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Measurements of (n,α) cross-section of small samples using a lead-slowing-down-spectrometer

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Abstract

At the Los Alamos Neutron Science Center (LANSCE) a compensated ionization chamber (CIC) was placed in a lead slowing down spectrometer (LSDS) to measure the ^{6}Li(n,α)^{3}H cross-section as a feasibility test for further work. The LSDS consists of a 1.2 m cube of lead with a tungsten target in the center where spallation neutrons are produced when bombarded with pulses of 800 MeV protons. The resulting neutron flux is of the order of 10^{14} n/cm^2/s which allows the cross-section measurement of samples of the order of 10's of nanograms. The initial experiment measured a 91 μg sample of natural lithium flouride. Cross-section measurements were obtained in the 0.1 eV–2 keV energy range. A 62 μg sample was placed in the chamber with a higher neutron beam intensity, and data was obtained in the 0.1–300 eV range. Adjustments in chamber dimensions and electronic configuration will improve gamma flash compensation at high beam intensity, decrease the dead time, and increase the energy range where data can be obtained. The intense neutron flux will allow the use of a smaller sample.

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Keywords: Lead-slowing-down spectrometer; Lithium; Alpha; Cross-section; Neutron reactions

1. Introduction

Measurements of (n,α) cross-sections for a broad range of masses at low energies are important to the study of astrophysics when modeling the p process of nucleosynthesis. Measurement of (γ,α) and (α,p) rates used in explosive nucleosynthesis studies are difficult to measure directly and must be calculated to determine abundances. High accuracy (n,α) cross-section data will allow the calculation of reaction rates involving α particles [1].

At the Los Alamos Neutron Science Center (LANSCE) a compensated ionization chamber (CIC) was placed in a lead-slowing-down-spectrometer (LSDS) to measure the ^{6}Li(n,α)^{3}H cross-section as a feasibility test for further work. The LSDS consists of a cube of lead with a tungsten target in the center which is bombarded with pulses of 800 MeV protons from the Proton Storage Ring. Neutrons, that are produced by spallation in the tungsten target, slow down in the lead resulting in a neutron flux that varies from approximately 10^{10} n/cm^2/s/MeV at 1 MeV to 2×10^{13} n/cm^2/s/MeV at 0.1 eV. The high neutron flux allows cross-section measurements of very small samples of the order of 10's of nanograms. This means that measurements of rare

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isotopes, isotopes with small cross-sections (microbarns) or very short half-lives are obtainable.

2. Lead-slowing-down spectrometer

The lead-slowing-down spectrometer [2] consists of 36 blocks of high-purity lead which, when assembled, form a 1.2 m cube weighing 20 tons. Through the center is a 10 cm by 10 cm channel where the 800 MeV proton beam enters the cube and collides with a tungsten target 25 cm long and 7 cm in diameter. The proton beam can operate at an average current of up to 1 μA at a rate of 20 Hz with a pulse width less than 200 ns. Approximately 13 neutrons per proton are produced in the target through a spallation process where the neutrons have an average energy of about 2 MeV. The total neutron flux delivered is up to 10^4 times higher than conventional time-of-flight experiments of equal energy resolution. The neutrons scatter in the lead and, as they slow down, the energy distribution becomes more focused. However, some neutrons escape the lead and thermalize in the room. To prevent them from returning to the lead, a layer of cadmium surrounds surface of the cube. The energy–time relationship of the neutrons is characterized by

$$\bar{E} = \frac{K}{(t + t_0)^2} \tag{1}$$

where $\bar{E}$ is the average neutron energy in keV, K is the slowing-down constant in keV μs^2, t is the neutron slowing-down time, and t_0 is the time needed by the neutrons to reach the time–energy relation in Eq. (1). For this LSDS, the value of K is 161 ± 5 keV μs^2, and t_0 is 0.4 ± 0.1 μs [2].

3. Detector design and electronics

The compensated ionization chamber consists of 3 plates that are 3.15 cm in diameter, spaced 2 cm apart and mounted on ceramic rods. The chamber is filled with P-10 gas at local atmospheric pressure (0.78 atm) with a constant slow flow to maintain the integrity of the gas. The distance between the plates was determined by the range of 2.05 MeV α particles due to a ^{6}Li (n,α) ^{3}H reaction. A SRIM/TRIM [3] calculation indicates that the range of the α particles in P-10 at 0.78 atm is 1.91 cm and the energy deposited in the chamber is 0.9–2.05 MeV depending on the angle of emission and interaction with the Teflon spacers. This calculation takes into account the geometry of the chamber, but not the energy lost in the sample. The 2.73 MeV triton will only deposit 0.12–0.42 MeV which is not enough to be seen above the noise level. Therefore, the effect of the tritons can be neglected.

The sample is placed on the cathode plate facing the top plate, and the electrons created due to ionization of the gas by α and tritium, as well as the incident background γ-rays move toward the top plate. The bottom half of the chamber is the compensating side, where the electrons, due to ionization of the gas by γ-rays, move toward the cathode. The maximum drift velocity of the electrons in P-10 in a field of 135 V/cm/atm is 5.5 cm/μs which corresponds to a total collection time of 0.36 μs. During the experiments the bias can be varied from 0 to ±500 V in order to provide the best compensation, however, this will decrease the collection time.

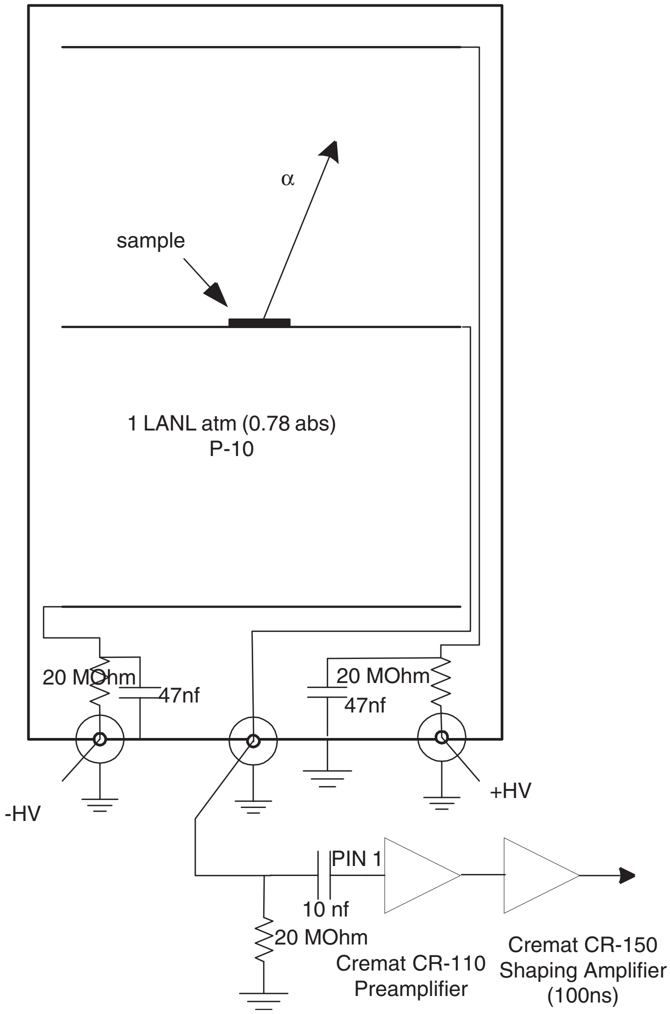

Fig. 1. Diagram of compensated ionization chamber.

The electronics diagram is shown in Fig. 1. A positive bias is placed on the top plate, and a negative bias is placed on the bottom plate.

The signal from the cathode is filtered through a 10 nf capacitor with a 20 MΩ resistor to ground prior to reaching the preamplifier. The charge sensitive preamplifier is a Cremat CR-110 with a shaping constant of 140 μs and a gain of 1.4 V/pC. The signal is then amplified by a Cremat CR-150 shaping amplifier placed on a Cremat CR-160 board [4]. The shaping constant is 100 ns and the gain can be adjusted from 10 to 10,000.

4. Detector behavior

The behavior of the detector was tested at RPI with α particles using a ^{235}U sample to ensure that they could be

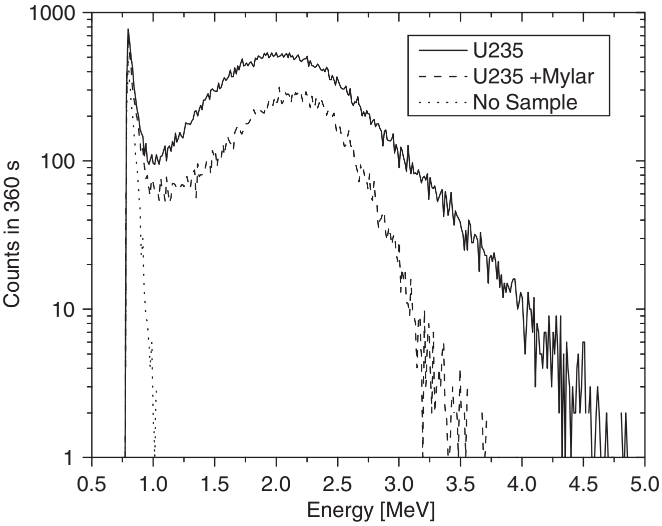

Fig. 2. α energy spectrum with and without mylar film.

seen above the background noise. The preamp, filter, and shaping amplifier were identical to those to be used during experiments at LANL. A mylar film was placed over the sample to reduce the energy of the α particles as they entered the chamber to better simulate the 2.05 MeV α from the (n,α) reaction of lithium. Fig. 2 shows the energy spectrum of the α with and without the Mylar film. The α particles can clearly be seen above the noise.

5. Experimental results

A LiF sample $91 \pm 29\,\mu\text{g/cm}^2$ with an area of $0.7\,\text{cm}^2$ ($1.1 \pm 0.4\,\mu$g ^{6}Li) deposited on a 20 mil thick titanium backing [5] was used as the cathode in the CIC with the sample facing the top plate. The proton beam current was 25 nA at 20 Hz. In order to actively compensate the chamber, a positive bias of 200 V was placed on the top plate, and a negative bias of 400 V was placed on the bottom plate. The compensation of the gamma flash was not ideal and a dead time of about 7 μs was observed. These results are shown in the plot in Fig. 3(a). The drop in the cross-section between 300 and 1000 eV is due to electronic dead time that was not compensated for in this data.

The sample was then replaced with $62 \pm 7\,\mu\text{g/cm}^2$ with an area of $0.7\,\text{cm}^2$ of LiF ($0.76 \pm 0.09\,\mu$g ^{6}Li) and the proton beam current was increased to 300 nA as shown in plot (b) and 500 nA as shown in plot (c) of Fig. 3. The increased current lengthened the dead time to 20 μs due to the larger gamma flash. The top plate bias was −400 V and the bottom plate bias was 3 V to provide compensation. The compensation did not work well, probably due to the large resistor in the filter prior to the preamp which allowed the cathode to hold a charge. Future experiments will be conducted with a modified filter arrangement that includes a smaller resistor to ground. With proper compensation cross-section measurements can be extended to higher energies.

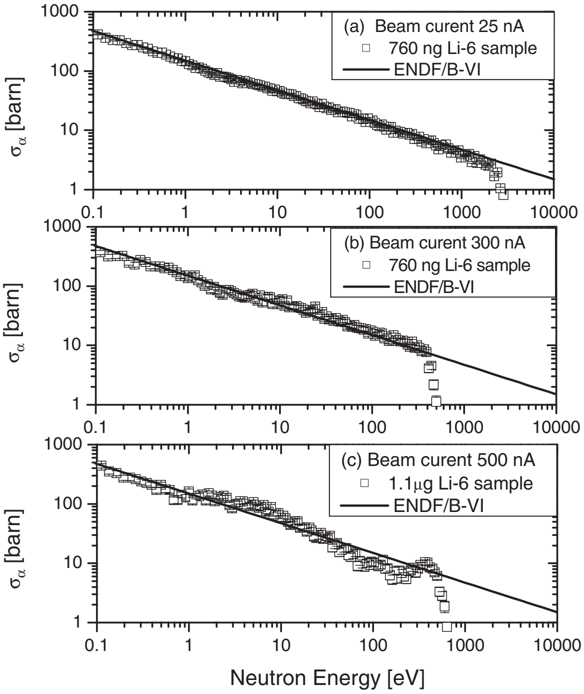

Fig. 3. Experimental results for the 25, 300, and 500 nA beam.

There are some areas in all three plots where the cross-section varies from a straight $1/v$ value. The dip at about 2–4 eV may be due to neutron interactions in the material of the chamber. Variations from the true cross-section become stronger as the beam current increases. The cause of this problem is saturation of the electronics, which will be investigated further through mathematical models of the flux in the area of the detector and investigating interactions with the material of the detector itself.

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