CERN - ISC - 97 - 27

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SCP

CERN/ISC 97–27
ISC/I 27
14 November 1997

Letter of Intent to the ISOLDE Committee

Study of neutron dripline nuclei using post accelerated ion-beams.

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Summary

The study of nuclei in the dripline regions attracts at present a large interest worldwide. The occurrence of halo structure has been one of the driving forces. The trend in present day experiments is to study both bound and unbound nuclear systems in the dripline regions to get clues for a deeper understanding of the structure at the edge of nuclear existence. The recent beta-decay experiments at ISOLDE have been combined with reaction experiments performed elsewhere and this combination of data have proven to give possibilities to make detailed conclusions of the structure of for example ^{11}Li. With the advent of REX ISOLDE it is clear that new possibilities open up both since it will provide a new energy regime, not accessible at ~~present, and also since the variety of different beams at ISOLDE is unique.~~ In this letter we want to show our intent to continue our studies of nuclei in the dripline regions also taking advantage of REX ISOLDE. We also give a short description of some simple experiments which we foresee can be performed already during the initial phase of the running of the new post-accelerator.

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1 Introduction

Against predictions [1], ^{11}Li was found to be bound in 1966 [2]. The first spectroscopic information was obtained 9 years later [3] at PS (CERN) where the mass excess, S_{2n} and half-life were determined. In the following nine years the beta-decay studies of ^{11}Li have shown that this nucleus is the most prolific one in different decay modes: β2n [4], β3n [5], $\beta\,^6$He [6] and βt [7] where first observed in the decay of ^{11}Li.

In 1985, Tanihata et al. [8] observed that the ratio of the matter-to-charge radius of ^{11}Li was abnormally large. The interpretation of this nucleus as a core of ^{9}Li surrounded in the far distance by the two neutrons [9] has opened a new field of research: the halo nuclei. This subject has become a very attractive topic in nuclear physics in the last decade (see the last review in the field [10] and references therein). This halo structure highlighted in nuclear reactions studies still present challenges: a good understanding of the two-neutron halo wave function is not yet achieved.

The basic motivation behind this letter of intent is to follow up our recent β-decay studies at ISOLDE [11, 12, 13, 14] utilizing low energy nuclear reactions with light neutron rich ion beams, which is now becoming possible using the REX installation. For the countrate estimates given we have used a transmission through REX-ISOLDE of 10% and a total beam energy of 2.0 MeV/u.

2 Physical problems to be addressed

2.1 Study of excited states in ^{11}Be

The β-decay of ^{11}Li populate excited states in ^{11}Be. To fully extract the information on the ^{11}Li structure that is contained in the β-decay data, one must know the structure of the ^{11}Be states. One example is the transition to the first excited bound state where information on the orbital structure of the two halo neutrons could be derived ([12] and references therein). Knowledge of the unbound excited states is more scarce and the aim of the suggested experiments is to improve upon this situation. To give definite examples we list first two cases where questions raised by the analysis of the β-decay data can be clarified.

The β-delayed deuteron decay of ^{11}Li has been observed [11] with a branching ratio of the ^{9}Li+d channel larger than 10^{-4}. A detailed energy spectrum could not be extracted and the decay mechanism could therefore not be settled. The first of the two suggested mechanisms involves decays directly to the ^{9}Li-deuteron continuum, in analogy to what has been observed in the β-decay of ^{6}He [15]. In this case one expects the decay to be rather sensitive to the outer spatial parts of the halo wavefunction. The other mechanism is sequential decay through an excited state at energy 18.15 MeV in ^{11}Be, which in turn decays through several channels. There is indirect evidence pointing towards the first mechanism. If the 18 MeV level decays to the deuteron channel the reduced width for this decay exceeds the corresponding Wigner limit by a factor of roughly two. Also, the first measurement of d+^{9}Li and t+^{8}Li spectra from the decay of the 18 MeV state fed in a charge-exchange reaction with ^{11}Li nuclei [16, 17] indicated that the βd branch in ^{11}Li should be one order of magnitude smaller than the βt branch. Experimentally they are about the same. However, the available data on the 18 MeV state [16] does not allow strong conclusions to be made and new independent reaction measurements are thus needed.

A detailed study of the decay channels of the 18 MeV state would also constrain further the analysis in [13]. Information about the structure of ^{11}Li could be derived there due to the rather strong β-feeding of the 18 MeV level; B_{GT} is at least 1.6. The suggestion [18] that states with pronounced cluster structure might exist in this excitation region in ^{11}Be could also be checked at the same time.

The 18 MeV state in ^{11}Be can be populated in the reactions number 3, 6 and 7 in Table 1. The first reaction should proceed through a mechanism analogous to the known reaction $^{7}Li(^{7}Li,\alpha)$, where the respective experimental cross-section can be used to estimate the counting rate. This reaction should be sensitive to ^{11}Be* states with a large triton spectroscopic factor. The second reaction has as mechanism a deuteron transfer from the ^{6}Li target to ^{9}Li, which is analogous to that proposed in a search for an excited 'halo' state in ^{8}Li (see [19]) and we assume the same cross section - 5 mb/sr - as a conservative estimate. Our experiment is more complicated, as we need to measure the energy spectrum of α-particles at large angles ($\sim 90°$), as well as α-d and α-t coincidences. Using two multi-strip Si detectors with a solid angle of 0.5 sr as coincidence-detector, we expect a counting rate of one event per 100 seconds. The third reaction, employing resonance elastic scattering as in our ^{11}N experiment at GANIL [20], is a complementary way of reaching the 18 MeV state. It could give high counting rate but needs a thick gas target.

It would be very interesting to go also to excitation energies around 21 MeV which is the position of the IAS in ^{11}Be , but such experiments will not be attempted in the first round. The reactions 3 and 1 can give spectroscopic data about the ^{11}Be* states in the excitation range of 6.3–20.6 MeV and thus address the question about a possible ~14.5 MeV state of ^{11}Be, whose β-feeding is an alternative explanation of the energy spectrum of ^{10}Be following the ^{11}Li beta-decay [13].

2.2 Spectroscopy of the ^{10}Li s-wave neutron state

The low-lying states of the nucleus ^{10}Li are important for understanding the neutron-halo of ^{11}Li, and therefore this nucleus has been investigated with many reactions. Nevertheless, the position and width of the ^{10}Li s-wave neutron state are still not finally determined.

The REX-ISOLDE facility gives opportunities to get precise ^{10}Li spectroscopic data using reactions 2 and 4. The highest rate is expected for the one-neutron transfer reaction $^{2}H(^{9}Li,p)^{10}Li$ due to the simple mechanism and high intensity of the ^{9}Li beam. A rough estimate of the counting rate in this case is 1 event per 10 second. Detection of the proton, of energy about 0.5 MeV, may cause problems in which case the less favourable (considering countrate) reaction 2 must be used.

There is also an indirect way of studying the ^{10}Li s-wave neutron state, namely via its isobaric analog state in ^{10}Be. This IAS could be measured in the elastic resonance scattering reaction 5, Table 1 with typical cross section of 0.1–1.0 b/sr in forward direction, which would give good experimental conditions with a high counting rate and reliable conclusions from the analysis.

3 Programme and future perspectives

The first part of our forthcoming programme will address the above mentioned physics cases. The reactions to be used are given in Table 1 as number 3, 6 and 7 for excited states in ^{11}Be and 2 and 4 for the ^{10}Li case. A detailed proposal for this including experimental details will be presented in 1998.

Table 1 also gives some reactions that should be taken up at a later stage when the first experiences from operation of REX-ISOLDE have been gained. New physics problems can then be attacked.

The first concerns the IAS of ^{11}Li. The position and width of the isobaric analog state of ^{11}Li in ^{11}Be*(21 MeV) is highly sensitive to relative weights of s- and p- components (see, for example, [21, 18]), these weights are still not finally determined. The only existing spectroscopic measurement of this state [17] gave values of E^*=21.16(2) MeV and Γ = 0.49(7) MeV, but an independent confirmation should be performed.

The ^{11}Li reactions 8 and 10 from Table 1 may be used to measure more precisely parameters of the IAS. The expected low ^{11}Li intensity requires rather long-time measurements, but with an optimistic cross-section assumption of 10 mb and a strip-detector, which can detect all reaction events (due to inverse kinematics) the expected counting rate for reaction 10 could be of the order 1 per hour. A cross-check of the isospin of the 21 MeV state could be made using reaction 3 from Table 1, which is selective to the ^{11}Be states with T=3/2 only, but it would require an increase of beam energy to 2.2 MeV/u.

Secondly, the question of the ^{11}Li structure is related to the investigation of its excited states, see e.g. the review [22]. Several spectroscopic studies of ^{11}Li have been performed [23, 24, 25, 26] by now. Three of them [23, 25, 26] observe an excited state at E^*=1.3 MeV, a candidate for a neutron halo excitation. Only a very crude measurement of the width of the state $\Gamma = 0.75 \pm 0.6$ MeV has been made and the suggested spin-parity, as well as the interpretation of the data in terms of such an excited state, is disputed [27].

We may contribute to these studies with accurate measurements of inelastic scattering of ^{11}Li on light targets (see reaction 11 in Table 1). Despite the low beam intensity, the estimated [25] cross-section of p(^{11}Li,p)^{11}Li* reaction at 0° is large – of the order 100 mb/sr. Assuming a similar cross section we can get reasonable statistics in a few days measurement (the counting rate can be up to 1 event per hour if the target thickness is $\sim$10 mg/cm^2).

Finally, reaction 9 is a candidate for an investigation of the low-lying states of ^{10}He, which have been studied in two experiments only.

Table 1: Reactions relevant for the study of neutron-rich nuclei. The energies E^{cm}_{max} are calculated assuming a beam energy of 2 MeV/u. The intensities are the ones from the primary ISOLDE target.

	Nuclei	Intensity, per sec.	Reaction	Q, MeV	E^{cm}_{max}, MeV
1	^{6}He	$1.6 \cdot 10^7$	$^9Be(^6He,\alpha)^{11}Be$	+6.3	7.2
2	^{8}He	$6.6 \cdot 10^5$	$^3He(^8He,p)^{10}Li$	+5.8	4.4
3	^{8}Li	$3.9 \cdot 10^8$	$^7Li(^8Li,\alpha)^{11}Be^*$	-4.9, for E^*=18.1 MeV	7.4
4	^{9}Li	$3.6 \cdot 10^7$	$^2H(^9Li,p)^{10}Li$	-2.6	3.3
5			$^1H(^9Li,p)^9Li$	+1.1 for $^{10}Be^*(18.1)$	1.8
6			$^6Li(^9Li,\alpha)^{11}Be^*$	-1.7, for E^*=18.1 MeV	7.2
7			$^2H(^9Li,d)^9Li$	-0.2 for $^{11}Be^*(18.1)$	3.3
8	^{11}Li	10^3	$^1H(^{11}Li,n)^{11}Be^*$	-1.2 for E^*=21 MeV	1.8
9			$^2H(^{11}Li,^3He)^{10}He$	-2.3	3.4
10			$^3He(^{11}Li,t)^{11}Be^*$	-0.4 for $^{11}Be^*(21$ MeV$)$	4.7
11			$^3He(^{11}Li,^3He)^{11}Li^*$	-1.25 for $^{11}Li^*(1.25)$	4.7

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