The experimental investigation of $^{10}B(n, \alpha_0)$ to $^{10}B(n, \alpha_1)$ branching ratio for neutron energy region from 4 to 7 MeV

I.P.Bondarenko, V.A.Khryachkov, B.D.Kuzminov, N.N.Semenova, A.I.Sergachev

FSUE "SSC RF – IPPE", Obninsk, Russia

Abstract

The method of branching ratio $^{10}B(n,\alpha_0)$ to $^{10}B(n,\alpha_1)$ experimental investigation is described in this work The ionization chamber with Frisch grid, filled up with gas mixture of 95% Kr and 5% BF_3, was used in these experiments. Using of fast neutron beam profiling method allied with digital signal processing allowed us to select particles, appearing in fixed volume of working gas. This method of branching ratio measurement is almost free from systematical uncertainties, which is typical for experiment, where the solid target is used. The branching ratio $^{10}B(n,\alpha_0)$ to $^{10}B(n,\alpha_1)$ measurement results for neutron region from 4 to 7 MeV are presented in this work.

Introduction

^{10}B $(n,\alpha)^7Li$ reaction is related to standard nuclear reaction and is of great importance for criticality control of any reactor type due to usage of boron as neutron absorber. In addition, this reaction is very important for dosimetric (neutron detectors, individual dosimetry) and radiobiological (neutron capturing therapy) applications.

All modern national and regional bases of evaluated nuclear data are represented by experimental cross section data related to $^{10}B(n,\alpha)$ reaction, caused by neutrons from 4 till 7 MeV energy region, obtained by Bonner's group in 1961 [1]. In that experiment considerable mistakes could be caused by side effect that relates from angular distribution of α- particles. This distribution is undefined and may vary from one neutron energy to another.

A new method based on gaseous target usage and digital signal processing was used in present work. The usage of this method allowed us to decrease parasitic reaction influence significantly and to rectify many systematical uncertainties that are so typical for classical spectrometers. In current work The branching ratio $^{10}B(n,\alpha_0)$ to $^{10}B(n,\alpha_1)$ measurement results for neutron region from 4 to 7 MeV are presented in this work. Typical uncertainty of data obtained is approximately 5 %.

Experimental method

Pulse ionization chambers with solid targets set on the cathode are widely used for direct measurement that based on number of appearing α-particles estimation. This method allows us to get double-differential cross-section, though it has a few drawbacks: 1) number of investigating isotope nuclei number, that could be set as a solid target, is relatively small due to α-particles energy loss in the target and their full absorption in it; 2) the determination of accurate nuclei number of target is a very complicated problem especially in case of the stable element; 3) in case of working with high energy neutrons the detector itself (chamber electrodes, target backing, chamber working gas) becomes a powerful source of background

from α-particles, protons, γ-rays and so on, 4) chamber response function, especially in case of light nuclei as emitters, becomes complicated – observable α-particles energy depends on emission angle due to in-target energy loss and kinematics. The emission of both reaction products inside the sensitive volume of the chamber (particles leakage) becomes kinematically possible. Amendments (on kinematics, energy loss in layer) are different for events taking place in solid target and working gas components. Still classical method (of working with analog signals) does not allow us to separate signals that makes obtained spectrum analysis much more complicated, 5) all measurements should be carried out twice to get full cross section – for direct (α-particles is emitted in neutron movement direction) and back (α-particles is emitted in opposite to neutron movement direction) geometryдля.

It is known from literature [1], that BF_3 (enriched with ^{10}B isotope) was used as the target and injected in work gas (Ar). This allowed to increase target nuclei number in 100 times approximately and to make simple analysis of one dimensional spectra for events number determination. Really, both α-particle and residual nucleus contributed to anode signal amplitude for the event took place on work gas components. In this case summarized energy (E_{Sum}) doesn't depend on emission angle and will be:

$$E_{Sum}=E\alpha + E_R=En+Q, \quad /1/$$

where Eα - α-particles energy , E_R – residual nucleus energy , Q – reaction energy. Besides, anode specter is discreet and every peak can be associated with exact channel of the reaction, that takes place on such and such isotope. In the described works the whole chamber was irradiated by fast neutron beam. Big uncertainty in number of investigating isotope nuclei estimating ought to be limitation of these methods. Especially due to great contribution that events on these nuclei make to complete absorption peak. Side effect is related from chamber geometry and reaction products angle distribution and can't be dtermined with adequate accuracy. Significant background that prevents events number determination is caused by events distorted with side effect, events take place on construction elements, and events from protons appearing in working gas.

That is why it was decided to use neutron collimator and digital processing methods for separating fixed gas sell in the working volume. This sell was chosen so that particles produced in it could not reach chamber electrodes or escape from sensitive volume of the chamber. Collimator is forming a truncated cone sell inside working gas, which height is set by developed digital signal processing method. Finally, effective number of engaged in the reaction boron atoms could be estimated from comparison of three factors: sell volume, working gas pressure, concentration of investigating atoms in working gas. But for α_0/α_1 branching ratio determination it is not necessary to know the number of atoms. It is only enough to provide number of atoms equality. Meaning the atoms forming peaks correspond to investigating reactions.

Digital spectrometer based on ionization chamber with Frisch grid was created for solving this problem. Detector construction scheme is on Fig. 1.

Krypton Kr(95%) and boron trifluoride BF3(5%) gas mixture with pressure of 3 atmospheres (absolute pressure) was used as working a gas. This gas mixture was made with high accuracy (9.10±0.27% BF3, other – Kr) by Linde AG, Linde Gas Deutschland.

Presenting in working gas boron was also the target where investigating reaction (n,α) took place. Falling neutron beam was coincide with chamber symmetry axis. The beam itself was formed by copper collimator. Experimental setup scheme is on Fig. 2.

Cathode and anode signals from main chamber was amplified and get to the wave form digitizer input to be converted into digital view. The described process was ruled by

standard signal gathered from cathode signal. Using of such signals converting scheme allows us to keep digitized information about experimental events on PC hard drive for further digital signal processing analysis [2].

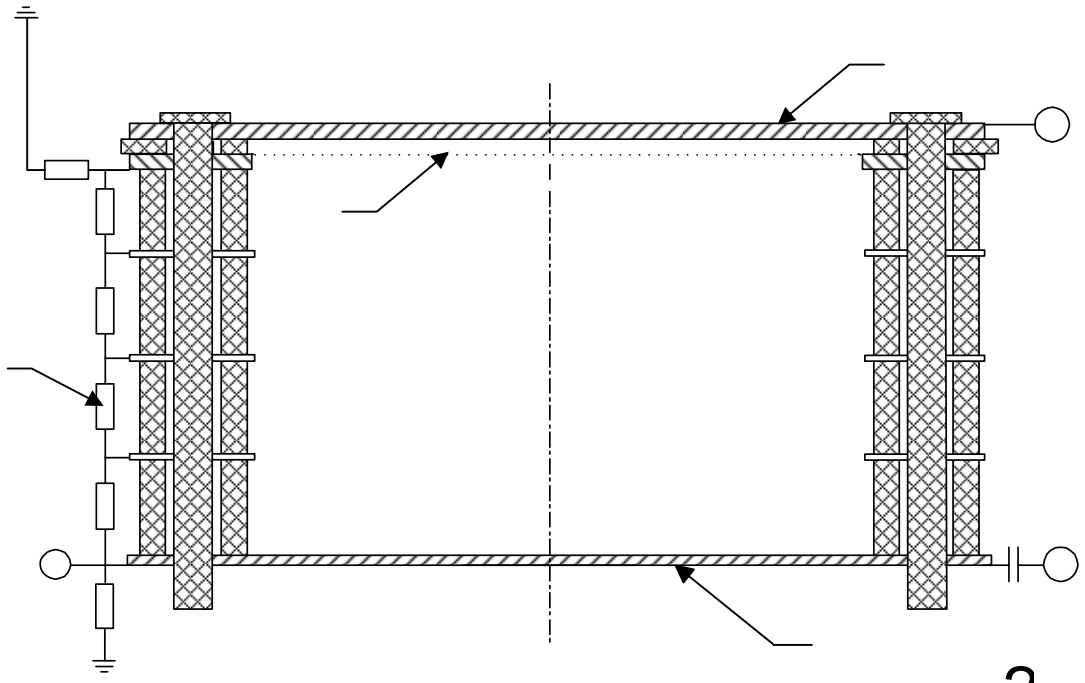

Figure 1. 1 – anode, 2 – Frisch grid, 3 – cathode, 4 – anode pin, 5 – cathode pin, 6 – voltage divider, 7 – guard electrodes

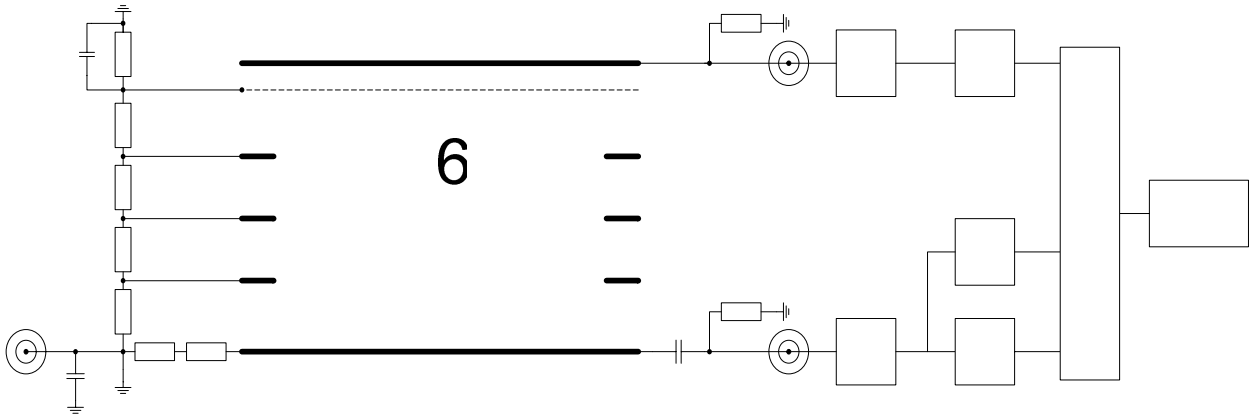

Figure 2. SPA – signal preamplifier, SA – signal amplifier, DU – delay unit, SD – signal digitizer, PC – personal computer.

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There are a few main parameters that we use: anode and cathode amplitudes, maximal electron drift time (that are the most distant from anode – the only beginning and the end of the track) TD=(TEA-TSC), and anode signal rising time (while anode collects electrons) TR=(TEA-TSA). Maximal drift time can be easily converted to distance between cathode and

track beginning (ending) at most distant from anode. Measurement of anode signal rising time allowed us to get the length of track projection on chamber axis. All further digital processing is based on these parameters.

Digitization of signals and their further digital processing allow us to develop superior method of particles registration and determination of their birth place in cathode – Frisch grid interval. Use of this method makes it possible to separate events take place in working gas from that take place on chamber electrodes and also from events distorted by side effect.

Results obtained

There are lots of data on (n, α_1) reaction channel determined by γ-rays. In case we know α_0/α_1 branching ratio, we can determine as α_0 cross section as full cross section. $^{10}B(n,\alpha_0)^7Li$ to $^{10}B(n,\alpha_1)^7Li$ branching ratio was obtained for 4 to 7 MeV neutrons. The data obtained both with nuclear data from ENDF/B-VII.0, JENDL 3.3, and also Bonner[1] and Sealock [3] data are shown on Fig. 3.

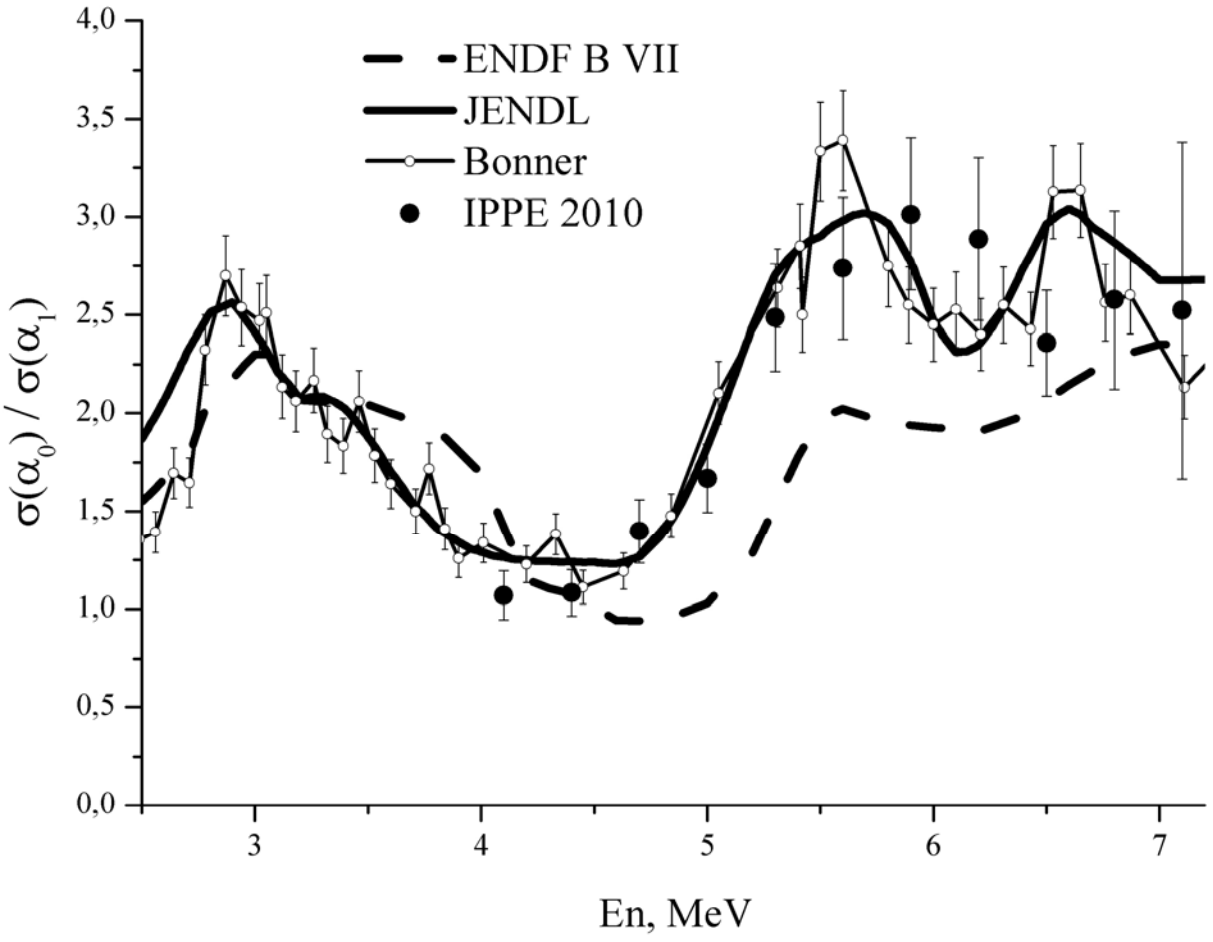

Figure 3. $^{10}B(n,\alpha_0)^7Li$ to $^{10}B(n,\alpha_1)^7Li$ branching ratio.

Conclusion

New method that makes it possible to use toxic and mordant gas BF_3 as working one was developed. This method is based on signal wave form digitizing allied with usage of ionization chamber working gas as a target. The fixed gas cell separation inside the sensitive volume of ionization chamber was used. The method allowed us to compensate electron loss due to their broad capture by very electronegative gas (BF_3). The energy resolution that permit us to separate α_0 and α_1 channels of reaction $^{10}B(n, \alpha)^7Li$ was obtained. The developed method of determining branching ratio of different reaction channels is almost free from statistical uncertainties. The branching ratio for neutron energy region from 4 to 7 MeV were obtained in this work. The obtained data is in a close fit with Bonner data and JENDL 3.3 estimation, but seriously (up to 30%) differs from ENDF B VII estimation.

All experimental and theoretical data that is obtained in this work can be used in different nuclear data libraries.

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References

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