ACCELERATION OF LOW-INTENSITY TRITON BEAMS WITH THE AGOR CYCLOTRON

S. Brandenburg, S. Kopecky and M. Versteegh, KVI, Groningen, the Netherlands
S. Galès, J. Guillot and H. Laurent, IPN, Orsay, France

Abstract

The (t, ^{3}He)-reaction is an interesting tool for the study of spin-isospin excitations in nuclei. Safety problems in the handling of tritium have sofar precluded its wide-spread use and have even led to the use of secondary triton beams. The feasibility of providing accelerated triton beams for experiments, with the constraint that no additional safety measures for the use of tritium are needed, is discussed. It is concluded that with the existing source triton beams with an intensity up to 10^7 pps and an energy up to 65 MeV per nucleon can be delivered; installation of a dedicated high efficiency ion source and a better transmission in the low energy beam lines will give a tenfold increase in intensity. These intensities require a tritium consumption of about 1.5 MBq per week.

1 INTRODUCTION

Charge exchange reactions are a powerful tool in the study of the spin-isospin response of the nucleus. Information on this response is important not only in nuclear physics but also in astrophysics: the study of the solar neutrino flux critically depends on the knowledge of nuclear transition matrix elements, which can be obtained from charge exchange reactions only [1].

Sofar mainly (p, n) and similar reactions such as (^{3}He, t); (^{6}Li, ^{6}He) etc. have been studied. The latter two reactions allow a much better resolution to be obtained because of the charged ejectile but the interpretation of the data becomes more and more complicated for heavier projectiles. Using these reactions a large body of information on the proton-rich members of isobaric multiplets has become available [2].

Information on the neutron-rich members, which can be obtained from (n, p) and similar reactions is much less abundant. The (n, p) reaction, using secondary neutron beams, suffers from bad resolution (around 1 MeV) [2]; while the (d, ^{2}He) and (^{7}Li, ^{7}Be) reactions require coincidence measurements, complicating the analysis of the data. Again the interpretation of the data becomes more and more complicated for heavier projectiles.

The (t, ^{3}He)-reaction does not suffer from the above mentioned drawbacks but is hampered by the radiation safety problems of the long-lived ($T_{1/2}$ = 12.3 y) tritium. Although the feasibility of accelerated triton beams has been demonstrated in the past [3, 4] there is at present no facility providing these beams. Recently experiments have been performed at NSCL with secondary triton beams of around 350 MeV, produced through the ^{9}Be(α, t) reaction at $E_\alpha \cong 600$ MeV [5, 6]. In these experiments the A1200 fragment separator was used to produce a dispersion matched triton beam and the S800 magnetic spectrometer to detect the ^{3}He ejectiles. Beam intensities up to 4.5×10^6 tritons per second were obtained.

At the AGOR-facility this scheme would produce an intensity at least one order of magnitude lower than at NSCL because of the lower α-energy (380 MeV) and the smaller acceptance of the beam guiding system [7]. It was then decided to consider the feasibility of accelerating tritons with an intensity comparable to that achieved for secondary beams.

2 RADIATION SAFETY

The amount of tritium that may be introduced into the facility (ion source; cyclotron, beam lines and experimental set-ups) in the course of time is determined by the boundary condition that the present practice for operation, maintenance and repairs can be maintained. As tritium is very mobile it is assumed that, although it is initially deposited at a few well-defined spots (ion source, inflector, extractor, slits and Faraday cups), it will spread through the entire system. This implies that tritium contamination of workers will occur. The individual and collective radiation doses contracted due to this contamination should be a small fraction of the doses already contracted (~0.5 mSv/y). Applying the methods used to determine the activity that may be manipulated in a radiochemistry laboratory we conclude that the tritium inventory should not exceed 100 MBq. Neglecting removal through pumping and disposal of contaminated parts this leads to a maximum tritium consumption of 5.5 MBq per year. Taking into account the limited duration of a programme using triton beams a consumption of 10 MBq is considered acceptable.

3 TRITIUM HANDLING

The amounts of tritium to be handled are very small (10 MBq corresponds to 0.1 mbar cc). Controlled storage and flow of such quantities can only be achieved by mixing them in a much larger quantity of carrier material. We have chosen for a 20 ppm concentration in deuterium because deuterium does not form ions with a charge-to-mass ratio Q/A = 1/3 interfering with the triton beam. The 5 cc STP deuterium containing 10 MBq are stored as

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

uraniumhydride (UH_3) in a stainless steel container containing 1.2 grams of depleted uranium [8]. The equilibrium pressure of hydrogen above the hydride strongly depends on the temperature, the tritium can thus be released by heating the container and is reabsorbed by cooling it again. At room temperature the theoretical equilibrium pressure for tritium is 2.5×10^{-6} mbar. In Fig. 1 the theoretical temperature dependence of the pressure for tritium and normal hydrogen is given together with measurements for deuterium in an identical container, which should fall in-between the two curves. No explanation for the discrepancy has been found.

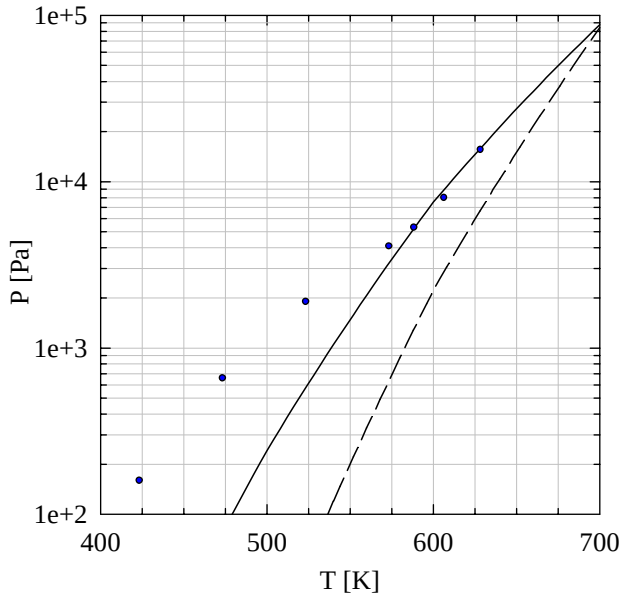

Figure 1: Hydrogen equilibrium pressure of UH_3 for hydrogen (dashed line); tritium (full line) and deuterium (datapoints)

The deuterium + tritium mixture (or deuterium from the other container) flows into the ion source through a fixed, calibrated leak of 10^{-6} Pa m^3/s (at STP). The flow is then controlled through the temperature of the container, which is regulated. At 350 °C the tritium flow is 3 Bq/s (1.7×10^9 atoms/s).

4 ION SOURCE

The KVI 14 GHz ECR ion source [9] was used to produce deuterium and tritium beams. The RF power is fed into the plasma via a coaxial line on the source axis. The source is pumped with a 170 l/s turbomolecular pumps at the RF entrance and a 700 l/s oil diffusion pump at the extraction side. Deuterium or the deuterium–tritium mixture was introduced into the source through the inner conductor of the coaxial line to obtain the best possible efficiency.

The ionisation efficiency of the source for deuterium was determined by measuring the intensity of a deuteron beam extracted from the cyclotron. The source was operated with a deuterium flow up to 10^{-6} cc STP from the deuterium container. No support gas was fed into the source; the pressure in the source was 10^{-5} Pa and was independent of the deuterium flow rate.

The transmission through the different parts of the set-up was measured with the molecular hydrogen beam, which is always present, before introducing deuterium into the source. Under these conditions the deuteron beam has a negligible intensity (~10^{-3} of the molecular hydrogen beam) due to the very low natural abundance of deuterium.

The ionisation efficiency was found to be independent of the deuterium flow rate; it depended about linearly on the RF power into the source up to 350 W, the limit set by the cooling of the vacuum chamber and hexapole of the source. At 350 W an efficiency of 13 % was found; the accuracy of this number is estimated to be 10 %.

The time constant for the response of the beam intensity after steps in the gasflow was found to be about 15 minutes. This is in marked contrast with long term memory effects observed in ECR sources.

5 CYCLOTRON SETUP

The intensity of the triton beam produced by feeding 3 Bq of tritium per second into the source is about 40 pA, well below the detection limit of the diagnostic equipment in the cyclotron and beamlines. Therefore a higher intensity pilot beam of a different species has to be used to tune the cyclotron and beamlines. For this purpose a singly charged ^{3}He beam of 43 MeV per nucleon was used. The ^{3}He gas was introduced into the ion source in the same way as the tritium in order to minimise memory effects after closing off the ^{3}He supply.

The transmission of the ^{3}He beam from ECR source to inflector entrance was about 8 %. This low value is a general feature for all beam produced with the ECR source; it is caused by a lack of focussing elements in the connection in the transport section of the injection beam line. The overall transmission through the cyclotron was 3.5 %, in strong contrast with the typical values 10 – 15 % and best value of 25 %. As the actual value of the transmission was not essential for determining the feasibility of the scheme, it was not attempted to optimise it.

5.1 Suppression of the ^{3}He beam

The relative mass difference between tritium and ^{3}He is only 6.6×10^{-6}, a factor 20 smaller than the Q/A-resolution of the cyclotron [10], both beams are thus extracted simultaneously and have to be separated by stripping the ^{3}He at the cyclotron exit. To measure the survival probability of singly charged ^{3}He two 12.5 µm Kapton stripper foils were installed; one at the cyclotron exit and one after the first bending magnet. The ^{3}He beam was dumped in a Faraday cup after the third bending magnet. The slits in the beamline were set such that they

just did not intercept the main beam; transmission from the cyclotron exit to the Faraday cup was essentially 100 %. After inserting the first stripper foil the Faraday cup was replaced by a fast scintillation detector, which showed a countrate of about 0.8 kHz/nA of primary intensity. Inserting the second stripper gave a decrease of the countrate by about 150 Hz/nA. From these measurements it was deduced that the survival probability for singly charged ^{3}He in the stripper foil is $< 3 \times 10^{-8}$.

5.2 Triton beam intensity

As a last step in the tests the deuterium + tritium mixture was fed into the ion source. A tritium flow of about 3.0 Bq per second was established by heating the tritium container to 350 °C. The resulting triton beam intensity was 5×10^5. Using the overall transmission measured for the ^{3}He beam the intensity of the triton beam extracted from the ECR source is found to be 1.8×10^8 per second; from the tritium flow and the measured ionisation efficiency for deuterium we derive an intensity of 2.2×10^8 per second. Taking into account the accuracy of the various measurements we consider the agreement between both numbers satisfactory.

6 CONCLUSIONS

A low-intensity triton beam has been accelerated with the AGOR cyclotron. In order to use this beam for experiments a number of improvements are still necessary:

- Ionisation efficiency.
  Small 2.5 GHz ECR ion sources based on the Nanogan source [11] have an ionisation efficiency of 70 % for singly charged ions. We plan to acquire such a source to replace the multicusp source.
- Transmission.
  For beams from the multicusp source an overall transmission of 10 – 15 % is routinely achieved, whereas for beams from the ECR and polarised source it is 1 – 2 % due to a low transmission of the low energy beamline. The beamline will be redesigned to obtain full transmission.

Implementation of these changes will result in an extracted beam of 10^8 tritons per second for a consumption of 3 Bq tritium per second. Taking into account the radiation safety aspects (sect. 2) this allows 800 hours of beamtime per year at an intensity of 10^8 tritons per second.

ACKNOWLEDGEMENT

This work has been supported by the Rijks Universiteit Groningen (R*u*G)and by the European Union through the Large-Scale Facility program LIFE under contractnumber ERBFMGE-CT98-0125.

It has been performed as part of the research programme of the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM), with support of the "Nederlandse organisatie voor Wetenschappelijk Onderzoek" (NWO).

REFERENCES

[1] J.N. Bahcall, Neutrino astrophysics, Cambridge University Press, Cambridge, 1988
[2] M.N. Harakeh and A. van der Woude, Giant resonances: fundamental high frequency modes of nuclear excitation, Clarendon Press, Oxford, 2001
[3] E.R. Flynn, J.W. Sunier, F. Ajzenberg-Selove, Phys. Rev. C 15 (1977) 879
F. Ajzenberg-Selove, R.E. Brown, E.R. Flynn, J.W. Sunier, Phys. Rev. C 32 (1985) 756
[4] K.I. Pearce et al., Phys. Rev. C 35 (1987) 1617
N.M. Clarke et al., J. Phys. G 14 (1989) 1399
[5] I. Daito et al., Nucl. Instr. Meth. Phys. Res. A397 (1997) 465
[6] B.M. Sherrill et al., Nucl. Instr. Meth. Phys. Res. A432 (1999) 299
[7] H. van der Ploeg, Internal report IPN Orsay, 1997
[8] manufactured by Tritec AG, Switzerland
http://www.rc_tritec.ch/
[9] AG. Drentje, H.R. Kremers and J. Sijbring, Proc. 12th Int. Workshop on ECR ion sources, Report INS-J82, eds. M. Sekiguchi and M. Nakagawa, Tokyo, 1995, p. 148
[10] H.W. Schreuder et al., Proc. 15th Int. Conf. on Cyclotrons and their Applications, IoP Publishing, Bristol, 1999
[11] Manufactured by Pantechnik SA, France