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THE MEASUREMENT OF NEUTRON SCATTERING CROSS SECTIONS AT SMALL ANGLES*

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The Measurement of Neutron Scattering Cross Sections at Small Angles*

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Abstract: A position sensitive neutron detector was used to measure the scattering cross sections of 14.7Mev neutron from Pb between 3^0 and 9^0 . The method to correct the effects of finite positional resolution by unfolding positional spectrum was studied.

1. Introduction

The angular distribution of elastic scattering of fast neutrons, prsent in general, a strong forword peak, i.e. The differential cross sections at small angles dominate over that at larger angles. Therefore a precise knowledge of small angles scattering is very important in nuclear reactor design. There are, however, only few experimental data for scattering angle less than 20^0.

Scattering measurements at small angles are more difficult not only a higher angular resolution is required but also the solid angle available is very small. So an improvement in the ratio of yield to background is desirable. On the other hand, the long term stability must be maintained, because the scattering counting rate is very low. Recently, a position sensitive neutron detector had been developed(1)(2) with which the differential cross section may be measured simultaneously at a certain angular range, so the time needed for measurements is reduced considerably. We have set up a position sensitive neutron detector system(3). The detector consists a long cylindic liquid scintillation tube and two photomultipliers at the both ends of the tube. The position of the incident neutrons is determined by the time difference between the two output signals of the phototubes.

The present experiment was undertaken in order to investigate

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the measuring method of small angle scattering of neutrons, so the detector was rather short. Pb sample was chosen in order to compare our results with that of other investigators.

2. Experimental equipments

a. Position sensitive neutron detection system

The detector consists of a liquid scintillator encapsulated in a quartz cylinder, 55cm in length and 3.8cm in diameter, with both endfaces in optical contact with GDB-49 photomultipliers. The detector was enclosed in an aluminium box 65.6cm in length, $10\times10\mathrm{cm}^2$ in cross section, 1mm in thickness.

The time of flight (TOF) and pulse shape discrimination were used for identifying scattered neutrons from the random background. The block diagram of electronics is shown in fig 1. The time difference informations were analyzed by time amplitude conversion (TAC1)

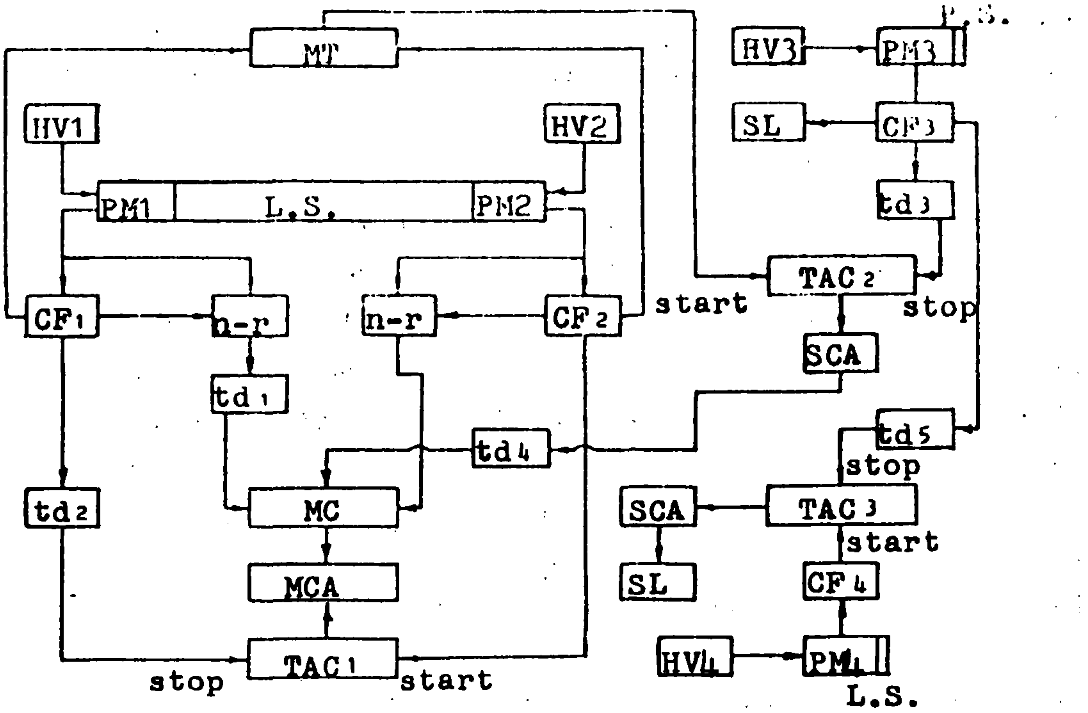

Fig 1. Block diagram of electronics

and multichannel analyzer (MCA). The TOF technique was based on the associated particle method.There was a meantimer because the detector was quite long. The position difference of incident neutrons would induce a difference in delay time of phototube output signals. So that the time resolving power of TOF was degnaded. The meantimer was designed to equalize the photon transit time by providing an output pulse at a fixed delay time independent of the position of neutrons incidence. The resolving time of TOF was 1.1ns (FWHM) and 2.2ns (FWTM) for 14.7Mev neutrons. 14.7±2Mev neutrons were extracted by a single channel analyzer (SCA). The neutrons of different energies and gamma ray produced near the target and impinging on the liquid scintillator (L.S.) were excluded in this way.

When a narrow collimated neutron beam hits the L.S. in the perpendicular direction, one can obtain the response function of the system. The position of peak of the response function is a linear function of the position of incident neutrons. The resolving time of the system is 404 ns average corresponding to position resolution (FWHM) 3.13cm or the standard deviation =±1.33cm.

b. Experimental arrangements

The 230 kev collimated beam of deuterons from Cockroft Walton accelerator was used to generate neutrons from the T(d,n) ^{4}He reaction. The diamenter of the target spot is 3mm, Alpha particles emerging from the reaction at an angle of 135° were detected in a thin plastic scintillator.

Neutron beam was collimated in a ±0.5° cone by a collimator located in a shield, 52.2cm in thickness of iron and 54.3cm in thickness of polyethence. Scattering sample was placed in position P, at a distance 110cm from target, for the scattering measurements and position Q, at a distance 3.5cm from target, for the background measurements. Scattered neutrons were detected by the position sensitive detector, at 1.5M from the scattering sample and just over the profile of the direct neutron beam. A smaller liquid scintillator at 400cm from the target, was used to monitor the associated neutron yields through the collimator. The TOF technique was used too. Scattering sample position sensitive detector and the monitor were all placed in a room, 2.8 M×2M×2.72M, which was surrounded by the shielding water wall, 30cm in thickness. The experimental arrangements are shown schematically in fig 2.

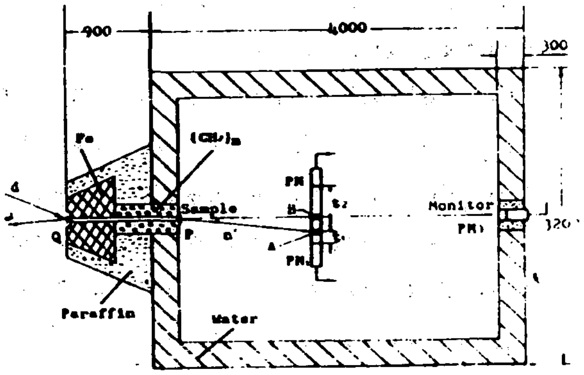

Fig 2. Schematic diagram of experimental arrangement

Scattering samples were solid cylinders of analytically pure lead, 2.8cm in diameter, 2cm and 3cm high, which corresponds to neutron transmissions 70% and 60% respectively. Oriented with their axes parrallel to the beam direction, all neutrons leaving the collimator were intercepted by the scatterer.

3. Experimental Methods

a. Basic formula

If the intensity distribution of the incident neutron beam was uniform and the intrinsic efficiency of the liquid scintillator was proportional to the length traversed by neutrons in the liquid scintillator, the differential cross sections is given by the approximate formula:

$$\sigma(\theta)=\frac{n(\theta)}{n_0\cdot\cos\theta}\cdot\frac{k}{ntd\Omega}$$

where $n(\theta)$ is the counting rate without background of the detector element A at the angle , n_0 is the counting rate of the element B with the liquid scintillator on the direct neutron beam, k is the ratio of the solid angles subtended by the element B to that subtended by the scattering sample at the neutron source position, $d\Omega$ is the solid angle subtended by the element A at the scattering sample, n is the number of nuclei in the scatterer of unit volume, t is the thickness of the scatterer.

b. The methods of measurements

The collimation system was initially aligned with a laser beam simulating the neutron flight path. Neutron beam distribution at 1.5M from scatterer were measured by counts of position sensitive detector at the various position of the detector. The counts were normalized to the counts of the neutron monitor. The position of the detector could be controlled by a electric device in the measuring room. The distribution was widened, owing to the diameter of the detector, essentially, and the scattering by the Al shell of the detector and air. According to the geometry of the collimator, the diameter of the neutron beam profile at the L.S. shoud be 5.0cm, in which the intensity of neutron beam varied 10%. The position detector was put at the center of the collimated beam, when n_0 was measured and just over the collimated beam when the $n(\theta)$ was measured.

As the tritium at the surface of the target was exhausted and the target was contaminated by oil, the effective energy of the deuteron was reduced. So the direction of the associated neutron beam would drift. In order to reduce the effect of the beam drift, the solid angle subtended by Alpha window was increased. The alpha particle might be counted if the energy of deuteron was between 60Kev and 230Kev. The spectra of direct neutrons, scattered neutrons and the background were measured in turn. When the round is completed, the spectrum of direct neutrons was measured again. If the peak of the direct neutron spectrum did not remain in its precision position, the deuteron beam energy should be increased.

4. Data processing

a. The method of unfolding positional spectrum

The positional spectum of incident neutron was distorted by the detection system, because of its finite resolution. In order to correct for the effect of response function, the following method was adopted. At first, we must establish its relation of the response function versus the position of the incident neutrons. The positional spectrum measured was the linear weighted sum of the response function and the weights depend on the relative intensities of incident neutrons at various positions. The method of least squares was used to obtain the relative intensities by iterative method while the spectrum of linear sum was approximated to the spectrum measured.

b. The data of differential cross section were corrected for multiple scattering and attenuation in the scattering sample, finite geometry of sample and detector by Monte Carlo Method.

5. Results and discussion

The results of the differential cross sections are shown in tab 1. The errors are due to statistical uncertainties only. The data roughly agree with the data of Bucher and Hollandsworth[4]. The results of unfolding positional spectrum shows that the effect of response function of the position sensitive detection system is negligible, because the angular resolution owing to the geometry is poor.

Table 1. Cross sections for scattering neutron from Pb.

$\sigma(\theta)$ \ θ smples	3^0	4.5^0	6^0	7.5^0	9^0
2cm	13.8±0.7	12.5±0.7	11.6±0.6	11.4±0.6	9.1±0.5
3cm	12.6±0.8	11.7±0.8	10.8±0.8	10.1±0.7	8.8±0.6

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