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Study of ^{60}Fe(n,γ)^{61}Fe reaction of astrophysical interest via d(^{60}Fe,pγ) indirect reaction

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Abstract. INTEGRAL and RHESSI spacecrafts recently detected the 1.173 and 1.333 MeV γ-ray lines coming from the ^{60}Fe - ^{60}Co - ^{60}Ni radioactive decay chain. The long lived isotope ^{60}Fe ($T_{1/2} = 1.5\ 10^6 y$) is believed to be primarily produced in core-collapse supernovae. However the interpretation of the observations is difficult because of the large uncertainties concerning ^{59}Fe(n,γ)^{60}Fe and ^{60}Fe(n,γ)^{61}Fe cross sections, involved in ^{60}Fe nucleosynthesis.

The direct component of the ^{60}Fe(n,γ)^{61}Fe reaction was studied indirectly via the d(^{60}Fe,pγ)^{61}Fe transfer reaction. The experiment performed in GANIL in spring 2009 will allow to determine the excitation energies of the populated excited states of ^{61}Fe and for the first time their spectroscopic factors as well as their transfer angular momentum.

I will first give an overview of the astrophysical context, then I will describe the experimental setup and finally present some preliminary results of the ongoing analysis.

Keywords: Nuclear astrophysics, ^{60}Fe , transfer reaction, radioactive beam
PACS: 25.60.Je, 26.20.Kn, 29.38.c, 26.50.+x

1. MOTIVATIONS

RHESSI and INTEGRAL missions were designed for γ-ray astronomy. In 2004, the γ-ray lines at 1173.23 and 1333.44 keV from the ^{60}Fe - ^{60}Co - ^{60}Ni radioactive decay-chain were detected with RHESSI for the first time [3], and confirmed with INTEGRAL in 2006 [2]. Those lines are a proof that ^{60}Fe nucleosynthesis is active nowadays, since ^{60}Fe half-life ($T_{1/2} = 1.49 \pm 0.27$ Myrs) [4] is very small compared to the timescale of our Galaxy.

^{60}Fe is believed to be mainly produced in core-collapse supernovae, and in a lesser

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extent in AGB stars. It is produced by successive neutron captures (s-process) with ^{56}Fe as a seed nucleus. However, stellar models suffer from astrophysics and nuclear uncertainties, which makes interpretation of observations very difficult. In case of ^{60}Fe isotope, the predicted yield suffers from large uncertainties on the cross-section of ^{59}Fe(n,γ)^{60}Fe and ^{60}Fe (n,γ)^{61}Fe reactions, respectively responsible for production and destruction of ^{60}Fe .

Uncertainties surrounding ^{60}Fe(n,γ)^{61}Fe are much larger than for the production reaction, because of the lack of spectroscopic information on ^{61}Fe. Therefore, we decided to study the ^{60}Fe(n,γ)^{61}Fe reaction.

2. EXPERIMENT

2.1. Indirect method

Producing an ^{60}Fe target with a sufficient density to perform a direct measurement of ^{60}Fe(n,γ)^{61}Fe with a neutron beam being very difficult, we chose to study the direct component of the ^{60}Fe(n,γ)^{61}Fe via (d,p) transfer reaction. This will allow us to determine excitation energies, spin and angular momentum of the populated states of ^{61}Fe and their spectroscopic factors, which are important to determine the direct capture component of ^{60}Fe(n,γ)^{61}Fe cross section.

2.2. Experimental procedure

Beam. The experiment was performed at Ganil in April 2009, using an ^{60}Fe beam at 27 MeV/u, produced at LISE by fragmentation of ^{64}Ni at 55 MeV/u on a Be target of 500 μm. The desired energy was obtained thanks to a 700 μm thick degrader. ^{60}Fe was selected by two dipoles and a Wien filter, then sent to the experimental area on the CD$_2$ target (2mg/cm^2). The ^{60}Fe beam was obtained with a purity of roughly 70%, the main contaminant being ^{62}Co (13%).

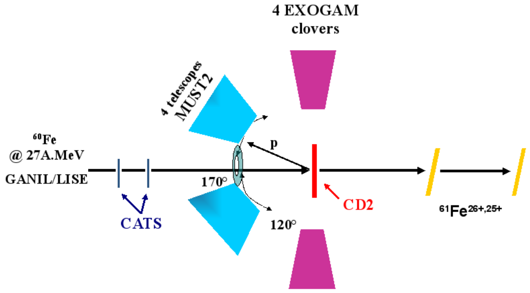

FIGURE 1. Description of the experimental setup used for ^{60}Fe(d,pγ)^{61}Fe transfer reaction

Setup. The experimental setup (see Figure 1) was composed of particle and γ-ray detectors, as well as an ionization chamber and a plastic placed downstream to the target, allowing an identification in Z of the heavy fragments via time of flight and energy loss measurement.

Two beam tracking detectors CATS [5] were placed in the beam upstream the target, in order to access the position of the interacting point on the target. CATS detectors are multi-wire proportionnal chambers (70 × 70 cm^2 active area, two planes of 28 strips in X and Y and a plane of anode wires).

Protons were detected at backward angles by a Silicon annular detector and 4 MUST2 telescopes [1]. Those telescopes are made of three stages. The first one is a Double Sided Strip Detector (10 ×10 cm^2, 300 μm 128 +128 strips) for position and energy loss measurement (35 keV resolution with a triple alpha source). The second one is composed of 16 pads of Si(Li) (5 mm thick, 2.5×2.5 cm^2). The last one, which was not used for this experiment, consists in 16 CsI crystals (4 cm thick).

Since MUST2 resolution is not good enough ($\sim$ 240 keV for the detected protons) to separate some of the levels of ^{61}Fe, 4 EXOGAM clovers ($\sim$3 keV resolution at 1.3MeV) were used to detect in coincidence the γ-rays which will help to discriminate the different populated levels.

3. ONGOING ANALYSIS : CATS DETECTORS

CATS detectors detect the position of incident ions event by event. The combined information of the two CATS then allow to reconstruct the position of beam interaction on the target, which is crucial in this experiment because the beam spot is large when using a fragmentation beam.

Calibration in charge was performed with a pulser delivering signals of known amplitude on the anode plane, inducing a signal on each strip. In order to have a precise determination of the beam position, the detector was calibrated using a mask with a specific hole pattern.

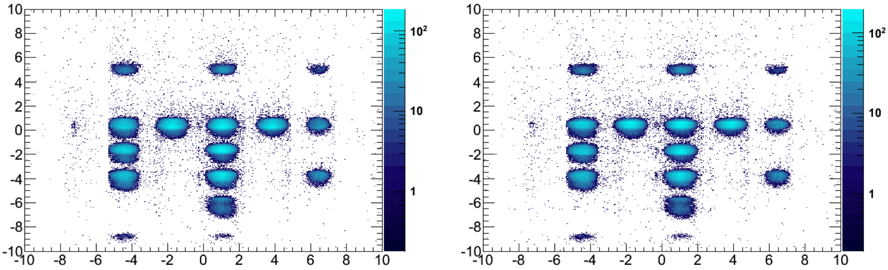

FIGURE 2. Position reconstruction for one of the CATS detectors with hyperbolic secant method (left) and corrected barycentric method (right)

To reconstruct position with a better accuracy than a strip width (2.54 mm), different methods were used, ranging from simple barycentric method to more complex method such as the hyperbolic secant method [5]. After correction of the discrete structure of barycentric method, both techniques gave equivalent results and reproduce the mask, as we can see on Figure 2.

4. CONCLUSION AND PERSPECTIVES

In summary the astrophysical motivation to study ^{60}Fe(n,γ)^{61}Fe was presented, as well as the experimental method and setup used at GANIL. After the analysis of CATS detectors and beam reconstruction on target, an analysis of MUST2 and the Si-annular detector data will be performed in order to determine excitation energies of the populated states of ^{61}Fe and the corresponding angular distributions. Thanks to DWBA calculation, spectroscopic factors will be deduced. At the end, a comparison with existing shell-model calculation and an estimation of the reaction rate will be done.

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