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EXPERIMENTAL POSSIBILITIES TO SEARCH FOR CHARMED NUCLEI IN NUCLEUS-NUCLEUS COLLISIONS

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A close resemblance of quark structures of the strange hyperon Λ_s^o (u,d,s) and charged baryon Λ_c^+(u,d,c) has been a natural reason to suggest the existence of a charm analog of hypernuclei (the so-called "supernuclei"[1]). The supernuclei become the subject of intense activities of theorists[2-10], who have started with extending the one-boson-exchange model from SU(3) to SU(4) symmetry to compare Λ_s-N and Λ_c-N interactions in nuclei. These interactions are expected to be similar in the framework of such universality assumption. This leads to a conclusion that binding energies Λ_c^+ in nuclei (B_{Λ_c}) could be substantially higher than the corresponding values of B_{Λ_c} just by virtue of the heavy mass effect[8]. However, more detailed theoretical treatment has shown that the mentioned universality assumption does not appear to be reasonable due to a different contribution of $\overline{K}(\overline{K}^*)$-exchange and its charmed analog exchange via $\overline{D}(\overline{D}^*)$-mesons which heavy masses make their contribution very short-ranged and therefore much less important (at least for light nuclei). On the other hand, the Coulomb interaction of charged Λ_c^+ in nuclei should not be neglected when comparing with neutral Λ_s^o. It has been pointed out[5] that this factor makes the binding energy unsaturated with increasing nuclei mass numbers (in contrast with B_{Λ_s}): the corresponding values of B_{Λ_c} are expected to reach a maximum at A ~ 40 and to decrease afterwards.

Taking into account these main factors, which seem to be somehow balanced, most theorists have come to the conclusion that the binding energies of Λ_s^o and Λ_c^+ particles in nuclei do not differ greatly (at least for $A \lesssim 40$).

It is reasonably expected that the nuclear environment does not affect substantially the decay properties of the bound Λ_c^+-baryon due to its multiparticle decays with rather large energy release.

Therefore the lifetime of charmed nuclei is predicted to be almost the same as that of the free Λ_c^+-particle ($\tau_c \sim 2 \cdot 10^{-13}$s) what is about three orders of magnitude less than the lifetime of hypernuclei and it poses a great problem for the observation of charmed nuclei decays due to their very short ranges.

Another challenge to experimentalists is a very low probability of Λ_c-nuclei formation.

The charmed baryon production itself (at least in unflavoured beams) is a rare process. Moreover, massive Λ_c-particles produced on quasi-free nucleons in nuclei, have rather large energies due to substantial momentum transfer. Thus, several elastic and/or inelastic interactions are needed to slow down a Λ_c^+-baryon in the nucleus to a low enough energy for being captured in one of its fragments.

It is reasonable to hope that cascade processes with initially produced $\bar{D}$-mesons will also contribute substantially to A_c -formation.

Tremendous cascade calculations (using poorly known amplitudes of binary reactions) are necessary to evaluate a relative A_c -yield (W). Only crude estimations could be possible at the present time, and physicists ought to be ready to face with the value of W_p being as small as 10^{-8} (or even less) per one pA-interaction at energies of a few hundreds GeV.

Such exotic phenomena as Λ_c^+-interactions with fluctons in nuclei could probably increase this value up to $W_p \leq 10^{-6}$ (from optimistic estimations[10]).

These problems (very short A_c -decay ranges and low probability of their formation) make extremely difficult the search for charmed nuclei. That is why the only purposeful search for A_c' s has been undertaken[11,12] during the 15-year period of charmed particle investigations with thousands of detected events. One could remember that the discovery of hypernuclei had taken about 5 years after first Λ_s-detections.

An emulsion was exposed to a 250 GeV proton beam and 3 events were distinguished having some features of charmed nuclei, but other important expected peculiarities were not observed in these events. The upper limit for A_c -yield estimated by the authors (($W_p \leq 3\cdot10^{-6}$) appears to be far from the expected value of W_p ($\sim10^{-8}$).

Thus, the A_c-search in "usual" approaches (when A_c-nuclei are expected to be formed in the target-nucleus rapidity region or even in midrapidities[10]) seems to be beyond the recent experimental possibilities*.

The situation appears to be quite different if relativistic charmed nuclei are planned to be produced and searched for as fragments of projectile nuclei in $A_p A_T$-collisions with $A_p > A_T$,

*This also concerns the supposed experiments [10,13,14] in colliding e^+e^--beams under conditions (extra high luminosity and collimation) which will hardly be available in the near future.

in particular, at the SPS (CERN) and at the future RHIC(BNL). In this case $\Lambda_c^+(\bar{D})$-particle, produced in one of many NN-interactions within the overlapped nuclei zone, could be slowed down in a high density region* and captured by one of projectile spectator fragments forming the charmed nucleus with relativistic velocity which is close to that of A_p -nucleus.

Main advantages of the proposed approach are the following:
a) greater Λ_c^+ ($\bar{D}$)-yields due to many nucleons of A_T effectively involved in an interaction within the overlapped region of colliding nuclei;

b) more frequent secondary interactions (due to a high density of the overlapped and compressed zone) and a more effective slowing down of produced Λ_c^+ ($\bar{D}$)-particles;

c) longer decay ranges of A_c-nuclei formed in projectile spectator fragments (<r> ~ 10 mm for 170 A GeV) what makes it possible:

- to use rather thick targets (some mm),
- to employ coordinate/charge detectors (e.g., thin Si-strips) including them in a trigger,
- to detect A_c -decays inside a vacuum cavity in order to eliminate the background from interactions in the decay volume.

Additional favourable peculiarities of the proposed approach will be of great importance in the future experiments:

- emission angles of relativistic A_c-nuclei and their decay products are very narrow (Θ < 30 m rad) what makes possible using spectrometers with small apertures,
- velocities of detected A_c^+-nuclei are near the same what allows to obtain the lifetime by measuring their ranges (after vertex reconstruction of their decays),
- decay products of A_c -nuclei having close velocities** could be distinguished by their masses, as their rigidities (being proportional to value of m) could be measured using magnetic spectrometers.

Facilities in such an experiment (see the figure) could be similar to those as in our relativistic hypernuclei studies[15,16], but with much smaller transverse dimensions and with replacing the most of MWPC coordinate detectors by Si microstrips. Three sets of coordinate detectors are supposed to be used:

- C_{1-3} for tracking projectile nuclei interacting in the target T,

*A considerable stopping with rather high density in the overlapped zone has been observed in AA-collisions even at CERN energies (see, e.g., [20]).
**At least heavier decay products ($\Sigma^{\pm}$, p, $K^{\pm}$).

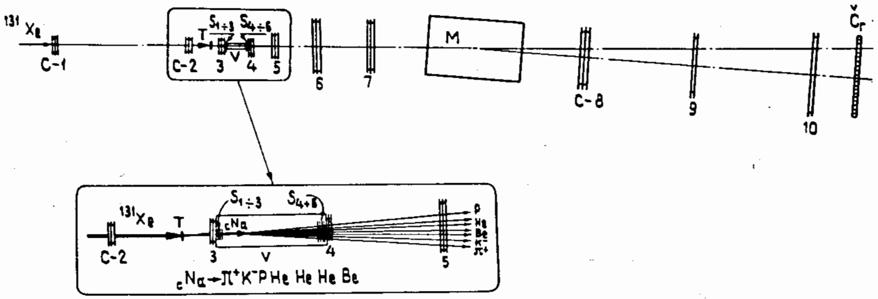

Fig. A preliminary layout (not in the scale) of the proposed experiment to search for charmed nuclei in ultrarelativistic A_p beams (with a possible detection of the decay $_c$Na→π^+K^- p He He He Be in the vacuum cavity V,for example): C_{1-3} - coordinate detectors for tracking the projectile nuclei (e.g. ^{131}Xe), interacting in target T (e.g., Fe); S_{1-3} and S_{4-6} are two sets of charge and coordinate detectors (Si-microstrips); C_{4-7}, coordinate detectors (Si-strips) for tracking of decay products upstream the analyzing magnet M and for vertex reconstruction; C_{8-10}, coordinate detectors for tracking decay products and for measuring of rigidities; $\check{C}r$, sectioned charge detectors for decay products.

- C_{4-7} for tracking products of A_c-decays upstream the analysing magnet M and for reconstructions of their vertices.

- C_{8-10} for tracking products of A_c-decays and for measuring their rigidities in magnet M.

The projectile nucleus A_p going through C_{1-3} could interact in the target T (a few mm thick) with a possible formation of A_c-fragment and its decays in the vacuum cavity V (with two sets of Si sectioned charge detectors S_{1-3} and S_{4-6} inside it).

The A_c -decay could be detected for a subsequent off-line analysis using at least three levels of triggering with following logic:

- an increase of multiplicities (due to A_c -decay inside V) detected by S_{1-3} and S_{4-6},*

- a decrease of the A_c -nucleus charge (as a result of its decay and fragmentation within V) detected with dE/dx charge detectors S_{1-3} and S_{4-6} by amplitudes being proportional to Z^2,

*The Si-microstrips successfully used for multiplicity measurements in A_pA_T studies (see, e.g., /17/) might appear to be not so effective in such triggering for very large $A_T(A_p)$.

- reconstruction of a vertex inside the vacuum cavity V using coordinate detectors C_{4-7} and fast processors.

A rather sophisticated algorithm of A_c-event selection should be developed with these triggerings in order to use high intensity beams of nuclei spread in diameter of 5-20 mm. The main background loading of the first levels of trigger from A_p-interactions in S_3 would be substantially diminished by cutting high amplitudes in charge detector S_3, which are due to Si-nucleus fragmentation in A_p Si-collisions.

The only known process, which could contribute as a physical background, is the production of hypernuclei and their decays inside V. The A_s-production is expected to be by ~5 orders more frequent than that of A_c, what results in ~100 times more A_s -decays inside V (taking into account $\tau_c/\tau_s \sim 10^{-3}$). This background could be mostly eliminated* by triggering from A_c-decays (more than 50%) with decay product emission angles (Θ) greater than those from hypernuclear decay processes ($\Theta^{max} \simeq 4$ mrad for $\Lambda \to p\pi^-$ to be compared with $\Theta^{max} \simeq 30$ mrad for Λ_c^+-pionic decays).

The A_c-decays should be finally distinguished by the identification of heavier decay products (including nuclear fragments) when measuring their rigidities in the magnetic field M and determining their charges by a hodoscope ($\check{C}r$) of charge detectors. The range distribution of decaying A_c -nuclei, having close velocities, is expected to be exponential with $\langle r \rangle \simeq 10$ mm (in contrast with background A_s -decays which are practically uniformly distributed along a 30 mm path inside V).

The recent microstrip facilities with 2-3 μm resolutions/18,19/ could provide an accuracy better than $\Delta r \simeq 1$ mm for the most triggered A_c-decay configuration.

It seems to be reasonable to take $W_{pA} \simeq 10^{-8}$ for A_c -yield in pA-interactions in order to obtain a crude estimation of a data taking rate for A_c-events in A_pA_T collisions at 170A GeV.

The following additional factors could be expected for A_pA_T -interactions (supposing, e.g.,for $A_p = {}^{131}$Xe and $A_T = {}^{56}$Fe):

- many nucleons of A_T effectively involved in A_pA_T interaction to produce $\Lambda_c^+(\bar{D})$ within the overlapped region: ~ 20;

*A possible background from unknown excited states could be eliminated in a similar way.

- more effective slowing down of $\Lambda_c^+(\bar{D})$ in a high density nuclear matter (with greater flucton concentration): ~ 10*.

This gives $W_{AA} \simeq 2\cdot10^{-6}$ for A_c-formation per one XeFe-interaction. Other experimental conditions and appropriate factors are supposed to be:

- a flux about 10^7 nuclei/burst (i.e., $5\cdot10^6$ nuclei/sec) in a beam of ~5 mm diameter (~$5\cdot10^4$ nuclei per Si-strip);
- a target ~2 mm Fe: ~ about 0.1 interaction length;
- the decay factor for detected A_c's: ~ 0.2;
- a fraction of A_c-decays with Θ > 4 mrad (for A_s-discrimination): ~ 0.5;
- the overall efficiency of detectors: ~ 0.5.

These results for A_c-data taking rate:

$$N_{A_c} = 2\cdot10^{-6}\cdot10^7\cdot0.1\cdot0.2\cdot0.5\cdot0.5 \simeq 0.1,$$

i.e., about $2\cdot10^3$ detected A_c-events for 100 hour run at SPS (CERN).

Thus, the above considerations and preliminary performed estimations show that the proposed approach appears to make possible the search for charmed nuclei and investigation of their properties when heavier relativistic nuclei will be available at SPS (in 1993) and probably, at the future RHIC (BNL). Nevertheless the more detailed examination of this approach and tests of appropriate detectors in nuclear beams should be desirable to choose adequate experimental conditions for proposed investigations.

The author wishes to dedicate this work to the memory of Hiroharu Bandõ, the prominent physicist with outstanding contributions to many problems of nuclear physics. His theoretical treatment of hypothetical charmed nuclei has excited hopes for the existence of new flavor matter what has stimulated this work.

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*This is a result of a guess if one keeps in mind that interaction on fluctons (even in ordinary - not compressed - nuclear matter) could increase the A_c-yield by a factor of ≲ 100 /10/.

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Экспериментальные возможности поиска очарованных ядер в ядро-ядерных взаимодействиях

Предложен новый экспериментальный подход для поиска и исследований очарованных ядер (A_c), образованных при взаимодействии тяжелых релятивистских ядер с более легкими ядрами. В этом случае Λ_c^+-барион, образовавшийся в одном из многих нуклон-нуклонных взаимодействий в области перекрытия ядер и замедлившийся в веществе повышенной плотности, может быть захвачен фрагментом-спектатором налетающего ядра с образованием очарованного ядра. Ожидается, что при этом выход A_c-ядер будет значительно выше, чем в pA-взаимодействиях, а их распадные пробеги достаточно большими для того, чтобы: - использовать довольно толстые мишени (несколько мм); - применять детекторы для отбора триггером случаев A_c-распадов (тонкие Si-стрипы); - регистрировать A_c-распады в вакуумной полости, чтобы устранить фон от взаимодействий. Проведенное рассмотрение и предварительные оценки показывают, что предлагаемые эксперименты могут быть осуществлены в ядерных пучках SPS (ЦЕРН) и будущего RHIC (БНЛ).

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Experimental Possibilities to Search for Charmed Nuclei in Nucleus-Nucleus Collisions

A new experimental approach is proposed to search for and to investigate charmed nuclei (A_c) formed in collisions of ultrarelativistic heavy nuclei with lighter ones. In such a case the Λ_c^+-baryon produced in one of numerous nucleon-nucleon interactions within the overlapped nuclei region and slowed down in high density matter,could be captured by the projectile fragment-spectator with A_c-nucleus formation. Therefore the A_c-yield is expected to be considerably greater (than in pA interaction), and the decay ranges of A_c-nuclei will be long enough: - to use rather a thick target (a few mm); - to employ detectors for A_c-event triggering (e.g., thin Si-strips); - to detect A_c-decays in a vacuum cavity in order to eliminate a background from interactions. Consideration and preliminary estimations show that proposed experiments appear to be accessible in nuclear beams at the SPS (CERN)and at the future RHIC (BNL).

The investigation has been performed at the Laboratory of High Energies, JINR.

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