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HYPERNUCLEI AND HYPERNUCLEAR SPECTROSCOPY

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I should like to give a short account of the problems investigated or already solved in hypernuclear studies and to mention the perspectives for the future especially in the case of the hypernuclear spectroscopy. A part of my lecture summarizes some of the results presented last year at the Hypernuclear Conference in Argonne (*Proceedings of International Conference on Hypernuclear Physics*, Argonne 1969).

Identification of hypernuclei

One can say that at least 95% of all the experimental results from hypernuclear physics have been obtained by the emulsion technique and the remaining 5% — with the helium and heavy liquid bubble chambers. Hitherto only individual hypernuclear events have been recognized, identified, and examined and in principle mainly the kinematical analysis of the charged mesonic hypernuclear decays has been used as a basic source of all information. Only recently studies of the excited states of hypernuclei have been started using counter techniques.

From the total number of all the observed hypernucleus events exceeding 50 000, only some 3500 are considered to be uniquely identified and among them 19 different hypernuclides [3–10]. All of them are listed in Table I. Besides these uniquely identified

TABLE I

Uniquely identified hypernuclei

		${}^{3}_{\Lambda}H$	${}^{4}_{\Lambda}H$		
${}^{4}_{\Lambda}He$	${}^{5}_{\Lambda}He$	${}^{6}_{\Lambda}He$	${}^{7}_{\Lambda}He$	${}^{8(9)}_{\Lambda}He$	${}^{6}_{\Lambda\Lambda}He$
	${}^{7}_{\Lambda}Li$	${}^{8}_{\Lambda}Li$	${}^{9}_{\Lambda}Li$		
	${}^{7}_{\Lambda}Be$	${}^{8}_{\Lambda}Be$	${}^{9}_{\Lambda}Be$		${}^{10(11)}_{\Lambda\Lambda}Be$
	${}^{10}_{\Lambda}B$	${}^{11}_{\Lambda}B$	${}^{12}_{\Lambda}B$		
		${}^{13}_{\Lambda}C$			

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hypernuclides some possible identifications of other hypernuclei have been reported, [7, 16, 17]. The European K^--Collaboration should collect in the work done at present a three times larger sample of hypernuclei[1]. Many heavy spallation hypernuclei with the mass numbers sometimes close to that of heavy emulsion nuclei (*i. e.* Ag and Br) have been observed although they could not be uniquely identified [18–24]. For the present only two double hypernuclear events have been identified, they are ${}_{\Lambda\Lambda}^{10}\mathrm{Be}$ and ${}_{\Lambda\Lambda}^{6}\mathrm{He}$ with two lambda hyperons bound to the ^{8}Be or ^{4}He core nuclei [11, 12].

Binding energies of hypernuclei

Table II shows the hypernuclear masses and the B_Λ-values for different uniquely identified hypernuclei. B_Λ is the separation energy of the hyperon with respect to the nucleus which would be formed of all the nucleons left. It is a summary of the work done by the European K^--Collaboration, Enrico Fermi Institute for Nuclear Studies, Chicago and by the Northwestern University, Evanston [3–10]. B_Λ-value for heavy hypernuclei with $40 < A < 100$ is based on a rather small number of mesonically decaying hypernuclei recognized as heavy [13–15, 20]. One might still consider as possible a misidentification of these events or their decay modes. The obtained value of $B_\Lambda = 23$ MeV leads to a rather small potential well depth ($\sim$ 27 MeV) of ΛN interaction. All the theoretical calculations for lambda bound in infinite nuclear matter even with the introduced corrections for the contribution of three body and tensor forces lead always to higher values [25, 26].

Table II contains also the B_Λ-values for the two double hypernuclei. The observed differences in the separation energies of the first and the second lambda correspond to a contribution of $\Lambda\Lambda$ interaction in these systems [11, 12].

Production of hypernuclei

Hypernuclei are mostly produced by K^--mesons interacting in flight or captured at rest. Table III shows the hypernuclear production rates for K^--mesons captured at rest by different target nuclei as it has been observed in emulsion and bubble chambers [27-30]. The emulsion data have to be considered rather preliminary due to still not very well recognized corrections. In the case of K^--mesons interacting in flight the total production rates are rather low [31–33]. However, one may expect that this rate should be enhanced for the heaviest hypernucleus from a given target in coincidence with the accompanying

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[1] European K^--Collaboration:
Bn, Deutsche Akademie der Wissenschaften zu Berlin
Bx, Université Libre de Bruxelles
DIAS, Institute for Advanced Studies, Dublin
UCD, University College, Dublin
UCL, University College, London
WCL, Westfield College, London
Ww, University of Warsaw and Institute for Nuclear Research, Warsaw
Recently the Laboratory of the University in Beograd has joined the Collaboration.

TABLE II

The hypernuclear masses and the lambda separation energies in MeV*

Hypernuclei		
$^{3}_{\Lambda}H$	2991.12±0.06	B_{Λ} = 0.06±0.06
$^{4}_{\Lambda}H$	3922.45±0.05	2.02±0.05
$^{4}_{\Lambda}He$	3921.63±0.03	2.31±0.03
$^{5}_{\Lambda}He$	4839.84±0.02	3.08±0.02
$^{6}_{\Lambda}He$	5779.14±0.15	4.28±0.15
$^{7}_{\Lambda}He$	6715.66±0.18	5.38±0.18
$^{7}_{\Lambda}Li$	6711.46±0.06	5.56±0.06
$^{7}_{\Lambda}Be$	6715.71±0.12	5.09±0.12
$^{8}_{\Lambda}He$	7653.2±0.8	7.4−B_n±0.8
$^{8}_{\Lambda}Li$	7642.52±0.05	6.80±0.05
$^{8}_{\Lambda}Be$	7642.86±0.07	6.81±0.07
$^{9}_{\Lambda}Li$	8578.59±0.13	8.25±0.13
$^{9}_{\Lambda}Be$	8563.69±0.04	6.63±0.04
$^{10}_{\Lambda}B$	9500.15±0.20	8.62±0.20
$^{11}_{\Lambda}B$	10429.69±0.10	10.19±0.10
$^{12}_{\Lambda}B$	11356.91±0.10	11.06±0.10
$^{13}_{\Lambda}C$	12278.95±0.15	11.32±0.15
heavy hypernuclei 40< A < 100		23.0±0.2

Double hypernuclei		
$^{6}_{\Lambda\Lambda}He$	5947.7±0.5	B'_{Λ} = 7.8 ±0.5 B''_{Λ} = 3.08±0.02
$^{10}_{\Lambda\Lambda}Be$	9668.3±0.4	B'_{Λ} = 11.0±0.4 B''_{Λ} = 6.63±0.04

*Systematic errors independent of the errors given in the Table: 0.05

pion if it takes over the momentum of the kaon and the lambda is left in the target with a low momentum within the limits of the Fermi motion. This should occur in the range of 400–600 MeV/c [99].

Hypernuclear spins

The spins of the three hypernuclei have been estimated from the branching ratios for different pionic decay channels of these hypernuclei or from a study of the final state interactions of the decay products [34–41]. The results obtained have also been confirmed by the observed angular distribution of the decay products. The estimated spins are presented in Table IV. The spins of the corresponding core nuclei are higher by 1/2 what is considered as an indication that the ΛN interaction is stronger in the singlet than in the triplet state, *i. e.* just opposite to the NN interaction.

TABLE III

Hypernucleus production rates for K^--mesons captured at rest by different target nuclei

Target	Total production rate	References
Helium	$(2.1\pm0.4)\%$	Keyes 1969
C, N, O (emulsion)	$(8\pm2)\%-(10\pm1.5)\%$	European K^--Coll. 1964, 1970
C, F (freon)	$(11\pm5)\%$	Csejthey-Barth *et al.* 1969
Br (freon)	$(52\pm15)\%$	Csejthey-Barth *et al.* 1969
Ag, Br (emulsion)	$(58\pm12)\%$	Lemonne *et al.* 1964

Production rates of different hypernuclides

Target	HF	Production rate	References
Helium	$^3_\Lambda$H	$(0.3\ \pm0.1)\%$	Keyes 1969
	$^4_\Lambda$H	$(0.53\pm0.14-0.65\pm0.20)\%$	Keyes 1969
	$^4_\Lambda$He	$(1.19\pm0.21)\%$	Keyes 1969
C, N, O emulsion	$^3_\Lambda$H	$(0.26\pm0.03)\%$	
	$^4_\Lambda$H	$(1.1\ \pm0.2)\%$	
	$^4_\Lambda$He	$(0.65\pm0.10)\%$	based on unpublished preliminary results of the European K^--Collaboration 1970
	$^5_\Lambda$He	$(2.7\ \pm0.3)\%$	
	$^{6,7}_{\ \Lambda}$He	$(0.16\pm0.03)\%$	
	$^{7,8,9}_{\ \ \Lambda}$Li	$(1.3\ \pm0.2)\%$	
	$_\Lambda$Be	$(1.1\ \pm0.3)\%$	
	$\geqslant {}_\Lambda$B	$(2.6\ \pm0.6)\%$	
	unrecognized as HFs mostly $\geqslant {}_\Lambda$B	$(1\pm1)\%$	

TABLE IV

Hypernuclear spins

$^3_\Lambda$H	1/2	core	^{2}H	1
$^4_\Lambda$H	0	core	^{3}H	1/2
$^8_\Lambda$Li	1	core	^{7}Li	3/2

Lifetimes

In the past 8 years many attemps have been made to estimate the lifetimes of the four lightest hypernuclei and that of the very heavy hypernuclei. Table V contains the results obtained with the emulsion and bubble chamber techniques based on some 250 hypernuclear decays in flight and 3600 events at rest or deduced statistically from the energy spectra of two body processes disturbed by the events in flight [42–62]. These results still leave much to be desired. Apart from statistical fluctuations they are influenced by undetectable scanning biases and by difficulties in identification of all the events in a given sample (*e. g.* compare the lifetimes for different decay channels). The theoretical predictions are mainly based on

TABLE V

Lifetimes of hypernuclei

HF	Decay modes	$\times 10^{10}$ (sec)	Flight+rest events	Technique	References
$^{3}_{\Lambda}H$	all	$1.05^{+0.20}_{-0.18}$	29+7	He B.Ch.	Block *at al.* 1963
	2-body	$0.9^{+2.2}_{-0.4}$	3+1	Emulsion	Prem and Steinberg 1964
	2+3	$3.4^{+8.2}_{-1.4}$	5 +18	Emulsion	Kang *et al.* 1965
	all	$2.28^{+0.46}_{-0.33}$	35+19	He B. Ch.	Keyes *et al.* 1969
	2+3	$2.85^{+1.27}_{-1.05}$	21.5+107	Emulsion	Phillips and Schneps 1969
	3	$1.28^{+0.35}_{-0.26}$	19.5+136	Emulsion	Bohm *et al.* 1970 (European K^--Coll.)
$^{4}_{\Lambda}H$	2	$1.2^{+0.6}_{-0.3}$	9+43	Emulsion	Crayton *et al.* 1962
	2	$1.8^{+2.5}_{-0.7}$	3+4	Emulsion	Prem and Steinberg 1964
	3	$2.4^{+6.0}_{-1.0}$	4+14	Emulsion	Kang *et al.* 1965
	3	$2.68^{+1.66}_{-1.07}$	11.5+85	Emulsion	Phillips and Schneps 1969
	2	$1.5^{+0.6}_{-0.4}$	138 statist.	He B. Ch.	Mc Kenzie 1969
	2	$2.0^{+0.5}_{-0.4}$	19+32	C_3F_8B.Ch.	Murphy *et al.* 1969
$^{4}_{\Lambda}He$		$2.28^{+2.33}_{-1.29}$	8.9+206	Emulsion	Phillips and Schneps 1969
$^{4,5}_{\Lambda}He$		$1.2^{+1.0}_{-0.4}$	5+99	Emulsion	Ammar *et al.* 1963
		$2.2^{+1.5}_{-0.6}$	8+117	Emulsion	Kang *et al.* 1965
		$2.43^{+0.60}_{-0.43}$	25+611	Emulsion	Phillips and Schneps 1969
$^{5}_{\Lambda}He$		$1.4^{+1.9}_{-0.5}$	3+25	Emulsion	Prem and Steinberg 1964
		$2.51^{+1.90}_{-0.73}$	16.1+452	Emulsion	Phillips and Schneps 1969
		$2.74^{+0.60}_{-0.50}$	27+1640	Emulsion	Bohm *et al.* 1970 (European K^--Coll.)

the impulse model approximation eventually corrected for some secondary effects [42, 47, 51, 54, 55, 59]. The lifetimes of hypernuclei may exceed the lifetime of a free lambda hyperon if the Pauli principle rules out some of the final states of the system or if the available phase space is reduced, on the other hand they should grow shorter with an increase of the mass number A. It is an effect of a stimulation of Λ-decay by the nucleons which opens new non-mesonic decay channels, unexisting in a free Λ-decay. The values down to 1.2×10^{-10} sec are actually to be expected [59]. Very low values for the lifetimes of heavy spallation hypernuclei, much below the expected ones have been obtained from the observed assymetry in the angular distribution of the decay products [61, 62]. Unfortunately just in the case of heavy hypernuclei this analysis might easily be biased by a high number of unrecognized events with inconveniently situated tracks. A systematic study of all possible biasing effects is now in progress in our laboratory.

One of the most puzzling problems in hypernuclear studies has been the estimation of the lifetime of ${}^3_\Lambda$H. The first obtained results gave 2.5 times shorter lifetime than that of a free lambda in a glaring contradiction with expectations for this loosely bound structure [42, 43, 100]. It is suggested now that the events with an overlay of a free Λ-decay on a deuteron track have biased some of the results obtained with the helium bubble chamber if they are based on 3-body decay [50]. On the other hand the Coulomb interaction of heavy nuclei may release the lambda from ${}^3_\Lambda$H in flight strongly affecting the lifetime estimated with the emulsion technique [45, 47, 51]. For the present one cannot come to any decisive conclusion with the lifetime of this hypernucleus [42–52]. Since the lifetimes of hypernuclei should depend on their spin then a good estimate of these lifetimes might help to find the hypernuclear spins, although the experimental difficulties do not make it very promissing.

Nonmesonic decays

The nonmesonic decay rates should give important information of the ΛN weak interaction and help to answer the question of the spin and charge dependence of this interaction. Some data on the branching ratios of nonmesonic to π^--mesonic decays of hypernuclei are presented in Table VI. The results concerning the proton-to-neutron stimulation ratio in the reactions $\Lambda+p = n+p$, and $\Lambda+n = n+n$ are still very poor and uncertain [63–66].

These results seem to suggest that ΛN weak interaction is strongly spin dependent with more pronounced triplet interaction [59].

π^+-decays

Among the charge pionic decays statistically significant samples of π^+-decays of ${}^4_\Lambda$He have already been collected. The estimated branching ratios R = (all π^+-decays)/(all π^--decays) are given in Table VII (70–75). In principle there are three different models which may possibly explain the π^+-decay of hypernuclei: charge exchange of $\pi^0 \to \pi^+$, π^+-decay of a virtual Σ^+ hypernuclear state and a stimulated pionic decay of Λ: $\Lambda+p \to \pi^+ + 2n$ [67–69]. We cannot say much how effective should be the third mechanism but the first two lead rather to much lower values of R especially if we consider the avarage value experimentally obtained by the European K^--Collaboration from the sample of 22 uniquely identified and 6 possible ${}^4_\Lambda$He π^+-decays.

π^+-decays of some heavier hypernuclei (*e. g.* ${}^7_\Lambda$Be) have also been observed (*e. g.* [73]).

TABLE VI

Non-mesonic decay branching ratios

$$Q^{-} = \frac{n.m.\text{-decays}}{\text{all } \pi^{-}\text{-decays}}$$

HF	Q^-	Reference
${}^{13}_{\Lambda}\mathrm{H}$	$(1.2 \pm 0.4) \times 10^{-2}$	theor. Rayet and Dalitz (recalc.)
${}^{4}_{\Lambda}\mathrm{H}$	0.26 ± 0.13	Block *et al.* 1963
${}^{4}_{\Lambda}\mathrm{He}$	0.52 ± 0.10	Block *et al.* 1963
${}^{5}_{\Lambda}\mathrm{He}$	1.31 ± 0.09	Coremans *et al.* 1960 (European K^--Coll.)
Li and Be	2.4 ± 0.7 } 3.2 ± 0.7	Holland 1964
$\geqslant {}_{\Lambda}\mathrm{B}$	5.3 ± 1.5 }	
${}_{\Lambda}\mathrm{He}$	1.01 ± 012	Chaudhari *et al.* 1969
${}_{\Lambda}\mathrm{Li}$	2.55 ± 0.66	Chaudhari *et al.* 1969
${}_{\Lambda}\mathrm{Be}$	6.6 ± 1.4	Chaudhari *et al.* 1969
${}_{\Lambda}$heavy HF	~ 150	Key *et al.* 1964
${}_{\Lambda}$heavy HF	$120-180$	Longnaux *et al.* 1964 (European K^--Coll.)

TABLE VII

π^+-decay branching ratio for ${}^{4}_{\Lambda}\mathrm{He}$

$$R = \frac{\text{all } \pi^{+}\text{-decays}}{\text{all } \pi^{-}\text{-decays}} \times 100\%$$

R %	Number of the observed π^+-decays	References
4	2	Block *et al.* 1963
2.7 ± 1.1	7 (compil)	Beniston *et al.* 1964
9 ± 3	10+(1)	Mayeur *et al.* 1966 European K^--Coll.
$3.6^{+1.2}_{-1.3} - 5.0^{+1.5}_{-1.7}$	12+(5)	Bohm *et al.* 1969 European K^--Coll.
1.6 ± 1.3	3	Phillips and Schneps 1969
1.5 ± 1.0	2	Chaudhari *et al.* 1968
$5.4^{+1.5}_{-1.7} - 6.9^{+1.8}_{-1.7}$	22+(6) (compil)	European K^--Coll. 1969

Final state interaction

There are several papers published on the final state interaction among the decay products of different hypernuclei. They may lead to some information on the possible formation of the resonant excited states of some compound nuclei and help to estimate the hypernuclear spins (${}^{8}_{\Lambda}\mathrm{Li}$) nevertheless I shall omit them in this survey (see *e. g.* [76, 40]).

ΛN-interaction

From the hypernuclear data one can obtain information about the ΛN strong and weak interactions. For the present, only strong interactions could be investigated systematically. In a phenomenological description of hypernuclei initiated by Dalitz and Downs in 1958 [78] and developed by other authors (*e. g.* [79, 80]) it was initially assumed that two body ΛN forces are dominant, that they are charge independent and that the contribution of the non-central forces can be neglected. It was a satisfactory approach for the *s*-shell hypernuclei ($A \leqslant 5$) but a rather strong spin dependence had to be assumed. The Λ-N interaction usually considered as an *s*-state interaction was consequently described by two separate attractive potentials a stronger one (V_s) for the singlet and a weaker one (V_t) for the triplet state. The best approach has been obtained with the hard core potentials and intrinsic ranges corresponding to the two pion exchange model. This approach when extended to the *p*-shell hypernuclei has already led to some controversies. In the case of the *s*-shell hypernuclei besides these charge symmetric (CS) potentials an additional charge symmetry breaking (CSB) potential [81] had to be introduced to describe the observed differences in B_Λ-values of the two mirror hypernuclei ${}^4_\Lambda$H and ${}^4_\Lambda$He ($\Delta B_\Lambda = 0.29 \pm 0.06$, see Table II and *e. g.* Ref. [6]). For the present the observed difference cannot find any good explanation due to the inaccuracy of the emulsion technique or secondary core nuclear effects (see *e. g.* a review paper [102]).

TABLE VIII

Parameters of ΛN-potentials

	$r_c(F)$	$b(F)$	$a_s(F)$	$r_{os}(F)$	$a_t(F)$	$r_{ot}(F)$	Ref.
Λ-p elastic scattering			−1.8	2.8	−1.6	3.3	a)
			−2.0	5.0	−2.2	3.5	b)
Hypernuclei	0.45	1.5	−3.13 ±0.50	1.91 ±0.08	−0.71 ±0.06	3.74 ±0.26	c)
Λ-p potential	0.45	1.8	−1.77	3.07	−1.75	3.08	d)
Λ-n potential	0.45	1.8	−2.48	2.69	−1.57	3.24	d)

a) 378 ebvents, Rehovoth-Heidelberg group, Alexander *et al.*, 1968.
b) 224 events, Maryland group, Sechi-Zorn *et al.*, 1968.
c) Herndon and Tang, 1967.
d) best fit to the Λ-p elastic scattering data and to the B_Λ-values of ${}^3_\Lambda$H, ${}^4_\Lambda$H and ${}^4_\Lambda$He, Tang 1969.

In the past few years a sample of 602 events of free lambda-proton elastic scatterings have been collected in the low momentum region of the hyperon (120–320 MeV/c) [82, 83].

The values of the total cross-sections for this scattering are systematically larger than one could expect for the ΛN potentials deduced from the hypernuclear data, moreover the spin-dependence of ΛN interaction seems to be not much pronounced. Fig. 1 and Table VIII illustrate the actual situation. Similar conclusions as far as it concerns spin-dependence can be deduced from a hyperon-nucleon interaction observed in the reaction $K^- + d \rightarrow \pi^- + + p + \Lambda$ at rest [84]. Different explanations of the observed discrepances have been offered if one assumes that they do not result from any experimental inaccuracy [85–87, 80]. Since the strong spin-dependence is mainly resulting from the too low B_Λ-value of ${}^5_\Lambda$He then the

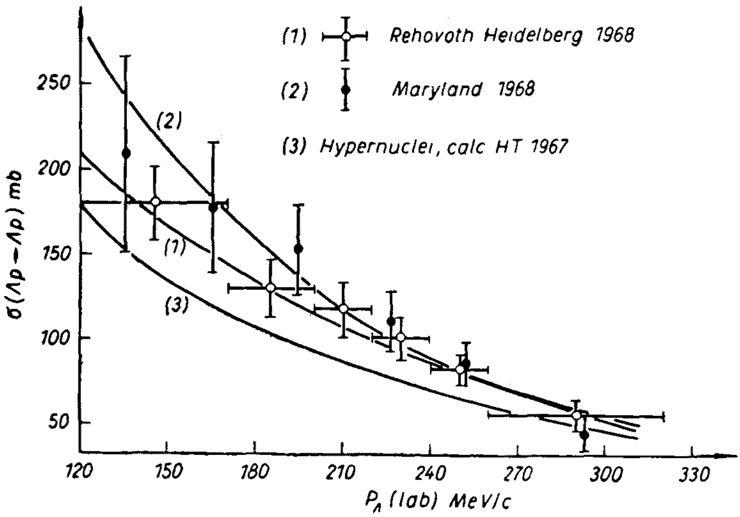

Fig. 1

consistency should be achieved if one finds arguments which could explain the diminished B_Λ-value of this hypernucleus. Usually the contribution of the tensor and three body forces and a suppresion of Λ-^{4}He interaction resulting from some iso-spin restrictions are considered. Moreover ΛN interaction seems to be suppressed in the case of odd-parity states that might be deduced from F/B ratio of Λ-p elastic scattering. This effect can be neglected in the case of s-shell hypernuclei. All these proposed refinements are introduced in the form of some correction terms to ΛN potentials. Tang [88] proposes some interpolated CS potentials with the CSB spin dependent term which are consistent with Λ-p elastic scattering data and the binding energies of the three lightest hypernuclei (Table VIII). Corrections resulting from the three suppression effects mentioned above lead to a proper value of B_Λ for ${}^5_\Lambda$He [77, 88].

Excited states of hypernuclei

An investigation of the excited states of hypernuclei should essentially enrich the information on ΛN interaction. Certainly the most important information would be the level distance of a Λ-spin doublet and the level position when lambda is bound with higher angular momentum.

In principle, hypernuclear spectroscopy may concern short lived hypernuclear resonances disintegrating through a fast decay or states that decay by the γ-transition and the isomeric states appearing when the Λ-decay of a hypernucleus can successfully compete with the γ-transition.

Recent experimental and theoretical investigations of K^--mesic atoms have led to the conclusion that the K^--capture in the light nuclei occurs from p or d states and in the heavy ones from g or even higher states [89, 90]. K^--captures may then lead to hypernuclear resonances with the hyperon bound in states different from the s-state. One may expect that for the hypernuclei with $A = 12$ lambda p-state is possibly stable against the hyperon but not the nucleon emission. If $A \approx 100$ all the states up to g-state might be stable against the hyperon emission [103].

Resonant states

Actually two hypernuclear resonances of ${}^{12}_{\Lambda}C^*$ and ${}^{14}_{\Lambda}N^*$ have been recently observed by the European K^--Collaboration [91]. They are produced in the following reactions:

$$K^- + {}^{12}C = \pi^- + {}^{12}_{\Lambda}C^*, \quad K^- + {}^{14}N = \pi^- + {}^{14}_{\Lambda}N^* \ldots (*)$$

and both decay through the proton emission:

$${}^{12}_{\Lambda}C^* \to p + {}^{11}_{\Lambda}B, \quad {}^{14}_{\Lambda}N^* \to p + {}^{13}_{\Lambda}C$$

The final result is the production of a hypernucleus with the mass number A-1 (where A is the mass number of the target nucleus) accompanied by a pion of uniquely defined energy. Unfortunately the range of this pion ($\gtrsim 20$ cm) cannot be directly measured but the best fit procedure enables us to estimate the required energy with an error of only ~ 0.1 MeV.

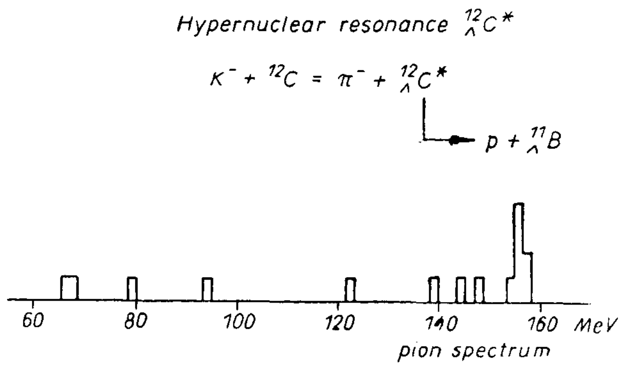

Fig. 2

The production of 15 ${}^{11}_{\Lambda}B$ out of 26 uniquely identified hyperboron 11 events is consistent with the reaction (*). The corresponding pion spectrum is presented in Fig. 2. One can clearly see a sharp peaking at 156 MeV that leads to an excited state ${}^{12}_{\Lambda}C^*$ placed $\sim$ 11 MeV above the ground state. This level might correspond to the p-state of lambda decaying by proton emission (Dalitz [92]). The exitation energy cannot be much different from the lambda separation energy although the width of this level seems to be 1-2 MeV. The p-state interpretation of this level might be questioned nevertheless it is an intermediate state for the production of a rather high percentage of ${}^{11}_{\Lambda}B$ from the carbon target and it should be easily detected with a pion spectrometer. Probably some other hypernuclear resonant states are also good candidates for pion spectroscopy measurements.

For the present no evidence of ${}^{5}_{\Lambda}$He* (T = 2), ${}^{9}_{\Lambda}$Be* (T = 1), ${}^{6}_{\Lambda}$Li (*g. s.*)-resonant states have been found with the emulsion technique [93, 94].

Hypernuclear isomers

${}^{7}_{\Lambda}$He* and may be ${}^{7}_{\Lambda}$Li* are the possible candidates for the hypernuclear isomeric states [95–98]. Since the hypernucleus Λ-decay may occur from the isomeric state, then its existence should be manifested by a diminished B_{Λ}-value or by a broadening of the estimated B_{Λ}-distribution. In fact among 12 ${}^{7}_{\Lambda}$He events considered to be uniquely identified 10 lead to an average value of $B_{\Lambda} = 5.38 \pm 0.18$ MeV whereas two events show much lower values 3.75 ± 0.28 MeV and 3.52 ± 0.50 MeV. (Two more events with even still lower B_{Λ} values are sometimes cited in a larger sample of ${}^{7}_{\Lambda}$He-hypernuclei although the identification might be not so certain). The isomeric states cosidered here would be due to the excitation of the core nuclei with the hyperons bound in the *s*-states, and the isomerism itself due to a delayed quadrupol electric γ-transition.

γ-spectroscopy of hypernuclei

In the past two years hypernuclear γ-spectroscopy experiments have been started with the counter technique (by Dubna-Warsaw group in 1968, by CERN-Heidelberg-Warsaw group in 1969), (see also [101]). It is expected that K^{-}-beam stopped in a target should produce hypernuclei in the excited states with the efficiency probably below 0.5%. The preliminary results obtained at CERN seem to indicate that in some energy regions we could detect them even if the efficiency was as low as ~0.1%. The hypernuclear γ's are looked for with NaJ scintillation counters in coincidence with kaons identified in a counter telescope (a set of Cerenkov and dE/dx counters). A separate spectrum is taken in coincidence with high energy pions accompanying hypernuclei at the production (>150 MeV) to select the heaviest hypernuclei obtained from different targets. Some promising preliminary results have already been obtained at CERN. The main problem is the heavy continuous and partly discrete background of γ-quanta produced in coincidence with kaons. One can see several sources of this background: the electromagnetic cascade of decaying π^{0}'s, the positrons annihilation, γ-nuclear transitions induced in the target, counters, and shielding, counts resulting from fast neutron interactions most dangerous if they occur in the γ-counters. All nuclear and hypernuclear lines corresponding to the fast γ-transitions are broadened by the Doppler effect since the nuclear and hypernuclear fragments are in flight (time of flight — few picoseconds). The broadening is of the order of1 0% of the total energy of γ-quanta [104]. This makes the scintillation counter a better tool than the germanium counter if the γ-lines are of very low intensity.

The investigation of the excited states of ${}^{4}_{\Lambda}$H* ($J = 1$) and ${}^{4}_{\Lambda}$He* ($J = 1$) can be the most promising since the estimation of their position would solve the problem of the ΛN spin-dependence. With the Tang interpolated potentials different for Λn and Λp interactions the excitation below 1 MeV for both is expected and for ${}^4_\Lambda$He* rather a higher value than for ${}^4_\Lambda$H* [88]. According to Dalitz's calculations based on the ΛN potentials with strong spin dependence deduced from hypernuclear data only, these excitations should be as high as 1.2 MeV [85]. The data on the three excited states of ${}^7_\Lambda$Li may help to solve the problem of the non-central forces contribution. ^{7}Li-target is the most convinient for ${}^7_\Lambda$Li* investigations in coincidence with the pions. ^{6}Li-target seems to be the best for ${}^4_\Lambda$H* and ${}^4_\Lambda$He* production without any prompt γ-nuclear line originated in the target.

One may hope that the hypernuclear spectroscopy investigations give crucial information for the analysis of ΛN interaction.

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