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A HYPERNUCLEAR PROGRAM FOR THE NUCLOTRON ACCELERATOR

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Hypernuclei have been investigated (production and decays) in the Dubna synchrophasotron beams. However, the experiments were interrupted due to a low data collection rate. The beams of the new accelerator Nuclotron allow one to increase the available statistics by a factor of 100 or more. Therefore hypernuclear lifetimes can be measured within 2% errors significantly exceeding the results of the previous experiments. The study of $^3_\Lambda$H properties is discussed. It is possible to make an attempt to investigate the Coulomb dissociation of the hypernucleus.

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

Программа гиперядерных исследований для нуклотрона

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В пучках синхрофазотрона ОИЯИ были проведены исследования гиперядер (рождения и распада), но эксперименты были прекращены из-за малой скорости накопления данных. Пучки нового ускорителя (нуклотрона) позволят увеличить статистики в 100 или более раз. Это позволит измерить вермена жизни гиперядер с точностью 2%, что существенно превышает ранее полученные результаты. Обсуждается также исследование свойств $^3_\Lambda$H, в частности — кулоновской диссоциации этого гиперядра.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

At the end of the 80-ies hypernuclear experiments were performed on the Dubna synchrophasotron ion beams ^{3}He, ^{4}He, ^{6}Li). The production cross sections of $^4_\Lambda$H and $^3_\Lambda$H as well as the lifetime of $^4_\Lambda$H [1,2] were measured. The advantage of these experiments were low background, unambiguous identification of the observed hypernuclei and a reasonable trigger efficiency. It was also shown that in the case of lifetime measurements this approach was practically free from systematic errors and very effective. However, the experiments were interrupted because of the low statistics available due to the large memory time (3–5 μs) of the streamer chamber used in these experiments, combined with a low value (3—5%) of synchrophasotron duty cycle.

Because of the scheduled ion beams [3] of the new Nuclotron accelerator there is expected a significant increase of the registration rate. The most obvious source of the improvement may come as a result of a significantly enlarged beam duty time value (75%). Another way to increase the data-collection rate is the use of proportional chambers for momentum measurements. Either way, the data-collection rate can be increased by at least a factor of 100.

This increase is most important when estimating the possible results of our hypernuclear program for the Nuclotron accelerator. It was suggested to measure the lifetimes for ${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H and ${}^{6}_{\Lambda}$He hypernuclei as well as the absorption cross sections of ${}^{3}_{\Lambda}$H and ${}^{6}_{\Lambda}$He on different targets during the initial runs of the Nuclotron. If the statistics are increased by a factor of 100 the lifetimes will be measured within a 3—5% accuracy — significantly better than in previous experiments [2,4,5] where an accuracy of 12—20% was achieved in the best case while the lifetime of the ${}^{3}_{\Lambda}$H was known with errors not better than 50%.

As in our previous experiments [2], the two-particle decay of hypernuclei will be used when a π^- is emitted:

$$ {}^{A}_{\Lambda}Z \rightarrow {}^{A}(Z+1) + \pi^-. \tag{1}$$

Let us consider the method of registration using the production and decay of a hypertriton as an example:

$$ {}^{3}\mathrm{He} + C \rightarrow {}^{3}_{\Lambda}\mathrm{H} + \ldots \tag{2}$$

$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^-. \tag{3}$$

A schematic layout of the detectors is presented in the Figure. The ^{3}He beam hits target (T) where ${}^{3}_{\Lambda}$H hypernuclei are produced. If the hypernuclei decay inside a vacuumized volume, then the direction of ejectile nuclei as well as of π^- is measured in the chambers H_1 and H_2 and the decay point of hypernuclei is determined. In the chambers H_3 and H_4 the direction of ejectile nuclei is determined downstream the analyzing magnet (M) and the momentum of the ejectile is thus measured.

The trigger is desinged to register a specific change of nuclear charge in the decay reaction (3). The counters B (Cerenkov and scintillators) should be tuned to register a relativistic particle (${}^{3}_{\Lambda}$H) with charge 1 in coincidence with the counters C which had to define that the same nucleus has now

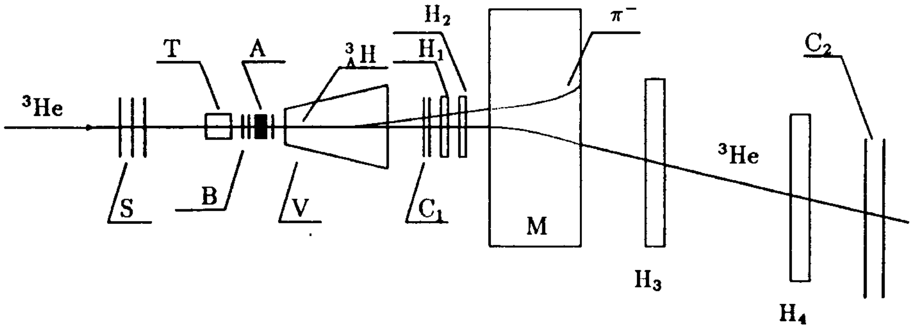

Figure. A schematic (not scaled) layout of the experimental facility. *S* — beam counters; *T* — target; *A* — absorber; *B*, C_1 and C_2 counters measuring the charge of a nucleus; *V* — vacuum tank; *M* — analyzing magnet; H_{1-4} — proportional chamber units

charge 2 after the decay. Our expriments [2] have shown a background damping of 5—6 orders and a high geometrical acceptance.

To estimate the available registration rate for any experiment one should know the production cross sections. The production cross sections for ^{3}He, ^{4}He, ^{6}Li, ^{7}Li, ^{12}C and ^{19}F beams were calculated in [6,7] at a 3.7×*A* GeV energy. Our experiments on the $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H production cross sections in the ^{3}He, ^{4}He and ^{6}Li beams at the same energy have confirmed [2] these calculations. Considering the energy dependence, there are controversial predictions: calculations of [8] give an increase of the production cross sections by a factor of 2—3 at a 6×*A* GeV energy available on the Nuclotron accelerator while in the model [6,7] no increase is predicted (see [9]). However, the energy dependence has not been proved experimentally and we use cross sections measured [2] or calculated [6,7] at 3.7×*A* GeV for all estimations.

The Table shows our estimations of the expected number of hypernuclear decays per a day of Nuclotron run. *N* shows the number of events that can be observed and identified. We take into consideration: fraction of decays with π^- emitted, fraction of decays inside the vacuum volume *V*, efficiency of the counters, losses of hypernuclei or daughter nuclei due to their interactions in detector elements and losses of nonidentified events when the angle between π^- and the daughter nucleus is too small. The expected number of the events allows one to be quite realistic in hoping to measure the lifetimes of hypernuclei within 3—5% errors.

The expected accuracy of the experiments will be sufficient to check the calculations [10,11] for the models where variations of the order of 10% in hypernuclear decay rates are predicted depending on different assumptions

Table. Expected number N events per 24 hours

Beam	Hypernucleus	N
^{3}He	$^3_\Lambda$H	100
^{4}He	$^4_\Lambda$H	600
^{6}Li	$^6_\Lambda$He	400

of ΛN interaction characteristics. When models of ΛN interactions include a set of assumptions on nuclear and hypernuclear wave functions, distortion of pion wave function, etc., one may assume that a set of lifetime measurements must be obtained to exclude accidental coincidence between the model prediction and experimental value for a hypernucleus. On the other had, in experiments, where the lifetime is measured as a delay of a counter signal, errors are of the order of 10% [5]. It seems to be a rather hard task to reduce them. Really, the main source of these errors are technical and background problems, and a very sophisticated apparatus must be invented to solve these problems. Considering the experimental data on lifetime of the $^3_\Lambda$H hypernucleus obtained up to now, the errors are so large (≅ 50%) that these results are practically useless for contemporary theory. In other words, for the $^3_\Lambda$H hypernucleus suggested experiments will provide a dramatic improvement in accuracy. Moreover, these suggested experiments will provide data on lifetimes of different hypernuclei that can be used as a real test of models.

Considering experiments in a ^{3}He beam, we can, for the first time, investigate the interactions of hypernuclei. Indeed, the decay range of $^3_\Lambda$H produced in the Nuclotron ^{3}He beam is of the order of 45 cm, therefore one can insert different absorbers into «the beam of $^3_\Lambda$H» to study the electromagnetic dissociation of the hypernuclei.

It should be noted that the hypertriton is very important for theory as the lightest stable nuclear system with strange particle (Λ) embedded. In any case this system is significant to calculate few body models as well as to understand ΛN interaction. The binding energy B_Λ of the hypertriton is one of the basic parameters (see [12,13]). From the analysis of experimental data in [14], $B_\Lambda = 0.13 \pm 0.05$ MeV was obtained. The error is statistical. The systematic error was estimated [14] to be 0.04 ± 0.02 MeV. The mass of Λ also was measured in [14], and the result $m_\Lambda = 1115.57 \pm 0.03$ MeV differs by 3 values of standard deviation from the recent measurement [15], where $m_\Lambda = 1115.678 \pm 0.063 \pm 0.006$ MeV. This discrepancy also indicates the presence of problems because of systematic errors in [14]. Anyway, the binding energy of Λ in the hypertriton nucleus can be between 10—20 KeV and 200—250 KeV. The systematic error exceeds the lowest possible value of the binding energy, and therefore the measurement accuracy cannot be improved by using this method. However, such a low binding energy can be measured using the investigation of Coulomb dissociation of the ${}^{3}_{\Lambda}H$ hypernucleus. The calculations [16] have shown that the Coulomb dissociation cross section increases from a barn value up to tens of barns, while the assumed value of binidng energy runs from 200 KeV down to 10 KeV. Such a dramatic sensitivity to binding energy allows one to eliminate significantly uncertainty in B_{Λ} by quite a crude measurement of the Coulomb dissociation cross section. It should also be noted that this method is more sensitive and precise at the lowest values of B_{Λ} where the traditional approach fails.

The study of Coulomb dissociation in ${}^{6}_{\Lambda}He \rightarrow {}^{5}_{\Lambda}He + n$ is also interesting. In this case the measured [14,17] separation energy of the neutron is equal to 0.17 ± 0.10 MeV. The calculated cross section of Coulomb dissociation changes by a factor of 4 if the separation energy of a neutron varies in the measured limits.

Of course, it should be noted that the experiments are not simple because the cross sections of the Coulomb dissociation are not measured directly. When an absorber *A* (see the Figure) is displaced downstream the target *T*, an interplay of two cross sections will be registered — nuclear and Coulomb absorption of hypernuclei. Nevertheless, when different absorbers are used, the cross section of the Coulomb dissociation can be estimated well. We should point out that *A* and *Z* dependence of the interactions is rather different. On the basis of the Glauber model calculations, $A^{0.6}$ rule for nuclear cross section [18] and $Z^{1.7}$ rule [19,20,21] for Coulomb absorption, the cross section of Coulomb dissociation in case of hypernuclei can be determined [19—21] like in experiments with ^{11}Li. Our estimates show that the reasonable Nuclotron run time is enough to obtain a 10—20% accuracy by using thick absorbers which damp a «hypernuclei beam» by a factor of 6—10.

The results of the suggested experiments may be distorted significantly by background effects. However, our experience in previous experiments and calculations show that it is possible to solve the background problems in scheduled experiments. Indeed, only one process can occur inside the vaccum tank — decay of a hypernucleus. One should measure the directions of the ejectile nucleus and π^{-} to fix the decay point inside the vacuum tank and thus identify the hypernucleus decay. Obviously, the distribution of the decay points is used to determine the lifetime of the hypernucleus.

At the same time some problems can arise if the trigger is overloaded by background signals. In our experiments the physical background for hypernuclei production is charge exchange reactions that simulate the same trigger. Fortunately, the cross section of charge exchange reaction is not too large, and the number of background charge exchange events, produced in the target, in the walls of vacuum tank or in the counters, will be approximately of the same order or slightly larger than the number of hypernuclear events. Moreover, some of background channels are not allowed in the reactions we have chosen. For example, in the ^{4}He beam we are free from reactions with ^{4}H production and corresponding charge exchange $^4\mathrm{H} \to {}^4\mathrm{He}$ due to a short ^{4}H lifetime. It should also be noted that all evaluations and Monte-Carlo calculations are quite realistic as they are based on our experimental experience: the hypernuclear production cross section [2] and the data [22] on charge exchange reactions.

It seems that the suggested experiments are based on quite realistic estimations and experience and can be realized as soon as extracted beams are available on the Nuclotron accelerator. In the suggested experiments only a few isotopes of hypernuclei will be investigated nevertheless the results can be significant for model tests. For the first time the interactions (dissociation) of hypernuclei can be investigated.

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