Preliminary study of the $^{19}F(^7Li,^7Be)^{19}O$ reaction at 52 MeV with MAGNEX

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Abstract
The $^{19}F(^7Li,^7Be)^{19}O$ charge-exchange reaction at 52 MeV incident energy has been performed at INFN-LNS in Catania using the MAGNEX spectrometer. The use of an algebraic ray-reconstruction technique has allowed to extract the ^{19}O excitation energy spectrum and the experimental angular distributions obtained with a single angular setting of the spectrometer.

1 Introduction

Over the last years, a general interest has concerned the study of nuclear structure and reaction dynamics far off the stability valley, arising from the possibility to explore new and exciting phenomena characteristic of those systems. The present study of the ^{19}O neutron-rich nucleus via the $(^7Li,^7Be)$ charge-exchange reaction is well inserted into this general context.

The investigation of this nucleus belongs to a research line that aims to a systematic exploration of both structural properties of a particular category of light neutron-rich nuclei, for which an inner core of an integer number of α particles is coupled to three external neutrons ($N\alpha$ + 3 neutrons). The $(^7Li, ^7Be)$ reaction at about 8 MeV/A incident energy has shown to be a suitable tool to explore such systems, as demonstrated by previous studies on other nuclei belonging to this category: ^{11}Be and ^{15}C [1], [2]. In fact, this process in such energy range proceeds with a considerable predominance of the direct one-step mechanism, thus being an useful probe for spectroscopic studies. In addition it has turned out to be suitable to populate configurations more complex than the single-particle ones, providing, thanks also to the good resolution achievable, complementary information on nuclear structure.

2 Experimental Setup

The $^7Li^{+++}$ beam at 52.2 MeV was accelerated by the Tandem facility of INFN-LNS. The ^{19}F target was a 80 μg/cm^2 thick AlF_3 foil evaporated on a gold backing of 250 μg/cm^2 produced at the chemical laboratory of LNS. A ^{27}Al target (116 μg/cm^2) was also used in order to estimate the aluminium presence in the target compound and subtract it in the final spectra. Supplementary runs were done also on a WO_3 target (150 μg/cm^2 on 20 μg/cm^2 carbon backing) and on a carbon target (76 μg/cm^2) for the subtraction of the contribution in the final spectra due to the oxygen and carbon impurities in the AlF_3 target.

The reaction ejectiles were momentum analyzed by the MAGNEX large acceptance magnetic spectrometer A picture of MAGNEX is shown in Fig.1. The MAGNEX quadrupole and dipole fields and the α-surface coil, together with the position of the Focal Plane Detector (FPD), were set in order to focus the ^7Be ejectiles relative to the $^{19}O_{g.s.}$ in the focal plane position corresponding to a momentum deviation $\delta = 0.08$ with respect to the central one.

The FPD [3],[4] was filled with 99.95% pure isobutane gas at 7 *mbar* pressure. The cathode was supplied at –950 V while the Frish-grid was grounded. The high voltage in the proportional wires was +750 V, and the lateral shaping wires between the Frish-grid and the proportional wires were maintained at increasing voltage by a separate power supply at +400 V. The silicon detectors were powered with +60 V voltage in a full depletion mode.

In the data analyzed up to now the spectrometer was located at a central angle of $\theta_{lab} = 12.25^{\circ}$ with respect to the beam incidence direction. Due to the large angular acceptance of MAGNEX (horizontally –0.090 *rad*, +0.110 *rad*, vertically ±0.125 *rad* in the spectrometer reference frame), this angular setting corresponds to a covered angular range $7.1° < \theta_{lab} < 19.8°$ in the laboratory reference frame. Measurements at $\theta_{lab} = 0^{\circ}$ and $\theta_{lab} = 6.25^{\circ}$ were also performed and the data analysis is in progress.

Fig.1: General view of the MAGNEX spectrometer. From the left to the right the scattering chamber, the quadrupole, the dipole and the Focal Plane Detector are visible.

3 ^{19}O excitation energy spectra

The identification of the ^{7}Be ejectiles was done by the MAGNEX Focal Plane Detector through a *ΔE-E* technique combined with the measurement of the magnetic rigidity vs. the kinetic energy of each detected particle [5].

An algebraic technique of ray-reconstruction of the detected ions [6] has been used to relate the final parameters measured at the focal plane to the initial phase space parameters. Such ray-reconstruction technique is based on the formalism of *Differential Algebra* [7]. It is a perturbative technique to solve the differential equations describing the motion of ions through the spectrometer and to obtain the Taylor coefficients of the flow linking the initial phase space with the final one. In this mathematic environment, the integration of the differential equations results a simpler algebraic task and very high order of the perturbation series can be treated.

With this technique, if the appropriate positions and directions of the detected ions are determined by measurement at the focal plane, one can reconstruct the full trajectories back to the reaction target and consequently obtain the scattering angles and the initial momenta of the reaction products, by the application of the inverse map of the measured phase space parameters.

In Fig.2 a reconstructed spectrum of the ^{19}O excitation energy is shown. The spectrum obtained from the data with the AlF_3 target is shown with superimposed that related to the aluminium target. The contribution of the *Al*-derived reaction is the only one up to about 6 MeV ^{19}O excitation energy.

Several excited states are observed and identified in the low excitation energy region. The well isolated peaks are labelled with the relative excitation energy in MeV. Peaks marked with an asterisk refer to the transitions in which ^{7}Be ejectiles are in the first excited state at 0.43 MeV. Most of the ^{19}O states have been observed in the past by one and two neutron transfer reactions [8], thus confirming the capability of the (^{7}Li,^{7}Be) reactions to populate such states. For most of them the shell structure configuration is quite well known as for example for the 1.47 MeV excited state ($1/2^+$) which is mainly a single-particle state with the configuration of one neutron in the $2s_{1/2}$ orbital on a $^{18}O(0^+)$ core.

The estimated energy resolution is about 80 KeV (FWHM). In a previous test run, realized with the same experimental setting in order to check the feasibility and study the working conditions, a better resolution was achieved (about 50 KeV) [9]. There are two main reasons causing the lack of resolution in the present experiment. First, the gold backing of the AlF_3 target was thicker (250 μg/cm^2) in the present experiment compared to 120 μg/cm^2 in the test run, thus producing less straggling in the target. In addition, in the test run the magnetic fields were set to focus the ^7Be relative to the $^{19}O_{g.s.}$ in a different focal plane position, closer to the spectrometer optical axis ($X_{foc} = 0$), where a minor contribution of aberrations is expected.

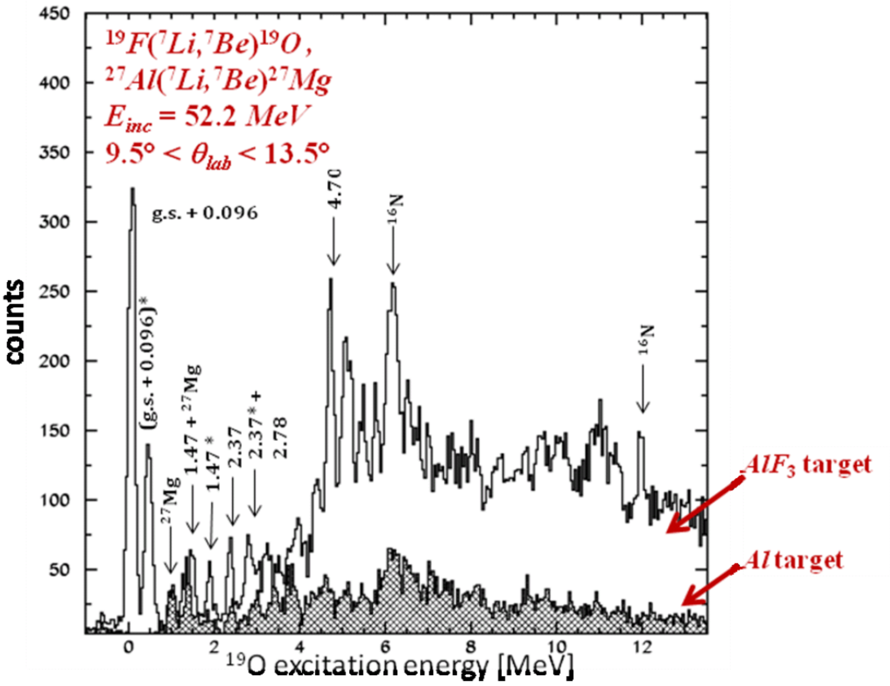

Fig.2 ^{19}O excitation energy spectrum obtained using the AlF_3 target and, superimposed, the normalized spectrum obtained from the aluminium target. The known states of ^{19}O are indicated with their energy. The presence of ^{27}Mg and ^{16}N impurity states are also shown. Peaks marked with an asterisk refer to the transitions in which ^7Be ejectiles are in the first excited state at 0.43 *MeV*.

4 Angular Distributions

One of the advantage of working with a large acceptance spectrometer is that, in a single setting of the instrument, several scattering angles are covered. As a consequence, a consistent part of a cross section angular distribution can be measured in a single run in the same experimental conditions, resulting in a reduction of the uncertainty due to the normalization of runs at different angles.

In the present case, a single set of measurements at central angle $\theta_{lab} = 12.25°$ allows to obtain an angular distribution for scattering angles about $10° < \theta_{CM} < 21°$ in the centre of mass reference frame.

In Fig. 3 the measured angular distributions for the transition to the not resolved doublet of ^{19}O ground and first excited state at 0.096 MeV is shown. In Fig. 4 the angular distribution for the transition to the $^{19}O(1.47\text{MeV}, ½^+)$ excited state is shown.

A theoretical analysis of the $^{19}F(^7Li,^7Be)^{19}O$ reaction in the framework of the Charge-Exchange Quasiparticle Random Phase Approximation (CEX-QRPA) [10] is on the way. This approach is very powerful since can be used to describe the ^{19}O nuclear structure and also to calculate the transition densities connecting the ^{19}F ground to the $1p$-$1h$ states of ^{19}O, thus allowing a direct connection to reaction cross section calculations by a suitable Distorted Wave Born Approximation (DWBA). The use of a realistic semimicroscopic interaction [11], that includes the tensor contribution, in both structure and reaction calculations, has allowed in the past to describe very well reactions similar to the present one as the $^{11}B(^{7}Li,^{7}Be)^{11}Be$ and $^{15}N(^{7}Li,^{7}Be)^{15}C$ in the same energy region [1], [2].

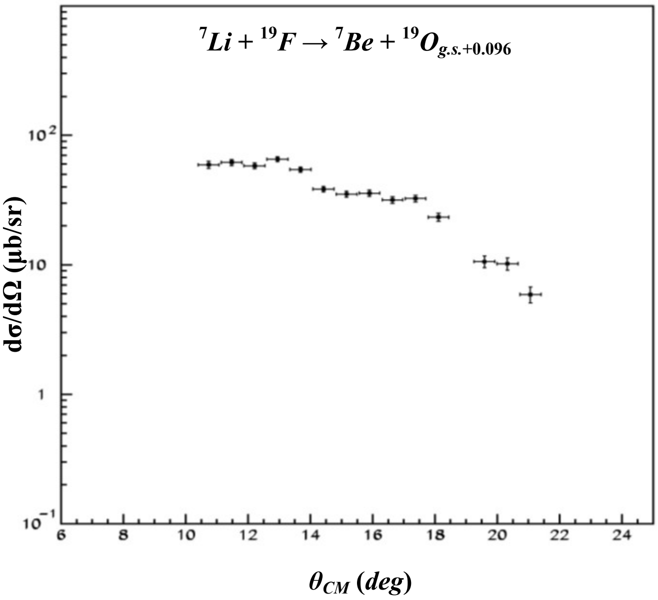

Fig.3 Measured angular distribution for the $^{7}Li + ^{19}F \rightarrow ^{7}Be + ^{19}O$(g.s. + 0.096MeV) transition.

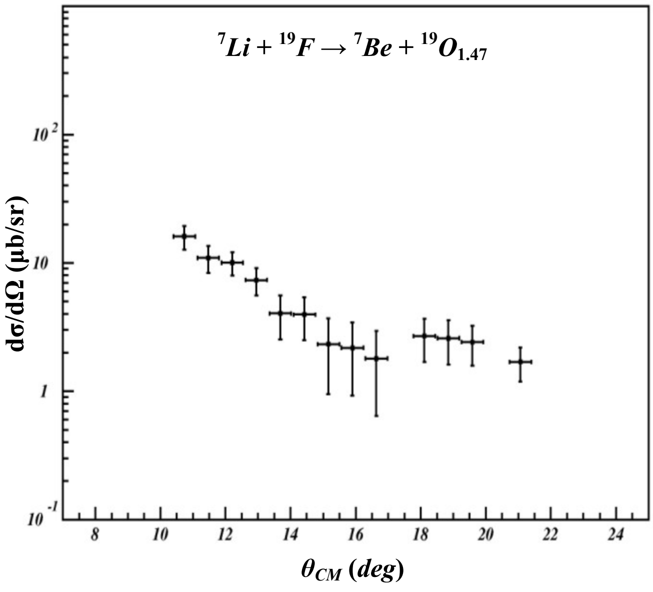

Fig.4 Measured angular distribution for the $^{7}Li + ^{19}F \rightarrow ^{7}Be + ^{19}O$(1.47MeV) transition.

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