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INTERNATIONAL ATOMIC ENERGY AGENCY

CONFERENCE ON NUCLEAR DATA-
MICROSCOPIC CROSS SECTIONS AND OTHER
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A NOVEL METHOD FOR VERY HIGH RESOLUTION CROSS-SECTION MEASUREMENTS.

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A neutron time-of-flight spectrometer has been put into operation using the Karlsruhe isochronous-cyclotron as a very intense pulsed neutron source. The very high recurrence frequency of the microstructure bunches from the cyclotron was reduced using a novel "bunching-deflection" system to avoid frame overlap problems while largely preserving the high average neutron intensity available from the internal beam. The performance data of the spectrometer are as follows: flight path 57 m, neutron pulse length 1 ± 0.3 ns full width at half maximum, integrated time averaged neutron flux ($0{,}2 \leq E_n \leq 50$ MeV) $\phi = (5 \pm 2) \cdot 10^4$ n.cm^{-2}s.$^{-1}$ at 57 m, while using a thick natural uranium target and deuterons of (45 ± 5) MeV.

With the present flight path a maximum resolution of 0.02 ns/m has been determined for the spectrometer. The time-of-flight apparatus and the first total cross-section measurements for some light and medium-weight nuclei in the energy region between 0.5 and 10 MeV will be presented.

1. Introduction

In the measurement of nuclear coss-sections basic for reactor various techniques and neutron sources have been involved. In the energy range below several hundred ev one is in the measurement region mainly accessible to crystal spectrometers, choppers and pulsed electron accelerators. Above that energy up to several hundred kev, most cross-section measurements have been made with pulsed Van de Graaff accelerators, linear accelerators, and synchrocyclotrons. Above about 100 kev one is in the most useful region of the electrostatic accelerator monoenergetic neutron sources.

The best resolution in these measurements have been confirmed to be some tenths of nsec per meter with a lower dispersion limit of about 0.1 ns/m.[1] The limitation in energy resolution in time-of-flight experiments is determined by the maximum total neutron output of the source and the minimum pulse width obtained with the pulsed-beam neutron producing device.

Neutron time-of-flight spectrometers with a resolution up to several tenths of nsec per m, however, work at the extreme limit of their capabilities. Unfortunately the extremely small pulse width obtainable with the pulsed Van de Graaff devices is associated with a limited total neutron output, while for linear accelerators and synchrocyclotrons a moderate pulse length (10 - 20 nsec) is connected with an excellent total neutron output.

Both advantages, an extremely small pulse width and a high total neutron output, can be obtained with isochronous cyclotrons. The disadvantage is however in the high recurrence frequencies of the microstructure pulses of these machines, so that overlap problems arise. By solving the frame overlap problem while largely preserving the high average neutron output obtained from the internal beam, a new method for very high resolution cross-section measurements has been developed at the Karlsruhe isochronous cyclotron. By means of a novel "bunching-deflection" system, described elsewhere,[2] the repetition rate of 33 Mc/s of the microstructure pulses was reduced to 20 kc/s while the neutron intensity was reduced only by a factor of about 30. With this facility a further improvement in resolution of nearly one order of magnitude is envisaged. The useful energy range of the continous neutron spectrum from the source covers an energy region from several hundred kev to more than 10 Mev. This is an essential portion of the energy range which is of interest to reactor physicists. These facts indicate that our spectrometer may represent useful supplement of the existing facilities employed in neutron cross-section work.

The neutron time-of-flight spectrometer will be described in more detail in section 2 of this paper, while in the third section total cross-section measurements for some light and medium-weight nuclei will be presented.

2. The neutron time-of-flight spectrometer

The overall layout of the neutron time-of-flight apparatus is shown in fig. 1. For neutron production a natural uranium target, 10 cm wide, 1 cm in height and thick enough to stop 50 Mev deuterons is used. The two collimators along the flight path have been chosen such that a neutron beam with an angular spread of $\sim 0.5^{\circ}$ is obtained. At the end of the evacuated flight path neutrons are detected by a liquid proton-recoil detector with an effective area of 90 cm^2 and a thickness of 2 cm. For the purpose of neutron beam monitoring a small liquid scintillator is placed in a second neutron beam at an angle of 6° to the main flight path.

A typical neutron spectrum obtained from the uranium target, plotted per unit energy interval, is shown in fig. 2. This spectrum is not corrected for the energy dependent detector efficiency. The high energy part with a broad maximum at about 20 Mev is produced by neutrons from deuteron break-up and possibly stripping reactions. The distribution of low energy neutrons including the maximum at about 1.6 Mev is due to evaporation and fission processes. This part of the spectrum is in a first approximation not very different from a fission spectrum.

The energy resolution of the spectrometer has been determined both by the time distribution of γ-rays within the peak of the promt γ-rays from the target and by measuring the two pairs of closely spaced resonances of Fe^{56} near 512 and 530 kev respectively. The resonances at 512 kev are shown in fig. 3 in comparison with the measurements of Reitmann and Smith(3) which were performed with a resolution of about 0.06 to 0.08 nsec/m. In the measurements of Reitmann and Smith the cross section at 512 kev shows only a weak indication of the presence of two resonances, while in our measurement these two resonances are well resolved. From the measured half-width of these resonances, the resolution in this energy region seems to be at least equal to or better than 400 ev. From a calculation of the maximum resonance cross-section, an energy resolution of 200 ± 50 ev was deduced assuming the 513 kev resonance to be an s-wave resonance. Similar results were obtained for the case of the resonances at 530 kev. The theoretical value calculated from the neutron pulse width and the length of the flight path is 165 ev.

Because all γ-rays have the same time-of-flight, the width and the shape of the γ-peak reflects the time distribution of the neutron burst at the target plus any finite time resolution inherent in the recording equipment. With this method a resolution of 0.024 ns/m was determined.

The characteristic features of the spectrometer are shown in table 1.

3. Total cross-section measurements

Transmission measurements have been carried out in the energy range between 0.5 - 30 MeV for the following materials: carbon, oxygen, aluminum, calcium and iron. In the measurements a digital time-sorter (HC 98 Intertechnique) was employed; a range of 4000 channels and 2 ns channelwidth was used. The output signals from the time-sorter were transfered to the Karlsruhe MIDAS Data Aquisitation System. The events were accumulated in an 8 K memory block.

In the carbon transmission experiment a graphite sample ($n = 0.2343$ at/barn) was used. The total cross-section in the energy range between 2 - 10 MeV is shown in fig. 4. The general behavior is in reasonable agreement with the published [4] cross-sections.

The oxygen transmission was obtained with a distilled water sample ($n_{O2} = 0.0835$ at/barn) contained in a thin aluminum can. The wall exposed to the neutron beam was only 0.2 mm thick. An identical empty can was put into the sample position during the open beam measurements. The total cross-section for oxygen was obtained from the measurements corrected for the hydrogen content, according to the published [4] total neutron cross-section of hydrogen. The results (fig. 5) have been corrected for the multiple scattering in the sample.

The results for aluminum and iron in the energy range between 0.5 - 10 MeV are shown in fig. 6 and 7. For aluminum a sample thickness of $n = 0.1508$ at/barn and for iron a sample with $n = 0.1653$ at/barn were chosen. For comparison the recent results of Carlson and Barschall [5] and Reitmann and Smith [3] are included in the figures.

For studying the total cross-section of calcium a granulated metal sample (n = 0.1690 at/barn) was used; it was contained in a thin aluminum can to avoid oxidation effects. As an example the total cross-section in the energy range from 0.4 to 1.4 MeV is shown in fig. 8. This fig. also includes the high resolution measurements carried out by Bowman, Bilpuch and Newson [6].

A punched card data bibliography of all the data available will be prepared.

References:

(1) H.W. NEWSON - Proceedings of the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, July 1965, North Holland Publ. p. 195.

(2) S. CIERJACKS, B. DUELLI, L. KROPP, M. LÖSEL, H. SCHWEICKERT, H. UNSELD - International Conference on Isochronous Cyclotrons, Gatlinburg, Tennessee.

(3) D. REITMANN and A. SMITH, - WASH-1044, EANDC (US) - 41 "U".

(4) D.J. HUGHES and R.B. SCHWARTZ - Neutron Cross-Sections, BNL 325 (1958).

(5) A.D. CARLSON and H.H. BARSCHALL - International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, July 1965.

(6) C.D. BOWMANN, E.G. BILPUCH and H.W. NEWSON - Ann. of Phys. 17, 3 (1962), 319

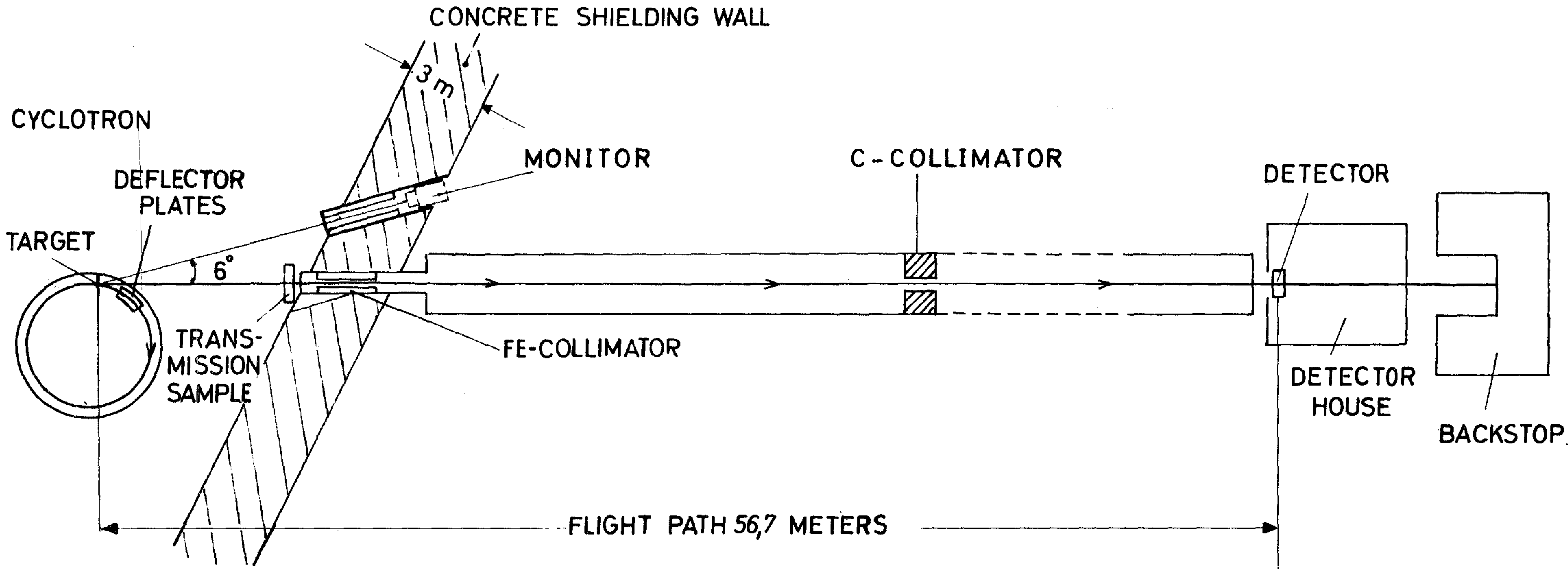


Fig.1 : Geometry of the Karlsruhe isochronous cyclotron neutron time-of-flight spectrometer (top view).

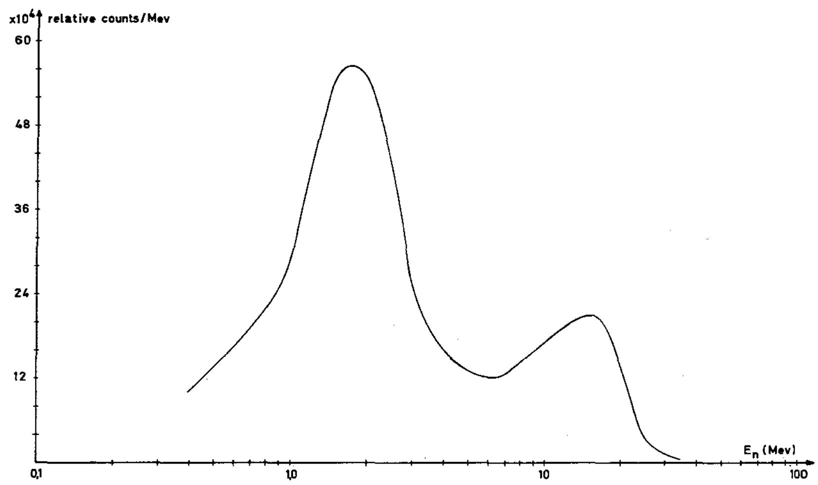
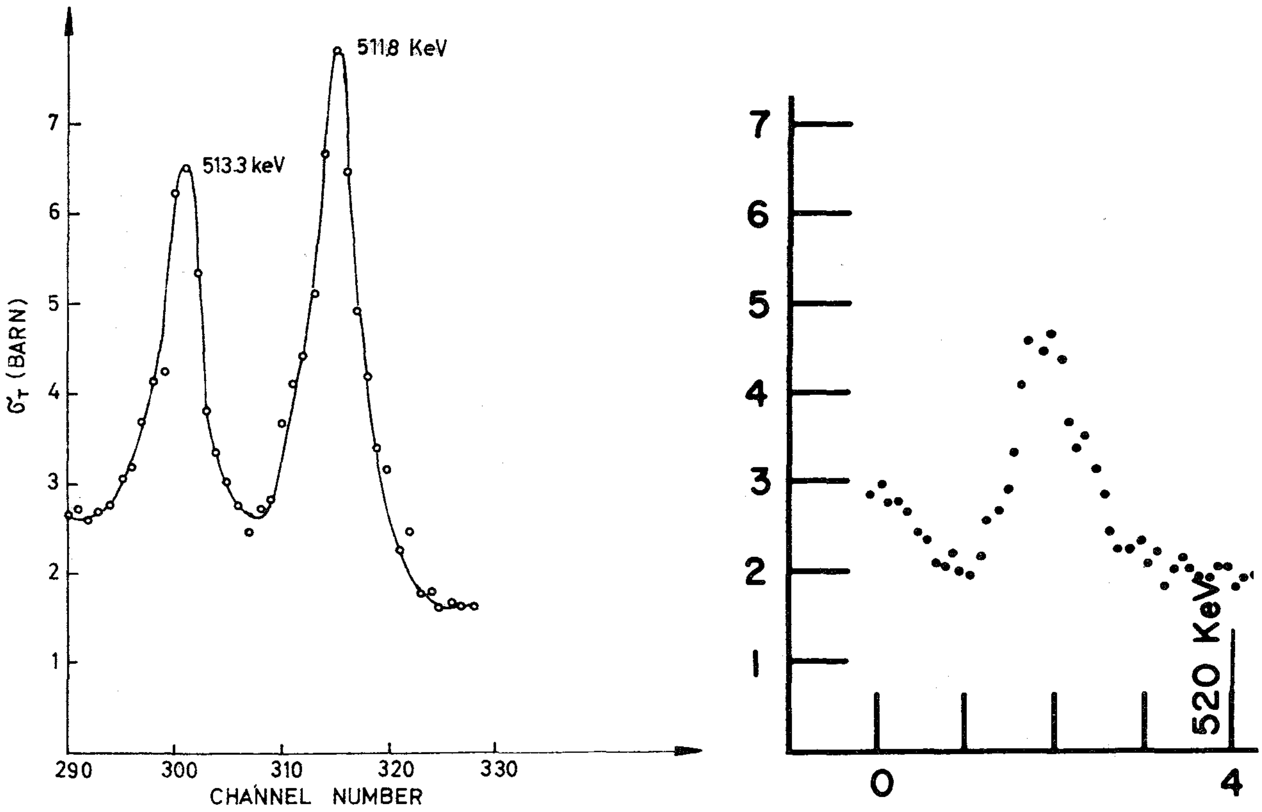


Fig. 2 - Typical neutron spectrum



a) Present measurement

b) Measurement by ref. (3)

Fig. 3 - Fe resonances at 512 Kev

Flight path	56 - 57 m
Deflection radius	0,930 m (40,5 MeV deuterons) to 1,030 m (50 MeV deuterons)
Time resolution	(1 $\pm$ 0,3)ns full width half maximum
Energy resolution	200 eV at 0.5 MeV
Resolution of Spectrometer	0,02 nsec/m
Integrated neutron flux at 3 μA target current	(5 $\pm$ 2) $\cdot$ 10^4 neutrons cm^{-2} sec^{-1} above 250 keV at 56 m

Table I - Time-of-flight apparatus

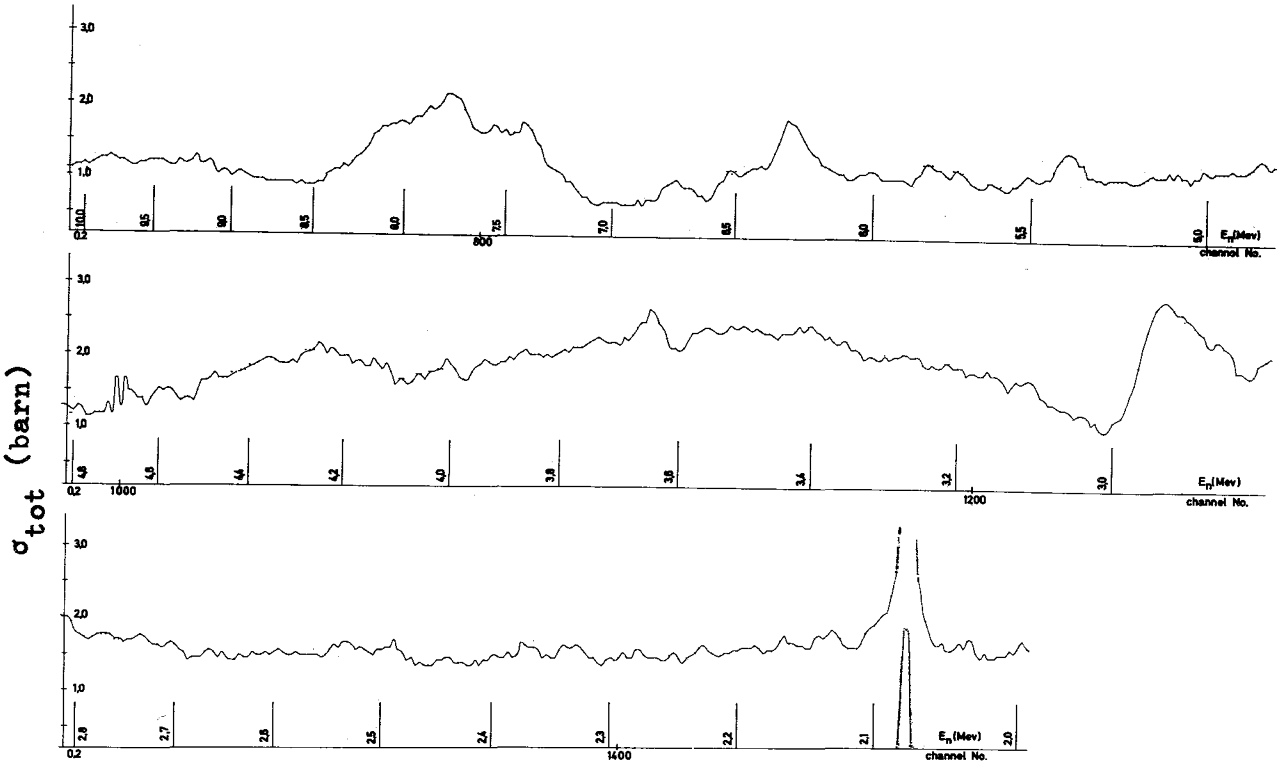


Fig. 4 - The total neutron cross-section of Carbon

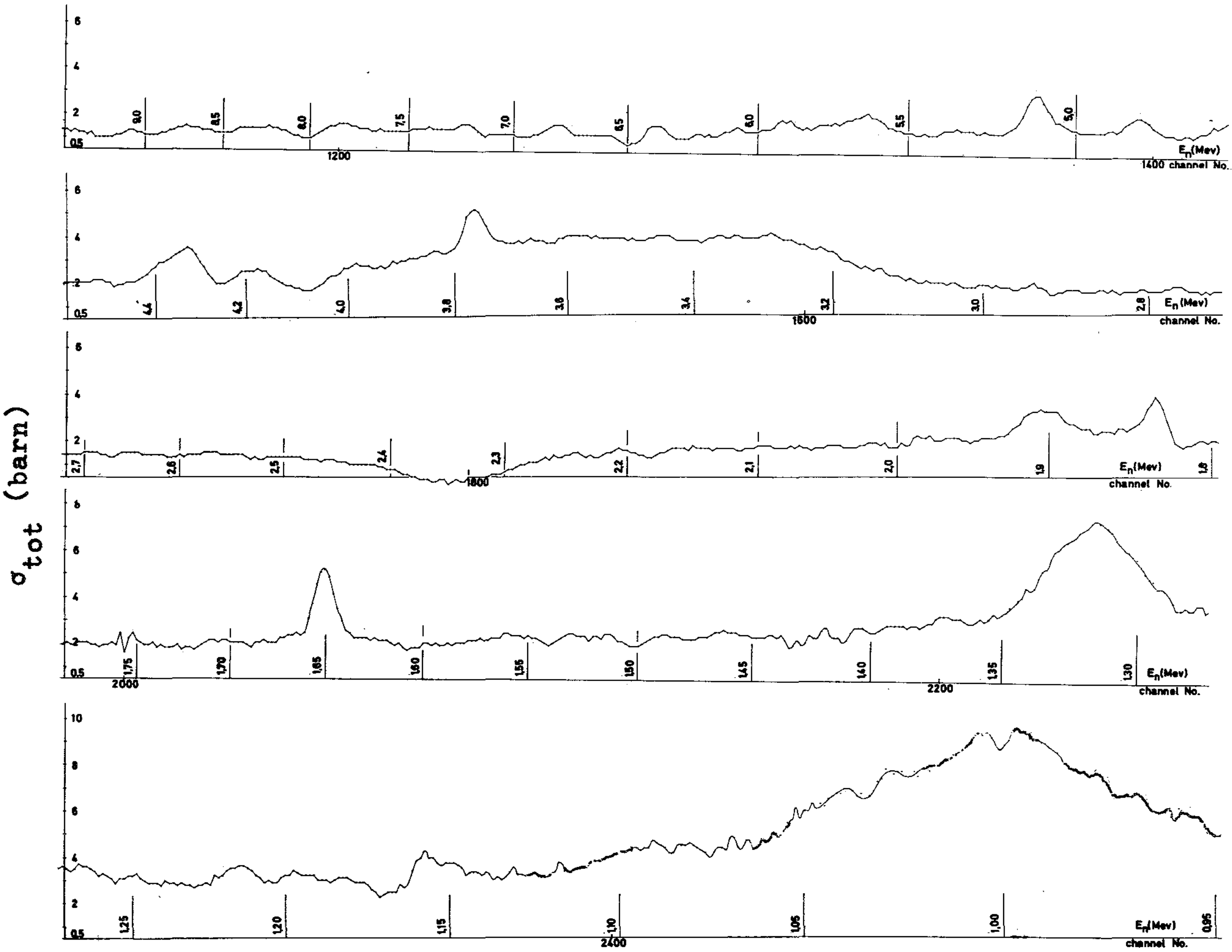
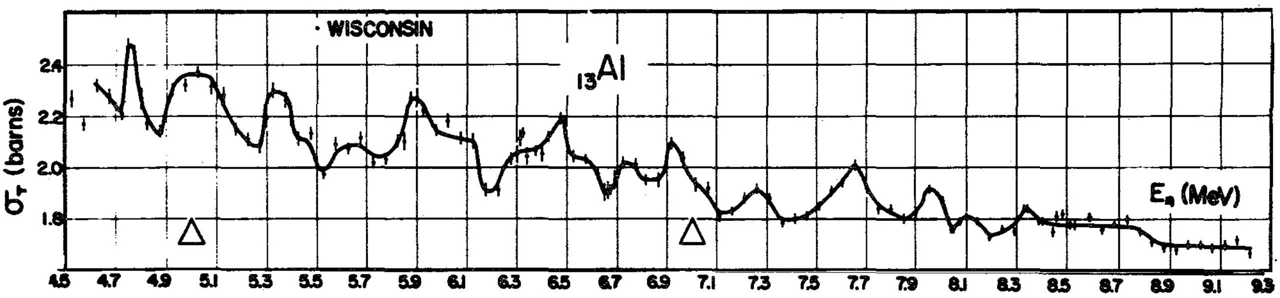
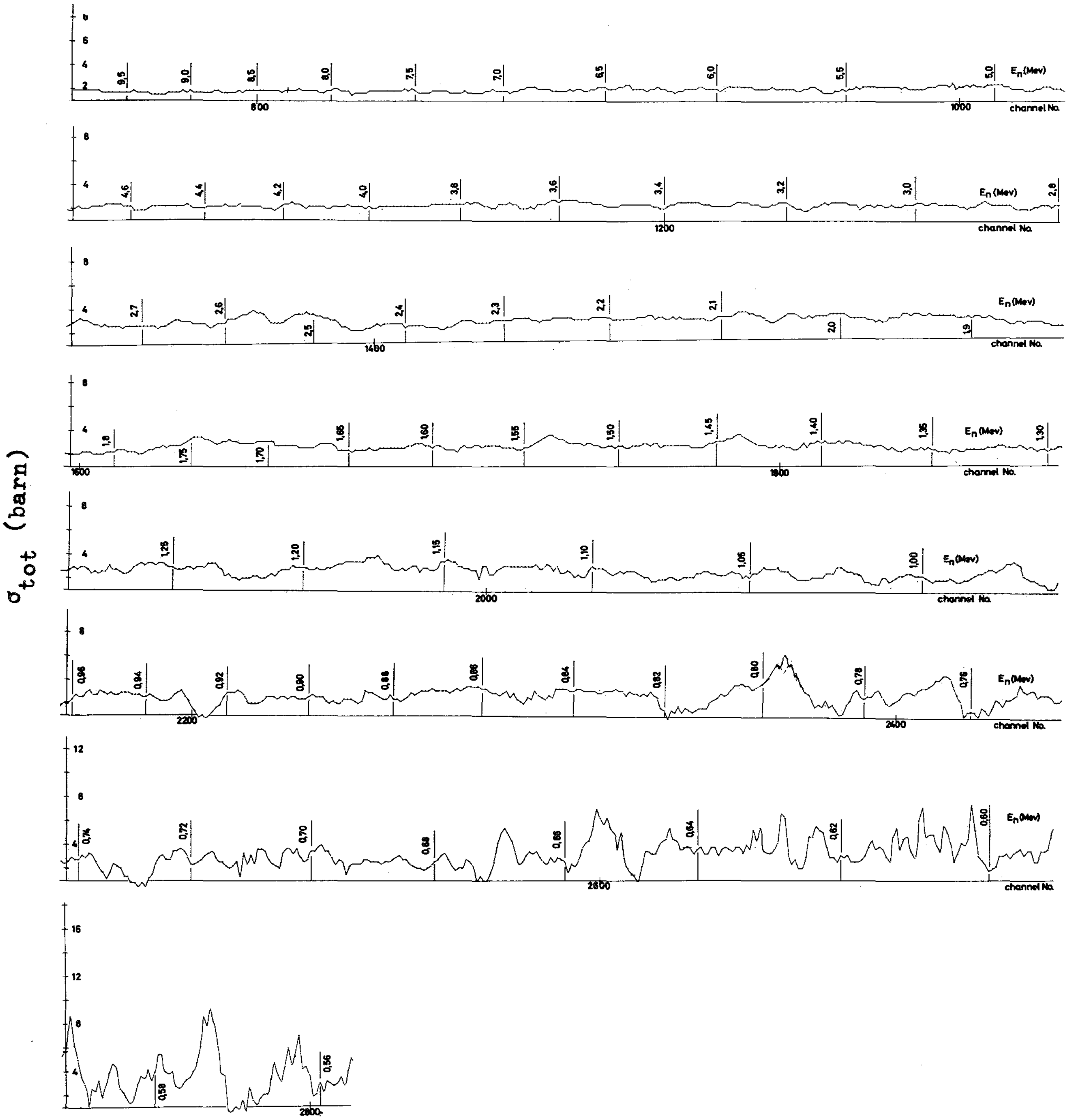


Fig. 5 - The total neutron cross-section of Oxygen

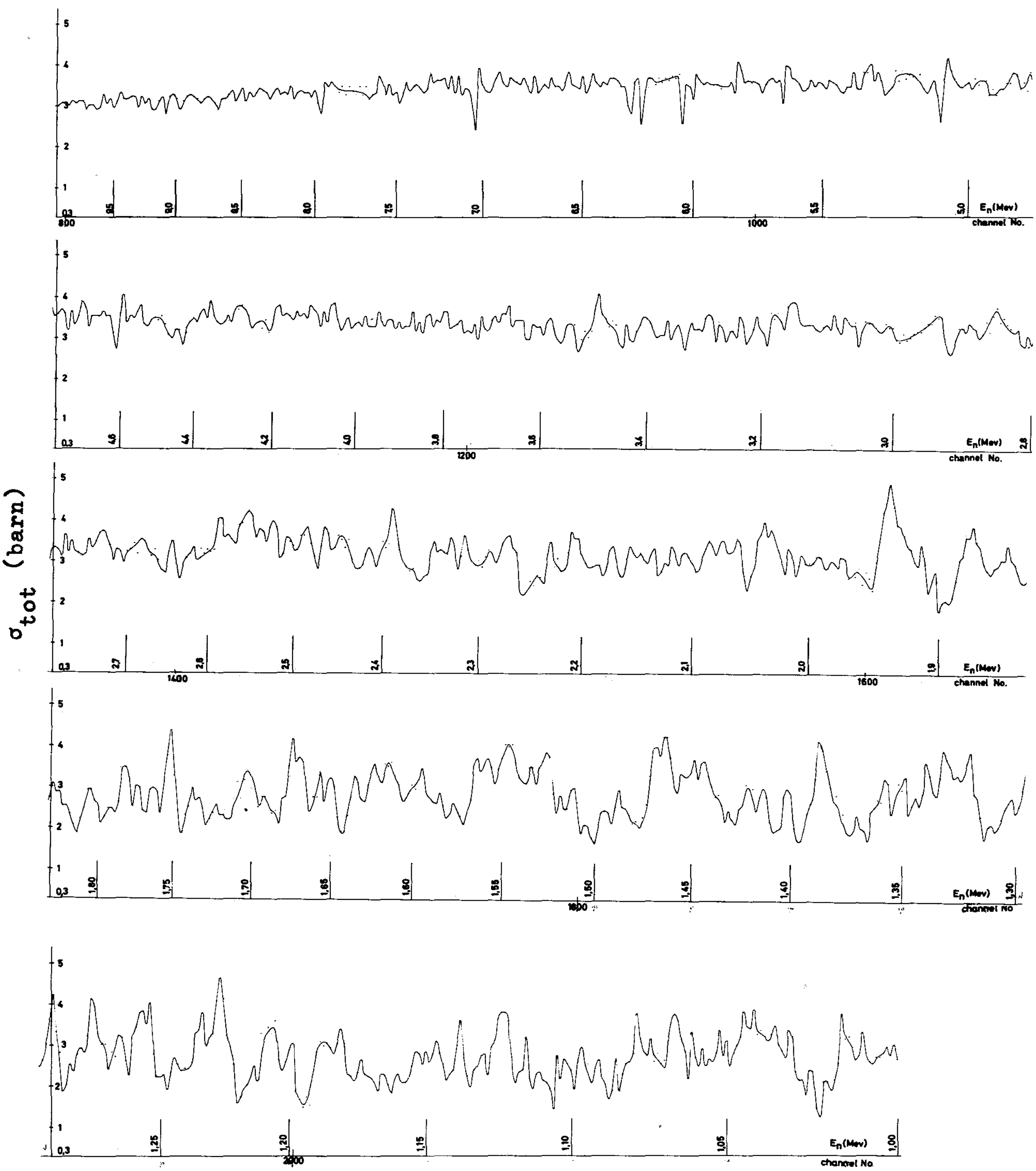


a) Measurement by ref. (5)



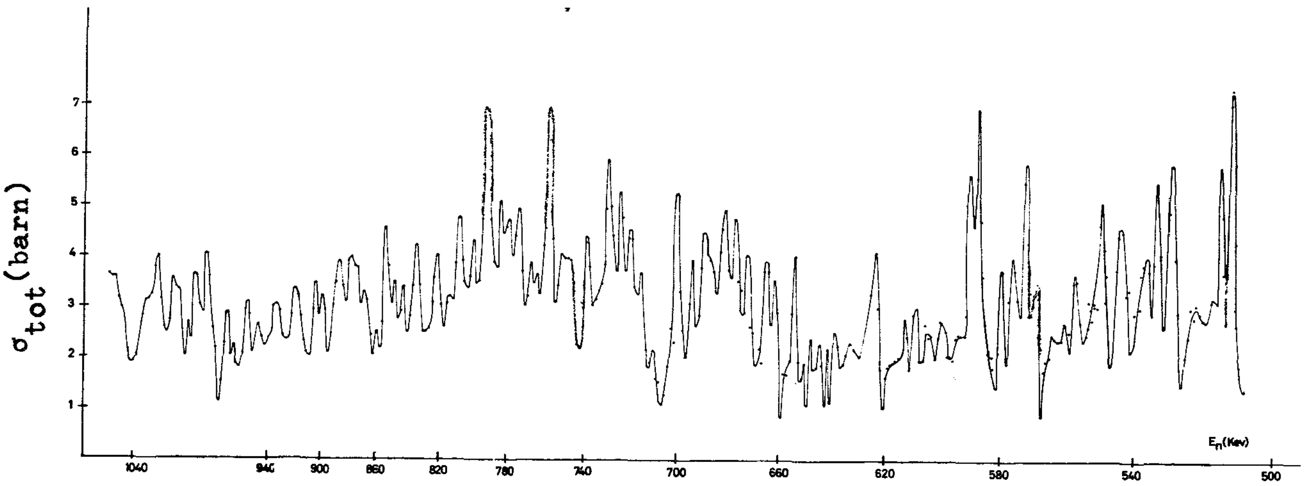
b) Present measurement

Fig. 6 - The total neutron cross-section of Aluminum

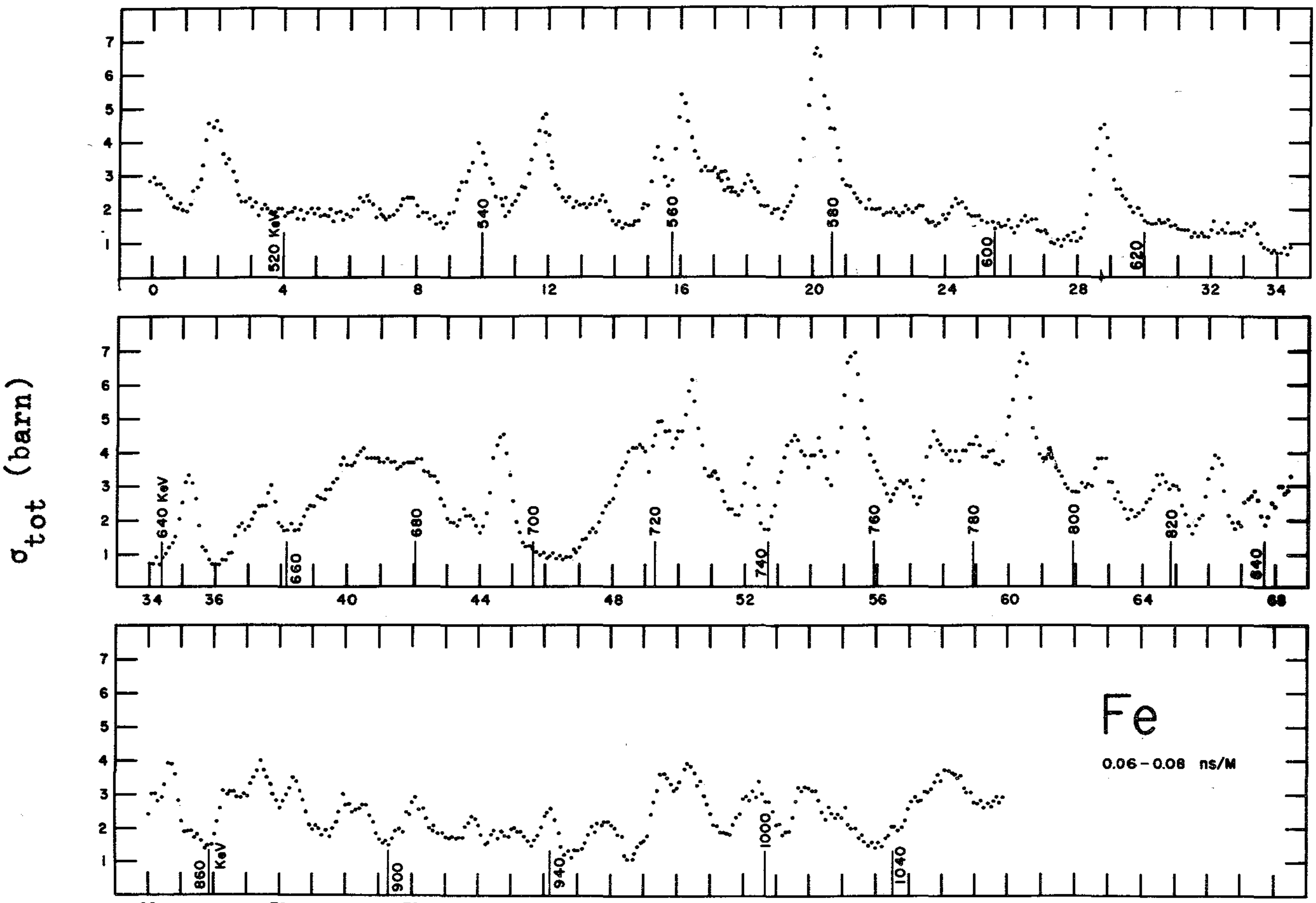


a) Present measurement

Fig. 7 - Total neutron cross-section of Iron (high-energy part)

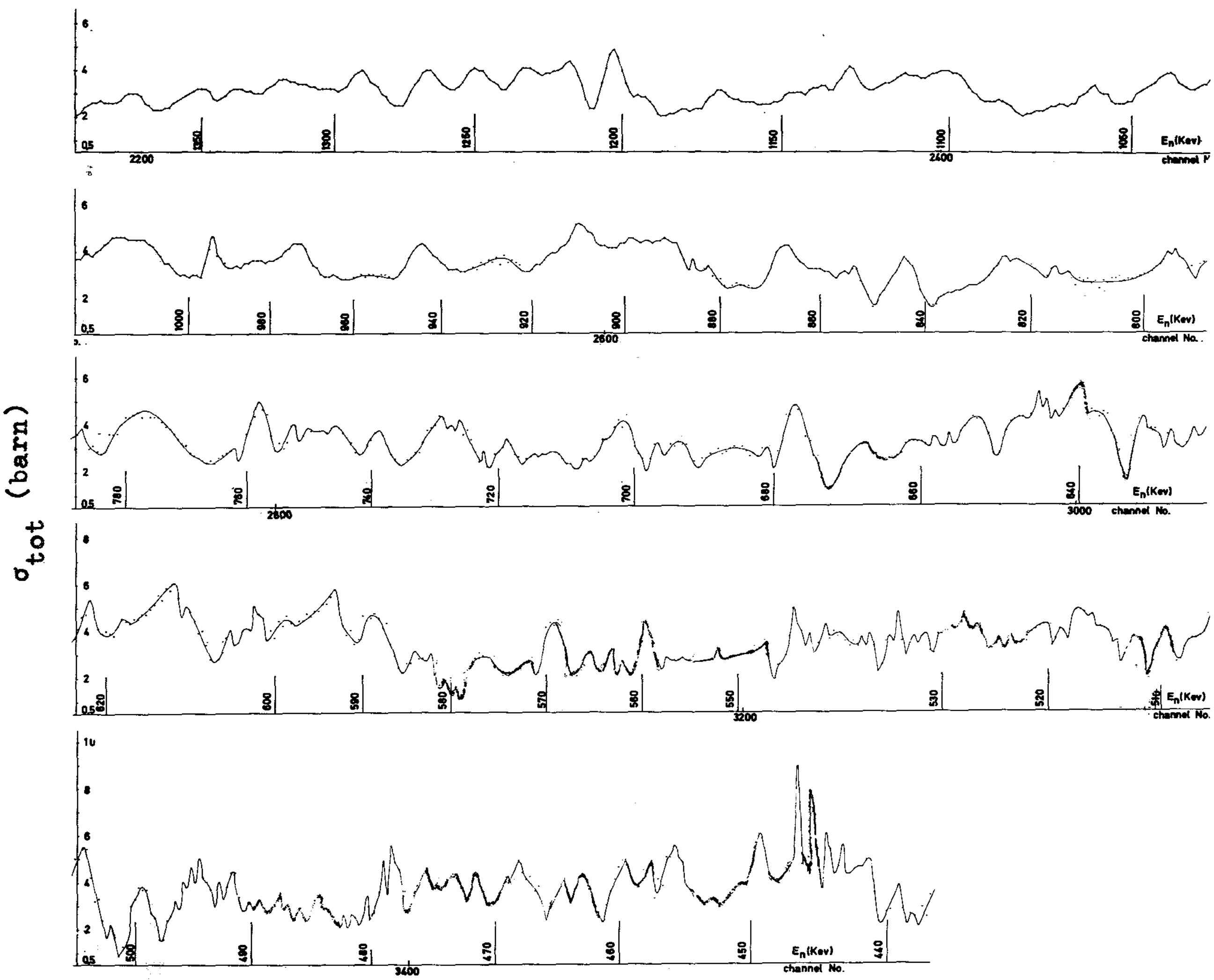


a) Present measurement

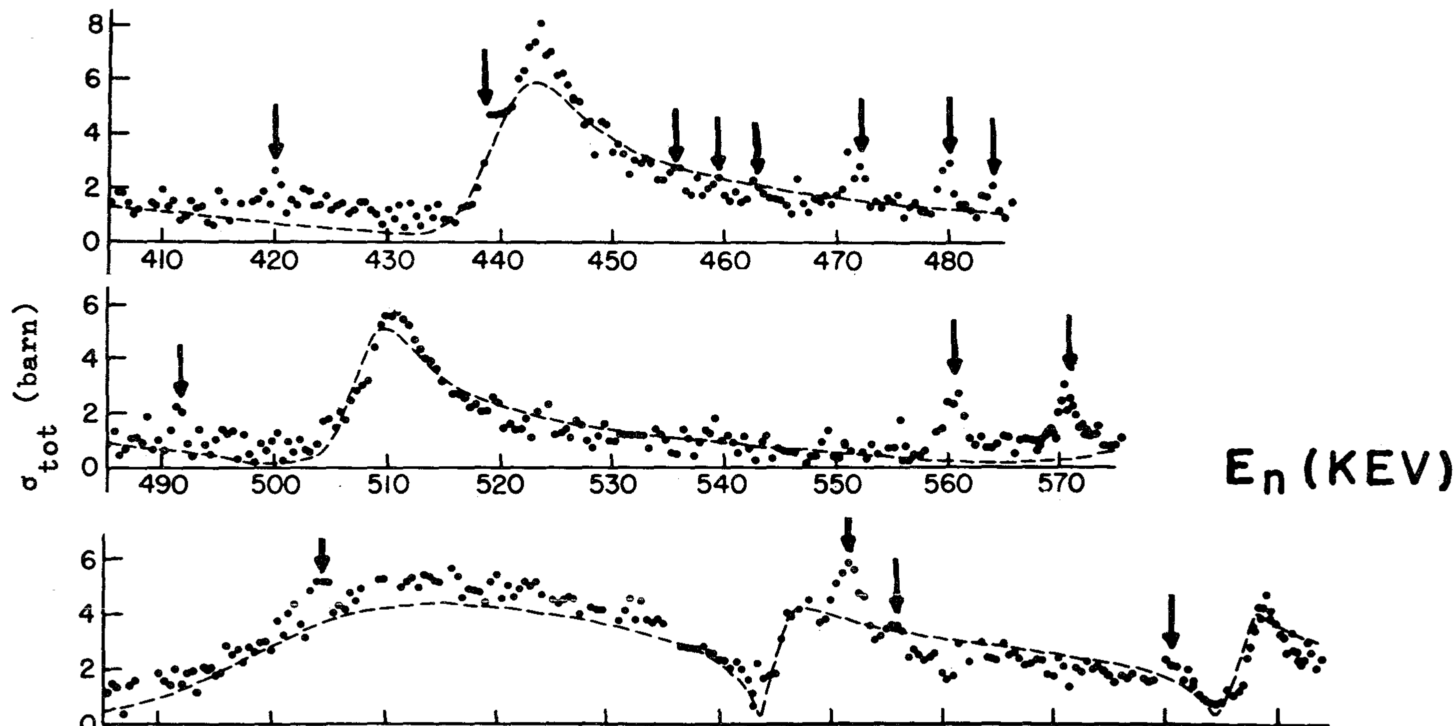


b) Measurement by ref. (3)

Fig. 7 - Total neutron cross-section of Iron (low-energy part)



a) Present measurement



b) Measurement by ref. (6)

Fig. 8 - Total neutron cross-section for Calcium