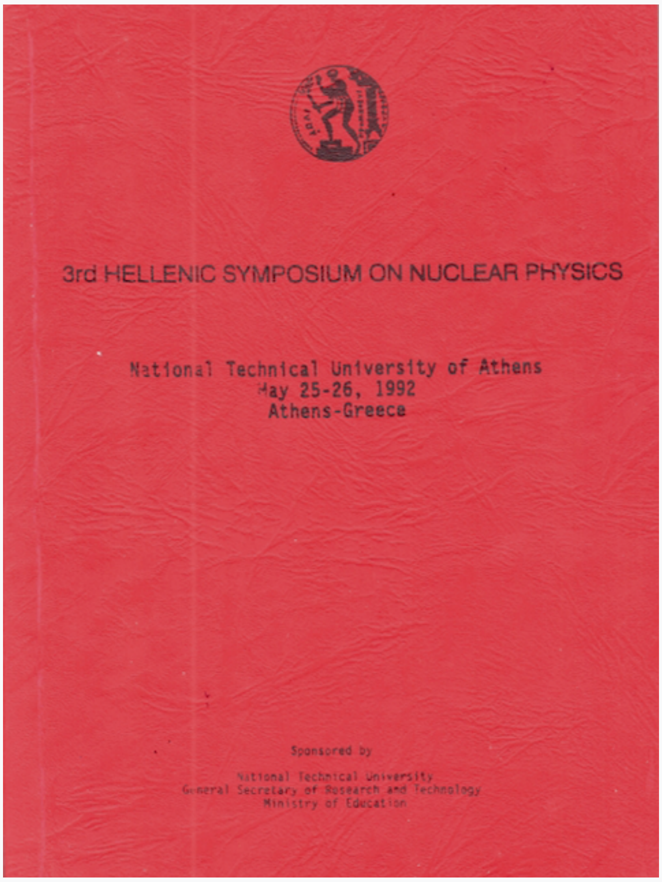
HNPS Advances in Nuclear Physics

Vol 3 (1992)

HNPS1992



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doi: [10.12681/hnps.2386](https://doi.org/10.12681/hnps.2386)

ENERGY AND FLUX MEASUREMENT OF THE NEUTRONS PRODUCED IN A GAS CELL*

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1. Abstract

The neutron flux and energy distribution of the neutrons produced in a gas cell were measured using a silicon semiconductor detector. The energy spectra produced by the borbardment of the silicon detector with neutrons were simulated using Monte Carlo techniques and were compared with the measured spectra.

1. Introduction

In this paper we report om the use of a gas cell for the production of monoenergetic neutrons, in the energy region E_n=5–12 MeV, via the $D(d,n)^3He$ reaction. The neutron beams, produced in the gas cell, have been used for cross section measurements of the excitation functions for neutron induced reactions of astrophysical importance[3.4]. Knowledge of the energy distribution and flux of the neutrons impinging on the target is essential to such measurements. Both of these quantities can be either calculated or measured. In this work the neutron energy distribution and flux were calculated using Monte Carlo techniques. The neutron flux was measured using three different methods: a BF_3 counter, the activation technique and a silicon semiconductor detector. Silicon semiconductor detectors have been used, by several investigators [2] , for neutron energy and flux measurements via the detection of the nuclei produced in the nuclear reactions induced by neutrons on the isotopes of silicon. Most of the investigators have discussed the shape and position of the energy spectra, measured in a silicon semiconductor detector, in terms of various effects, however a complete and detailed analysis that takes into account all effects quantitatively has not been reported. In this work, the energy spectra produced by neutrons in a silicon semiconductor detector were simulated using the Monte Carlo method. The results of this calculation furnished information on the fraction of protons or alphas escaping

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the detector, the limitations on the energy resolution of the detector and the various factors affecting the formation of the peaks in the energy spectra.

2. The gas cell

The gas cell is made of stainless steel with a wall thickness of 0.2 mm and external diameter 1 cm. Several gas cell have been made with lengths varying from 3.7 cm to 5.7 cm. In order to reduce the production of bachground neutrons, the interior of the gas cell is lined with Ta. The beam stops on a 0.9 mm Pt foil, silver soldered to the end of the cell and it is air cooled during the runs. As entrance windows were used Mo and Ti foils 5 mgr/cm^2 and 2.5 mgr/cm^2 thick respectively. These foils were bombarded, for several days, with deuteron currrents up to 7 μA and deuterium gas pressures up to 1.5 atm, before a permanent pin hole developed. A Teflon piece electrically isolates the gas cell from a 3 mm diameter Ta collimator. An electron supression ring is used in order to determine correctly the accumulated charge on the gas cell. To monitor the gas pressure in the gas cell, a semiconductor pressure sensor is used together with associate electornics, which produce an audible alarm when the cell pressure falls below a preset level. More details about the gas cell may be found in ref. [1].

This gas cell has been used for the measurement of the $^{11}B(n,\alpha)^8Li$ cross section, in the experiments reported in refs. [3,4]. In these experiments the deuteron beam was stopped every 4 secs and for a time interval of 4 secs, using an electromechanical beam chopper. A 150 mm^2 silicon semiconductor detector, 50μm thick, was placed at a distance d from the end of the gas cell, with a ^{11}B target directly in front of it. During the beam–on time, the detector measured the neutron flux via the the charged particle reactions induced by the neutrons in silicon. During the beam–off time, the detector measured the two alphas from the delayed activity of ^8Li, namely $^8Li(\beta\nu)^8Be^*(2\alpha)$. This system was used [4] for measurements at $E_n = 7.5-8.0MeV$, i.e. near the threshold of the $^{11}B(n,\alpha)$ reaction, where the cross section drops very fast with energy. The thin silicon semiconductor detector provided the low background detection system required for these measurements. At higher energies i.e. $E_n = 8.0-12MeV$ we used a BF_3 counter which served both as target and detector [3].

3. Calculation of the Energy Distibution of the Neutrons

The energy distribution of the neutrons impinging on a detector placed at 0^o with respect to the deuteron beam direction and at a distance d from the end of the gas cell , is determined by the the folllowing factors: the size of the deuteron beam spot on the cell entrance foil, the dimensions of the gas cell and the detector as well as the distance d. It depends also on the energy losses, energy straggling and angle straggling of the incident deuterons in the entrance foil and the deuterium gas in the cell. All these factors were included into a Monte Carlo calculation. An incident deuteron hits the foil at the point P_0 and is subsequently deflected, due to multiple scattering in the foil, to the direction P_0P_1. At the point P_1 it interacts with a deuteron nucleus and the neutron emitted from the D(d,n) reaction hits the detector at the point P_2. In the Monte Carlo calculation, the points P_0, P_1 and P_2 are selected randomly assuming a uniform deuteron beam intensity, a gaussian distribution in angle straggling in the entrance foil and using the reported values for the angular distribution of the D(d,n) reaction, respectively.

The result of such a calculation for d=4 cm, gas cell length 3.7 cm, detector area 150 mm^2, Mo entrance foil and 500 mbar deuterium gas pressure, is shown in fig. 1. This setup corresponds to the $^{11}B(n,\alpha)$ cross section measurements, near threshold, described above. It should be noted that the neutron flux intercepted by the detector can be calculated with the previously described M.C. code if one includes in the calculation the deuteron beam charge accumulated on the gas cell.

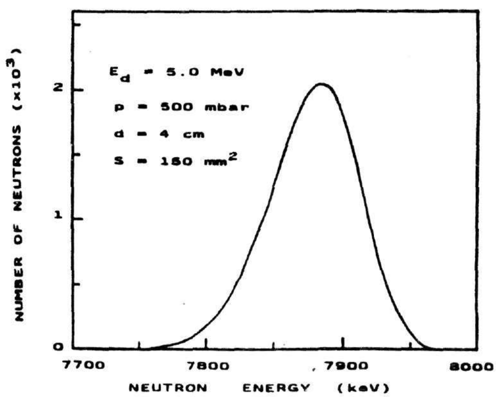

Fig. 1.

The energy resolution of the neutron beam impinging on the detector can be obtained from the standard deviation of the calculated distribution. The energy resolution can be minimized by moving the detector far away from the gas cell and also by reducing the deuterium gas pressure. For large gas cell–detector distances and very small gas pressures the limitting factor to the neutron energy resolution is the energy straggling in the entrance foil, which for the 5 mgr/cm^2 thick Mo foil is 45 keV (fwhm) and for the 2.5 mgr/cm^2 Ti foil is 12 keV (fwhm). For better energy resolution thinner foils or foils of elements with lower Z are needed. Such foils were tried but without success. The foils tried were either not vacum tight or they developed pin holes soon after beam bombardment. Thus the best energy resolution that we were able to obtain with the present gas cell was 28 keV (fwhm).

4. Measurement of the Energy Distribution of the Neutrons

When a silicon semiconductor detector is bombarded with neutrons nuclear reactions are induced within the volume of the detector. The most important of these reactions are the (n,p) and (n,α). The proton groups that are so close in energy that they cannot be resolved by the detector are denoted with a two digit index in fig. 2; for example by p_{10} is denoted the double peak that consists of the p_0 and the p_1 peaks. Fig. 2 shows an enery spectrum taken with the 150 mm^2, 50μm thick silicon semiconductor detector. The energy resolution of the detector was 50 keV. The deuteron bombarding energy, the gas cell pressure and the detector distance were those listed in fig. 1, for the neutron energy distribution calculated with the M.C. computer code; that is the spectrum was taken at a mean neutron bombarding energy of 7.880 MeV.

The peaks in the spectrum of fig. 2, correspond to the sum energy of the charged particle (proton or alpha) and the recoiling nucleus (Mg or Al) produced in the indicated reactions. The position in energy, and shape of each peak is determined by the energy distribution of the incident neutrons (fig. 1), the energy resolution of the detector, the pulse height defect of the recoiling Mg or Al ions and the angular distribution of the corresponding reaction. The M.C. calculation that was performed, by taking into consideration all these factors, for the (n,p) reaction, is shown in fig. 3 and for the (n,α) reactions, is shown in figs 4 and 5.

The width of the α_0 peak is about 150 keV fwhm. If in the M.C. calculation we use zero dispersion in the energy of the incident neutrons and zero energy resolution for the detector we obtain a width of 100 keV fwhm for this peak. This means that

100 keV is about the best energy resolution for neutron energy measurements that can be obtained using a silicon semiconductor detector. This limitation arises from the energy dispersion in the PHD displayed by the recoiling heavy ion.

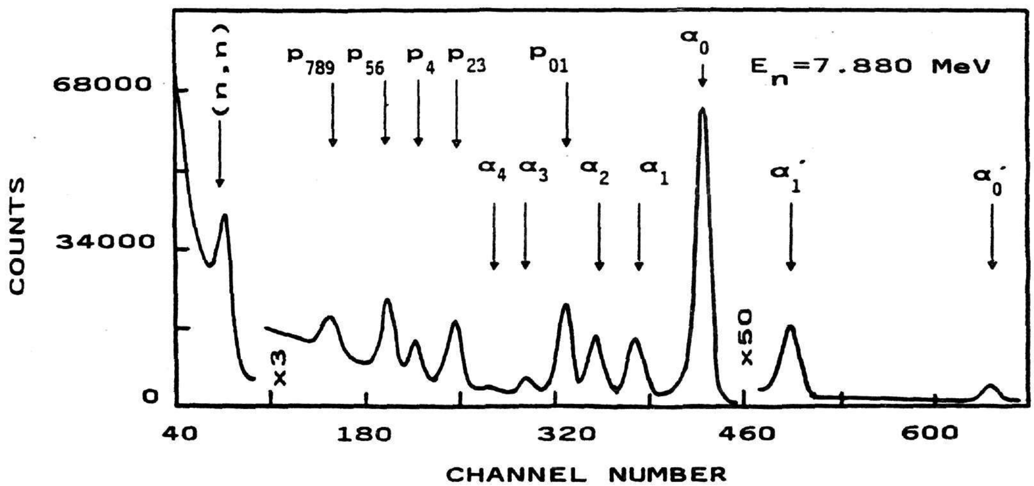

Fig. 2.

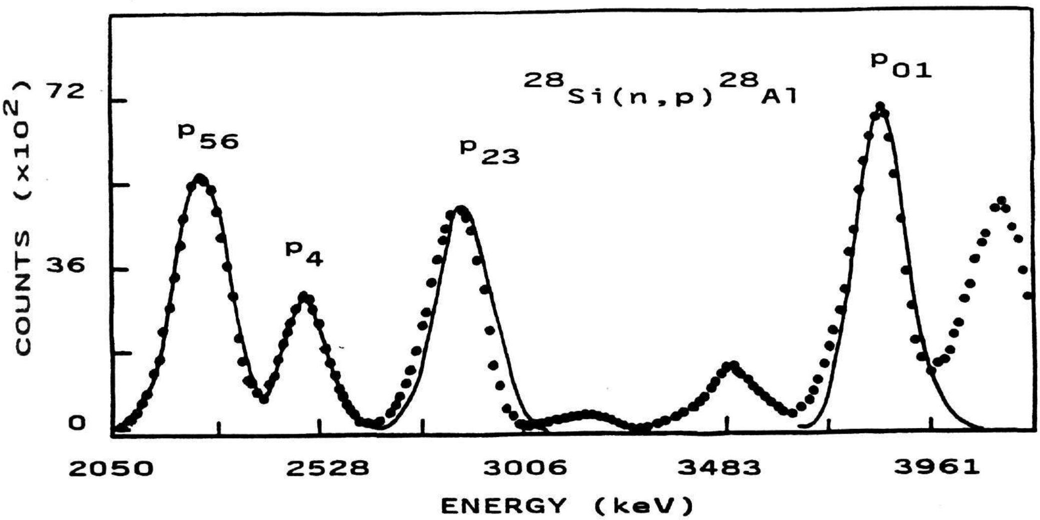
COUNTS (x10^2)
72
36
0
$^{28}Si(n,p)^{28}Al$
p_{56}
p_4
p_{23}
p_{01}
2050
2528
3006
3483
3961
ENERGY (keV)

Fig. 3.

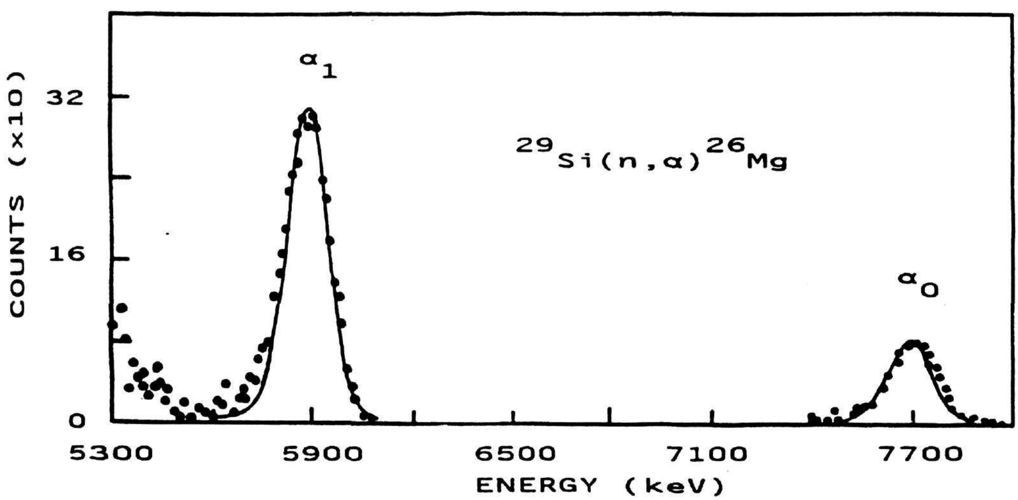
COUNTS (x10)
32
16
0
α_1
$^{29}Si(n,\alpha)^{26}Mg$
α_0
5300
5900
6500
7100
7700
ENERGY (keV)

Fig. 4.

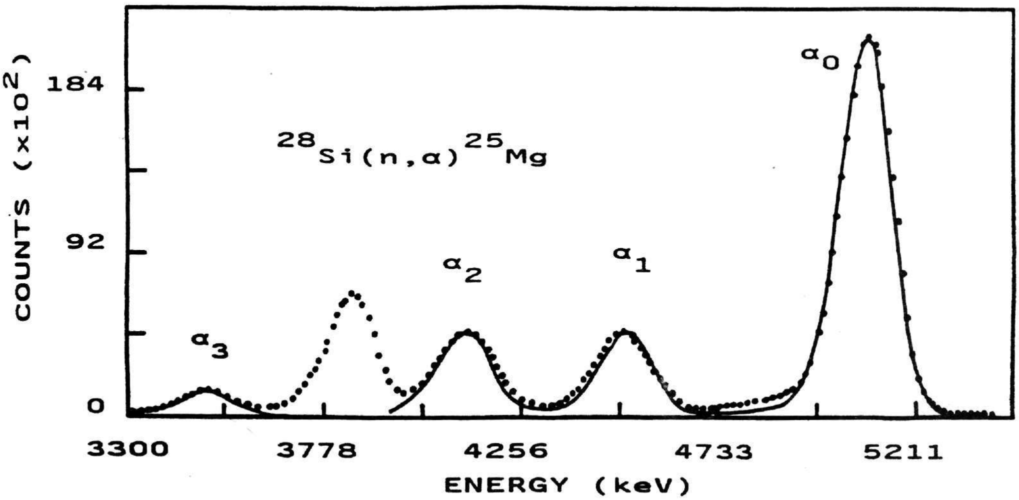

Fig. 5.

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