LFEUI - Investigation Proposal
Detection of Li in Technological Materials through Nuclear Reactions

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Abstract

In the following document we present a proposal for a scientific research being developed at CTN Lisbon in December 2023. Our work consists of the detection of ^{7}Li in two different samples through nuclear reactions. This document describes the time required for the project as well as it's goals, theoretical background, experimental technique, safety considerations and expected results. In addition, we also present a brief description of the experimental set-up.

1 Proposal Summary

Goal Our main goal is to develop a scientific research project alongside three senior investigators from CTN (Centro Tecnológico e Nuclear), Rodrigo Mateus, Rui Silva and Norberto Catarino.

Our project will be focused on the detection of Li in technological materials through nuclear reactions. The main motivation for this project is to study and develop a detection technique for elements such as Li with high sensitivity.

Scientific Background This detection method is based on the nuclear reaction between the element we want to detect (^{7}Li) and a proton, as follows:

$$^{7}\mathrm{Li} + {}^{1}\mathrm{H} \longrightarrow {}^{8}\mathrm{Be} \longrightarrow 2\,\alpha \tag{1}$$

The reaction results in the production of a ^{8}Be nucleus which then rapidly decays into two alpha particles. These are the particles we detect.

According to the incident proton's energy and the scattering angle of the detectors ($\theta = 165$ degrees) we were able to use the NRA Calculator [5] to calculate the energy of the alpha particles resulting from the reaction as well as it's Q value:

$$\begin{aligned} E_{\alpha_1} &= 7.65320 \text{ MeV} \\ E_{\alpha_2} &= 10.89305 \text{ MeV} \\ Q &= 17.34625 \text{ MeV} \end{aligned} \tag{2}$$

The formula this website uses to compute the energies is on the page 382 of the book [4].

2 Experimental technique

Set-up The experimental set-up consists of a Tandem accelerator, a beam line with an electromagnet and a chamber with both the samples and the detectors. The accelerator produces a beam of protons with a kinetic energy of up to 5 MeV which is deviated by the electromagnet and hits the sample. The electromagnets deflect particles with different angles according to their charge-to-mass ratio and, with that, allows us to remove any unwanted particles from the beam and only let the protons pass through. The detectors used are silicon detectors - these detect charged particles through the ionization they produce in the silicon.

In addition, they are connected to a electronic system that amplifies the signal and sends it to a computer where we can see the results.

The beam line is under a vacuum of around 10^{-7} mbar in order to avoid the protons colliding with other particles and losing energy. They reach the sample with the specified kinetic energy and cause a nuclear reaction whose products are the charged particles detected. We aim to analyze the energy spectrum of these particles.

The following diagram shows the experimental set-up: Note: We use a tandem accelerator, so the image should have 2 tubes inside the accelerator.

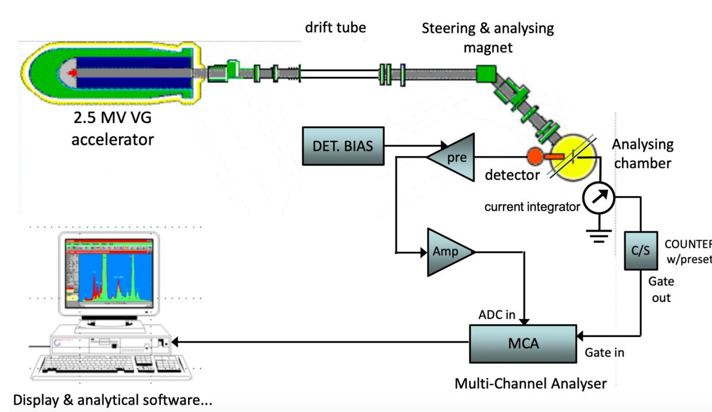

Figure 1: Experimental set-up.

Samples We are going to work with two different Lithium-7 samples: one of them is a glass sample composed of silicon, boron and lithium and the other one is a implant sample, which is a thin layer of lithium implanted in a silicon substrate.

WorkPlan Obtaining the energy spectrum of the alpha particles resulting from the reaction between the protons and the samples will evolve the following steps:

1. Accelerator Startup;
2. Calibration of the detectors with a sample of known composition;
3. Obtaining the energy spectrums of both samples with the appropriate beam energy;
4. Analysis of the results.

Beam Energy In order to choose the energy of the beam we need to take into account the cross section of the reaction between the the protons and the Li-7. We collected data from the IBANDL [3] database for this reaction in a range of [0.5, 7] MeV and plotted it in the following graph:

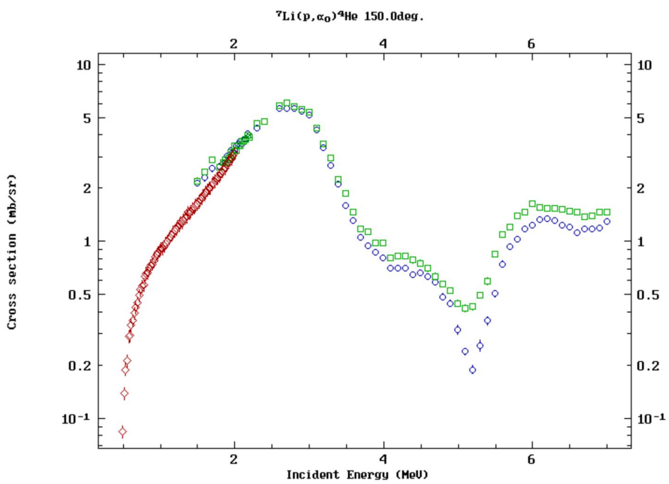

Figure 2: Cross section of the reaction between protons and Li-7 as a function of the beam energy.

We are only interested in the energy range of [0.5, 5] MeV because the energy of the beam is limited by the accelerator. As we can see in figure 2, the cross section of the reaction is maximum in the [2.5, 3] MeV range. Therefore, since we want to detect the Li-7 in the samples, we should choose the energy of the beam to be in this range.

3 Safety considerations

During the experiments, the accelerator will be producing a beam of protons with a kinetic energy of up to 5 MeV. Because of this there will be a high radiation level near the accelerator. There are radiation maps that show the radiation levels in different areas of the laboratory and need to be strictly followed.

4 Beamtime requested

In order to complete our project we will need one full day of beamtime at the CTN laboratory [1]. Alongside this day, we will also meet with the investigators at CTN for another two mornings to discuss the project, before the experiment and the results after the experiment:

Phase	Date	Duration
Theoretical Background, Planning and Lab Overview	30/11/2023 9h30	4h
Experiment	7/12/2023 8h00	8h
Results Discussion	To be arranged	4h

5 Expected Results

We will obtain the energy spectrum of the alpha particles resulting from the reaction between the protons and the samples. For the glass samples, we expect to see a profile due to the particles that come from different depths of the sample and therefore have lost different amounts of energy. In the implant samples, we expect to see a peak at the energy corresponding to the energy of the alpha particles produced by the reaction. In both cases, the samples are composed by other types of atoms such as silicon and boron, which will also emit charged particles. By obtaining the expected energy spectrums we can infer the presence of Li in the samples. If possible we will also try to quantify the amount of Li present by analyzing the amount of energy deposited in the spectrums.

Energy Values The alpha particles are supposed to have the energies calculated in equation 2 (E_{α_1} and E_{α_2}). In the glass sample, we expect to see an energy profile before each peak and in the implant sample we only expect to see the peaks.

Other phenomena such as Rutherford Backscattering and Elastic Scattering are also expected to occur. These are responsible for energy peaks in both sample's spectra at lower than the expected energy values.

6 Concluding remarks

By identifying the presence of light isotopes at low energies ($<$ 5MeV), we achieve a practical method to evaluate the presence and the amount of these light isotopes in technological materials. Until now, the only way to do this was through atomic spectroscopy, which, besides not being able to detect the presence of light isotopes, is a much more complex and expensive method.

References

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[4] Kenneth S. Krane. *Introductory Nuclear Physics*. John Wiley & Sons, Inc., 1988.

[5] *Nuclear Reaction Analysis (NRA) Energy Calculator*. https://www.se.ctn.tecnico.ulisboa.pt/FisNuclear/NRA.html.