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Development of a secondary triton beam from primary ^{16,18}O beams for (t,^{3}He) experiments at intermediate energies ☆

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Abstract

The in-flight heavy-ion fragmentation technique has been used to produce a secondary beam of tritons (^{3}H) at intermediate energies ($E_t > 100$ MeV/nucleon) from primary ^{16,18}O beams of 150 and 120 MeV/nucleon, respectively. The best results are obtained with a ^{16}O beam of 150 MeV/nucleon, producing a 115 MeV/nucleon triton beam. The triton beam will be used in (t,^{3}He) charge-exchange experiments at the S800 spectrometer at the NSCL. At the target of the S800, a triton rate of 5×10^6 particles per second is achieved, for a primary ^{16}O beam of 100 pnA. The (t,^{3}He) reaction using this beam was tested with a ^{24}Mg target. An excitation-energy resolution of 190 ± 15 keV is achieved.

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1. Introduction

Charge-exchange (CE) reactions at intermediate energies ($\gtrsim 100$ MeV/nucleon) are widely used to study the spin-isospin response of nuclei [1,2]. A variety of probes are available which can be categorized as either being of the $\Delta T_z = -1$ type, such as the (p,n) or (^{3}He,t) reactions, or of the $\Delta T_z = +1$ type, such as the (n,p), (d,^{2}He) or (t,^{3}He) reactions. Of these probes, the (t,^{3}He) reaction has been employed the least extensively,[3] mainly because of radiation-safety concerns involved with ion sources for tritons.

Recently, the (t,^{3}He) reaction was studied on ^{12}C, ^{26}Mg and ^{58}Ni targets [3,4] and it was shown that this probe is a valuable addition to (n,p) [5,6] and (d,^{2}He) [7,8] reactions for extracting Gamow–Teller strength distributions. These

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[3](t,^{3}He) experiments with primary triton beams have been performed at lower energies: $E_t = 5.7-7.8$ MeV/nucleon at the Los Alamos Van de Graaff accelerator [13–15], $E_t \approx 12$ MeV/nucleon at the Daresbury Tandem Van de Graaff accelerator [16,17] and $E_t = 40$ MeV/nucleon at the Kernfysisch Versneller Instituut in Groningen [18,19].

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(t,^{3}He) experiments were performed at the NSCL, using a secondary 115-MeV/nucleon triton beam, produced from a 140-MeV/nucleon primary ^{4}He-beam [9–12]. Energy resolutions varied from 200 to 300 keV (full-width at half maximum (FWHM)).

The triton-beam intensities achieved with the primary α beam were $\sim 1\times10^6$ pps. To improve the efficiency of (t,^{3}He) experiments, a higher intensity is desirable. In addition, a significant amount of overhead time is now involved in producing a primary α beam since the NSCL K1200 cyclotron has to be operated in stand-alone mode, instead of the usual K500$\otimes$K1200 coupled operation [20].

Here we describe an alternative way to produce a secondary triton beam and to improve the triton-beam intensity. This study, using fragmentation of primary beams of ^{16}O (150 MeV/nucleon) and ^{18}O (120 MeV/nucleon), is the subject of this paper. These are the lightest available beams that can be accelerated in coupled-cyclotron operation. Since ^{18}O is more neutron-rich than ^{16}O, a higher triton yield was expected, but since the goal is to reach triton energies in excess of 100 MeV/nucleon, the higher ^{16}O beam energy could be advantageous. Fragmentation methods for producing secondary beams of unstable particles have been widely employed [21], but parameterizations used to predict yields of light fragments from heavy-ion beams [22] in simulation codes of fragment separators such as LISE [23] are not necessarily reliable, since many intermediate channels can contribute. In fact, such calculations performed for the current work based on the EPAX2.15 parametrization [22], underestimated the measured rates by a factor of about 30.

Besides the energy of the primary beam, the energy of the secondary triton beam is constrained by the capability to transport the tritons from the production point to the S800 magnetic spectrometer [24]. Depending on the ion-optical tune, the maximum magnetic rigidity ($B\rho$) achievable in the transfer lines ranges from 4.8–5.0 Tm, corresponding to triton energies of 115–125 MeV/nucleon. In order to obtain high-resolution (t,^{3}He) data, the beam lines and spectrometer must be operated in dispersion-matching mode. This limits the momentum spread of the triton beam to $dp/p_0 = 5\times10^{-3}$ [24], where p_0 is the central beam momentum and dp the full momentum spread.

2. Experiments

A series of test experiments were carried out to determine the optimal mode of operation for producing a secondary triton beam. First, the triton production rates were determined using a 120 MeV/nucleon ^{18}O primary beam. Secondly, a similar study was performed using a 150 MeV/nucleon, ^{16}O primary beam. The transmission of the triton beam to the S800 magnetic spectrometer was investigated. Finally, using the ^{24}Mg(t,^{3}He) reaction we determined the excitation-energy resolution achievable in experiments with the secondary triton beam.

2.1. Triton production with a primary ^{18}O beam

A 120 MeV/nucleon $^{18}O^{8+}$ beam produced in the NSCL CCF bombarded a Be production target placed at the entrance of the A1900 fragment separator [25]. Three production targets with thicknesses of 1170 mg/cm^2, 2609 and 2938 mg/cm^2 were used. Triton yields at magnetic rigidities of 4 and 5 Tm (corresponding to triton energies of 82 and 125 MeV/nucleon, respectively) were measured, so that a rough dependence of yield on triton energy could be investigated. The momentum acceptance was limited to $dp/p_0 = 5\times10^{-3}$ by placing a slit at the intermediate image of the A1900.

The secondary particles were detected in the focal-plane of the A1900 and identified by measuring the time-of-flight (TOF), relative to the radio-frequency (RF) signal of the cyclotron, and the energy losses in a detector stack consisting of a 100-mm thick plastic scintillator and a 0.5-mm thick silicon PIN detector. Tritons were cleanly separated from other particles produced in the production target, as shown in Fig. 1. The relative contribution from contaminants increased at lower magnetic rigidities. For $E_t \geqslant 110$ MeV/nucleon, it was found that tritons dominate the production yield ($\geqslant$85%). Although further suppression of background was possible by inserting a wedge in the intermediate image of the A1900 and making use of the difference in energy loss for the various secondary products, it also slightly reduced the triton rate. In (t,^{3}He) experiments, the background stemming from reactions involving beam contaminants is small and can

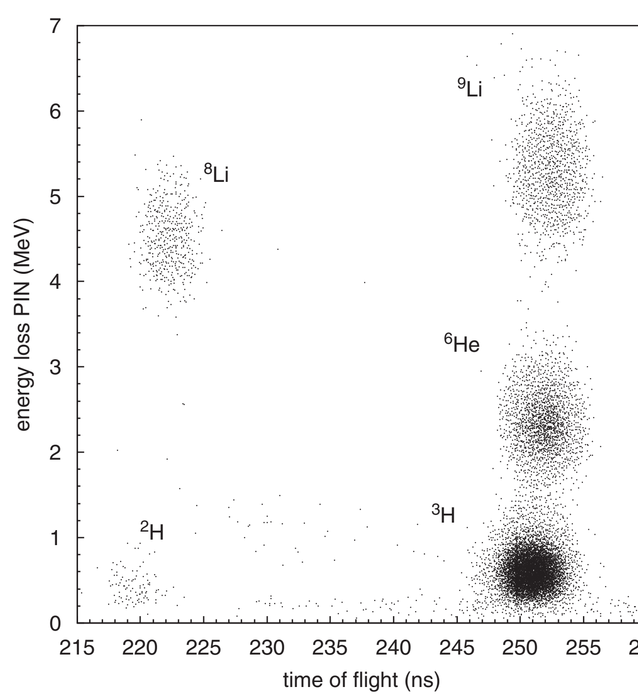

Fig. 1. Typical particle identification spectrum measured in the focal plane of the A1900 during the triton production experiments: the energy loss in the PIN detector is plotted versus TOF. The different species can be clearly separated.