Production of an Isomeric Beam and Total Reaction Cross Section Measurement

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1 Motivations

The production of energetic secondary beams of excited long lived nuclei (isomers) at GANIL is mainly motivated by the growing interest to extend our knowledge on nuclear structure and on the mechanisms of excitation as well as deexcitation of isomeric levels.

Furthermore, energy storage or GRASER (gamma LASER) could be direct applications in the future of these studies on isomers.

In a first step, as for exotic proton or neutron-rich exotic beams, isomeric beams are a powerful mean for testing classical nuclear models. Indeed, isomeric states have different properties like angular momentum (spin isomers) or deformation (fission isomers...), as they are excited states with different particule-hole configurations than that of the ground state.

In this paper, we present recent results on the production of isomeric beams at GANIL and report on a first experiment of the measurement of the total reaction cross section induced by a nucleus in an isomeric state.

2 Production of a $^{42}Sc^m$ Isomeric Beam with LISE3

Projectile fragmentation has been extensively used to produce secondary exotic beams at GANIL. Binary nuclear reactions, e.g. transfer, are an other possibility. In this case, reverse kinematics is used to obtain a focussed beam, the opening angle of the ejectile being mainly determined by the kinematics. In addition, we take advantage of selection rules of transfer reactions to populate preferentially the isomeric state.

During the period 1992-1995, we have tested both methods using the LISE3 spectrometer for the selection of a secondary $^{42}Sc^m$ beam. We were interested in measuring the isomeric purity of the secondary beam (number of isomers over total number of ^{42}Sc) as well as the intensity and the isotopic purity of the secondary beam.

In a first experiment, we have established that a pure isomeric beam could be produced at GANIL [1]. A ^{40}Ca primary beam at 30 MeV/A bombarded a ^{nat}C target (5 mg/cm^2 thick). A secondary $^{42}Sc^m$ ($J^\pi = 7^+$, E_γ=617 keV) beam was separated with LISE3. It reached about 100 pps for a 5 nAp ^{40}Ca primary beam intensity. 30% of residual ^{40}Ca which has the same A over Z ratio contaminated the isomeric beam.

Isomeric purity was determined by measuring the γ-ray activity of ^{42}Sc identified and implanted in a solid state telescope, using a HPGe detector. The obtained value of 98% ± 5% is consistent with EFR-DWBA calculation predictions [2].

In order to increase the isomeric beam intensity, the production of $^{42}Sc^m$ by fragmentation has been investigated in a second experiment. For that purpose, a primary beam of ^{50}Cr which has a close N over Z ratio and a heavier mass than ^{42}Sc was accelerated at GANIL for the first time. Three different production targets (Be, C, Ni) were bombarded. The yields obtained are higher than for the transfer experiment (around 1000 pps). However, the isomeric purity is lower around 28% and is not affected -to first order- by the target nature. As for other measurements done elsewhere [3], theoritical models still fail to reproduce these results. A paper will be submitted shortly.

3 Total Reaction Cross-Section Measurements

The measurement of the total nuclear reaction cross section (σ_r) induced by a secondary isomeric beam has been performed recently. In a semi-geometrical framework, one can easily conceive that σ_r is sensitive to a significant difference of shape or radius between the isomeric and the ground state. Indeed excited and ground states exhibit different orbital wave functions. This experiment aimed at measuring the difference on σ_r induced by ^{42}Sc beams with various isomeric purities.

In this experiment, transfer reactions have been used to produce a $^{42}Sc^m$ beam via neutron-proton pick up from a ^{40}Ca primary beam at 30 MeV/A. Three systems have been studied : $^4He(^{40}Ca,^{42}Sc)d,^3He(^{40}Ca,^{42}Sc)p,^{12}C(^{40}Ca,^{42}Sc)^{10}B$ in order to measure the different isomeric purities. For the ^{12}C and ^4He targets, the direct transfer to the ground state is forbidden and it has been shown experimentally [1] that the population of the isomeric state is favored. For the ^3He target, the selection rules allow both ground and isomeric states to be populated.

Isomeric purities were measured with the same method than previously and results are shown in Table 1.

Production target	F(%)	I (pps)
^4He	63±5	≈300
^3He	55±5	≈ 300
^{12}C	84±5	≈ 300

Table 1 : Isomeric purity (F) and yield (I) for the different reactions.

The isomeric purities obtained are unexpectedly close to deduce fine differences in σ_r. This also shows that other channels are open. Indeed, these channels are kinematically allowed by the large spectrometer energy acceptance, especially for the helium targets. As a matter of fact, with an uncertainty of 10% on the total cross section measurement with the three mixed beams, only a ratio R = $\sigma_r^m/\sigma_r^{g.s}$ of 2 or more could be significantly deduced with the isomeric purity obtained.

For this reason, neighboring nuclei like ^{41}Ca and ^{38}Ar are used to validate the experimental method by the absolute value of the total cross section measured in the three experiments. They happen to induce similar total cross section values than the ^{42}Sc ground state. By comparison with these nuclei, one can increase the sensitivity of the R ratio, e.g. R=1.2 for a 10% uncertainty on the experimental results.

For this purpose, tuning of the LISE3 spectrometer was quite different than in the first experiment in order to allow those neighboring nuclei to be transported at the end of the beam line. This could also explain the difference of isomeric purity obtained with the carbon target compared to the first experiment based on the optimisation of the isomeric purity by transfer reaction. This confirms the sensitivity of the isomeric ratio to the different parameters of LISE3 that act in a different way as cuts in the excitation energy spectrum of the primary excited ^{42}Sc produced [6].

For the measurement of the total reaction cross section , the method of the associated γ-rays previously used at GANIL and SARA [4] [5] has been chosen. The experimental set up placed at the end of LISE3 and displayed on Figure 1 is the following:

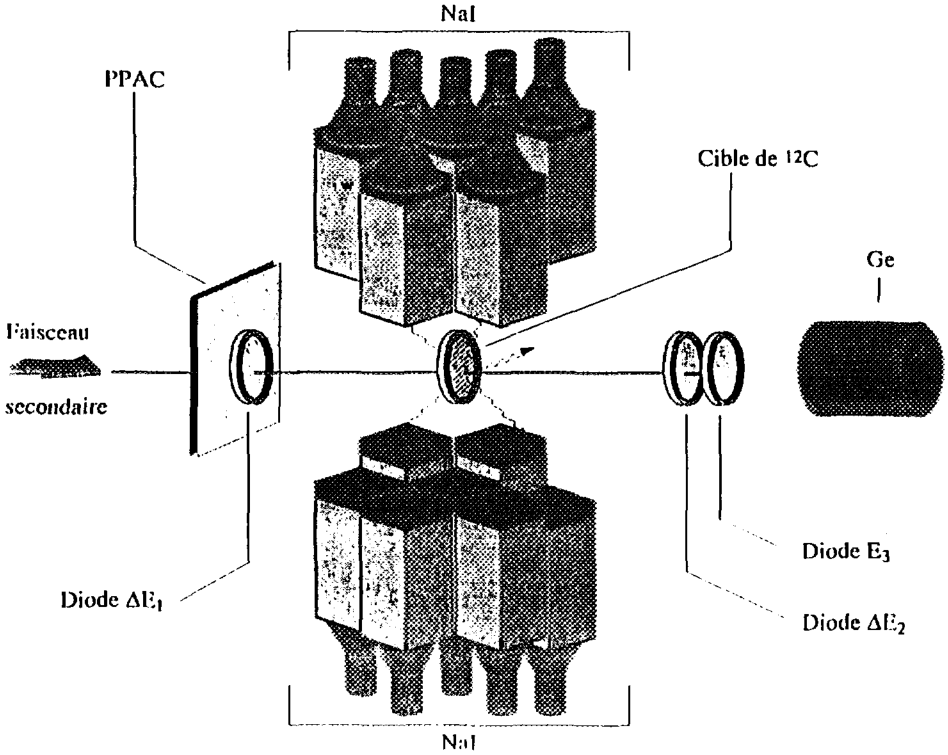

Figure 1: Experimental set up

The γ detector consists of 14 individual NaI counters arranged in a 4π geometry around the interaction target which is ^{12}C (11.45 mg/cm ^{2} thick). The efficiency of this set up is very high because of multiplicity and high intrinsic efficiency. Detectors are also very sensitive to the room γ background so they are surrounded by a lead shielding. A 50μm Si detector (ΔE1) used for identification of the incoming particles is placed 53 cm upstream the interaction target and a Parallel Plate Avalanche Counter (PPAC) gives also x,y position for each incident particle. A ΔE-E telescope and a HPGe detector used for identification of the isomers as in previous experiments is placed 39 cm after the interaction target. Coincidences between ΔE1 and the 4πNaI detector sign nuclear reactions to determine σ_r.

The experimental results are still under analysis. They will be published in a near future. Nevertheless, the very preliminary results seem to show that there is no significant enhancement of the value of the total reaction cross section on the isomeric state with respect to the $^{42}Sc^{gs}$ and the neighboring nuclei. We also see that the results are compatible with the Kox empirical formulae [7].

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