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THE PRODUCTION OF NEGATIVE LITHIUM BEAMS BY CHARGE EXCHANGE IN CESIUM VAPOURS

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Abstract

These measurements were carried out at the Holifield Radioactive Ion Beam Facility of the Oak Ridge National Laboratory (ORNL-HRIBF) by researchers from the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS), Catania, Italy and local staff. The Charge Exchange Cell (CEC) consisted of a vacuum chamber containing cesium vapours at a variable temperature T, in which positive ions accelerated from an ion source were transformed into negative ones by collisions with the Cs atoms. The main goal of this test was to measure the production efficiency for ^{7}Li$^-$ ions at different operating conditions, such as ^{7}Li$^+$ beam energy (5 to 55 keV) and Cs temperature (190 to 300 °C). Moreover, the efficiency measurements performed with a ^{6}Li$^+$ projectile beam gave clear indications about the isotopic shift effect. These results are useful to estimate the charge exchange efficiency for $^{8,\,9}$Li, which will be the first radioactive beams to be produced at the EXCYT facility (EXotics with CYclotron and Tandem). The data showed that the charge exchange efficiency at the minimum energy suitable for beam handling (20-25 keV) is around 1%.

INTRODUCTION

The EXCYT facility at the INFN-LNS is based on a K-800 superconducting cyclotron injecting stable heavy-ion beams into a target-ion source assembly to produce the required nuclear species, and on a 15 MV Tandem for post-accelerating the radioactive beams [1].

By its nature, the Tandem requires the injection of negative ions, usually obtained either by direct negative ionisation or by inserting a CEC on the extraction side of a positive ion source. In addition, only nuclides with A < 40 can be post-accelerated to the kinetic energies generally required for experiments in nuclear physics and astrophysics. By taking into account this restriction, the availability of the MAGNEX detector [2] by the beginning of 2005, the requests from the "Big Bang" collaboration [3] and the RSM experiment [4], we decided to deliver ^{8}Li as the first EXCYT radioactive beam.

Li$^+$ can be obtained with high ionisation efficiency (> 70%) by means of a positive ion source with a W (Re-lined) ioniser [5]: therefore the most appealing scheme to get negative lithium ions is to couple a CEC to the aforementioned ion source.

In this work, we report the charge exchange efficiencies measured for $^{6,\,7}$Li$^+$/$^{6,\,7}$Li$^-$ with energies from 5 to 55 keV into cesium vapours at temperatures ranging from 190 to 300 °C and the estimated efficiency curves for some radioactive lithium isotopes.

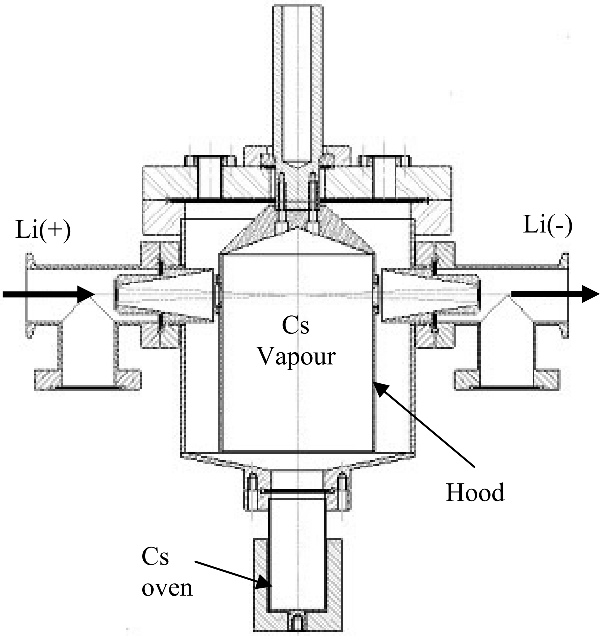

Figure 1: Cross sectional view of the Cs vapour cell.

THE CHARGE EXCHANGE SYSTEM

The charge exchange system used in this experiment consists of a Cs-vapour cell (Fig. 1) followed by a set of three Faraday cups. The vapour cell is equipped with:

1) an oven operated at temperatures up to 300 °C;
2) a recirculation system with a hood kept at 100 °C,

which respectively allow the Cs to evaporate and to flow back into the oven after condensation. The housing of the cell and the Cs oven are made of stainless steel while the internal hood and the apertures along the beam path are made of copper, plated with nickel to prevent chemical etching from Cs. In this system the Li$^+$ beam passes through a jet of Cs atoms, the density of the latter along the beam path being controlled by the temperature of the Cs oven. The double charge exchange from Li$^+$ to Li$^-$ occurs mainly in a two-step process [6, 7] and depends both on Li$^+$ kinetic energy and on the density of the Cs vapours along the projectile beam path.

This density together with the charge-exchange Cs target thickness, Π (atoms/cm^2), have been determined throughout the whole operational temperature range as follows. The cylindrical oven can be considered as a Knudsen effusion cell [8] with cesium atoms being continuously evaporated. We calculated the Cs vapour pressure from literature data [9] and the relevant flow by taking into account the oven transmission factor, which depends on its length and diameter [10, 11]. The angular distribution of the Cs flow is influenced by the oven geometry [12] as shown in fig. 2; the lithium beam path is within 0° and 22.5°. Since the probability of finding a Cs atom in the flow is proportional to its own velocity, it turns out that the speed of the Cs atoms does not follow a Maxwell-Boltzmann distribution.

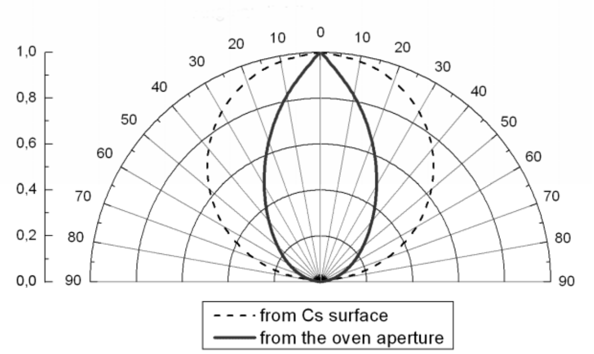

Figure 2: Angular distribution of Cs flow.

Therefore we estimated the cesium atomic density along the lithium beam path by integrating from 0° to 22.5° the function reported in Fig. 2, also taking into account the CEC geometry and the atomic velocity distribution; the Cs target thickness is shown in Fig. 3.

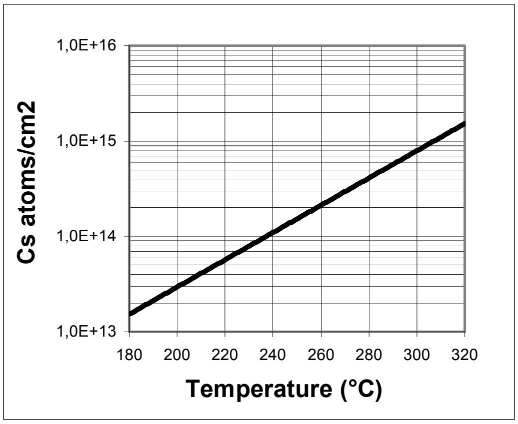

Figure 3: Cesium target thickness, *Π*.

After the charge exchange cell, there are a set of electrostatic plates and an array of three Faraday cups (provided with suppressors for secondary electrons) to measure the currents of the positive, negative and neutral beams coming out of the cell. The neutral particles are measured in the central Faraday cup by collecting the electrons that are emitted when the particles are stopped in a carbon disk. This cup has a special geometry: its bottom is electrically insulated from the rest of the cylinder. This feature allows the cup to be operated either in "normal" or in "neutral" mode, so the efficiency for collecting the secondary electrons can be calibrated. In the normal mode, the bottom is electrically connected to the cylinder and the positive current is measured in a standard way. In the neutral mode, the cup cylinder is positively biased, thus the electrons emitted in the beam impact are collected inside the cup while the suppressor acts as a repeller. The beam current is still read from the bottom of the cup. By measuring the current of a positive beam with the cup in the normal mode and soon after in the neutral mode, it is possible to estimate the number of secondary electrons produced by the beam impact. In this way the cup can be calibrated to read neutral beams; however one has to bear in mind that the calibration has to be frequently repeated since the number of the emitted secondary electrons is strongly dependent on the operating conditions (vacuum, graphite surface contamination, etc.).

EXPERIMENTAL REMARKS

We carried on routine measurements of the positive, neutral and negative beam intensities at several energies and Cs-oven temperatures. For ^{7}Li, the energy range was within 5 and 55 keV in steps of 5 keV each; the Cs temperature was varied within 190 and 300 °C. For ^{6}Li, the energy range was within 10 and 50 keV in steps of 10 keV each; the Cs temperature range was the same as above.

The fraction, F_i , of the particles emerging from the target in the charge state, i , was found by normalizing the total transmitted beam [13]:

$$F_i = \frac{N_i}{\sum_i N_i} \tag{1}$$

where i = -1, 0, 1 and N_i is the number of particles in the charge state, i. Only charge states –1, 0 and 1 were recorded since charge state 2 was never significantly populated.

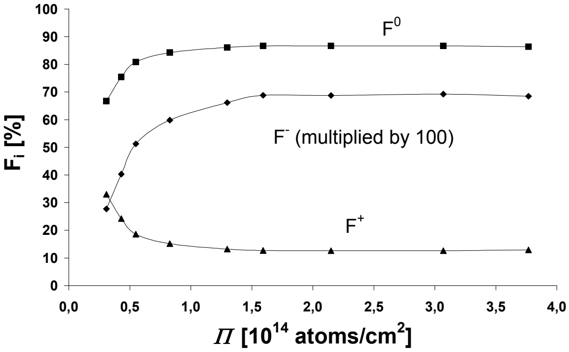

Figure 4: Lithium charge-state fractions at 25 keV.

In almost all cases we found that the maximum negative fraction, F_{-1} , occurred at an oven temperature of 260 °C corresponding to 2.15 * 10^{14} Cs atoms/cm^2. Set of growth curves like that shown in Fig. 4 was plotted from charge-state distributions recorded for any given projectile energy at each oven temperature. From the plot it is clear that a minimum target thickness, Π, is needed to reach the charge-state equilibrium, i.e. the flat portions of the curves.

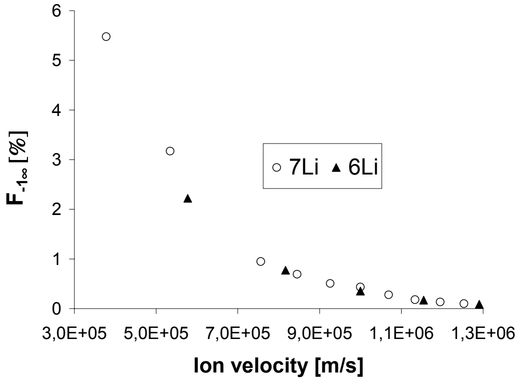

Figure 5: Negative charge-state fractions versus projectile velocity.

We took the negative equilibrium fraction, $F_{-1\infty}$, as the maximum value for each of the curves relevant to the charge state –1: all of them occurred in the “plateau” area. In addition, we assume that the charge-exchange efficiency at a given cesium target thickness is the same for all the lithium isotopes, provided they have the same velocity. In fact, the chemical system stays the same and the only variable parameter is the impact velocity. This assumption is supported by the data drawn in Fig. 5, where the negative equilibrium fractions of ^{6,7} Li have been plotted as a function of the projectile velocity. The measured negative equilibrium fractions for ^{6,7}Li versus the projectile energies are plotted in Fig. 6. In the same figure, predictions for the radioactive isotopes ^{8,9}Li are also drawn. We remark that the charge-exchange efficiency for ^{8,9}Li at the minimum energy suitable for beam handling (20-25 keV) is around 1%.

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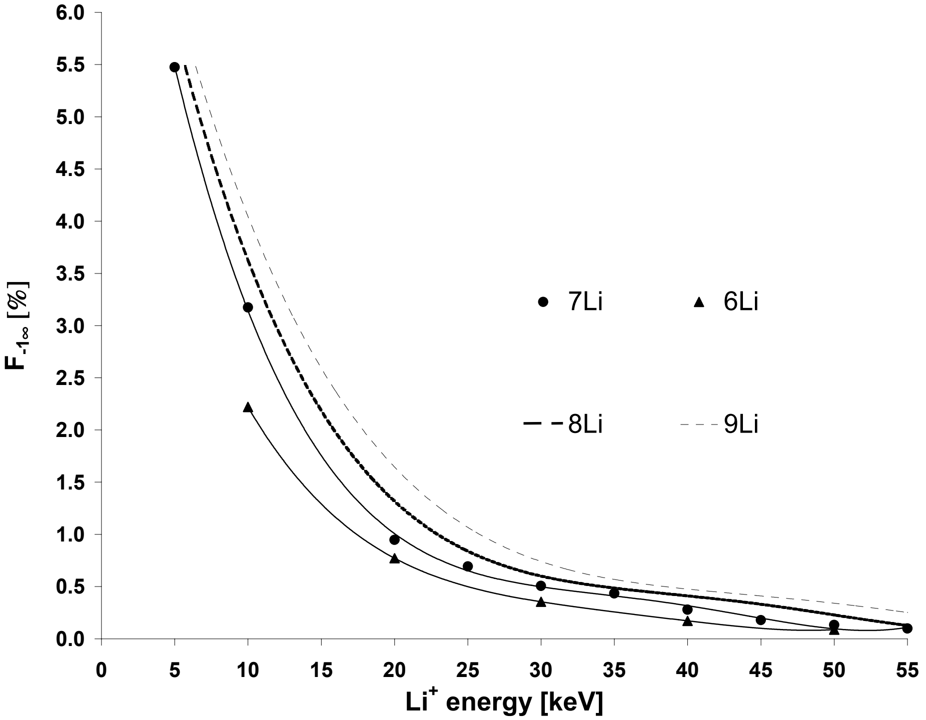

Figure 6: Negative equilibrium fractions for Li isotopes in Cs target atoms. The dashed curves are estimations.