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Neutron total cross section of ^{31}P between 0·75 MeV and 9·00 MeV

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Abstract. The total neutron cross section of ^{31}P has been measured from a neutron energy of 0·75 MeV to 9·00 MeV. Good agreement is obtained with the calculated values using the generalized optical model potential of Wilmore and Hodgson.

1. Introduction

The authors are currently studying neutron inelastic scattering from nuclei in the neighbourhood of the p wave optical model resonance which occurs around $A = 28$. A knowledge of the total neutron cross sections of the target nuclei is needed for multiple scattering correction of the results. An examination of the literature reveals a gap in the neutron total cross section of ^{31}P between 1·20 and 2·00 MeV. The second edition of Stehn *et al* (1964) quotes the results of Cabe *et al* (1963) over the energy range 0·83 to 1·20 MeV. Above 2 MeV the results of Tsukada and Tanaka (1963), Cuzzocrea *et al* (1960), Nereson and Darden (1954), Hansen *et al* (1953) and Ricamo (1951) are given. There is however considerable disagreement among them. Although the recently published results of Foster and Glasgow (1970) improve the situation above 2 MeV, their measurement was done with only moderate energy resolution (2 to 4 %). Consequently it was judged necessary to measure the total neutron cross section of ^{31}P between 0·75 and 9·00 MeV with better energy resolution (ie 5 keV at 1 MeV and 135 keV at 9 MeV).

2. Experimental procedure

The neutron flux employed in the total cross section measurement was produced using the nanosecond pulsed beam facility of the electron linear accelerator in the Kelvin Laboratory. A detailed description of the facility is given by Crawford *et al* (1972). The flight path was at 124° to the electron beam. Two collimators at 1·5 m and 3·5 m, each comprising 0·6 m of paraffin wax and 0·3 m of lead, were used to provide a beam of neutrons 33 cm in diameter at the detector position 20 m from the neutron producing target. The absorbers were placed approximately midway between source and detectors. They subtended at the target twice the solid angle subtended by the detector. In-scattering was less than 1 in 10^6.

The procedure adopted in the experiment was firstly to measure the incident flux with the empty target holder in position, and then the transmission spectrum for both the holder and the sample. In this way, the effect of the holder was automatically removed from the measurement. The ^{31}P sample was in red powdered form. It had an isotopic purity of 100% and a chemical purity of 97%.

A summary of the apparatus is given in table 1.

Table 1. Summary of the apparatus

Accelerator	
PRF	480 pulses/s
Pulse width	3·5 nsec FWHM
Peak current	100 mA
Electron energy	100 MeV
Neutron source	
Reaction	mainly (γ, n) from bremsstrahlung
Target	2·5 cm diameter sphere of natural lead
Spectrum shape	typical evaporation spectrum peaking at about 2 MeV
Samples (chosen to give 20% absorption)	
^{12}C	thickness 0·88 cm
^{31}P	thickness 2·47 cm
Distance from source	9·15 m
Target container	fixed rectangular perspex box: wall thickness 2·2 mm
Detector	
Distance from source	19·95 m
Scintillator	(2·54 × 2·54) cm^2 cylinder NE 102A
Photomultiplier	56 AVP
Instrumental time resolution	1·0 nsec FWHM
Threshold	0·5 MeV (^{241}Am photopeak)

The electronic configuration was a conventional time of flight spectrometer using a 1024 channel ADC feeding a PDP-7 computer. The beam monitor was a (2·54 × 0·64) cm^2 plastic scintillator NE 102A mounted on a 56 AVP photomultiplier which was set at the same bias level as the main detector. The monitor was placed near the edge of the beam in such a position that it lay outside the shadow from the sample created by the neutron producing target. This was confirmed by ensuring that the count rate in the monitor was the same for the sample in and sample out. The reliability of this monitor was checked against a second similar monitor in another beam line.

A 2·54 cm thick lead filter was placed behind the first collimator to reduce the γ flash in the monitors and detector and thereby minimize the occurrence of after pulsing in the photomultipliers. The accelerator current was regulated to produce a count rate in the detector of about one tenth of the accelerator pulse rate. Since only the first stop pulse could be detected corresponding to any given start pulse, this meant that there was a 10% pile up correction to be applied to the low energy end of the time of flight spectrum. The pile up factor was calculated using the formula

$$\Delta n_i = \sum_{j=1}^{i=1} n_j \frac{1}{N_{\mathrm{T}}}$$

where n_j = counts in jth channel, Δn_i = fraction of counts lost in ith channel and N_T = total number of accelerator pulses.

Since the shape of the spectrum distortion is essentially the same for both the 'blank target holder' and 'absorber in' spectra, the error in the total cross section due to pile up even when no corrections were made is at worst 8 % for a 20 % absorption in the sample and a count rate of 10 % of the accelerator PRF. The validity of the correction depends on the count rate remaining constant. During the experiment the count rate was held constant to within 10 %, so that the errors from pile up in the corrected spectra are less than 1 % for all neutron energies.

An absolute measurement of the total neutron cross section of ^{12}C was made to test the system stability and monitor normalization, and was found to agree to well within the statistical errors (typically 5 to 10 %) with the recommended curve published in Stehn *et al* (1964). The ^{31}P measurement was absolute and done independently of the ^{12}C measurement.

A time calibration of the ADC was obtained using a Tennelec time calibrator (TC-800) with the 2·076 MeV absorption line in ^{12}C as an absolute reference. The time stability of the apparatus was checked by periodically delaying the γ flash in the stop channel of the TAC by a fixed amount using a cable delay and ensuring that the resulting sharp line on the TAC output always occurred in the same position. The size of the delay was chosen to produce the peak in the linear part of the time range. At the same time the bias levels on the monitors and main detector were checked.

The statistical errors in the total cross section are ±5 % at 1 MeV, ±9 % at 5 MeV, and ±12 % at 8 MeV.

3. Discussion

Figure 1 shows the total cross section of ^{31}P between 0·75 MeV and 9·00 MeV and the results of the theoretical cross section calculated using the Wilmore and Hodgson (1964) generalized optical model potential. In the calculation, the S matrix elements for the first ten angular momentum channels were evaluated. The theoretical cross section exhibits the typical monotonic decrease with energy found at a p wave resonance. The agreement with the energy-averaged experimental results over the whole energy range therefore provides a striking example of the power of the optical model in reproducing total cross section measurements. Figure 2 compares the results of Cabe *et al* (1963) with the present experiment. The two sets of data agree very well above 0·93 MeV, but at 0·91 MeV there is a strong peak of magnitude 6·3 b in the present data of which there is little sign in Cabe's results, apart from a shoulder in the low energy side of the 0·93 MeV peak. A peak of this strength is unlikely to result from an impurity since other peaks due to the impurity would necessarily be present. To the authors' knowledge no element exists which has a single peak in the total neutron cross section at 0·91 MeV but is otherwise smooth between 0·82 and 1·18 MeV. Also, since the target was 97 % phosphorus, any impurity would need an enormous cross section at 0·91 MeV to cause a peak of 6·3 b in the total cross section. The most likely impurity might be expected to be oxygen which certainly has no resonance at this energy. It may well be that the resonance has been resolved by the improved resolution of the present work. In figure 3 a comparison is made with the best fit to the available data above 2 MeV given in Stehn *et al* (1964). In all three figures the full width at half maximum of the triangles shows the energy resolution in our experiment. Although a detailed comparison is difficult due

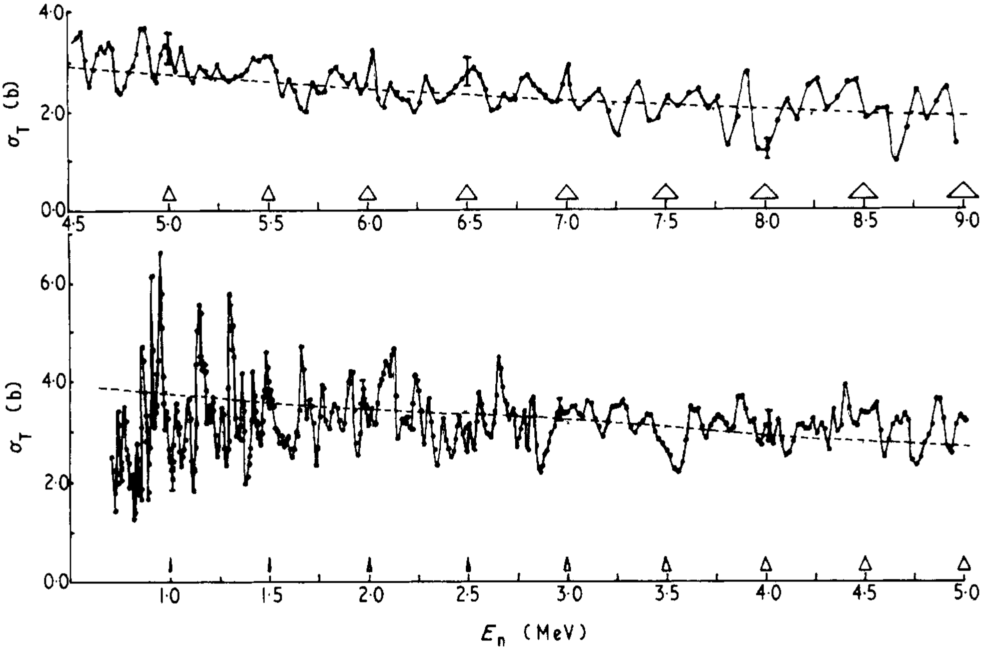

Figure 1. ^{31}P total neutron cross section. The full curves with full circles are the measured values of the present work and the broken curves are the optical model fits.

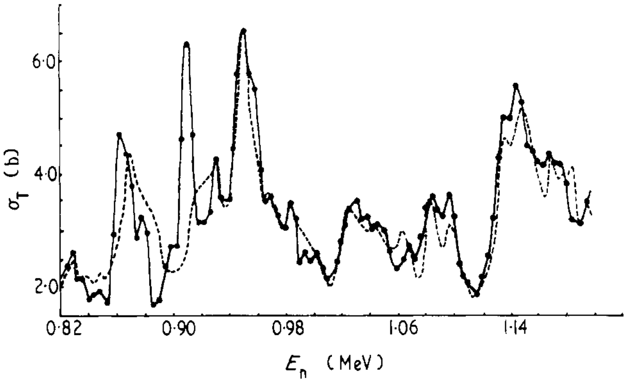

Figure 2. Comparison of ^{31}P total neutron cross section measured values with previously published data from 0·82 MeV to 1·20 MeV. The full curve with full circles is from the present work and the broken curve is from Cabe *et al* (1963).

to the better energy resolution in the data being presented here, it is apparent that there is good correspondence in the gross structure exhibited in the two sets of data. Similarly, due to the manner of presentation of the results of Foster and Glasgow and their poorer energy resolution, it is difficult to give a detailed comparison with the present data. It is apparent, however, that the cross section of Foster and Glasgow exhibits two prominent minima at approximately 2·8 MeV and 3·6 MeV which have values of about 2·4 b and 2·3 b respectively. These, although considerably lower than the Stehn *et al* (1964) best fit, are in good agreement with the data being presented here.

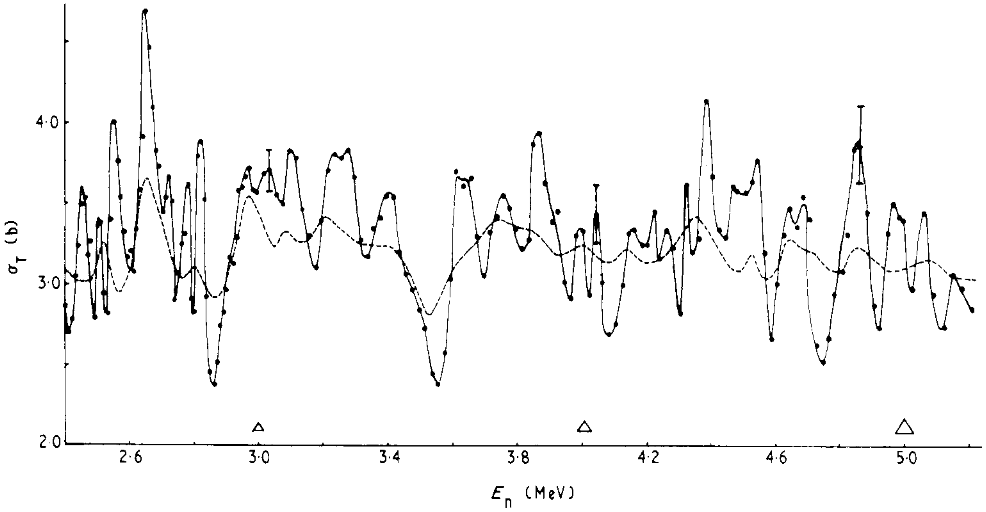

Figure 3. Comparison of ^{31}P total neutron cross section measured values with previously published data from 2·4 MeV to 5·2 MeV. The full curve with full circles is from the present work and the broken curve is from the best fit of Stehn *et al* (1964).

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