EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

(Following HIE-ISOLDE Letter of Intent I-108)

Transfer reactions at the neutron dripline with triton target

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Abstract: Two-neutron transfer to ^{9}Li will populate the ground state of ^{11}Li as well as low-lying resonances in a way that is complementary to studies of these states performed at higher beam energies. We aim at detecting the charged particles from the transfer reactions as well as neutrons coming from the decay of possible ^{11}Li resonances.

Requested shifts: 30 shifts, (split into 1 runs over 1 years)
Installation: 2nd beamline

1 Introduction

This proposal is a continuation of the Letter of Intent INTC-I-108 on transfer reactions at the dripline. The present proposal focusses on (t,p) reactions on ^{9}Li as a first step, the reactions proposed in the LoI with a ^{11}Li beam are postponed to a later stage since they need also the intensity increase that will come in a later phase of HIE-ISOLDE. (We want to express our interest in continuing these experiments also with other neutron-rich isotopes.) The physics program lies in direct continuation of the experiments IS367 on ^{9}Li [1] and IS446 on ^{8}Li [2] and extend the physics program performed with triton targets at ISOLDE e.g. in IS470 on ^{30}Mg [3] (triton targets are at the moment only available at ISOLDE and at Dubna [4]). As mentioned in the LoI the energy increase in HIE-ISOLDE beyond 3 MeV/u is what makes the (t,p) reaction to final unbound (or loosely bound) states energetically possible.

2 Physics case

Most studies of the halo nucleus ^{11}Li have concentrated on the ground state structure, but there is by now several interesting studies also of its excited states that all lie in the two-neutron continuum. A good overview of the litterature is given in the very recent TUNL evaluation [5] where both experimental and theoretical works are collected. Our interest is mainly in the structures observed at low excitation energies that in many previous experiments also are the ones populated most strongly (somewhat simplistically, one could expect final states with low neutron momentum to be more sensitive to the halo structure and structures at higher energies to reflect more possible changes in the core). The ^{11}Li+p scattering at 68 MeV/u gave evidence [6] for a $L = 1$ excitation to a fairly broad state at 1.3 MeV (width about 0.5 MeV), a structure that has been observed in several other reactions as well [7, 8, 9]. However, the identification of this structure as a state has been questioned [10] and a three-body model seem to explain the feature as a dipole excitation into the continuum [11]. The low-lying continuum spectrum of ^{11}Li is dominated by broad structures whereas narrower peaks have been proposed from 3.7 MeV to 6.2 MeV, see [5] for details. Since only a few of the experiments detect both feeding and decay of the suggested structures, it is crucial to obtain information from new experimental probes. If we are dealing with a genuine state its properties should be independent of the feeding reaction, whereas a dipole response would be mainly observed when starting from the ^{11}Li ground state. The only experiment so far that may have observed the 1.3 MeV structure without starting from ^{11}Li is the ^{14}C(π^{-},p+d) reaction [8] and the resolution did here not allow for a detailed characterization. The two-neutron transfer to ^{9}Li is therefore a logical way of probing the continuum structure of ^{11}Li.
Experimental information on whether the structure at low excitation energy is due to resonances or a feature of the reaction may be provided by the energy and angular distributions among the "^{11}Li* decay products". Calculations from the Aarhus-Madrid few-body group [12] do find several resonances (1^{-} excitations on the ground state, i.e. final states with $J^{P} = 1/2^{+}, 3/2^{+}, 5/2^{+}$) at excitation energies from 0.6 to 1.0 MeV. The energy distribution of the neutrons and ^{9}Li emerging from decays of these resonances have also been

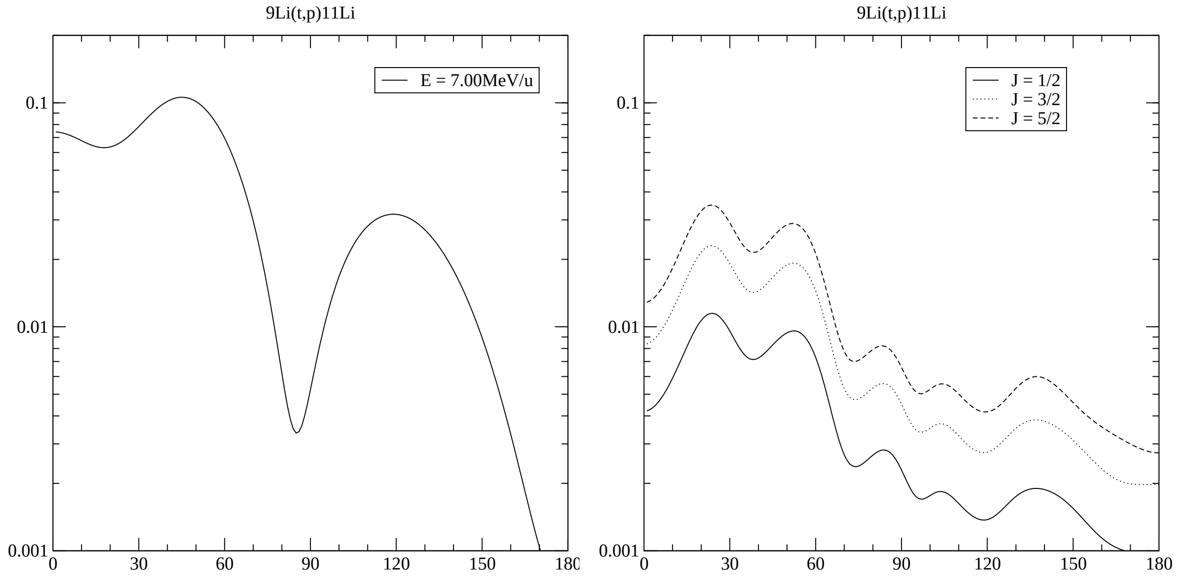

Figure 1: The cross section (mb/sr) for the ^{9}Li(t,p)^{11}Li reaction as a function of centre-of-mass angle from DWBA calculations. Left side for the transition to the ground state and right side for the transitions to the 1^{-} excitations.

calculated [13] and carry a quite striking signature: strong enhancement beyond the phase space distribution at neutron energies close to maximum and to zero. The physics reason behind this signal is the large scattering length existing in the neutron-neutron as well as in the neutron-^{9}Li systems that favours forming subsystems at very low relative energy. If resonances of this type do exist their experimental signature should make them easy to identify. Later calculations show that a $3/2^{+}$ resonance, corresponding to a 0^{-} excitation, may also be present slightly above the 1^{-} states [14]. If a resonance is populated, we expect the decay products, in particular the neutrons, to be significantly more uniformly distributed in angle (the standard difference between compound and direct reactions).

We note further that the (t,p) reaction to the ground state of ^{11}Li would complement the ^{11}Li(p,t)^{9}Li experiment carried out at Triumf [15], both reactions being sensitive to the halo composition in ^{11}Li. There will of course be other reaction channels open that would enhance our understanding of this interesting part of the nuclear chart. One reaction we would like to single out is ^{9}Li(t,α)^{8}He that could be compared to proton knock-out reactions performed at in-flight facilities. The corresponding ^{7}Li(t,α)^{6}He reaction has been used on a few occasions and is known to populate the ground state as well as several excited states in ^{6}He. If the (t,α) reaction turns out to be a useful spectroscopic tool in this mass range, it would be very interesting to employ it in a later experiment with a ^{11}Be beam to populate ^{10}Li.

In order to estimate the beam time needed we have carried out DWBA calculations with potentials based on [16]. These cannot be expected to give an accurate description of the process, but contains the main kinematical features and most likely provide lower bounds for the cross sections. The figure shows the resulting cross sections in the centre-of-mass system. With a beam energy of 7 MeV/u we can populate the continuum up to about 9 MeV. At this beam energy there will be a significant cross section for fusion reactions between ^{9}Li and the Ti backing in the target. The proton background coming from these reactions must be measured with a separate pure Ti target. We note that similar background were present in our previous ^{8,9}Li experiments (C background in a deuterated polyethylen target) and did not pose a real problem.

3 Set-up

The experimental set up will for the ^{9}Li beam be based on the one used for the earlier experiments in the second beamlline. We shall attempt neutron detection and therefore must minimize the material around the secondary target, it is therefore imperative to employ the "second beamline" also for this experiment. Gamma detection would only give extra physics information for the less interesting channels. Concerning the scattering chamber containing the target and our Si telescopes (DSSSDs with backing detectors) the main requirements are to cover a large solid angle and allow particle identification of the outgoing light charged particles at low energies (i.e. reduce the DSSSD thickness). An optimized chamber may be constructed before the experiment will take place. The Si detectors needed for this experiment are available.

Concerning neutron detection we shall make use of the SAND array from University of Huelva that consists of 30 modules each a $10 \times 10 \times 10$ cm^{3} plastic scintillator equipped with fast PM tubes. This array can be configured specifically for our experiment and we intend in the first run to focus on total neutron efficiency. The intrinsic efficiency of the detectors for our neutron energy range (roughly 3–10 MeV) is about 30% slightly depending on energy. The timing resolution of these detectors is about 0.3 ns, so when we at a later stage move to measurement of neutron energies via time-of-flight the main limitation in resolution will be due to the depth of the detectors (a 7 MeV neutron travels 1 m in 27 ns). There are recent developments [17] that will allow Si detectors to reach the needed time resolution.

4 Beam requirements

We plan to run on fully ionized Li so that $A/q = 3$ and shall assume a beam energy of 7 MeV/u for the following estimates. As a back-up solution we shall consider also acceleration of $^{9}\mathrm{Li}^{2+}$ with $A/q = 4.5$ that will deliver 5.5 MeV/u. The main contaminants we have to worry about are ^{18}O and ^{12}C. Only the former one will be accelerated on $A/q = 4.5$ and it will be further reduced by a factor more than 200 [18] by inserting a stripper foil after acceleration. This is already a factor ten better than our running conditions at the present REX. For our favoured solution at $A/q = 3$ both $^{12}\mathrm{C}^{4+}$ and $^{18}\mathrm{O}^{6+}$ may appear as contaminants. A stripper foil after acceleration will reduce their intensities by factors $5 \cdot 10^{-5}$ and $6 \cdot 10^{-4}$, respectively. This is expected to give an acceptable background; if not, we shall have to go to $A/q = 4.5$ and 5.5 MeV/u.

The expected beam intensity of ^{9}Li after acceleration is 10^{6} s^{-1}. Using a target thickness of 40 μg/cm^{2} for the tritium and a crossection of 0.1 mb/sr we obtain a count rate of the produced protons of about $2 \cdot 10^{-3}$ s^{-1} which corresponds to about 60 protons per shift for protons feeding the ground state. If we also populate low-lying resonances the summed

feeding to the 1^- excitations could be 30 protons/shift. Having the neutron detectors in a compact geometry (distance to target 0.5 m) we obtain a total neutron detection efficiency of 3%. This only allows to answer yes/no-questions such as whether the neutrons will be forward focussed (as the protons) or not. If a higher cross section is obtained, we shall move part of the array to a larger distance to obtain more information.
The beamtime requested is 20 shifts for the main ^{9}Li run, 10 shifts for the background run with pure Ti target, in total 30 shifts.
The radiation levels from the beam and the decay of it (as well as any reaction-induced activity) will be sufficiently low to not cause any problems. The tritium target has been employed in several previous (t,p) experiments (IS470, IS499,IS504) and follows CERN specification No 4229RP20070405-GD-001. The Si detectors for charged particle identification and plastic detectors for neutron identification do not pose any safety risks.
Summary of requested shifts: 30 shifts in one run. Installation: 2nd beamline

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: REX 2nd beamline, reaction chamber and neutron detector array

Part of the	Availability	Design and manufacturing
Si detector array	☒ Existing	☒ To be used without any modification
SAND array	☒ Existing	☐ To be used without any modification ☒ To be modified (new stand)
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT

Additional hazards:

Hazards	[Part 1 of experiment/ equipment]	[Part 2 of experiment/ equipment]	[Part 3 of experiment/ equipment]
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	1 kV (phototubes)		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	^{3}H (as in IS470, IS499, IS504) less than 10 GBq		
Beam particle type (e, p, ions, etc)	^{9}Li		
Beam intensity	10^{6}		
Beam energy	7 MeV/u		
Cooling liquids			

Gases			
Calibration sources:	ISOLDE triple alpha source		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300 MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chem. agent], [quant.]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chem. agent], [quant.]		
Corrosive	[chem. agent], [quant.]		
Irritant	[chem. agent], [quant.]		
Flammable	[chem. agent], [quant.]		
Oxidizing	[chem. agent], [quant.]		
Explosiveness	[chem. agent], [quant.]		
Asphyxiant	[chem. agent], [quant.]		
Dangerous for the environment	[chem. agent], [quant.]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		

Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

Hazard identification:

Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): [make a rough estimate of the total power consumption of the additional equipment used in the experiment]: less than 2 kW