REVISTA MEXICANA DE FÍSICA S**53** (3) 74–77 FEBRERO 2007

Use of the associated particle technique for the measurement of neutron cross sections at small angles

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Recibido el 2 de marzo de 2006; aceptado el 18 de agosto de 2006

Even when much nuclear data has been generated during the last 50 years, the need and demand for scattering information of fast neutrons is still a present matter for basic science and technology. Attending its application, it is relevant to observe that, in general, the data is scarce for small angle scattering of (MeV) neutrons for elements of technological importance such as V, Ti, Fe, Cu, Zr, etc. With this in mind, we have contemplated the measurement of neutron scattering cross sections, at angles < 40 degrees for some of these elements, using the associated particle technique, and for which a versatile (thin wall) vacuum scattering chamber is to be constructed. Some preliminary results concerning the scattering of 2.2 MeV neutrons by natural Pb, using the D(d,n)3He reaction as a source, are presented.

Keywords: Neutron cross sections; associated particle technique.

Aún cuando durante los últimos 50 años se ha producido mucha información nuclear, la demanda y la necesidad de información de dispersión de neutrones rápidos sigue presente para la ciencia básica, como para la tecnología. En atención a sus aplicaciones, es de relevancia observar, en general, la escasez de datos experimentales -a pequeños ángulos- de muchos elementos de interés tecnológico, como V, Ti, Fe, Cu, Zr, etc. Atendiendo esta aplicación, hemos contemplado la medida de secciones de dispersión de neutrones a ángulos $< 40^\circ$ para algunos de estos elementos, usando la técnica de la partícula asociada, y también para lo cual se plantea la construcción una nueva cámara de dispersión al vacío (con ventana delgada). Se presentan, sobre todo, algunos resultados (preliminares) de la dispersión de neutrones de 2.2 MeV sobre plomo natural, usando la reacción D(d,n)3He como fuente.

Descriptores: Secciones transversales para neutrones; técnica de la partícula asociada.

PACS: 29.25Dz; 29.30Hz

1. Introduction

Fast neutron scattering information is still strongly demanded for fundamental nuclear physics and astrophysics, as for diverse applications concerning cosmic radiation, material science, detector and electronic devices and nuclear reactor technology. Our research group at ININ has been working for more than 20 years in applications related to fast neutron physics supported by a tandem accelerator (EN model, HV Eng. Corp., Mass., USA).

In recent years a strong collaboration has been established between the accelerator (neutron) group at ININ and an experimental nuclear research group at IFUNAM in topics of common interest, including neutron physics. In this last regard, we agreed to measure and generate data related to neutron scattering by elements of technological importance (like V, Ti, Fe, Cu) at a few MeV energies and small angles ($\leq$ 40 degrees). At this point, we have performed some preliminary measurements of 2.2 MeV neutron scattering on a natural lead sample, using the associated particle technique (APT) based on the D(d,n)3He reaction, and completed the design of a new scattering chamber, which are presented.

2. The associated particle technique

This work (actually in progress) is motivated by the fact that even when angular distributions of neutron scattering were profusely measured some decades ago, the lack of experimental points, for many elements, at small angles ($<$ 25 degrees), is evident. This had to do with some technological limitations related to detector and electronic developments, restricted usually by the need to use heavy shieldings (slabs, shadow cones, collimators) to hide the scintillators from the source neutrons and to reduce the background radiation [1]. Using time of flight (TOF) methods, accelerator sources at low energies ($\approx$ 0.1 - 15 MeV range) are commonly provided by reactions such as 7Li(p,n)7Be, T(p,n)3He, D(d,n)3He and T(d,n)4He [2].

The associated particle technique (APT) is a well known method [3-4], that profits the time and space correlation between conjugated particles in two body nuclear reactions. In our case, the use of the D(d,n)3He reaction and a fast coincidence (time of flight: TOF) between the neutron and its associated 3He nucleus, permits to "select" the common events of the pair of detectors employed to record these particles (an organic scintillator and a solid state silicon surface barrier detector, respectively). Moreover, a mono energetic neutron beam of known flux can be obtained if appropriate target and kinematical conditions are used, described in detail elsewhere [5-6].

To asses the most relevant features of this method using the D(d,n)3He reaction, we present in Figs. 1 and 2 a simplified drawing of the experimental arrangement and the electronic block diagram, respectively, to be used (for three neutron detectors), taken from Ref. 6, where further details are given. Basically, as it was discussed [5-6], upon using a thin (100 to 300 μg/cm^2) deuterated polyethylene target, the neutron beam profile is a function of the deuteron beam spot on the target, the associated particle's solid angle and, in the horizontal plane, of the kinematics of the d+d reaction. In order to validate the neutron cone characteristics, beam profile measurements are taken in the horizontal and vertical planes by scanning the scintillators position along the (mean) conjugated angles. This is also necessary to obtain an absolute efficiency calibration of the scintillator (assuring that the neutron cone is properly covered by the detector), if the 3He

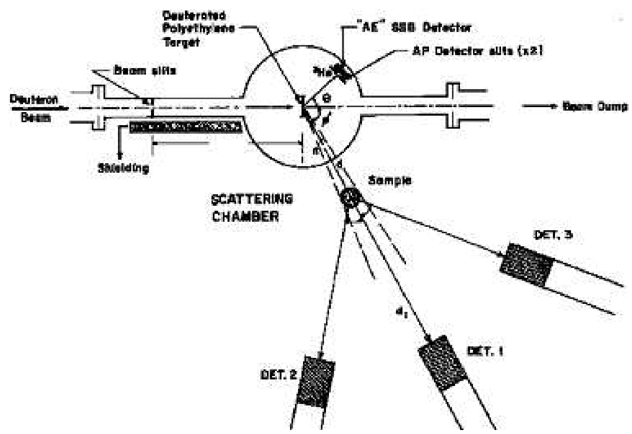

FIGURE 1. Typical experimental layout of the vacuum scattering chamber, showing the arrangement for three neutron detectors (NE-102A) and a (common) "ΔE" solid state silicon surface barrier detector (SSBD) employed in the APT with the D(d,n)3He reaction. The specific Pb scattering conditions, are given in the text, for which we employed only one scintillator.

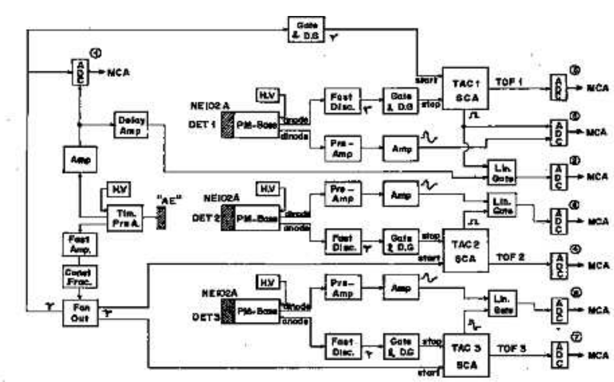

FIGURE 2. Electronic block diagram for a typical associated particle technique spectroscopy system, comprising three neutron detectors for neutron scattering measurements using the D(d,n)3He reaction. It is worth to note, that a common timing signal from the "ΔE" charged particle detector (with 3He events) are used as a "start" input at each time to amplitude converter (TAC) and, through a "stop" input from each scintillator, a time of flight (TOF) spectrum is obtained.

events are unambiguously resolved in the charged particle spectrum, which then is simply given by the relation:

$$\text{efficiency} = (\text{TOF\_counts})/(\text{3He\_counts}).$$

3. Experimental: scattering of 2.2 MeV neutrons by Pb

With the purpose of testing our experimental arrangement and give support to our proposal, we decided to perform some small angle measurements of neutron scattering by a natural lead sample, using the associated particle technique (APT) and the D(d,n)3He reaction, looking to compare our results with previous data.

After preparing some deuterated polyethylene targets [7], a 170 μg/cm^{2}one was mounted on a rotating target assembly at the center of a small scattering chamber (20.3 cm diameter) dedicated to fast neutron spectroscopy using the APT [5-6]. Using a 2 MeV deuteron beam collimated to approximately 2 mm at the entrance port of the chamber, the scattered ^{3}He ions coming from the D(d,n)^{3}He reaction were recorded by a 15 μm thick silicon surface barrier detector (SSBD) located at 7 cm from the target and 25° with respect the incoming beam direction. To reduce the aperture of the tagged neutron cone, the ^{3}He particles were captured through a small rectangular slit in front of the detector (1.5 mm wide, 2.5 mm high). Under these conditions, we calculated to have 2.20 $\pm$ 0.06 MeV neutrons, emerging at 120$\pm$ 1.5° degrees though the thin chamber window. By placing a 1.70 cm thick natural Pb sample (2 cm wide, 3 cm high) at a mean distance of 11.2 cm just outside the chamber, based on calculations, we would expect a 6 mm (horizontal) by 4 mm (vertical) tagged neutron spot on the sample.

After performing rough horizontal and vertical scannings of the tagged neutron beam with an NE-102A scintillator (50 mm diameter, 76 mm long), set at 15 cm from the polyethylene target, we confirmed our estimates within the experimental errors. Previous to the scattering measurements, the scintillator was positioned further away, at 57.9 cm from the polyethylene target, and another horizontal scan was taken, serving the propose of calibrating the detector and as a mean to correct small angle scattering points due to direct source neutrons. In agreement with an appropriate bias imposed (through the scintillator's constant fraction discriminator), we obtained an efficiency of 0.243 $\pm$ 0.013 (counting uncertainty) for the NE-102A scintillator at this energy, 2.2 MeV.

Once that the sample was fixed in position and aligned intercepting the tagged neutron beam, at 11.2 cm from the neutron source and 46.7 cm from the front face of the scintillator, a transmission measurement was taken to obtain the total cross section. The measured transmission turned out to be 68.6%, and after some calculations, the total cross section obtained was 6.7 $\pm$ 0.4 barn (without taking into account multiple scattering). This mean value is quite close to reported and compiled total cross measurements given elsewhere [8].

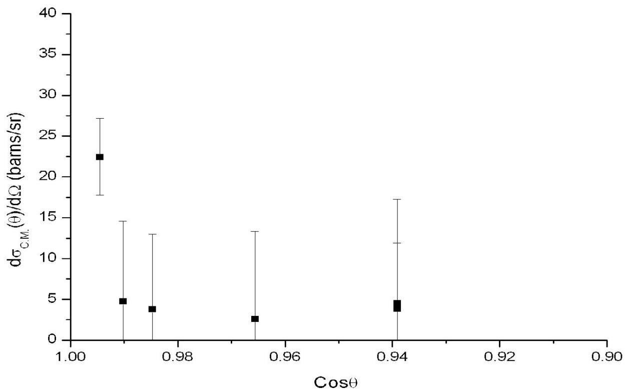

FIGURE 3. Experimental low angle (4 - 20 degrees) cross sections for Pb scattering of 2.2 MeV neutrons obtained using the APT and the D(d,n)3He reaction, given for the center of mass system. These (preliminary) data points are accompanied by estimated error bars.

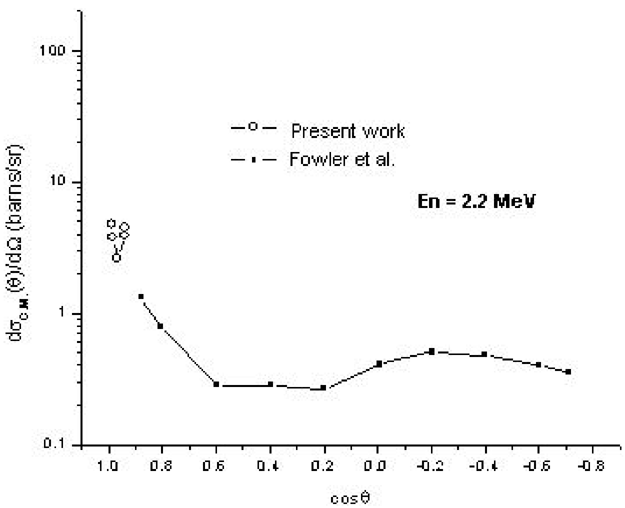

FIGURE 4. Experimental cross section data points for 2.2 MeV neutrons scattered by Pb obtained in this work, accompanied by larger angle values of a publication of J.L. Fowler and E.C. Campbell given in Ref. 9.

These (preliminary) data points, complemented with larger angle values from a publication of J.L. Fowler *et al.* [9], are shown in Fig. 4, where a reasonable matching is obtained.

The estimated differential cross sections, taken at (one-sided) laboratory angles of 6, 8, 10, 15 and 20 degrees with respect to the neutron beam direction and the Pb target, are shown in Fig. 3 with (approximate) statistical uncertainties added. These crude values were not corrected by any polarization effects, and a rough correction was applied to the experimental points due to additional counts from direct source neutrons, by taking into account the scintillator's diameter and position , and the tagged neutron's aperture.

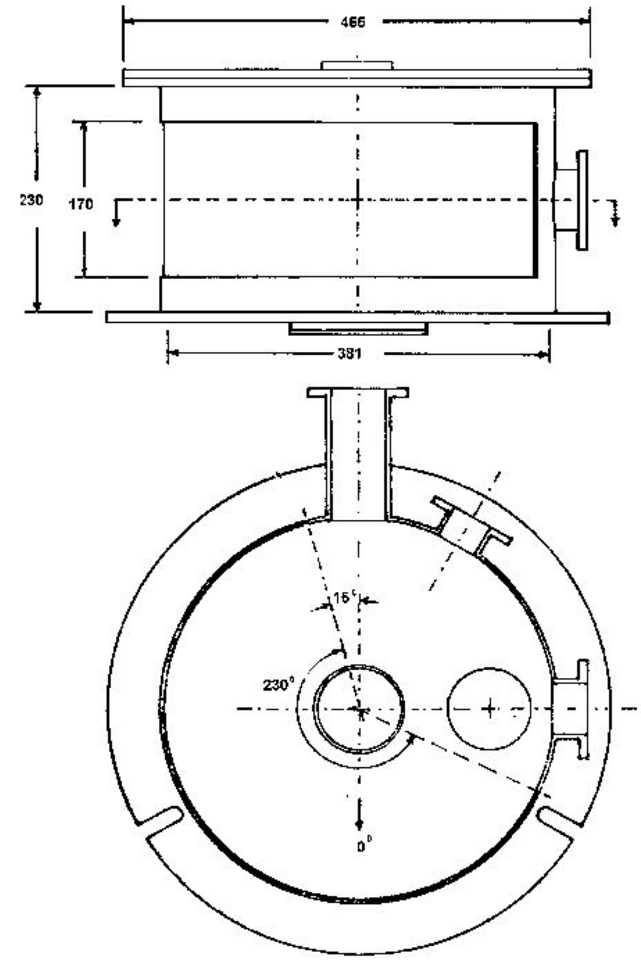

FIGURE 5. Schematic drawings of the 15" (381 mm) diameter vacuum scattering chamber, under construction, to be used for neutron (APT) scattering experiments and gamma ray spectroscopy applications. As shown, this apparatus is to be provided with an ample 230 degrees -16 cm wide- thin stainless steel window (1.28 mm thick), assuring small attenuations for neutron and gamma radiation measurements outside the chamber. A sectional view is presented at the bottom; in these drawings, quotations are given in mm.

4. A new scattering chamber

In fact, the possibility to perform reliable measurements using the associated particle technique, as well as for experiments involving gamma ray spectroscopy, is through the use of a more flexible and bigger vacuum scattering chamber. The actual chamber is small for our needs (20 cm in diameter), does not permit to accommodate more than two silicon surface barrier detectors (which result to be too close to the targets), and without the possibility to observe neutrons or gammas along the zero degrees, primary beam path, direction.

A simplified drawing of the main cylindrical body of a new 15 inch inner diameter (381 mm) vacuum scattering chamber (under construction) is presented in Fig. 5, which is to be provided with an ample 230 degrees -16 cm wide-, stainless steel window. In this figure, a sectional cut view is presented at the bottom, and for which quotations are given in mm. This thin window (1.0 mm thick), to be welded on a machined frame around the cylindrical wall, covers a range from +65 to -165° measured in relation to the beam path direction (0°) and the center of the chamber.

The sectional view presents a circular perforation on the center of the chamber's base (8.5 cm wide) designed to house (from the bottom) a HPGe detector near a target, for gamma ray experiments. This perforation serves, besides, to fix a ring support for centering a rotating charged particle detector table (not shown) of 35 cm diameter. The off center perforation shown serves to receive the tubing structure for a vacuum system beneath the chamber. The lateral flanged tubes at 90 and 150° serve usually as viewing ports, or to fix (at 150°) an external detector for x-ray analysis (through a thin plastic window).

The chamber's (removable) top cover has three flanged ports: the central one for a sliding multi target frame, a rear end port for receiving a Faraday cup assembly, and one located near the primary beam entrance serving various applications (as an extra collimator, a target support, a multiple connector, etc.).

5. Conclusions

With these preliminary results we proved to have adequate experimental conditions to perform reliable neutron small angle scattering measurements using the associated particle technique with the D(d,n)3He reaction as the neutron source. We also expect to have the new scattering chamber, more adequate for these experiments as for gamma ray spectroscopy, by the end of next spring.

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