объединенный
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исследований
дубна

E2-92-442

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PRODUCTION OF Λ HYPERNUCLEI WITH A LARGE NEUTRON EXCESS

Talk presented at the National Conference on Physics of Few-Body and Quark-Hadronic Systems, Kharkov, Ukraine, June 1-5, 1992

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1992

1 Introduction

In the last few years a new branch of nuclear physics, namely physics of light neutron-rich nuclei has been constitued [1]. These exotic nuclei may be produced in various reactions:

nucleon transfer in heavy ion collisions [2]

$$^{9}Be(^{13}C,^{14}O)^{8}He, \qquad (1)$$

or double charge exchange pion scattering [3]

$$^{9}Be(\pi^-,\pi^+)^{9}He. \qquad (2)$$

The purpose of this contribution is to discuss the possibilities of another reaction, *strange and double charge exchange* ($S\&DCX$): (K^-,π^+), which couples together two processes:

-strangeness exchange reaction (K^-,π^0) and

-pion charge exchange scattering (π^0,π^+).

2 Hypernuclei Production

In the last 15 years many hypernuclei have been produced in the controlled way by a simple strangeness exchange reaction

$$K^- + n \longrightarrow \Lambda + \pi^-, \qquad ^{A}Z(K^-,\pi^-)^{A}_{\Lambda}Z \qquad (3)$$

The missing mass spectrum of emitted pions (at a fixed angle) was recognized as a good signature of hypernucleus production [4]. The Λ hyperon is not inhibited by the Pauli principle, therefore the wave function of the ground state of any hypernucleus can be written down as a simple product

$$|^{A}_{\Lambda}Z(gs)> = |s_\Lambda> * |^{A-1}Z(gs)> \qquad (4)$$

There are many examples of the stabilizing role of the Λ hyperon:

- stable hypernuclei with unstable nuclear core: $^{6}_{\Lambda}He = s_\Lambda * {}^{5}He$ [5]
- bound excited state of Λ-hypernuclei with particle unstable nuclear core: $^{7}_{\Lambda}Li(5/2^+, 2.02MeV) = s_\Lambda * {}^{6}Li(3^+0; 2.2MeV)$, [6].

It is obvious that the progress in the hypernuclear physics depends crucially on the kaon beam's quality. Up to now it suffers in two points:

-low intensity and

-large impurity.

A substantial break-through in both directions is expected in the nearest future when new facilities such as KAON, CEBAF, PILAC and ϕ-factory DAΦNE (Frascati) start to operate. Then it will be possible to study more complicated reactions, for example, two steps *strangeness and double charge exchange* reaction.

There are two paths how to arrive at the Λnp^{-2} state:

either

$$K^- + p \longrightarrow \Lambda + \pi^0; \qquad \pi^0 + p \longrightarrow n + \pi^+ \qquad (5)$$

or

$$K^- + p \longrightarrow \pi^+ + \Sigma^-; \qquad \Sigma^- + p \longrightarrow n + \Lambda. \qquad (6)$$

We see that in a process of this type one may produce a hypernucleus with a large neutron excess.

In what follows I confine myself only to two points:

- the stability of the neutron rich hypernuclei;
- the identification of these exotic species at DAΦNE.

3 The Stability of Neutron Rich Hypernuclei

One can estimate the binding energy of the new hypernuclei easily. As the dependence of $B_\Lambda(A)$ is very smooth, it is sufficient to extrapolate the experimental data. The stability threshold against the neutron emission can be estimated by using masses of light nuclei [7]. The net result is presented as a chart of hypernuclei (see Table).

Few comments are in order:

1. ALL Λ-hypernuclei produced in a $S\&DCX$ reaction (marked by ♠) are NEW, they have not been observed until now.

2. SOME of the new species MUST BE STABLE, because their nuclear core is already stable.

3. The possibility of production of very HEAVY HYPERHYDROGEN isotopes $^{6}_{\Lambda}H$ and $^{7}_{\Lambda}H$ is also predicted.

4 Φ - Factory DAΦNE

The ϕ-factory DAΦNE is the electron - positron collider tuned to production of the $\phi(1020)$ meson [8]. It will be an extremely pure source of the slow kaons. Not only primary beam is exclusively pure [9]:

ϕ decay mode:	$K^+ + K^-$	$K_L + K_S$	$\rho + \pi$	$\pi + \pi + \pi$	$\eta + \gamma$
branching ratio:	49.5%	34.4%	12.9%	1.9%	1.3%

There is also a possibility of identification of all charged particles [8,10]. They will be

- *primary pions* accompanying the *production* of hyperons,
- *secondary pions* from the *decay* of hyperons $Y \longrightarrow N + \pi$, and
- *protons* accompanying the *interaction* of hyperon in nuclei

$$\Sigma^+ + n \longrightarrow \Lambda + p; \qquad \Lambda + p \longrightarrow n + p.$$

Very important is the possibility to determine simultaneously both the pions momentum and their charges. This is the clue to identify uniquely the rare or exotic processes discussed here. At first the events with π^- and π^+ mesons must be picked out. Then the momentum distribution of π^- and π^+ not only *recognizes* the Λ hypernucleus produced ($q_{\pi^-} \approx 100$ MeV/c) but also *discriminates* between primary Λ hypernucleus ($q_{\pi^+} \approx 250$ MeV/c, process (5)) and primary Σ hypernucleus ($q_{\pi^+} \approx 170$ MeV/c, process (6)). However, the prevailing number of $\pi^+\pi^-$ events comes from the quasi-free Σ hyperon production

$$K^- + p \longrightarrow \pi^+ + \Sigma^-; \qquad \Sigma^- \longrightarrow n + \pi^- \tag{7}$$

and/or

$$K^- + p \longrightarrow \pi^- + \Sigma^+; \qquad \Sigma^+ \longrightarrow n + \pi^+ \tag{8}$$

with $q_{\pi^+} \approx q_{\pi^-} \approx 150 MeV/c$.

5 Conclusion

The DAΦNE will be an extremely useful device:

- Besides its main programme which consists in the *CP* VIOLATION studies,
- it will be a unique source of NEW HYPERNUCLEAR DATA not only as a very pure source of kaons, but also as a very efficient tool. It will be possible in a single experimental run to study both the sectors (Λ and Σ) of hypernuclei at all successive stages from their production, through intermediate state transformation ($\Sigma \rightarrow \Lambda$, $\pi^0 \rightarrow \pi^+$), until their weak decay.
- Among the variety of new results which one expect from DAΦNE [11] there is the production of neutron rich hypernuclei in Strangeness and Double Charge Exchange reaction (K^-, π^+), in particular really very exotic HEAVY isotopes of HYPERHYDROGEN ${}^{6}_{\Lambda}H$ and ${}^{7}_{\Lambda}H$.

Chart of light Λ hypernuclei with binding energies B_Λ and particle instability thresholds.

						${}^{16}_{\Lambda}O$ 13.0 p 6.7		
					${}^{14}_{\Lambda}N$ 12.17 p 2.42	${}^{15}_{\Lambda}N$ 13.59 p 8.97	${}^{16}_{\Lambda}N$ (13) n 10.2	
				${}^{12}_{\Lambda}C$ 10.80 p 9.25	${}^{13}_{\Lambda}C$ 11.69 Λ 11.69	${}^{14}_{\Lambda}C$ 12.17 n 5.43	${}^{15}_{\Lambda}C$ (13.6) n 9.6	♠ ${}^{16}_{\Lambda}C$ (13) n 0.6
		${}^{9}_{\Lambda}B$ 8.29 p 1.59	${}^{10}_{\Lambda}B$ 8.89 p 2.00	${}^{11}_{\Lambda}B$ 10.24 p 7.71	${}^{12}_{\Lambda}B$ 11.37 Λ 11.37	${}^{13}_{\Lambda}B$ (11.7) n 3.7	♠ ${}^{14}_{\Lambda}B$ (12.2) n 5.4	♠ ${}^{15}_{\Lambda}B$ (13.6) n 2.4
	${}^{7}_{\Lambda}Be$ 5.16 2p 0.7	${}^{8}_{\Lambda}Be$ 6.84 τ 5.31	${}^{9}_{\Lambda}Be$ 6.71 α 3.50	${}^{10}_{\Lambda}Be$ 9.11 n 4.07	${}^{11}_{\Lambda}Be$ (10.2) n 7.9	♠ ${}^{12}_{\Lambda}Be$ (11.4) n 1.6	♠ ${}^{13}_{\Lambda}Be$ (11.7) n 3.5	
	${}^{6}_{\Lambda}Li$ 4.50 p -0.6	${}^{7}_{\Lambda}Li$ 5.58 d 3.93	${}^{8}_{\Lambda}Li$ 6.80 t 6.15	${}^{9}_{\Lambda}Li$ 8.50 n 3.73	♠ ${}^{10}_{\Lambda}Li$ (9.1) n 4.6	♠ ${}^{11}_{\Lambda}Li$ (10.2) n 0.3		
${}^{4}_{\Lambda}He$ 2.39 Λ 2.39	${}^{5}_{\Lambda}He$ 3.12 Λ 3.12	${}^{6}_{\Lambda}He$ 4.18 n 0.17	${}^{7}_{\Lambda}He$ 5.23 n 2.92	${}^{8}_{\Lambda}He$ 7.16 n 1.49	♠ ${}^{9}_{\Lambda}He$ (8.5) n 3.9			
${}^{3}_{\Lambda}H$ 0.13 Λ 0.13	${}^{4}_{\Lambda}H$ 2.04 Λ 2.04	${}^{5}_{\Lambda}H$ (3.1) n -1.8	♠ ${}^{6}_{\Lambda}H$ (4.2) 2n .06	♠ ${}^{7}_{\Lambda}H$ (5.2) 3n 0.4				

Acknowledgement

I would like to express my sincere thanks to Prof. T. Yamazaki and Prof. T. Bressani for illuminating discussions and to Dr. M. Sapozhnikov for providing me with reports presented at Workshop on Physics and Detectors for DAΦNE. I am indebted also to Dr. Yu. Batusov, Prof. R. Eramzhyan, Dr. V. Fetisov and Dr. F. Gareev for many stimulating discussions. It is a pleasure to thank Prof. A. Shebeko and his colleagues from the Organizing Committee of the National Conference of Physics of Few - Body and Quark - Hadronic Systems for warm hospitality in Kharkov.

References

[1] K.K.Seth, *in* Nuclei far from Stability, Proc. 5th Int. Conf., Rosseau Lake, Ontario, Canada, 1987 (ed. I.S. Towner), AIP Conf. Proc. v.164, p.324 and references therein; A.A.Ogloblin, Vestnik Ac. Sci. USSR, 1986, No 5, 107; A.Shirokov, ^{11}Li in the Three body Cluster Model, these Proc.; E.Kolganova, Hallo effect in the Light Nuclei, these Proc.

[2] H.C.Bohlen *et al.*, Spectroscopy of Neutron Rich Light Nuclei, contribution to Int. Nucl. Phys. Conf., July 1992, Wiesbaden, Germany.

[3] K.K.Seth *et al.*, Phys. Rev. Lett. 58 (1987) 1930.

[4] R.E.Chrien and C.B.Dover, Ann. Rev. Nucl. Part. Sci. 39 (1989) 113; H.Bandō, T.Motoba and J.Žofka, Int. J. Mod. Phys. A 5 (1990), 4021; J.Žofka, L.Majling, V.N.Fetisov and R.A.Eramzhyan, Sov. J. Part. Nucl. 22 (1991) 628.

[5] R.Dalitz and R.Levi Setti, Nuovo Cim. 30 (1962) 489; R.H.Dalitz, Proc. Int. School of Physics 'Enrico Fermi', Course 38, Academic Press, 1967, p.89.

[6] M.May *et al.*, Phys. Rev. Lett. 51 (1983) 2085.

[7] F.Ajzenberg-Selove, Nucl. Phys. A 490 (1988) 1; A 506(1990) 1; A 523 (1991) 1.

[8] T.Bressani, *in* Proc. Workshop on Physics and Detectors for $DA\Phi NE$ (ed. G.Pancheri), April 1991, INFN, Frascati, Italy, p.475.

[9] Particle Data Group, Phys.Lett. 239B (1990) 1.

[10] T.Yamazaki, *in* Proc. Workshop on Physics and Detectors for $DA\Phi NE$ (ed. G.Pancheri), April 1991, INFN, Frascati, Italy, p.315;

[11] L.Majling, *in* Proc. Int. Symp. Mesons and Light Nuclei V, September 1991, Prague, (eds. E.Truhlik and R.Mach), Few-Body Systems, Suppl. 5 (1992) 348.

Received by Publishing Department
on November 2, 1992.