Nuclear Physics

Adelaide Jesus

Introduction

The group has been involved in the study of proton-induced nuclear reactions with the objectives to obtain cross sections of nuclear reactions relevant to nuclear astrophysics and to extend analytical capabilities to light elements.

So far, the experimental work has relied upon ITN – Ion Beam Laboratory, based on a 2.5MV Van de Graaff accelerator. This facility has allowed the development of an accurate method to measure in an absolute way cross sections of relevant nuclear reactions. Also for the applied point of view an effort has been done to complement the already installed PIXE facility by developing a set-up of PIGE analysis for light elements.

In order to proceed with experimental work related to astrophysically relevant nuclear reactions it is imperative to be able to measure the respective cross sections at very low energies, where the cross sections are lower than the picobarn. At these energies several challenges must be overcome: the effects of cosmic rays in the detectors must be reduced to almost zero with an adequate detector shielding, the Coulomb barrier is partially screened by the atomic electron cloud surrounding the nuclei, which leads to an enhanced cross section compared with bare nuclei cross section; stopping powers are not well known. So, we have joined LUNA (Laboratory for Underground Nuclear Astrophysics) collaboration. Work under LUNA collaboration has been centred on the study of electron shielding effects on nuclear reaction cross sections at very low energies and on the study of the reactions $d(p,\gamma)^{3}He$ and $^{14}N(p,\gamma)^{15}O$. Target preparation and stoicheiometry analysis by ERD, RBS, PIGE and NRA, has been done at ITN.

In the short term the work to develop a calibrated PIGE set-up will be concluded, opening new perspectives in apllied work for Environment, Materials and Health Sciences and Geology. Also, work under LUNA collaboration will proceed with the study of relevant reactions of the p-p chain and CNO cycles. This collaboration will imply some experimental work at ITN, namely for target preparation and stoicheiometry analysis by ion beam techniques and cross section measurements for normalisation of LUNA measure-ments.

In the medium term, the acquisition of a new accelerator would open new research areas within nuclear astrophysics, as the study of relevant reactions of the p-process nucleosynthesis.

Nuclear Physics

Research Team

Researchers

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- MICAELA FONSECA, Diplomma Student

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FCT:	€ 8000
Total:	**€ 33000**

Publications

Proceedings: 2 (2 in press)
Conf. Communications: 3

Simultaneous Analysis of Thin and Thick Samples Using the PIGE and the PIXE Techniques

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Objectives

In this document, we relate the use PIGE and PIXE techniques for a simultaneous analysis of thin and thick samples. For PIGE analysis we employ a method not dependent of standards, based on a code we have developed.

This code is based on the excitation functions of the adequate nuclear reactions and the division of the surface samples in sublayers along their depths (in the case of intermediate and thick samples).

The analytical procedure related to the PIGE technique is different from thin to intermediate or thick samples analysis. We present two different works related to the study of these two distinct cases. Aerosols reveal light and heavier elements in their composition. Samples are collected with the use of thin filters and they are usually considered as thin samples. Tourmalines are a family of silicate minerals that present important amounts of Li, B, F, Na, Al, Si, K, Ca, Mn, Fe, Zn and Ga in very distinct zones. Ordinary compositions are well known by the authors.

Results

1. The case of aerosols samples analysis.

The samples were collected with the SARA aerosol sampler in the ITN *campus*. We collected sets of diary and periodical samples. The second ones are related to distinct diary collection periods along some days. Samples were studied with a simultaneous analysis using PIGE and PIXE techniques. We found correlations between the results of different group of elements, for both fine and coarse particles. In particular, the comparison between the Na and Cl concentrations in coarse particles shows that there is another important factor, beyond the sea influence, that is responsible for the presence of Na and Cl in the ITN *campus*. This conclusion is easily obtained from the study of coarse particles in the periodical samples. The amount of Cl decreases between 00h to 16h, accordingly to the change of the sea temperature. In opposition, Na amount has a maximum between 16h and 20h. We observed the same characteristic in other elements, as Al, Si, K, Ca, Ti, Mn, Fe and Pb. Different authors associated these kind of emissions to the automobile traffic. Mass measurements of both fine and coarse collected material show a stability of the fine particles and an increase of the second ones between 12h and 20h. These measurements are in agreement with the analytical results.

2. The case of tourmaline samples analysis.

In this work, a milliprobe system was used. It combines the focusing properties of the ITN Van de Graff accelerator and a collimator system including apertures of 1mm diameter. This system imposes the appropriate dimension to the beam spot. The scanning of the sample surface was achieved with a sample holder. The movements were accomplished with the use of a motorised X-Y table connected to the sample holder, with a travel of 25mmx25mm.

Experimental results related to five distinct zones revealed tourmaline compositions in agreement with the values obtained from the literature.

In order to validate the milliprobe analysis and study in more detail the frontier between zones of different colours, a microprobe analysis of the samples using PIXE technique was also done. All the new results were in agreement with the PIXE results obtained with the milliprobe system. They show that the use of a milliprobe is adequate and sufficient for the study of these minerals.

Published, accepted or in press work

1. R. Mateus, A.P. Jesus, J.P. Ribeiro, Quantitative Analysis of Light Elements in Thick Samples by PIGE, Proceedings of the 16th Conference on Ion Beam Analysis, Albuquerque, USA, **in press work**, Nucl. Inst. and Meth. B
2. R. Mateus, A.P. Jesus, J. Cruz, J.P. Ribeiro, Measurement of the Inelastic Scattering of protons by ^{23}Na in the Energy Range 1.25-2.40 MeV, Proceedings of the 16th Conference on Ion Beam Analysis, Albuquerque, USA, **in press work**, Nucl. Inst. and Meth. B

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Experimental Study of Nuclear Reactions for Astrophysics

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Objectives

A precise knowledge of nuclear reactions cross sections (or S-factor) of light elements is crucial for the understanding of the evolution of the very early universe.

Since these reactions occur in stars at very low energies (Gamow peak), with extremely low cross sections decreasing exponentially with energy, efforts to measure it at theses energies requires pure targets, low background environments and very stable accelerator machines. The going-on work program is related to:

1. Measurement at ITN of cross sections and angular distributions of the reaction $^{7}Li(p,\alpha)^{4}He$ and $^{6}Li(p,\alpha)^{3}He$.
2. Experimental work on reaction cross-sections at relevant energies (around the solar Gamow peak) under LUNA (Laboratory for Underground Nuclear Astrophysics) collaboration, namely the reaction $^{14}N(p,\gamma)^{15}O$.

Results

1. Lithium is one of the most interesting and puzzling elements in the field of nucleosynthesis. Its most abundant isotope, ^{7}Li, has the rather unique status of requiring three entirely different nucleosynthetic processes, which are not completely understood.

   The reactions $^{7}Li(p,\alpha)^{4}He$ and $^{6}Li(p,\alpha)^{3}He$ are the major reactions of Li destruction, having thus a crucial contribution to Li abundances. Even though there are several different cross sections measurements for these reactions, they lead to different astrophysical S-factors at relevant energies.

   At ITN, the experimental set-up for nuclear reactions measurements has been modified and optimized to study this reaction.
2. At Gran Sasso work on solid targets with Ge detectors have led to cross section values down to 140 keV. Data analysis has been finished during 2003 together with the theoretical fit to extrapolate to zero energy (fig. 1and 2). These results, recently submitted for publication in Phys. Letters B, give support to previous theoretical work of Angulo et al. Work has started on the same reaction using gas targets and BGO detectors. Although information related with capture for different states will not be available with this kind of set-up, lower energies will be attained leading to a more accurate value of the S astrophysical factor for total capture. Cross sections have already been measured down to 90 keV and experiments are proceeding to lower energies.

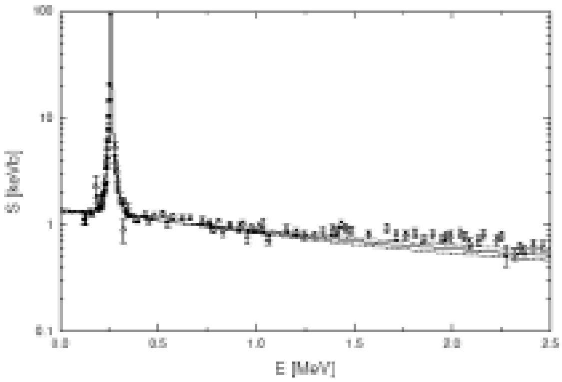

Fig. 1 Astrophysical S(E)-factor curve for the transition to the 6.79 MeV state in $^{14}N(p,\gamma)^{15}O$.

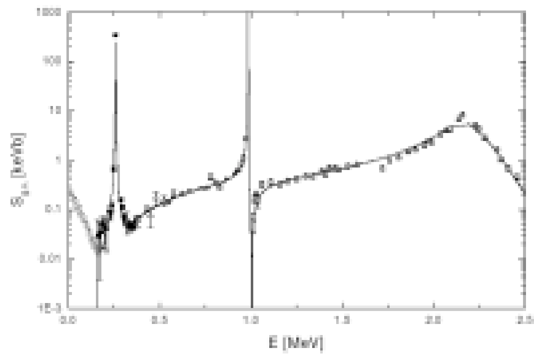

Fig. 2 Astrophysical S(E)-factor curve for the ground-state transition in $^{14}N(p,\gamma)^{15}O$.

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Measurement of the Sttoping Power of Protons in LiF

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Objectives

The measurement of nuclear reaction at low energies is crucially affected by the knowledge of the stopping power of incident ions in the targets, as these have always a finite thickness. Namely, the reaction $^{7}Li(p,\alpha)^{4}He$ has been studied to very low energies (20 keV) by several authors, due to its interest to nuclear astrophysics. The disagreement of their results, leading to different extrapolated astrophysical factors, is most probably due to target thickness problems, including stopping power values. In this context, we started a program to measure stopping powers of protons in LiF in the energy range (100-500 keV). In this range, discrepancies with Ziegler predictions are expected to be large and Bragg's law is expected to fail.

Results

LiF films on Al films were used; the Kα X-ray production cross section of Al was used to extract information on the energy loss; the thickness of the films was determined by RBS with 2.0 and 2.2 MeV.

alpha-particles. The results obtained are in disagreement with Ziegler plus Braag's law prediction and point to an unexpected effect (fig. 1). This may be related to the use of a molecular H_3 beam as the same exercise with H_2 beam lead to different results, although again, in disagreement with predictions (fig. 2).

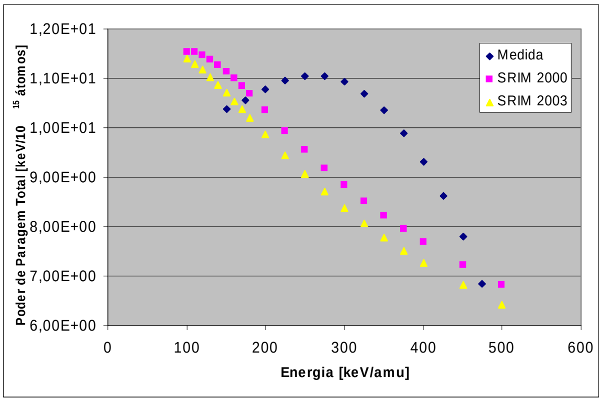

Fig. 1 Comparison of experimental results obtained for a molecular H_3 beam, with theoretical results of the stopping cross sections of protons in a LiF target.

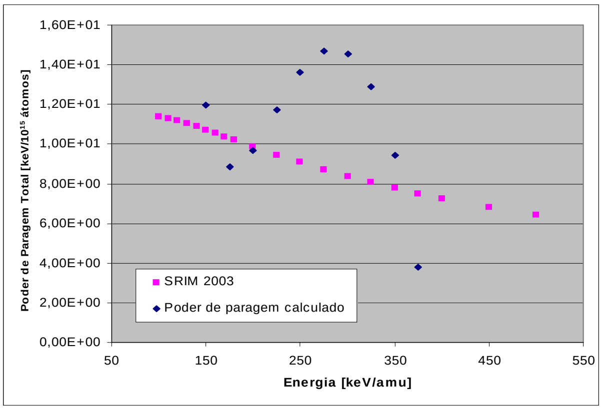

Fig. 2 Comparison of experimental results obtained for a molecular H_2 beam, with theoretical results of the stopping corss sections of protons in a LiF target.

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