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ELASTIC SCATTERING OF NEUTRONS FROM NATURAL SILICON

by

M. COPPOLA and H.-H. KNITTER

1966

Joint Nuclear Research Center
Geel Establishment — Belgium

Central Bureau for Nuclear Measurements — CBNM

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Printed by Van Muysewinkel s.p.r.l.
Brussels, April 1966

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Summary

Angular distributions of neutrons elastically scattered from natural Si were measured in the energy range between 0.57 and 2.28 MeV, using a fast neutron time-of-flight spectrometer. Corrections for beam attenuation and multiple scattering in the sample were performed. Differential cross section results were fitted with a Legendre polynomial expansion and the coefficients for the best fits are presented.

Introduction (°)

An accurate study of elastic scattering of neutrons from natural silicon was undertaken as part of a program to provide data, needed for reactor design.

Scarce systematic efforts were made in the last few years in order to determine differential cross sections for scattering of fast neutrons in the energy region up to 3 MeV. Using BF_3 counters as detectors, Lane et al. (1) measured scattering of neutrons from natural silicon in the energy range from 50 keV to 2.3 MeV. Later, with the same technique but with narrow energie resolution, they measured scattering on natural silicon in the energy range from 0.2 to 0.7 MeV, and determined P_2 (Θ) using partially polarized neutrons (2). Bredin (3) measured one angular distribution of elastic neutron scattering and polarisation at E_n - 1.95 MeV, using time-of-flight technique. His attempt of fitting the experimental results with calculations based on a local optical model failed when trying to fit both elastic scattering and polarisation. Optical model calculations using a non-local potential were made by Wilmore (4). No good fit with the available data of differential cross sections was generally reached in the neutron energy region below 2 MeV. Data on neutron total elastic scattering are available from ref. (1).

Experimental Equipment and Procedure

The measurements were made at the 3 MeV Van de Graaff accelerator of CBNM, using conventional fast neutron time-of-flight techniques (5). A pulsed proton beam, with 1 ns burst width and 1 MHz repetition rate was focused on an occluded TiT target, 1 mg/cm^2 thick. The produced neutrons were scattered by a natural silicon cylinder of 2.2 cm diameter and 3.0 cm height. The weight of this sample was (26.676 ± 0.001)g. The sample was placed at 15.0 cm distance from the target, under 0° with respect to the accelerated beam. The average proton current was between 4 and 7 μA. The neutron flux from the target was monitored with a long counter of the Hanson-Mc Kibben type (6). His stability had been checked and was found to be always within the statistical error of 1% required during the testing runs. The detector was inserted in a shielding which collimated the scattered neutrons.

(°) Manuscript received on Marche 26, 1966

The distance between scatterer and detector was 148.6 cm. The shielding including the detector could be rotated around the sample position in the horizontal plane. As an additional shielding of the detector against the direct neutrons, a shadow cone made out of brass was placed between neutron source and detector. The detector itself was a 56 AVP photomultiplier tube facing a stilbene crystal of 45 mm diameter and 30 mm thickness. The counting threshold was set to about 220 keV neutron energy, and the overall time resolution, observed on the time-of-flight spectrum of γ-rays from the target, was 2.1 ns. The stability of the threshold position was checked before starting the measurements and was controlled every few days during the experiment, by comparison with the 60 keV γ-photopeak of a ^{241}Am source. The long-time stability, over about 4 months, was found to be better than 1% or 2.2 keV neutron energy.

The relative detector efficiency was obtained by comparing the measured yield of neutrons scattered on hydrogen, at several angles between 20° and 67.5°, with the known n-p scattering differential cross section (7). These data on hydrogen were corrected for attenuation in the sample of outgoing scattered neutrons (8). As a scatterer a hollow polyethylene cylinder of 1.00 cm outside diameter, 0.60 cm inside diameter and 4.00 cm height was used. The weight was 1.840 g and the hydrogen content (14.31 ± 0.06)%.

Angular distributions of elastically scattered neutrons on Si were obtained at scattering angles between 20° and 148°. With the sample in position, a spectrum was taken for a certain preset number of counts in the monitor. The sample was then moved away from the detector collimation, and background was substracted for the same number of monitor counts. The contribution of the background was in the order of 20 to 30% of the counts within the peak of the elastic scattered neutrons. This procedure was repeated for each measured point several times till enough events were collected in the elastic peak. Statistical errors on the measured points were always in the order of or better than 2.0%.

Seven angular distributions were measured at incident neutron energies of 0.57, 0.84, 1.00, 1.41, 1.74, 1.94, and 2.28 MeV. The neutron energy spreads due to target thickness and finite geometry were 122, 110, 104, 92, 84, 82, and 71 keV, respectively. Absolute values of the differential scattering cross sections were obtained by comparing the angular distribution data for Si with scattering data on hydrogen. For each angular distribution one calibration point was measured on the polyethylene sample at an angle choosen between 30° and 50°.

Experimental Results

Fig. 1 shows a typical time-of-flight spectrum for primary neutron energy of 2.28 MeV. The channel width is about 0.7 ns. The small peak which appears in fig. 1 is due to the inelastic neutron group corresponding to the first excited level in ^{28}Si at 1.78 MeV.

The elastic scattering data were fully corrected for finite geometry, beam attenuation and multiple scattering. Corrections were calculated with a modified version of the program MAGGIE* [9]. The importance of multiple scattering is clearly shown in fig. 2 and 3.

Corrected differential elastic cross section data were then fitted with a Legendre polynomial expansion of the form

$$\frac{d\sigma}{d\Omega}(\vartheta) = \sum_{L=0}^{5} B_L P_L(\cos\vartheta)$$

and the resulting best fits are shown in fig. 2 and 3. Overall accuracies of the absolute cross sections are estimated to be around 6%. The available results of Lane et al. [1] at about the same neutron energies are also shown. The agreement between the two sets of measurements, which are made with completely different techniques, is reasonably good. Discrepancies in the shape of the angular distributions as well as in the absolute values can also be understood, considering the differences in energy and energy spread of primary neutrons,since the total neutron

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* by courtesy of Dr. R.Batchelor

cross section for Si shows a very pronounced resonance structure below 4 MeV.

The values of the six B_L coefficients obtained from the least squares fits are indicated in table I together with the computed errors.

The authors wish to thank Dr. J.Spaepen, director of CBNM, for supporting these measurements and Mr. K.H.Böckhoff for his kind interest in this work. Especial thanks are due to Dr. H.Horstmann for carrying out the computer calculations. We gratefully acknowledge the help given to us by Mr. C.Rousseau on the electronics side, and by the accelerator staff, as well as by the Sample Preparation Group of CBNM.

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TABLE I

Values of the Coefficients in the Legendre Polynomial Expansions, Expressed in mb/sr

E(MeV)	B_0	B_1	B_2	B_3	B_4	B_5
0.57	+ 350.5 ± 2.8	+ 211.8 ± 6.3	+ 169.8 ± 9.2	− 13.7 ± 18.7	+ 3.2 ± 3.1	− 28.6 ± 17.3
0.84	+ 355.2 ± 2.8	+ 332.7 ± 5.0	+ 170.3 ± 6.6	+ 8.2 ± 6.6	− 28.6 ± 9.1	− 14.7 ± 9.3
1.00	+ 342.1 ± 3.0	+ 439.1 ± 6.3	+ 219.7 ± 9.1	+ 3.4 ± 5.3	+ 5.0 ± 8.1	+ 3.3 ± 16.2
1.41	+ 210.6 ± 1.7	+ 211.4 ± 3.3	+ 103.7 ± 4.6	− 22.6 ± 5.4	− 8.0 ± 9.1	+ 9.2 ± 6.9
1.75	+ 144.4 ± 1.3	+ 111.1 ± 2.4	+ 121.5 ± 3.4	+ 68.4 ± 4.5	+ 23.0 ± 4.5	− 14.8 ± 5.6
1.94	+ 260.9 ± 2.5	+ 354.9 ± 6.1	+ 287.0 ± 8.2	+ 117.6 ± 10.2	+ 8.4 ± 4.8	+ 3.0 ± 4.5
2.28	+ 206.1 ± 3.1	+ 265.4 ± 5.8	+ 222.1 ± 8.4	+ 72.5 ± 11.3	+ 15.3 ± 15.3	− 12.4 ± 15.4

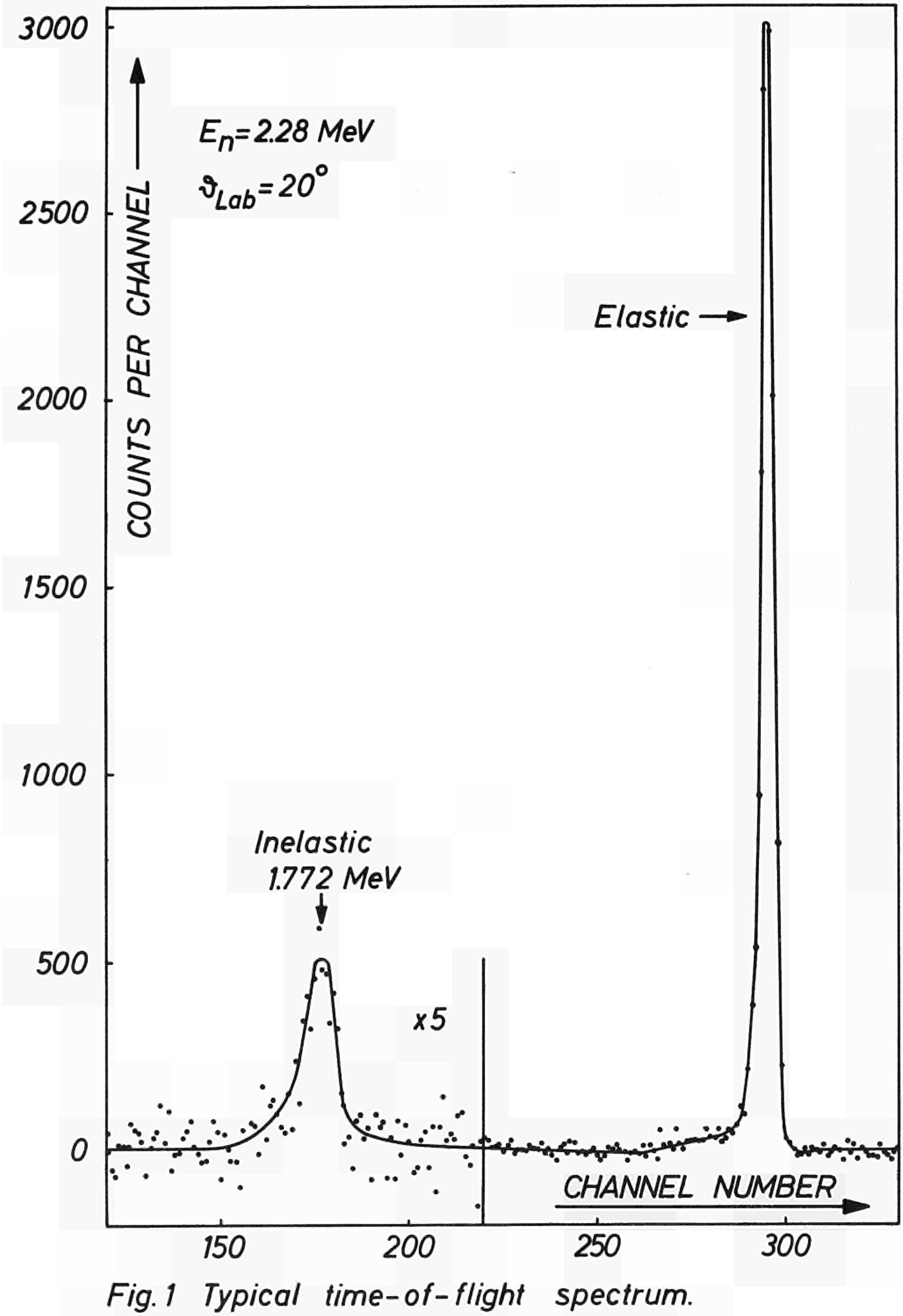

Fig. 1 Typical time-of-flight spectrum.

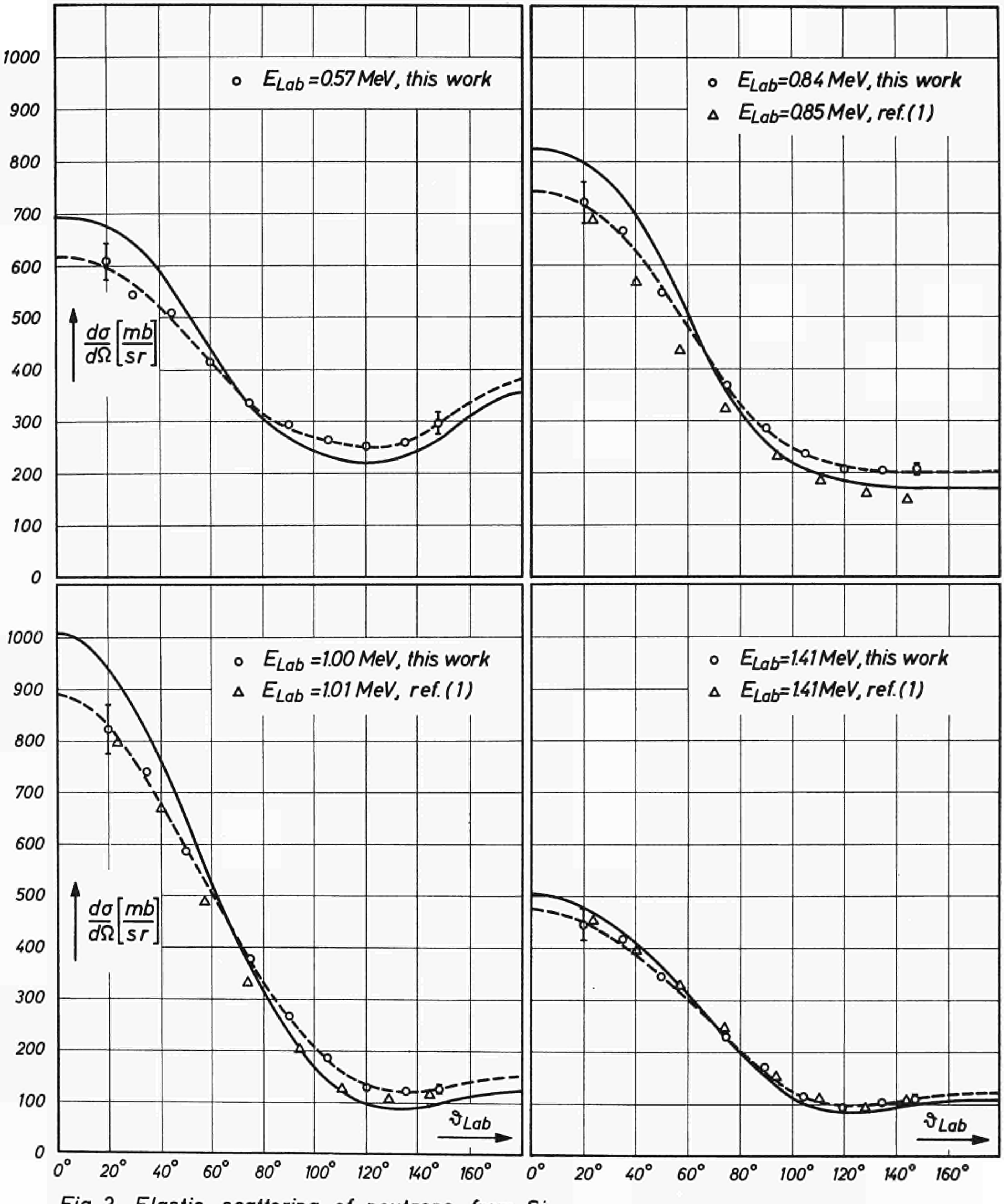

Fig. 2 Elastic scattering of neutrons from Si.
--- Best fits through uncorrected experimental data of this work.
—— Angular distributions corrected for multiple scattering.

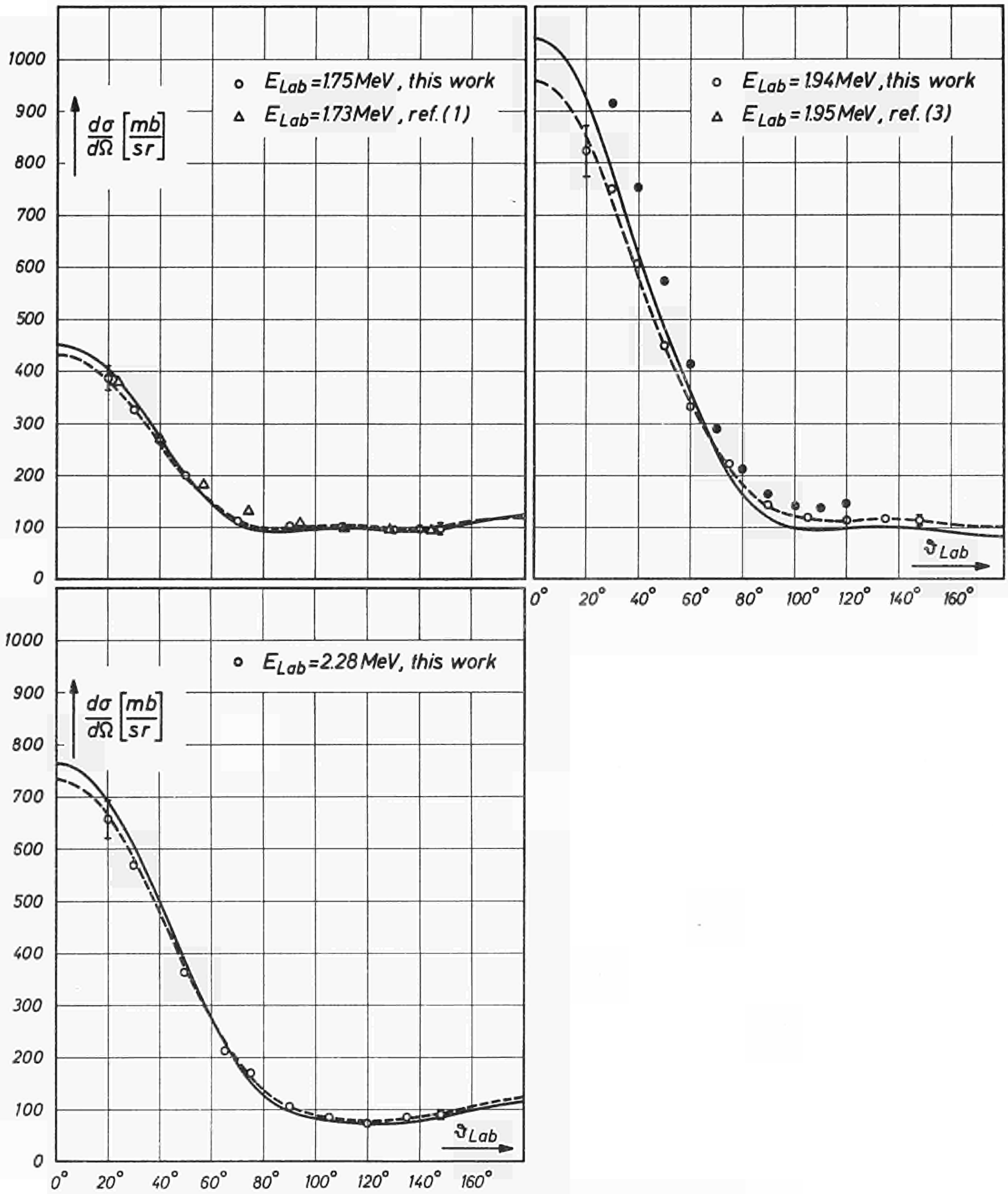

Fig. 3 Elastic scattering of neutrons from Si.

--- Best fits through uncorrected experimental data of this work.

—— Angular distributions corrected for multiple scattering.

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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