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Investigation of the $^{15}N(p,n)$ Reaction for Use as a Neutron Source in Scattering Experiments

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Neutron scattering cross sections have been determined with high precision at PTB for a number of years. So far, primarily the D(d,n) reaction has been used for the production of neutrons. Due to the *Q* value of +3.27 MeV and the deuteron energies available at the cyclotron of the TOF spectrometer at PTB, neutrons in the energy range from 6 MeV to 16 MeV can be produced. For the planned measurements of inelastic scattering cross sections of $^{206,207}Pb$ in the 2 MeV to 4 MeV region, the implementation of a new neutron source is required.
The $^{15}N(p,n)$ reaction was investigated with special regard to its suitability as a neutron source for scattering experiments. Angular distributions were measured at selected energies. The influence of the target thickness on the energy resolution and the neutron yield was investigated. Preliminary scattering experiments were carried out in this energy region to identify potential problems in the application of the $^{15}N(p,n)$ reaction as a neutron source in scattering experiments.

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1. Introduction

Differential inelastic scattering cross section data for Pb are required for the modelling of spallation neutron sources. The ENDF and JENDL evaluations show large discrepancies in the energy range from 1 MeV to 6 MeV. As an example, this is shown for the 1st excited level of ^{207}Pb in Fig. 1. Improved experimental data can help to decide which evaluation is better suited for neutron transport calculations.

Neutron scattering cross sections have been determined with high precision at PTB for more than twenty years. Scattering measurements were carried out in the energy range from 6 MeV to 16 MeV using a D_2 gas target. The data analysis is based on a realistic simulation of the measured time-of-flight spectra. For these simulations, data of the D(d,n) neutron source are needed, i.e. angular distributions of the monoenergetic neutrons as well as emission spectra for the deuteron breakup reaction. For the planned measurements of inelastic scattering cross sections of ^{206,207}Pb in the 2 MeV to 4 MeV region, however, the implementation of a new neutron source is required.

The main advantage of a gas target, compared with a solid-state target, is that it offers a complete background subtraction by gas-in/gas-out difference measurements, as well as a simple variation of the target thickness by an appropriate selection of the gas pressure.

Usually, neutrons with an energy of few MeV are produced using the T(p,n) reaction. This reaction cannot be used at the PTB TOF spectrometer as a tritium gas target represents a radioactive hazard.

Due to its large negative Q value of -3.54 MeV, the ^{15}N(p,n) reaction is a very promising candidate for the production of monoenergetic neutrons in the required energy range using a gas target. However, the resonance structure of this reaction requires a restriction to selected energies for which the excitation function shows a maximum. A detailed investigation of the neutron-producing cross sections as a function of the incident proton energy and the neutron emission angle around these resonances is a prerequisite for its successful application as a neutron source.

In the present work, measurements of angular distributions are reported at selected neutron energies between 1.9 MeV and 5.3 MeV. The source properties were studied for several gas pressures and beam conditions. Furthermore, preliminary scattering measurements were carried out at one energy to identify potential problems in the application of the ^{15}N(p,n) reaction as a neutron source in scattering experiments.

2. The PTB TOF spectrometer

An overview of the PTB TOF spectrometer is given in Fig. 2. The cyclotron (denoted by CY) can rotate from -20° to +110° with respect to detector D1, resulting in measurement angles between 0° and 160°. Pulsed beams with a time width of 0.8 ns to 2.0 ns can be produced. The gas target T has a length of 3 cm. Its entrance foil consists of 5 µm Mo. The scattering sample S is located at the pivot point. The flight path is 12 m.

Some parameters of the cyclotron are listed in Table 1.

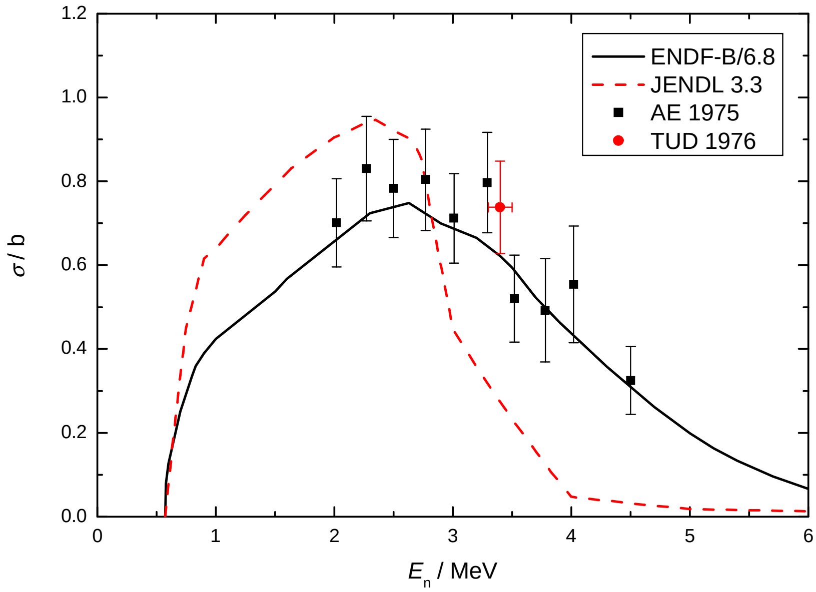

Fig. 1 Inelastic scattering cross section for the 1st excited level of ^{207}Pb [1].

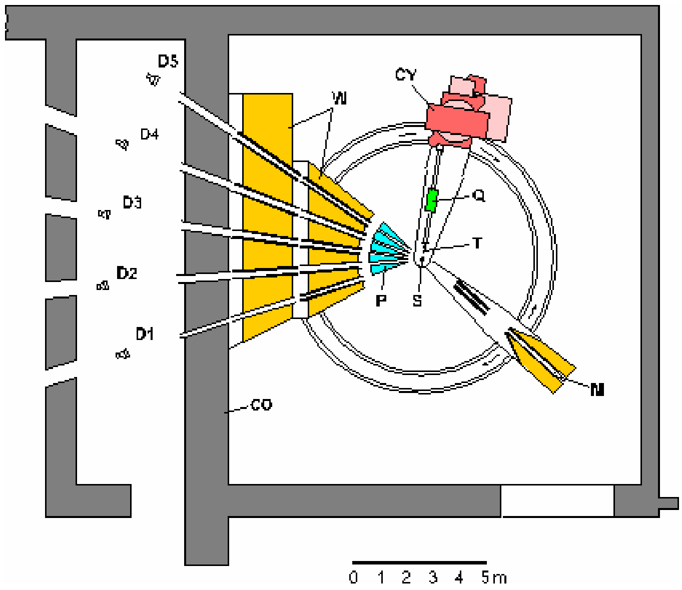

Fig. 2 Schematic view of the PTB TOF spectrometer.

Table 1 Parameters of the cyclotron.

projectiles	available energies	averaged beam currents
p	2 MeV to 19 MeV	0.5 μA to 1.2 μA
d	3 MeV to 13 MeV	0.5 μA to 1.2 μA
α	6 MeV to 26 MeV	0.2 μA to 0.4 μA

The detectors D1 (∅ 4″ × 1″), D2 – D5 (∅ 10″ × 2″) and the monitor detector M are NE213 liquid scintillation detectors sensitive to γ-rays and fast neutrons [2].

3. Properties of the ^{15}N(p,n) neutron source

In the long list of (d,n) and (p,n) reactions, the ^{15}N(p,n)^{15}O reaction appears as a promising candidate [3]. With the ^{15}N(p,n) reaction, monoenergetic neutrons in the energy range up to 5.7 MeV can be produced because of the high-lying 1st excited level E_1 = 5.18 MeV of ^{15}O [4]. The ^{15}N(p,n) reaction has a large cross section. A gas target allows background subtraction by gas-in/gas-out difference measurements as well as the easy variation of the target thickness by changing the gas pressure. ^{15}N is a stable isotope and the produced ^{15}O activity does not pose a radiological problem due to its short half life $T_{1/2}$ = 122 s. In contrast to this, the use of the T(p,n) reaction is not possible at the PTB TOF spectrometer because of the radioactive hazard.

A disadvantage of this reaction is the large energy loss $S = -dE/dx$ of protons in $^{15}N_2$ gas compared to that of deuterons in D_2 gas. A large energy loss causes a lowered neutron yield. In addition, due to the strong resonance structure of the reaction cross section, scattering experiments are only meaningful at selected energies. Differential cross sections (excitation function at 0°) for the ground state in ^{15}O are shown in Fig. 3.

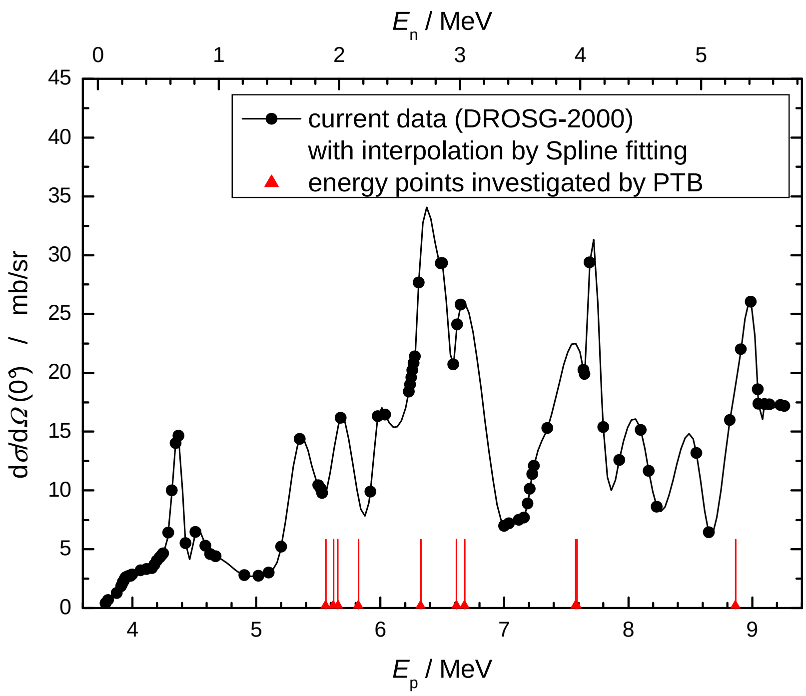

Fig. 3 Excitation function at zero degrees for the ^{15}N(p,n) reaction, taken from ref. [3].

4. Experimental Investigations

4.1 Influence of gas pressure on energy resolution and neutron yield

The analysis of scattering cross section measurements carried out at the PTB TOF spectrometer is based on realistic simulations of the TOF spectra. These simulations are carried out with the Monte Carlo code STREUER [5]. Fig. 4 shows such simulations for different gas pressures for a ^{nat}Pb sample. The simulation for a gas pressure p = 1000 hPa shows a larger neutron yield, but the 1st excited level of ^{206}Pb and the 2nd one of ^{207}Pb (ΔE = 95 keV) cannot be separated from each other. At a gas pressure of p = 400 hPa, the levels can be well separated, but the better energy resolution is accompanied by a lower neutron yield.

In addition to calculations, the influence of the gas pressure on the energy width was also investigated experimentally. Fig. 5 shows the results for $E_n \approx 4.2$ MeV. At these experimental conditions (flight path, time resolution, neutron energy), the width of the measured peak in the TOF spectrum is dominated by the energy spread of the neutrons. If the gas pressure is smaller than about 200 hPa, the energy spread is determined by the energy straggling in the entrance foil of the gas target [6]. A gas pressure of p = 400 hPa to 500 hPa is a good compromise for scattering experiments with a ^{nat}Pb sample. In scattering experiments with the D(d,n) reaction a gas pressure of p = 1800 hPA to 2000 hPa could be used because in this case the time spread of the neutron pulses dominates the time resolution in the TOF spectra. Here, the energy spread of the neutron pulses plays a minor role. The low gas pressure required in scattering experiments using the ^{15}N(p,n) reaction leads to a significantly smaller neutron yield. Therefore it is estimated that reliable neutron cross section measurements using the ^{15}N(p,n) reaction are limited to the differential cross sections dσ/dΩ above 10 to 20 mb/sr.

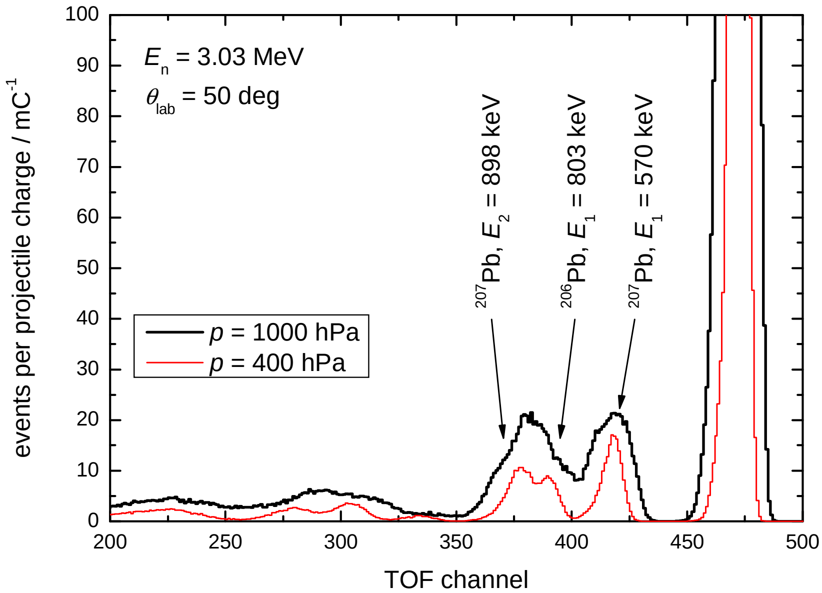

Fig. 4 Simulation of TOF spectra for a ^{nat}Pb sample with the Monte Carlo code STREUER.

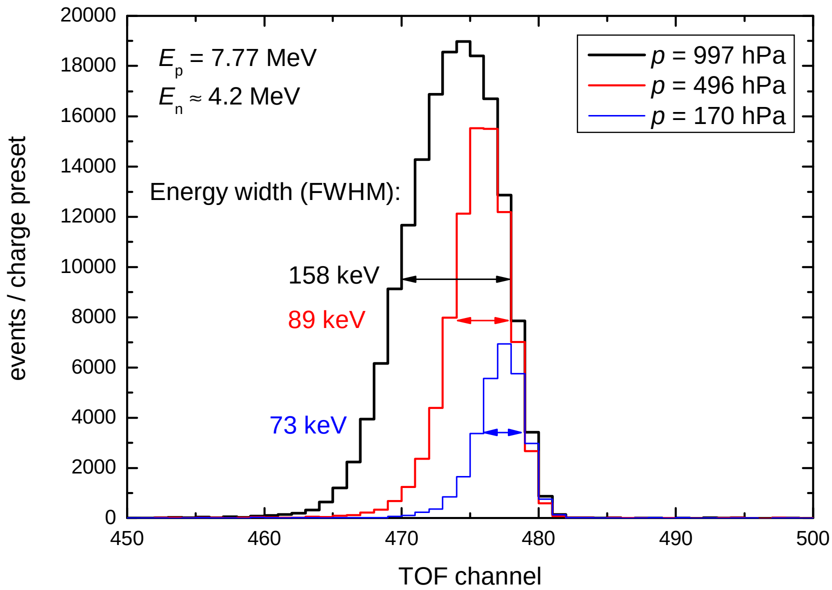

Fig. 5 Influence of the gas pressure on the energy width of neutron peaks in TOF spectra.

4.2 Measurement of angular distributions of the ^{15}N(p,n) reaction at selected energies

Due to the resonance structure of the ^{15}N(p,n) cross sections, scattering experiments are meaningful only at certain energies, i.e. at energies where the cross section is large and the angular distribution is strongly forward peaked. Angular distributions were measured at E_p = 5.56, 5.62, 5.66, 5.83, 6.33, 6.61, 6.68, 7.58, 8.87 MeV. The evaluated data (DROSG-2000 [3]) and the newly measured angular distributions permit the selection of optimum energies for scattering experiments as well as the selection of a good position for the monitor detector, i.e. to select an angle with a small gradient $d\sigma/d\theta$.

Fig. 6 shows, for comparison, two of the measured angular distributions as well as cross section data having been taken from DROSG-2000.

4.3 Test of scattering experiment

Preliminary scattering measurements were carried out for a polyethylene- and a ^{nat}Pb-sample at an incident neutron energy E_n = 3.03 MeV to identify potential problems in the application of the ^{15}N(p,n) reaction as a neutron source in scattering experiments. Fig. 7 shows TOF spectra for gas-in and gas-out measurements at an scattering angle in the laboratory system θ_{lab} of 50°. The peaks belonging to the ^{206}Pb(n,n$_1$), ^{207}Pb(n,n$_1$) and ^{206}Pb(n,n$_2$) neutron group, respectively, are clearly visible. Although the TOF peaks seem to be somewhat broader than it would have been expected from the calculation (see Fig. 4), a separation of the overlapping ^{207}Pb(n,n$_1$) and ^{206}Pb(n,n$_2$) peaks should be possible. Due to the differential neutron yield at zero degrees $dY/d\Omega(0°)$, which is about a factor 10 to 20 lower than that for the D(d,n) reaction, much longer measurement times are required to achieve good counting statistics. The measurement time was approx. 15 h for gas-in and 5 h for gas-out measurement, respectively.

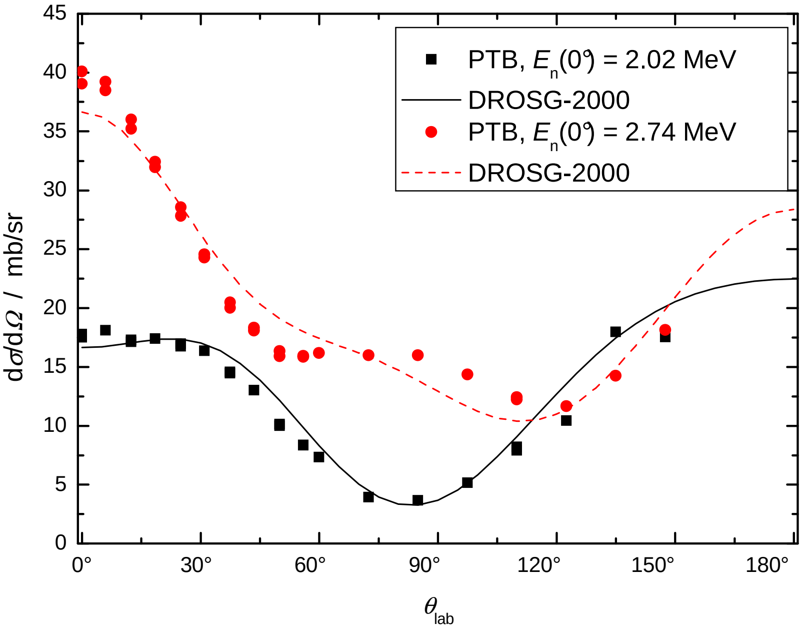

Fig. 6 Measured angular distributions of the ^{15}N(p,n) reaction for E_p = 5.62 MeV ($E_n(0°)$ = 2.02 MeV) and E_p = 6.33 MeV ($E_n(0°)$ = 2.74 MeV). Preliminary data. The statistical uncertainties are smaller than the size of the data points.

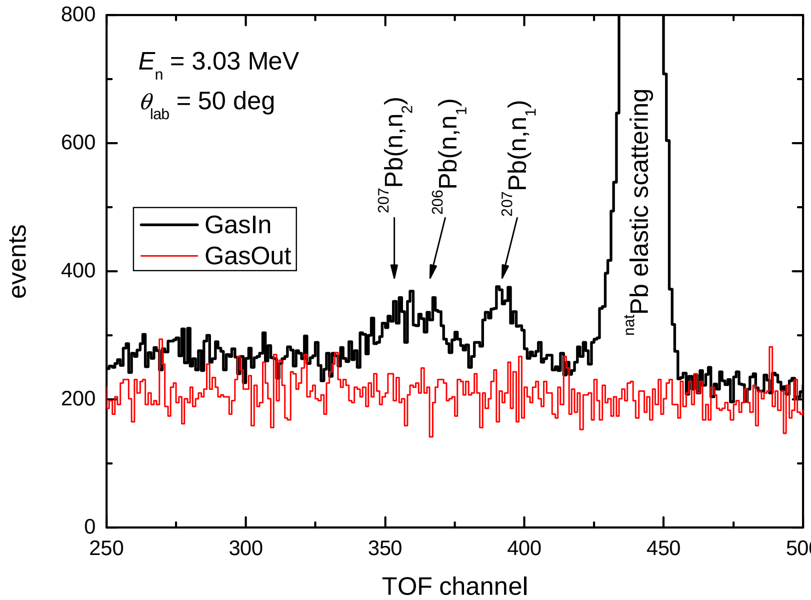

Fig. 7 TOF spectra from a preliminary scattering experiment using a ^{nat}Pb sample.

5. Conclusions

The influence of the target thickness, which is mainly influenced by the gas pressure, was investigated to find out the optimal compromise between energy resolution and neutron yield. Angular distributions of the neutron-producing reaction were measured at selected energies. The evaluated data (DROSG-2000) and the results of our measurements allow the optimum energies for scattering experiments to be chosen. Preliminary scattering experiments were carried out to test the ^{15}N(p,n) reaction as a neutron source. Although the neutron yield is one order of magnitude lower than for the D(d,n) reaction, the new neutron source can be used in scattering experiments.

References

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