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AN ASSOCIATED PARTICLE TOF SPECTROMETER AT CHIANG MAI

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Abstract: An associated alpha particle time-of-flight neutron spectrometer has been constructed using a 50 micron thick plastic scintillator and a 12.7 cm diam by 5.1 cm thick liquid scintillator. The neutron detector is housed in a massive shielding located at 3.34 m from the scattering sample. The experimental facility provides the capability of measuring scattered neutrons over the angular range from 15 to 155 deg.

Measurements of elastic and inelastic scattering cross sections for 14.1 MeV neutrons incident upon carbon are presented. The data are compared with the previous results of other investigators.

(Fast neutron spectrometer, associated particle, time-of-flight, natural C, neutron-induced reactions.)

Introduction

At Chiang Mai University the International Atomic Energy Agency (IAEA) has supported the establishment of the Fast Neutron Research Facility (FNRF) since 1982. The Facility operates a continuous beam 150 KV, 2.5 mA electrostatic accelerator producing 14 MeV neutrons for fast neutron activation analysis. The neutron generator need not be limited to nuclear analytical applications only. If properly modified it can also be used for the studies of fast neutron induced reactions.

Studies of fast neutron induced reactions are of significance for an understanding of nuclear reaction theory as well as for practical applications. For example, the secondary neutron energy and angular distributions from the (n,xn') reaction on certain materials are of importance for the development of fission and fusion reactor systems and accelerator based applications/1/. The spectrum of the emitted neutrons are usually measured using the time-of-flight (TOF) technique. For experiments using neutrons from $T(d,n)^4He$ with moderate energy resolution, the associated alpha particle method can be used with flight paths ranging typically from 2 to 5 meters. The advantage of the associated particle technique is that background in the TOF spectrum has no structure. Also, this technique is more convenient for measurements of neutron emission energy below 1 MeV as the low energy measurements require shorter flight paths and fewer angles. However, the intensity of the neutrons cannot be high so that the measurement usually involves long hours of data accumulation which requires a high quality deuteron beam to produce a stable correlated cone of neutrons. In addition there is the usual problem of long term drift in the associated electronic system.

We have initiated a programme to set up a facility to measure neutron emission cross-sections at an incident neutron energy of 14.1 MeV based on an associated alpha particle time-of-flight technique. The preliminary version of this spectrometer has been described elsewhere/2/.

Neutron Production

Neutrons are produced from an AID J25 electrostatic accelerator* by the $T(d,n)^4He$ reaction. The neutron generator is housed in a temperature and humidity controlled cage. The beam line is 2.50 meters above floor level. The low scattering experimental hall is 12 m by 12 m and 9.5 m high.

A 140 keV continuous D^+ beam from the accelerator first passes through a 3 cm diam aperture of the first water-cooled copper slit, where the unfavourable diverse component of D^+ beam is taken out. The beam can be moved horizontally and vertically by X-Y deflectors. After leaving the Y-deflector, the beam enters an electrostatic quadrupole doublet which focuses it through another 3 cm diam aperture of the second water-cooled copper slit. A retractable target and a rotating probe are parts of the beam line up stream from the 45 degree target holder. Beam tests and details of the beam line have been described elsewhere/3/. With the present set up we have been able to localize and stabilize the deuteron beam spot on the neutron production target.

The 45 degree stainless steel target holder has been designed in such a way that a collimated deuteron beam hits the tritium target about 1 cm off the central axis. The beam spot is about 1 cm in diameter. The tritium target is rotated after some hours of operation,when deuteron build up becomes noticable,in order to avoid contamination in the alpha detector from charged particles produced in the d-D and $d\text{-}^3He$ reactions. Each target can be rotated eight times so that fresh tritium surface is always exposed to the deuteron beam. Typically, deuteron beam current is only a few microamps and the tritium target can be cooled either by water or compressed air.

Experimental Facility

The associated alpha detector is a 0.050 mm thick NE-102A plastic scintillator viewed through a perspex light pipe by an RCA8575 photomultiplier tube. An aluminum foil shields the scintillator from the reflected light from the ion source and also from scattered deuterons; a cylindrical

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*Assistance Industrielle Dauphinoise (formerly SAMES) Meyland, France.

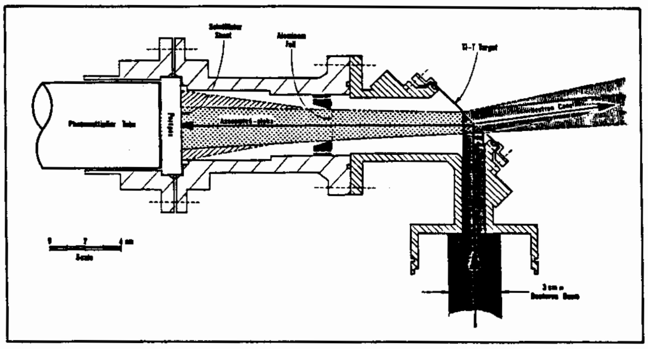

Fig.1 Schematic diagram of the alpha detector.

aluminum housing combines the light pipe, the scintillator and the photomultiplier tube into a vacuum sealed single unit as shown in fig.1. An aluminum collimator prevents scattered alpha particles from reaching the detector. The active area of the alpha detector can be varied by placing another aluminum collimator in front of the NE-102A. The neutron detector is a 12.7 cm diam by 5.1 cm long BC-501* liquid scintillator which is coupled directly to an Amperex XP2041 photomultiplier tube.

The photomultiplier base is a modified version of the one suggested by Finlay/4/. A pulse shape discriminator is used with this detector to reduce the gamma-ray background.

The neutron detector is placed inside a heavy movable shield as shown in fig.2. A shadow bar made of iron, paraffin, and lead shields the main neutron detector from direct neutrons. Criteria for the proper placement of a shadow bar in a neutron scattering experiment have been described by Hopkins et al./5/. This set up allows the measurement of scattered neutrons from 15 degrees - 155 degrees with a 3.34 m flight path.

Electronic circuitry for the TOF measurement is shown schematically in fig.3. The data acquisition and analysis system includes a MicroVAX II computer with 2 megabytes of 32-bit word memory for programming and data storage. The system is capable of working in such a way that for each event the following data can be acquired through a multiparameter system controlled by the MicroVAX II computer and recorded on magnetic tape: (1) the pulse height from the neutron detector, (2) the time interval between the passage of a particle through alpha detector and the detection of a particle in the neutron detector, (3) the PSD datum for the neutron detector.

Time-of-flight Measurements

During each experimental run the relative neutron flux was monitored by two NE-102A and one NE-213 scintillators. The yield of the 14 MeV neutron in these detectors was used as a relative

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*Supplied by Bicron Corp. Ohio, U.S.A.

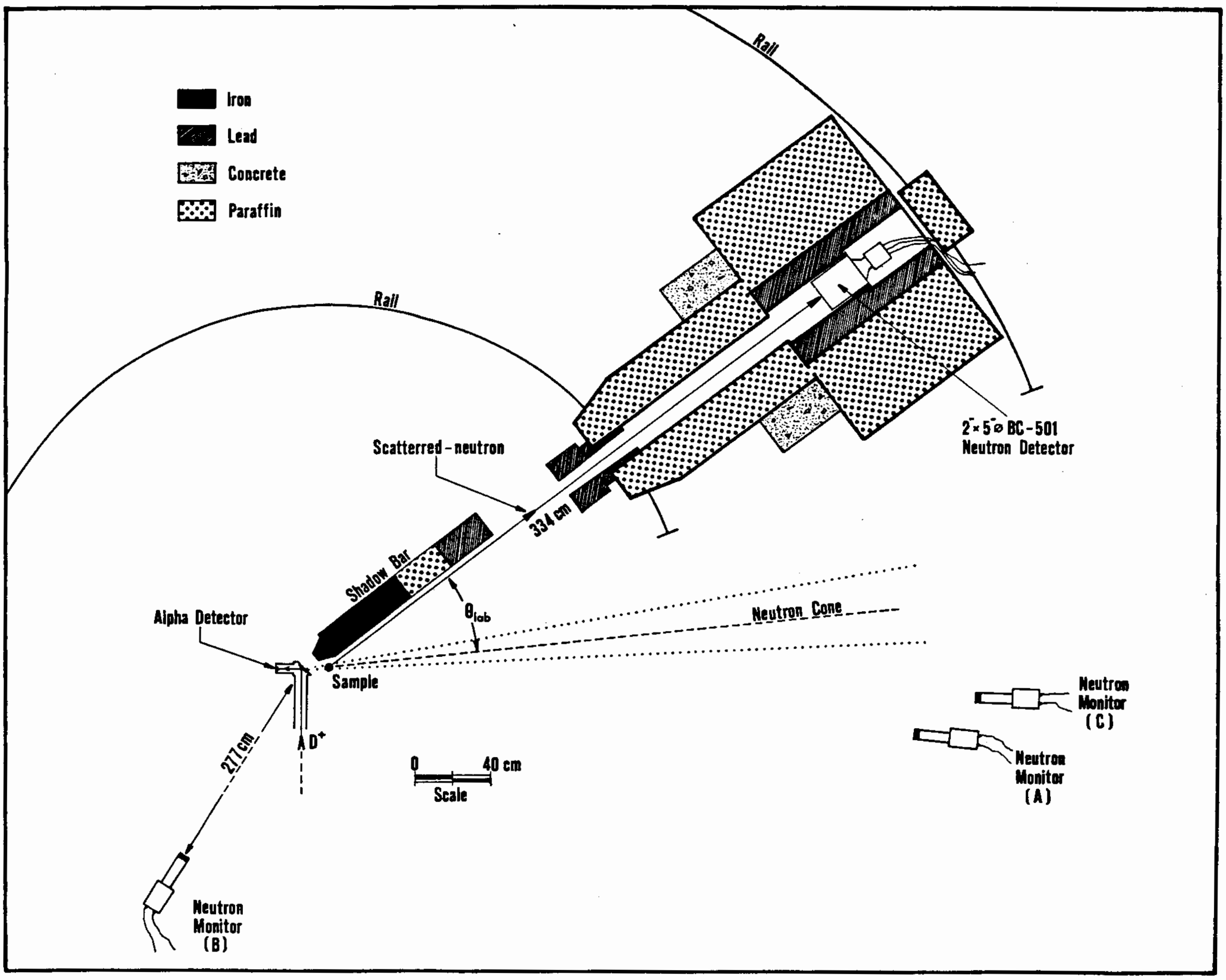

Fig.2 Experimental arrangement of TOF measurement by associated particle method.

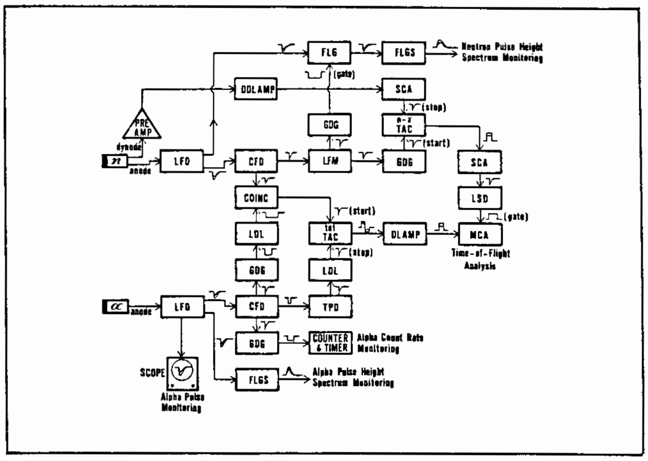

Fig.3 Block diagram of the electronic system.

measure of the integrated neutron flux at the samples during measurements with the main detector. The discriminating threshold of each neutron monitor was set at about 9 MeV which was above the energy level of most of the room scattered neutrons and gamma-rays. We confirmed this bias setting in a separate experiment. The use of counts registered by the alpha detector as a measure of the relative neutron yield is not consistently reliable since the alpha spectrum is always contaminated with signals of charged particles from ^{3}He(d,p) and D(d,p) reactions/6/. The relative neutron yield has been monitored with an accuracy of better than 1 percent.

The pulse height from each neutron detector was calibrated periodically with a series of radioactive gamma sources, namely, Cs-137, Na-22, and Co-60. The Compton peak in the gamma ray spectrum was used as a calibrating point. We associated the peak channel with an electron energy equal to 0.95 that of the maximum Compton energy/7/. The discriminating threshold of the main neutron detector was calibrated every six hours before and after each run. The stability of the photomultiplier tube gain is better than 1 percent. The scattering samples were 4.0 cm diam by 4.0 cm high cylindrical graphite and polyethylene. They were suspended with thin threads at a distance of 20 cm from the neutron producing target with the symmetry axis perpendicular to the scattering plane. The angular spread due to the finite size of the scattering sample and detector was about ±1.5 degrees. The position and the size of the scattering sample were inferred from the size of the correlated neutron cone which was predicted from Monte Carlo calculation. The exact position and size of the cone were determined with the time-of-flight measurement using a remote-controlled cone scanner/8/. The scanner has two principal parts. The first part is a neutron detector (0.5 cm x 0.5 cm NE-102A) scanner which can move the detector in the horizontal and vertical axis in 0.5 cm steps. The second part is the remote-controlled digital electronic circuit. The position and dimension of the correlated neutron cone was checked periodically throughout the experiment.

A typical spectrum for carbon is shown in fig.4. Data accumulation time was about 12 hours. Four peaks are observed clearly. The spectrum shows a time-independent (flat) background both before and after the region of interest. A sample out run also confirmed this time-independent nature. Time-of-flight spectra were measured in the angular range from 15 degrees to 155 degrees.

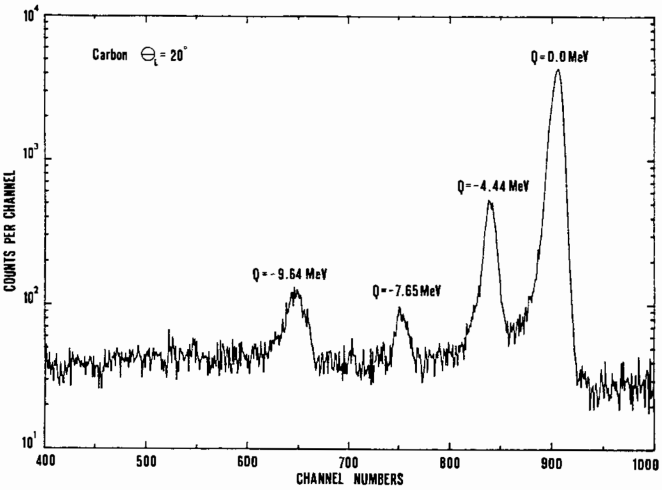

Fig.4 TOF spectrum for scattering of 14.1 MeV neutrons from carbon.

Conversion from yields to cross sections was accomplished by comparison with the n-p scattering cross sections using a polyethylene scattering sample. The polyethylene measurements were performed in the beginning of the experimental period and for each angular distribution. The neutron detection efficiency was measured the by TOF technique using a Cf-252 fission neutron source/9/ and also calculated with the Monte Carlo computer program of Cecil et al./10/. Fig.5 shows the experimental efficiencies compared with the calculations for a pulse height threshold of 1.2 MeV proton energy. In the region between 1 and 8 MeV results of the measurements and the calculation agree with each other to better than 3 percent prior to normalization. Multiple scattering corrections have been carried out with the MUSCC3 computer code/11/ which is based on the multipoint collision probability method. The overall systematic error in determining the efficiencies, the multiple scattering correction and the solid angles could be about 10 percent. Other sources of systematic error are relatively small and can be neglected. The statistical

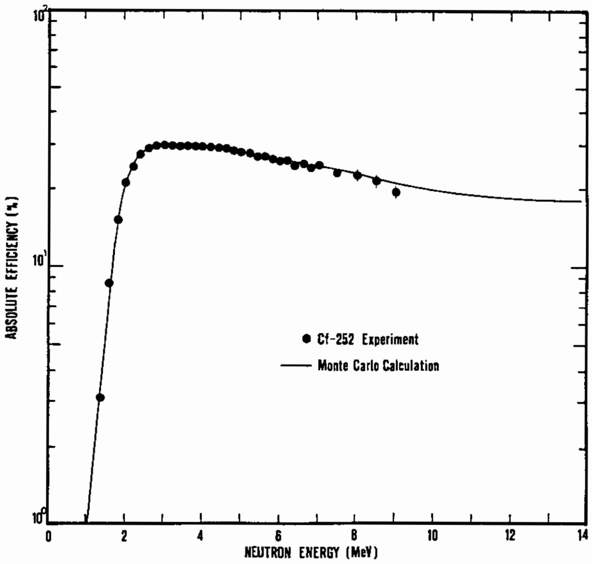

Fig.5 Neutron detection efficiency of the 12.7 cm diam by 5.1 cm thick BC-501 scintillator with discrimination threshold of 1.2 MeV proton energy.

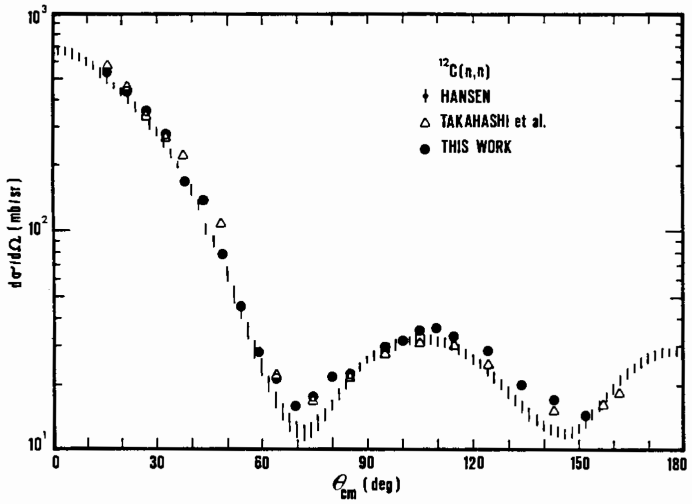

Fig.6 Angular distributions for neutron elastic scattering by carbon at 14.1 MeV. The data of Takahashi et al./12/ and Hansen/13/ are shown for comparison.

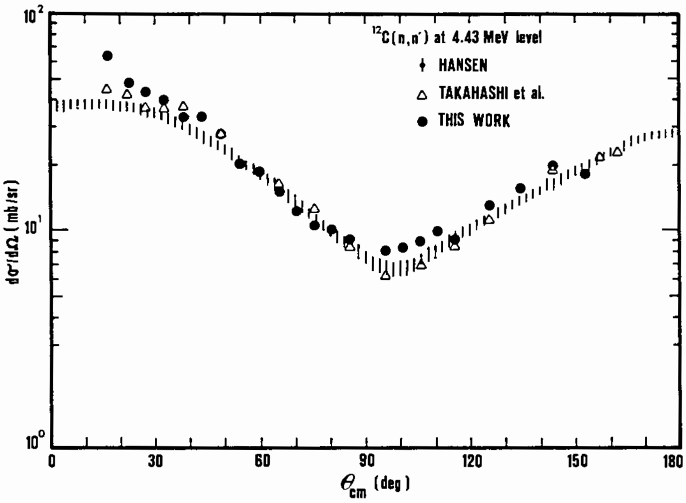

Fig.7 Angular distributions for neutron inelastic scattering by carbon at 14.1 MeV. The data of Takahashi et al./12/ and Hansen/13/ are shown for comparison.

uncertainty varies from ±1.6 percent to ±4.0 percent for the differential elastic cross sections and from ±2.6 percent to ±8.7 percent for the inelastic ones.

Results and Discussion

Differential scattering cross sections to the ground state and the first excited state of carbon are shown in fig.6 and fig.7, respectively. We also compare our measurements from carbon with data of Takahashi et al./12/ and the values recommended by Hansen/13/. The recommended set has been extracted from experiments carried out at various time-of-flight facilities since 1976. These measurements cover a range of incident neutron energies from 13.94 to 14.20 MeV. Within the limit of our estimated uncertainties, our results are in reasonable agreement with the results obtained by others indicating that our spectrometer works satisfactorily.

Acknowledgements

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