cross sections corresponding to various incident kinetic energies and spectator proton momenta by using Green's function method. A peak due to the formation of bound kaonic nuclear state is found in missing mass spectrum versus ppK^- energy. It is found that peak positions in all spectra give the binding energy of Λ^*p (ppK^-) to be 64 MeV for various incident kinetic energies. The optimum condition for this reaction is found to be 3.5 GeV incident energy and 200 MeV/c spectator proton momentum P_s which gives the differential cross section 10.95 μb/MeV Sr/MeV Sr. We have also investigated the effect of size of the Λ^*p system on the formation cross section and momentum transfer. It is observed that the smaller the size of Λ^*p, the larger the differential cross section is. The momentum transfer to Λ^*p relative motion is very large which is about 1.6 GeV/c. Therefore, it may be deduced that this reaction process is realized through a very short-range nucleon-nucleon interaction which results from a heavy meson exchange.

Introduction

Kaonic atoms and kaonic nuclei carry important informations concerning the K^- - nucleon interaction in nuclear medium. In recent years, there have been important developments in the studies of kaonic nuclear states, which are kaon-nucleus bound systems by the strong interaction inside the nucleus. This information is very important to understand the kaon properties at finite density and to determine the constraints on kaon condensation in high density matter. The exotic nuclear systems involving a $\bar{K}$ (K^- or $\bar{K}^0$) as a constituent have been predicted based on phenomenologically constructed $\bar{K}N$ interaction [1,2,3,4,5,6]. The basic ingredient for this new family of nuclear state is a quasi-bound state of pK^-, which is identified as the $\Lambda(1405)$ with a binding energy 27 MeV and a level width 40 MeV [1]. The lightest kaonic nucleus is ppK^- which was predicted to have binding energy 48 MeV and level width 61 MeV [2]. ${}^2_{\bar{K}}H$ is the abbreviation of ppK^-. Although the pp system is unbound, the presence of a $\bar{K}$ attracts two protons to form a bound state. $ppnK^-$ is a nuclear bound state which is denoted as ${}^3_{\bar{K}}H$. The deeply bound $\bar{K}$ nuclear state appears in this system with isospin I=0. Its energy level lies by 108 MeV from the $K^-+{}^3He$ threshold which is below the $\Sigma+\pi$ threshold, and the level width is 20 MeV. The other state with isospin I=1 state has binding energy 21 MeV and very large width of 95 MeV [1]. The nuclear bound state of $ppnnK^-$ (${}^4_{\bar{K}}H$) has a binding energy of 86 MeV and a level width of 34 MeV. Since this state is slightly below the $\Sigma+\pi$ threshold, and is open only for the $\Lambda+\pi$ channel, the width becomes fairly narrow[1]. The ${}^8Be$ nucleus is known to have a well-developed α-cluster structure. When a K^- is injected into ${}^8Be$, a deeply bound $K^-{}^8Be$ is formed. Its structure is analyzed within the framework of $\alpha\alpha K^-$ three-body system by using varitional method [1]. When the valence neutron in ${}^9Be$ is replaced by a K^-, it stickingly increases the binding energy to 113 MeV from binding energy of ${}^9Be$ (58.16 MeV), which is well below the $\Sigma+\pi$ threshold and the level width becomes 38 MeV, decaying to the $\Lambda+\pi$ channel. Whereas some evidences for kaonic nuclear clusters for K^-pnn (BE=194 MeV) [7] and ppK (BE = 115 MeV) [8] were reported, it is important to

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produce various $\bar{K}$ clusters by different nuclear reactions and thereby to examine their structure and properties.

In the FINUDA experiment, K^-'s can be stopped in very thin nuclear targets, and multitracks are detected in the FINUDA spectrometer [9]. It can be interpreted as a bound state composed of a kaon and two protons, hereafter abbreviated as ppK^-. The binding energy $B_{ppK^-} = 115^{+5}_{-5}(stat)^{+3}_{-4}(syst)MeV$ and the width $\Gamma = 67^{+14}_{-11}(stat)^{+2}_{-3}(syst)$ MeV are obtained from the fitting in the region of 2.22-2.33 GeV/c^2.

A recent KEK experiment (High Energy Research Accelerator Organization, Japan) was carried out neutron energy distribution [8]. A distinct peak was observed in the neutron spectrum, indicating the formation of a strongly bound kaonic system, $ppnK^-$ with the binding energy and width, $(BE)_{ppnK^-} = 173 \pm 4MeV$ and $\Gamma_{ppnK^-} \leq 25 MeV$, respectively.

The proton energy distribution is measured from ^4He (stopped K^-, p) reaction by means of time-of-flight from E471 experiment at KEK [10]. In this experiment, a significant peak from proton momentum spectrum is formed in the momentum region between 340 MeV/c and 700 MeV/c. A mono-energetic peak was observed, which is interpreted as the formation of a new kind of neutral tribaryon S^0 (3115) with isospin I=1 and strangeness S= -1. The mass and width of the state were deduced to be $3117.0^{+1.5}_{-4.4}$ MeV/c^2 and <21 MeV/c^2, respectively. The state mainly decays into ΣNN.

I. Comparison of Theoretical Results and Experimental Results for kaonic nuclei

System	Theoretical Results			Experimental Results		
	BE(MeV)	Γ(MeV)	isospin	BE(MeV)	Γ (MeV)	isospin
ppK^-	48	61	$^1/_2$	115^{+5}_{-5}	67^{+14}_{-11}	$^1/_2$
$ppnK^-$	108	20	0	*	*	*
$ppnK^-$	21	95	1	173 ± 4	≤25	1
$pnnK^-$	**	**	**	$196^{+1.5}_{-4.4}$	<21	1
$ppnnK^-$	86	34	$^1/_2$	*	*	*
$K^{-8}Be$	113	38	$^1/_2$	*	*	*

'*'= Experimentally not observed yet.

'** '= Theoretically not studied yet.

The theoretical results and experimental results of kaonic nuclear states are very different as shown in table (1). Therefore, there remains theoretically and experimentally to confirm that these events are really the deeply bound kaonic nuclei. Existence of the narrow kaonic nuclear states is still controversial and we need further studies and more experiments. From theoretical side, it has been explained that relativistic effect and medium effect should be taken into account to improve the theoretical results. Also more experiments with better statistics are needed to settle this problem. The purpose of this work is to perform theoretical