STUDY OF (n,α) REACTION CROSS SECTION ON A SET OF LIGHT NUCLEI.

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Abstract

An experimental setup based on an ionization chamber with Frisch grid and waveform digitizer was used for (n,α) cross section measurements. Use of digital signal processing allowed us to select a gaseous cell inside the sensitive area of the ionisation chamber with high accuracy. This kind of approach provides a powerful method to suppress background from detector components and parasitic reactions on the working gas. The new method is especially interesting for the study of reactions on elements for which solid target preparation is difficult (e.g. noble gases). Additionally it has the advantage of an accurate determination of the number of nonradioactive nuclei in the selected gas cell. In the present experiments a set of working gases was used, which contained admixtures of nitrogen, oxygen, neon, argon and boron. Fission of ^{238}U was used as neutron flux monitor. The cross section of the (n,α) reaction for ^{16}O, ^{14}N, ^{20}Ne, ^{36}Ar, ^{40}Ar reactions were measured for neutron energies between 1.5 and 7 MeV.

Experimental set up

A new spectrometer based on an ionization chamber with Frisch grid and digital signal processing [1] and a fast neutron beam profiling technique [2] were developed at IRMM in collaboration with IPPE. It allows to measure the cross section of the (n,α) reaction on constituents of the working gas with high precision [3]. This type of set up was later also built at IPPE and in comparison with the IRMM spectrometer a set of improvements were achieved. Specifically the new setup allows to reliably suppress background of recoil protons in hydrogenous working gases, determine the directionality of α–particle emission (in or opposite to the neutron beam direction), work with electronegative detector gases maintaining the possibility of good energy resolution, measure for a series of light gases the pulse height defect (PHD) which can be quite large. A new method for PHD compensation was also developed. Additionally the new setup allows the development of a novel method for the measurement of the angular distribution of the reaction products. All these improvements allowed us to extend the range of working gases and increase the number of elements which were successfully investigated at IPPE.

The block diagramme of the new setup, shown in figure 1, and the working principle of signal digitisation and storage are identical to those of the IRMM setup [1, 3]. They are presented here again taking into account that some hardware components are different in the two setups. The detector consists of two ionisation chambers. The main ionization chamber with Frisch grid (GIC) was used as detector for (n,α) reaction products. A parallel plate chamber which contains a thin solid ^{238}U layer was used as neutron flux monitor. The uranium sample was installed on the common cathode of the two chambers in a back-to-back geometry to the main chamber. In this way the neutron flux was measured very close to the position of the gas target simultaneously with the reaction under investigation.

The diameter of the electrodes was 12 cm, the distances cathode-to-grid and grid-to-anode were 40 and 3 mm, respectively. The axis of the neutron beam coincided with the symmetry axis of the GIC. Different isotopes existing in the working gas of the ionisation

chamber can contribute to the anode and cathode signals. The anode signal of the GIC and the common cathode signal at the exit of the corresponding charge sensitive preamplifiers were linearly amplified (without shaping) and fed to the inputs of a two channel waveform digitiser (WFD, LeCroy 2262, 10 bit). The digitisation rate was 80 MHz or equivalently a signal sample was taken every 12.5 ns. The required trigger for the WFD operation was obtained by splitting the cathode signal after the preamplifier. The WFD was operated in the so called pre-trigger mode.

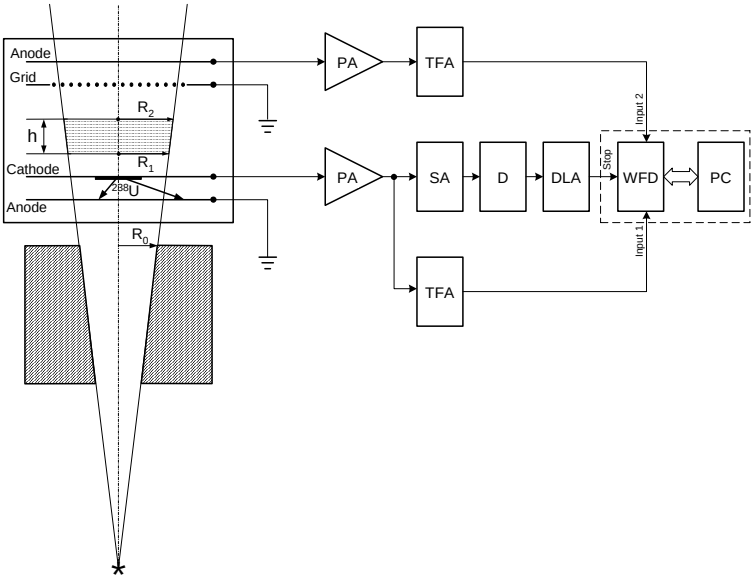

Figure 1. Block diagramme of the experimental setup. PA – preamplifier, TFA – Timing filter amplifier, D – discriminator, SA – spectroscopy amplifier, DLA – Delay line amplifier, WFD – Waveform digitizer, PC – Personal computer.

Digitization was started by the DAQ (data acquisition programme) and the WFD memory was continuously filled till a trigger occurred. At this moment the memory contents were frozen and sent for storage to the PC hard disk. Typical digitised signals of an α particle and a fission fragment can be seen in figure 2. They contain all needed information for the production of clean α particle and ^{238}U fission fragment signatures, which is a condition for accurate cross section measurements.

Digital signal processing of the recorded anode and cathode waveforms event-by-event provides information about amplitude, starting point, and end point for each signal. Joint analysis of this parameters allows to determine the following physical parameters for each event: total kinetic energy of the reaction products; full electron drift time (T_d) which can be transformed to a spatial coordinate in the interelectrode space where the reaction took place; anode signal rise time (T_r) which can be used to obtain the emission angle of the light charged particle in the lab coordinate system; particle type and emission directionality from the shape of the anode signal. The above information allows to localise the birth place of the detected particles and effectively suppress background from the surrounding detector components (electrodes and chamber wall). Additionally corrections can be made to the measured energy of the reaction products in order to compensate for electron loss on electronegative atoms and pulse height defect.

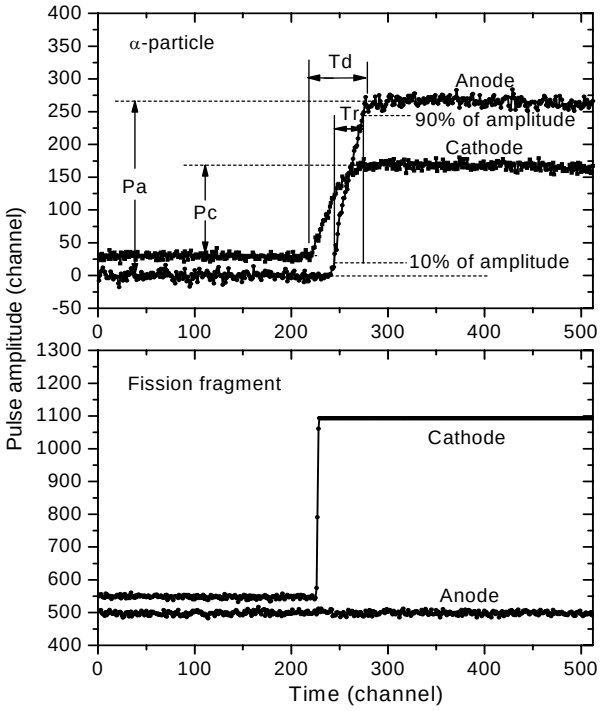

Figure 2. Examples of signals of the main and monitor chambers

There is a number of advantages using gas targets in cross section measurements instead of solid ones. The number of target atoms can be quite large. For 3% admixture of the concerned isotope in the working gas a 100 times larger number of atoms can be obtained in comparison with a conventional solid target situated on cathode d. There is freedom in the determination of an isolated target volume inside the detector's sensitive volume. This allows to achieve effective suppression of background from the surrounding detector components (electrodes and chamber wall) as mentioned above. Most of the light gases are not radioactive and the determination of the number of atoms is difficult. For a series of elements (e.g. the noble gases Ne, Ar and other) solid target preparation is not an easy task due to their physical and chemical properties. Use of gaseous targets solves thisproblem. The number of atoms in a gaseous target can be determined using simple laws for ideal gases. In a gaseous target with suitable pressure both reaction products are stopped within the effective volume and the sum of their kinetic energy is measured. Under these conditions the problems of passive energy loss in the target material and the particle leaking effect [4] are eliminated. Furthermore the energy deposited in the working gas does not depend on the emission angle of the detected particles so that the response function is linear to a good approximation. The detector registers particles in the full 4π solid angle and cross sections can be measured in one experiment without any event losses for emission close to 90^{o}. For solid targets two measurements are needed, one for forward and one for backward particle emission with the additional requirement for corrections near 90^{o}.

Fast neutrons were produced via the T(p.n) and D(d,n) reactions at the IPPE EG-1 accelerator. Solid deuterium and tritium targets with thicknesses from 1 mg/cm^2 to 2 mg/cm^2 were used.

The digitised fission fragment signals were used to generate a pulse height spectrum with a clean separation between neutron induced fission and natural α-particle decay. The settings of the cathode amplifier were optimised for α-particle detection in the GIC chamber. With these amplifier settings the fission fragment signals were saturated. This was not a problem because the purpose of the neutron monitor was to record only the number of fission events and not their real energy distribution. The total number of fission events was obtained by properly extrapolating the fission fragment spectrum to zero pulse height.

Results

a) Experimental investigation of the $^{16}O(n,\alpha)$ cross section.

In this experiment 96.84%Kr+3.16%CO_2 gas mixture was used. The gas manufacturer (Linde) guaranteed the number of oxygen atoms with a precision of better then 3%. Oxygen was as target for the (n,α) reaction study. Specifically the cross section of the $^{16}O(n,\alpha_0)$ reaction channel in the neutron energy range 1.7 – 7 MeV was measured. The result is shown in figure 3. The IPPE data set is in good agreement with the earlier measurement at IRMM [3] and the Harissopulos et al. data [5] below approximately 5.5 MeV.

In the present work the energy region 5.2-6.2 MeV was investigated in more detail than in the earlier work [3]. Particularly the new data show a neutron energy point to the left of which there is good agreement between our experiment and the ENDF B VII evaluation and to the right of it the existence of a large, 180% discrepancy.

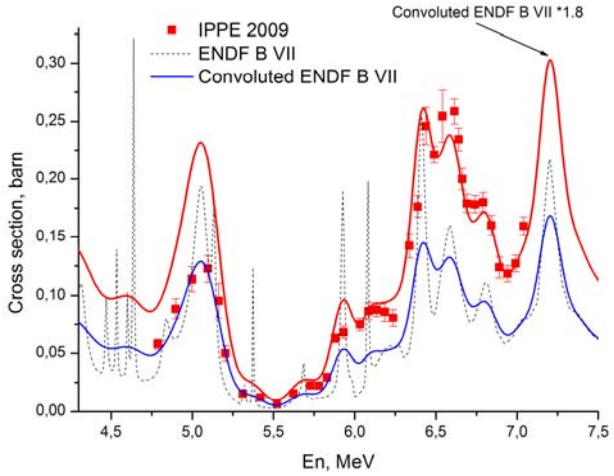

Figure 3. Energy dependence of $^{16}O(n,\alpha_0)$ cross section.

b) Experimental investigation of the $^{14}N(n,\alpha)$ cross section.

In this measurement a 97%Kr+3%N_2 gas mixture was used. The precision for the number of nitrogen atoms (3%) was taken from the specifications of the gas producer. Nitrogen present in the working gas was the target for the (n,α) reaction. It was also assumed that nitrogen as small detector gas admixture increases the electron drift velocity. Investigation of the $^{14}N(n,\alpha_0)$ $^{14}N(n,\alpha_1)$ and $^{14}N(n,\alpha_2)$ reaction channels in the neutron energy region 1.7 – 7 MeV was performed. The result is shown in figure 4. Our results are in good agreement with the ENDF VII evaluation and the Gabbard et al. data [6] in the energy regions 1.7-3 MeV and 6-7 MeV , but there is a large discrepancy in the energy region 4-6 MeV which can reach a factor of 3 and more . A possible explanation of this discrepancy could be

found by analysis of the energy spectra. In the energy region of the discrepancy the cross section rises steeply from low values above 5 MeV to large values down to 4 MeV. Under these conditions a small number of background neutrons can produce a lot of α particles. If the detector energy resolution is not sufficiently high this background component can contribute to the real events produced by the main group of neutrons so that larger cross sections than the real values can be obtained.

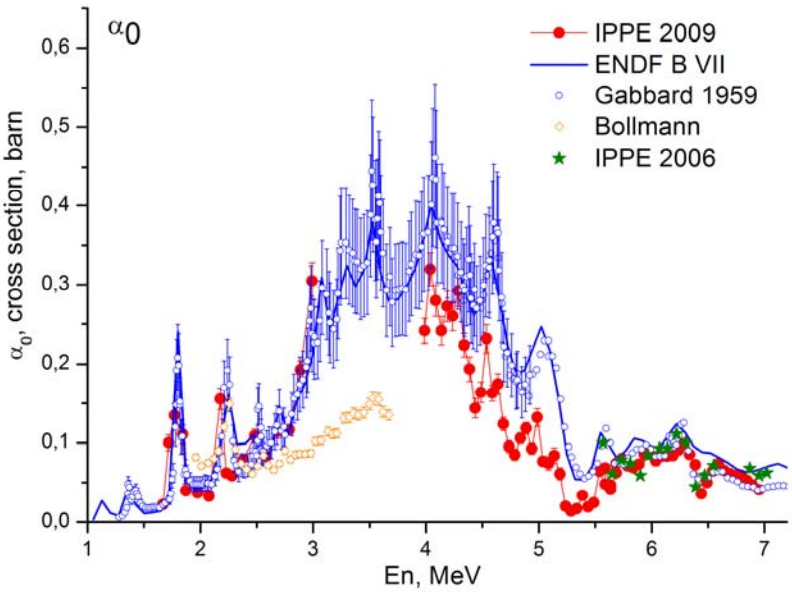

Figure 4. Energy dependence of $^{14}N(n,\alpha_0)$ cross section.

c) Experimental investigation of $^{20}Ne(n,\alpha)$ cross section.

In this measurement a 73.72%Kr+22.3%Ne+3.98%CO_2 gas mixture was used. The gas manufacturer (Linde) guaranteed the number of neon atoms with a precision better than 3%. Neon was the target for the (n,α) reaction. Carbonic acid was added to increase the electron drift velocity. Cross section data for the $^{20}Ne(n,\alpha_0)$, $^{20}Ne(n,\alpha_1)$, $^{20}Ne(n,\alpha_2)$ and $^{20}Ne(n,\alpha_3)$ reaction channels in the neutron energy range 4–7 MeV were produced. Partial cross sections for the $^{20}Ne(n,\alpha_0)$, $^{20}Ne(n,\alpha_1)$, $^{20}Ne(n,\alpha_2)$ and $^{20}Ne(n,\alpha_3)$ cannels were measured for the first time. A large pulse height defect was observed. The response function has "V type" shape. The right branch corresponds to α particles emitted in the neutron beam direction. The left branch corresponds to α particles emitted in opposite direction to the neutron beam. A similar effect was found in the work of Bell et al. [7]. They only measured the sum of the cross sections of the (n,α_0) and (n,α_1) channels . To make a comparison we added the partial cross sections for the (n,α_0) and (n,α_1) channels as shown in figure 5 together with the data of Bell et al. [7]. There is a large discrepancy between the latter [7] and our data of up to a factor of 3.

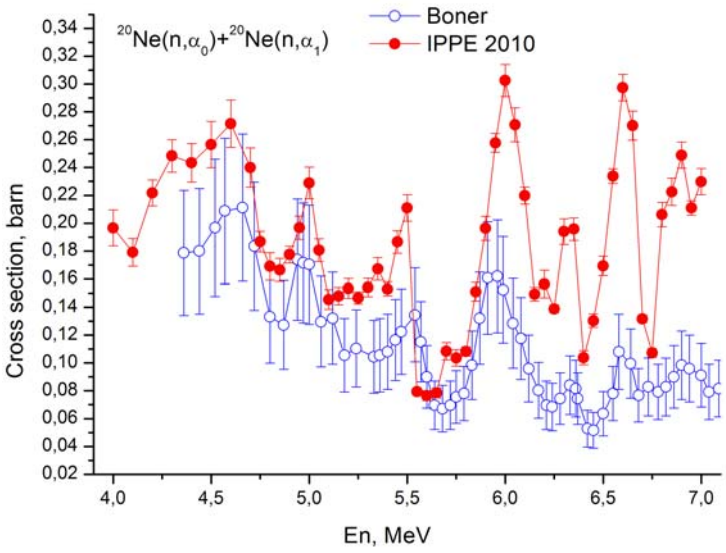

Figure 5. Energy dependence of 20Ne(n, α0+α1) cross section.

d) Experimental investigation of ^{36}Ar(n,α) u ^{40}Ar(n,α) cross section.

In this measurement a P10 (90%Ar+10%CH_4) gas mixture was used. The gas manufacturer (Linde) guaranteed the number of argon atoms with a precision better than 3%. Argon in the working gas was assumed to be the target in which the investigated (n,α) reaction took place. In this experiment we could not use carbonic acid to increase the electron drift velocity because the Q-value of the ^{16}O(n,α$_0$) reaction is close to that of ^{40}Ar(n,α$_0$). We used methane instead but in this case there were a lot of recoil protons inside the working gas. Using digital methods for pulse shape analysis allowed us to separate proton and α-particle signals. Investigation of the ^{36}Ar(n,α$_0$), ^{36}Ar(n,α$_1$) and ^{40}Ar(n,α$_0$) reactions in the neutron energy region 1.5–7 MeV was made. Some of the results are shown in figures 6 and 7 for the full and high energy ranges, respectively.

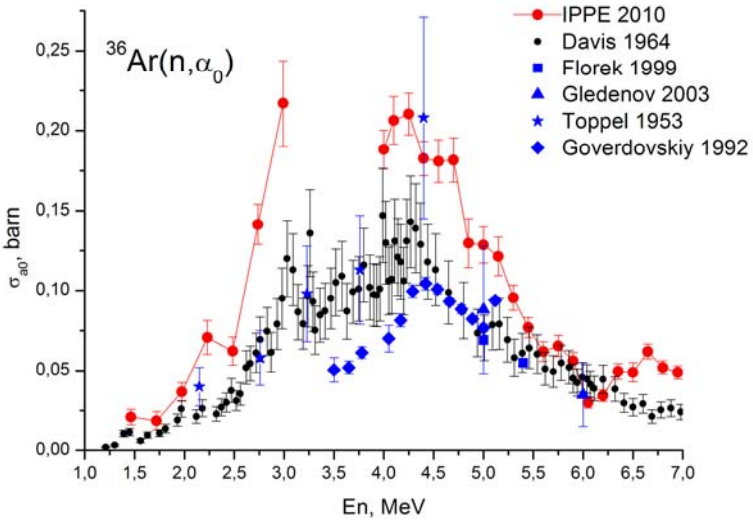

Figure 6. Energy dependence of ^{36}Ar(n,α$_0$) cross section.

In the full energy region we observed a large discrepancy (up to a factor of 2) between our cross sections and the data of Davis et al. [8]. In contrast to other reactions which were investigated by the latter $^{36}Ar(n,\alpha_0)$ has a large positive Q-value. For this reaction the wall effect is much larger than it was for the other reactions studied by Davis et al. It seems that the theoretical calculation of the wall effect correction [8] was not precise enough.

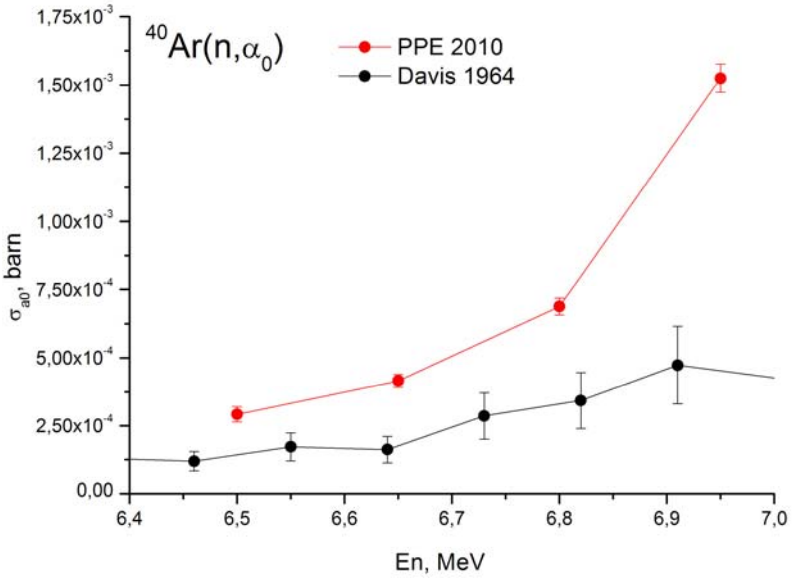

Figure 7. Energy dependence of $^{40}Ar(n,\alpha_0)$ cross section.

Conclusion

It was demonstrated that a new digital spectrometer with gaseous target allows to measure (n,α) cross sections with high precision. Measurement results show that in spite of a long time history of investigation of light elements the uncertainty of the cross section is currently of the order of few ten or hundred percent.

Common conclusion of this work is that existing evaluations for (n,α) cross sections can not describe the real situation. To solve this problem there is a real need for new experimental data and new evaluations.

References

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