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RELATIVISTIC HYPERNUCLEI: OLD PROBLEMS AND NEW PROSPECTS

or

"ALPHA" - DECAYS OF $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B HYPERNUCLEI:

A CLUE TO SOME PUZZLES IN NONMESONIC WEAK DECAYS

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SPECTROSCOPY of ^{9}Be $\rightarrow$ ^{8}Be + n

We propose to use the unique feature of the ^{9}Be nucleus :
after removing a neutron from its ground state

several groups of alpha-particles appear from different excited states of a residual nucleus ^{8}Be.

The probabilities of their feeding is governed by spectroscopic factors.

The spectroscopic factors are the standard nuclear structure ingredients in transition amplitudes for direct nuclear reactions
J. Bang, F. Gareev, W. Pinkston and J. Vaagen, Phys. Rept. **125** ('85).

Also ^{8}Li nucleus, product of pick up of proton from ^{9}Be ultimately decays into the $\alpha\,\alpha$ channel.
So, removing one nucleon from ^{9}Be and/or ^{9}B nuclei results in ^{8}Be*

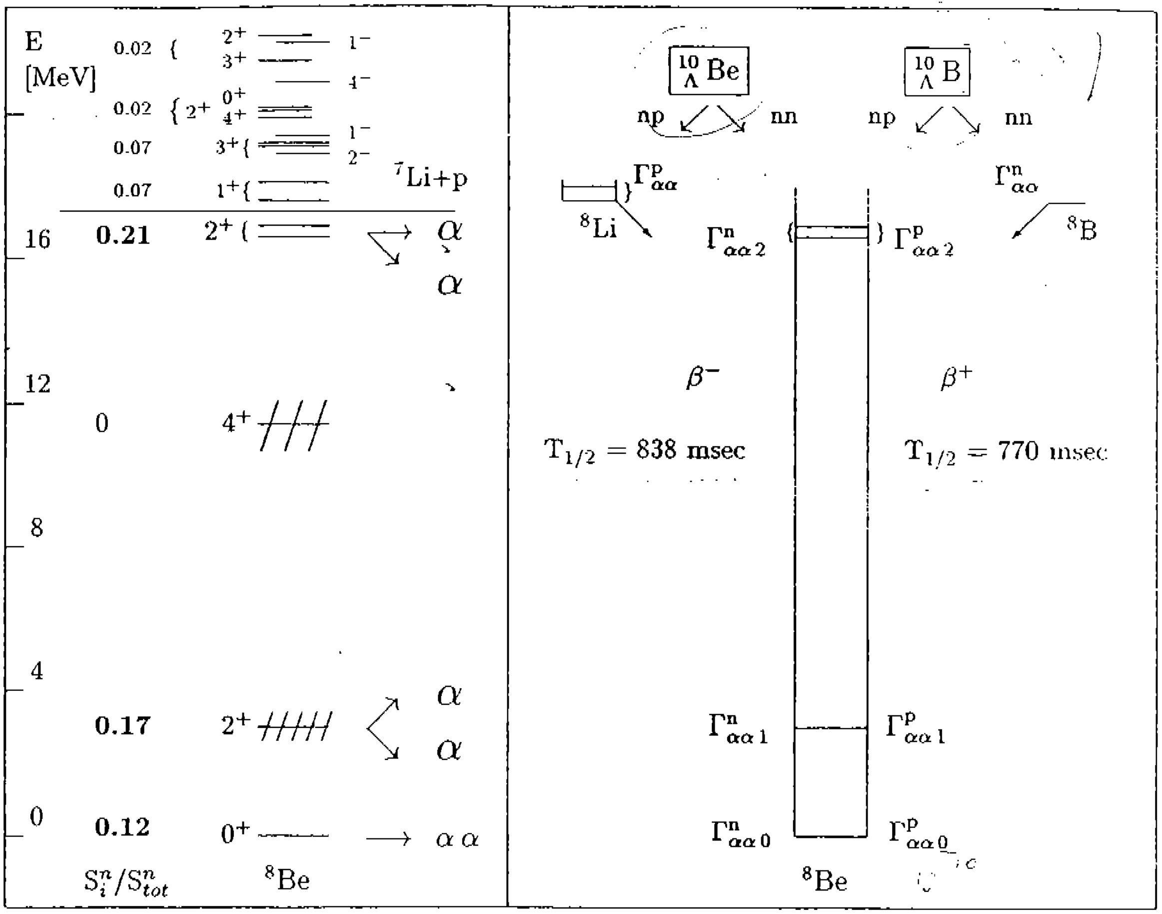
$$^9\mathrm{Be} \;\rightarrow\; \mathrm{n} + \boxed{^8\mathrm{Be}^* \rightarrow \alpha\alpha}$$

$$^9\mathrm{Be} \;\rightarrow\; \mathrm{p} + {}^8\mathrm{Li} \;\; (\stackrel{\beta^-}{\rightarrow}\; {}^8\mathrm{Be}^* \rightarrow \alpha\alpha)$$

$$^9\mathrm{B} \;\rightarrow\; \mathrm{p} + \boxed{^8\mathrm{Be}^* \rightarrow \alpha\alpha}$$

$$^9\mathrm{B} \;\rightarrow\; \mathrm{n} + {}^8\mathrm{B} \;\; (\stackrel{\beta^+}{\rightarrow}\; {}^8\mathrm{Be}^* \rightarrow \alpha\alpha).$$

Due to these specific properties of the core nuclei ^{9}Be and ^{9}B, it may be possible for the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei to measure the PARTIAL DECAY WIDTHS $\Gamma^{\tau}_{\alpha\alpha i}$ corresponding to states of the residual nucleus ^{8}Be decaying through the alpha alpha channel.



In Figure the relevant states of A = 8 isotopes are displayed, and the notation of the partial widths $\Gamma^{\tau}_{\alpha\alpha\, i}$ is explained. The similarity of the structure of $\Gamma^{n}_{\alpha\alpha\, i}\,(^{10}_{\Lambda}\text{Be})$ and $\Gamma^{p}_{\alpha\alpha\, i}\,(^{10}_{\Lambda}\text{B})$ is clearly seen.

Note that in such a way we can determine not only a partial rate (including neutron ones), but also an exactly one-nucleon stimulated process $\Lambda N \rightarrow NN$.

We recall that also ^{8}Li nucleus ultimately decays into the $\alpha\alpha$-channel. So, removing one nucleon from ^{9}Be and/or ^{9}B nuclei results in ^{8}Be*

$$^9\text{Be} \rightarrow \text{n} + \boxed{^8\text{Be}^* \rightarrow \alpha\alpha} \quad \text{and} \quad ^9\text{Be} \rightarrow \text{p} + {}^8\text{Li} \;\; (\overset{\beta^-}{\rightarrow}\ ^8\text{Be}^* \rightarrow \alpha\alpha)$$
$$^9\text{B} \rightarrow \text{p} + \boxed{^8\text{Be}^* \rightarrow \alpha\alpha} \quad \text{and} \quad ^9\text{B} \rightarrow \text{n} + {}^8\text{B} \;\; (\overset{\beta^+}{\rightarrow}\ ^8\text{Be}^* \rightarrow \alpha\alpha).$$

Due to these specific properties of the core nuclei ^{9}Be and ^{9}B, it may be possible for the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei to measure the **partial decay widths** $\Gamma^{\tau}_{\alpha\alpha\, i}$ corresponding to states of the residual nucleus ^{8}Be decaying through the alpha alpha-channel.

EXPERIMENTAL OPPORTUNITIES

The partial widths $\Gamma^{\tau}_{\alpha\alpha i}$ will be determined through

detection of tagged alpha particles.

Such tagged α-particles were recognized as 'hammer tracks' in the emulsion and were efficiently used for identification of $^{8}_{\Lambda}$Li ($\to \pi^{-}\ ^{8}$Be*)

G. Bohm *et al.*, NP **B 74** ('74);

D. Zieminska and R.H. Dalitz, NP **B 74** ('74).

High-statistics study of the production, decay and lifetime of the p-shell hypernuclei $^{7}_{\Lambda}$Li, $^{9}_{\Lambda}$Be and $^{10}_{\Lambda}$B is one of the main physics priorities of the experimental program for **FINUDA**

Feliciello *et al.*, NP **A 691** ('01).

So, there we can obtain $\sigma_{\rm prod}(^{10}_{\Lambda}{\rm B})$ as well as $\Gamma^{\rm n}_{\rm tot}(^{10}_{\Lambda}{\rm B})$ and $\Gamma^{\rm p}_{\rm tot}(^{10}_{\Lambda}{\rm B})$.

There is some hope that it will be possible to use **photoemulsion** there and gain $\Gamma^{\rm p}_{\alpha\alpha\,2}(^{10}_{\Lambda}{\rm B})$, $\Gamma^{\rm p}_{\alpha\alpha\,1}(^{10}_{\Lambda}{\rm B})$, $\Gamma^{\rm n}_{\alpha\alpha\,2}(^{10}_{\Lambda}{\rm Be})$, $\Gamma^{\rm n}_{\alpha\alpha\,2}(^{10}_{\Lambda}{\rm Be})$,

as well as $\Gamma^{\rm n}_{\alpha\alpha}(^{10}_{\Lambda}{\rm B})$ and $\Gamma^{\rm p}_{\alpha\alpha}(^{10}_{\Lambda}{\rm Be})$

exploring unique tracks $\ ^{8}{\rm Li} \xrightarrow{\beta^{-}} \alpha\ \alpha$ and $\ ^{8}{\rm B} \xrightarrow{\beta^{+}} \alpha\ \alpha$

LM & Yu. Batusov, Phys. At. Nuclei **64** ('01).

However, there is no experience of using photoemulsion in hypernuclear experiments at a collider yet.

Recently, the first hypernuclear spectroscopy experiment using the $^{12}_{\Lambda}{\rm C}(e, e'K^{+})^{12}_{\Lambda}{\rm B}$ reaction has successfully been performed at **CEBAF**

E.V. Hungerford. NP **A 691** ('01).

Here, the primary hypernucleus is produced with a large momentum and detection of α-particles with $E_{\alpha} = 8$ MeV would be possible.

So, $\Gamma^{\rm n}_{\alpha\alpha\,2}(^{10}_{\Lambda}{\rm Be})$ and $\sigma_{\rm prod}(^{10}_{\Lambda}{\rm Be})$ could be determined.

L. M., A. Parreño, A. Margaryan and L. Tang.

Mesons and Light Nuclei, AIP Conf. Proc. **603** ('01)

RELATIVISTIC HYPERNUCLEI

KINEMATICS

beam		target		SLOW secondaries		FAST secondaries
K^-	+	^AZ	$\rightarrow$	$^A_\Lambda Z$	+	π^-
^AZ	+	p	$\rightarrow$	K^+	+	$^A_\Lambda Z$ + n

FIRST EXPERIMENTS

1976	Berkeley	T. Bowen	PR C13	$^{16}_{\Lambda}O$
1989	Dubna	S. Khorozov, J. Lukstins	NC A 102	$^4_\Lambda H$
1992	Dubna	S. Khorozov, J. Lukstins	NP A 547	$^3_\Lambda H$

NEW PROPOSALS:
Dubna, Nuclotron, Juris Lukstins: Nucl. Phys A 691 (2001)

KEK, 50 GeV PS, A. Sakaguchi:
Int. Workshop on Nuclear and Particle Physics , KEK, Dec. 2001

RELATIVISTIC HYPERNUCLEI

The production of hypernuclei in **relativistic heavy ion collision** has several advantages:

- The points of the production and decay of relativistic hypernuclei are separated by many centimeters (instead of some microns in the emulsion);
- decay products are emitted into small laboratory solid angle.

M. I. Podgoretskii, E. O. Okonov. *in* Proc. Sem. Nuclotron and Relativistic Nuclear Physics, June 1974, Dubna

J. Bartke *et al., in* Proc. Int. Workshop on RELATIVISTIC NUCLEAR PHYSICS: from HUNDREDS of MeV to TeV, Varna, Bulgaria, September 2001.

At the end of the 80-ies hypernuclear experiments were performed on the Dubna synchrophasotron ion beams (^{3}He, ^{4}He, ^{6}Li) using the streamer chamber. The production cross sections as well as the lifetimes of $^4_\Lambda$H and $^3_\Lambda$H were measured S. Avramenko *et al.*, NP **A 547** ('92).

The advantage of these experiments were low background and unambiguous identification of observed hypernuclei.

The same group has prepared program for the Nuclotron accelerator: to measure the lifetimes for $^3_\Lambda$H, $^4_\Lambda$H and $^6_\Lambda$He hypernuclei during the initial runs of the Nuclotron J. Lukstins, NP **A 691** ('01).

The next step of the suggested hypernuclear experiments program will be investigation of nonmesonic decays by searching two α's from ^{8}Be. If ^{8}Be decays from the ground state, then the back to back momentum of two α's is very low and both α's hit the detectors at the same point. However, prevailing part of α's proceeds from **excited** states of ^{8}Be. These events **can be registered** by high resolution devices.

So, the **new trigger** tuned to search for two tagged α particles, opens an unprecedent possibility to **determine**

$\Gamma^{n}_{\alpha\alpha 2}(^{10}_{\Lambda}\mathrm{Be})$, $\Gamma^{n}_{\alpha\alpha 1}(^{10}_{\Lambda}\mathrm{Be})$, $\Gamma^{p}_{\alpha\alpha 2}(^{10}_{\Lambda}\mathrm{B})$ and $\Gamma^{p}_{\alpha\alpha 1}(^{10}_{\Lambda}\mathrm{B})$

at the **Dubna Nuclotron**.

WHAT THE "ALPHA" - DECAYS OF A = 10 HYPERNUCLEI TELL US?

The registration of correlated $\alpha\alpha$ pairs from the decay of ${}^{10}_{\Lambda}$Be and ${}^{10}_{\Lambda}$B allows one the determination all necessary matrix elements $w^{SJ}_{\ell\tau}$ and describe the nonmesonic decay of p-shell hypernuclei.

Even the measurement of few of partial widths opens the way for the **phenomenological analysis** matrix elements of weak interaction and reveals its peculiarities.

Our starting point is already classical phenomenological analysis developed in forty years ago by Block and Dalitz

M. M. Block and R. H. Dalitz: Phys. Rev. Lett. **11** (1963) 96.

for the studies of nonmesonic decay of the s-shell hypernuclei. Total widths of nonmesonic decays of four s-shell hypernuclei (${}^{3,4}_{\Lambda}$H, ${}^{4,5}_{\Lambda}$He) have been expressed as the sums of four rates $R_{\tau S}$

$$\Gamma_{\rm nm}({}^{3}_{\Lambda}{\rm H}) = \frac{\rho_3}{8}\,(3R_{n0} + R_{n1} + 3R_{p0} + R_{p1})$$

$$\Gamma_{\rm nm}({}^{4}_{\Lambda}{\rm H}) = \frac{\rho_4}{6}\,(R_{n0} + 3R_{n1} + 2R_{p0}) \equiv \Gamma^{n}_{\rm H} + \Gamma^{p}_{\rm H}$$

$$\Gamma_{\rm nm}({}^{4}_{\Lambda}{\rm He}) = \frac{\rho_4}{6}\,(2R_{n0} + R_{p0} + 3R_{p1}) \equiv \Gamma^{n}_{\rm He} + \Gamma^{p}_{\rm He}$$

$$\Gamma_{\rm nm}({}^{5}_{\Lambda}{\rm He}) = \frac{\rho_5}{8}\,(R_{n0} + 3R_{n1} + R_{p0} + 3R_{p1})$$

Some simple relations between the widths of nonmesonic decays of s-shell hypernuclei follow

$$\frac{\Gamma^{n}\left({}^{5}_{\Lambda}{\rm He}\right)}{\Gamma^{p}\left({}^{5}_{\Lambda}{\rm He}\right)} = \frac{\Gamma^{n}_{\rm H}}{\Gamma^{p}_{\rm He}}, \qquad \frac{R_{n0}}{R_{p0}} = \frac{\Gamma^{n}_{\rm He}}{\Gamma^{P}_{\rm H}},$$

$$\frac{R_{n1}}{R_{n0}} = \frac{1}{3}\left(2\,\frac{\Gamma^{n}_{\rm H}}{\Gamma^{n}_{\rm He}} - 1\right), \quad \frac{R_{p1}}{R_{p0}} = \frac{1}{3}\left(2\,\frac{\Gamma^{p}_{\rm He}}{\Gamma^{p}_{\rm H}} - 1\right)$$

Recently the values of $\Gamma^{\tau}({}^4_\Lambda\mathrm{H})$ and $\Gamma^{\tau}({}^4_\Lambda\mathrm{He})$ were calculated with several models of weak interactions between hyperons and nucleons

Two Pion Exchange	Itonaga, Ueda, Motoba: PR **C65** (2002),
Hybrid Quark	Sasaki, Inoue, Oka: NP **A707** (2002),
One Meson Exchange	Krmotić, Tadić, nucl-th/0212040.

Now it is possible now to extract ratios of $R_{\tau S}$

from theoretical $\Gamma^{\tau}({}^4_\Lambda\mathrm{H})$ and $\Gamma^{\tau}({}^4_\Lambda\mathrm{He})$ **values.**

We use results A. Parreño, A. Ramos, C. Bennhold, Phys. Rev. **C56** ('97).:

The interaction matrix elements for L=1 are very small, so we neglect them for a moment and write extremely simple expression for $\tilde{\Gamma}_i^{\tau}$

$$\tilde{\Gamma}_i^{\tau} = \nu_i\, \varepsilon_1^2\, \beta_0\, [\, G_i^0\, R_{\tau 0} + G_i^1\, R_{\tau 1}\,], \qquad (1)$$

where $R_{\tau S}$ are phenomenological rates introduced by Dalitz and Block;
ν_i - normalization of the spectroscopic factor; and
G_i^0 (G_i^0) - weight of the singlet (triplet) state in the wave function of the NΛ pair.
The coefficients ν_i and ε_i actually are related to strong interaction. They disappear in the ratio:

$$\gamma_i^{np} \equiv \frac{\tilde{\Gamma}^{\mathrm{n}}_{\alpha\alpha i}\,({}^{10}_{\Lambda}\mathrm{Be})}{\tilde{\Gamma}^{\mathrm{p}}_{\alpha\alpha i}\,({}^{10}_{\Lambda}\mathrm{B})} = \frac{R_{n0}}{R_{p0}} \cdot \frac{G_i^{(0)} + (1 - G_i^{(0)})(R_{n1}/R_{n0})}{G_i^{(0)} + (1 - G_i^{(0)})(R_{p1}/R_{p0})}, \qquad (2)$$

which depends on single structure characteristic, G_i^0, only.
But it differs strongly for two 2^+ states in ^{8}Be:

$$G_1^{(0)} = 0.5 \quad \text{for state at E} = 3 \text{ MeV}: \quad [4]\,{}^{11}\mathrm{D}_2,$$

and

$$G_2^{(0)} = 0.1 \quad \text{for state E} = 16.7 \text{ MeV}: \quad [31]\,({}^{13}\mathrm{P}_2 + {}^{33}\mathrm{P}_2),$$

Ratios $\gamma_i^{n/p}$ for different models of weak interaction.

model		$A=4$ R_{n0}/R_{p0}	R_{n1}/R_{n0}	R_{p1}/R_{p0}	$A=10$ $\gamma_1^{n/p}$	$\gamma_2^{n/p}$
IUM	V_π	2.0	1.0	27.0	0.14	0.08
	$+ V_{2\pi/\rho}$	2.5	2.6	35.0	0.25	0.19
	$+ V_\omega$	2.0	0.57	10.0	0.28	0.14
	$+ V_{2\pi/\sigma}$	2.0	0.39	3.40	0.63	0.28
SIO	π	2.0	0.54	15.0	0.19	0.09
	$\pi + K$	1.8	4.6	19.0	0.50	0.44
	HQ	0.85	1.3	0.74	1.12	1.41
	all	0.13	26	4.40	0.65	0.75
OME	π	2.0	0.7	12.1	0.25	0.13
	PS	2.0	7.6	30.0	0.56	0.51
	PS+PV	2.0	35	21.3	3.22	3.26
phenomenological						
	AG1	0.6	2.2	1.2	0.87	1.06
	AG2	2.0	2.2	5.0	1.07	0.90

Nuclotron		s-shell		model WI
$\Gamma^{\rm n}_{\alpha\alpha\, i}\ ({}^{10}_{\Lambda}\mathrm{Be})$	$\Leftrightarrow$	$\Gamma^{\rm n}({}^4\mathrm{H}),\ \Gamma^{\rm n}({}^4\mathrm{He})$	$\Leftrightarrow$	OME, TPE
$\Gamma^{\rm p}_{\alpha\alpha\, i}\ ({}^{10}_{\Lambda}\mathrm{B})$		$\Gamma^{\rm p}({}^4\mathrm{H}),\ \Gamma^{\rm p}({}^4\mathrm{He})$		Hybrid Quark

CONCLUSIONS

- Decays of ${}^{10}_{\Lambda}$Be and ${}^{10}_{\Lambda}$B hypernuclei give us unique information on nonleptonic weak decay matrix elements

- Experiment is approved for NUCLOTRON accelerator at Dubna

- Even preliminary results will be very interesting