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BUDAPEST

A SINGLE CRYSTAL SLOW NEUTRON SPECTROMETER AT THE PULSED REACTOR IN DUBNA

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Abstract

A spectrometer built for combination of monocrystal and time-of-flight techniques is described. The wavelength resolution is 1,5 %, while the time resolution of the spectrometer is 18 μsec/m with normal water and 25 μsec/m with the polyethylene-beryllium cooled moderator. For the latter the slow neutron flux at the sample is 3o neutrons/cm^2 sec. The background is less than 0,6 neutrons/hour for 16 μsec channel width on a detector surface of 25o cm^2. As an example of application the distribution curve for critical scattering on iron is presented.

Introduction

Since 196o several spectrometers suitable for solid state physical investigations have been succesfully operating at the pulsed reactor of the Joint Institute for Nuclear Research, Dubna, SSSR. [1] [2] [3] [4] [5]. However, for the study of small angle quasi-elastic scattering of cold neutrons on systems of critical state, a spectrometer of high energy resolution, with easily separable scattered beam was required. Since these conditions seemed to be best fulfilled by the combination of monocrystalline and time-of-flight techniques, a spectrometer that by construction can be used for measurements involving higher energy and momentum transfers, too, was built in cooperation of the Joint Institute of Nuclear Research /J.I.N.R./ Dubna with the Central Research Institute for Physics /C.R.I.P./, Budapest.

Description

The geometrical layout of the experimental arrangement is shown in Fig.1.

The fast neutrons leaving the core /1/ are partly slowed down by the moderator /2/. The neutron beam reaches the monocrystal /5/ surrounded by shield /4/ through the collimator /3/ mounted into the reactor shielding wall. The reflected beam is passed through Soller type collimator /6/ to the heated sample /7/ and the neutrons thus scattered are detected by the detector assembly /9/ located at the end of the vacuum flight tube /8/. The latter can be displaced over an angular range of 12o^{0} on rail /1o/ centered to the sample. If higher order reflections are undesirable, neutron filter /11/ may be placed before the sample.

A. The moderator

To start with, conventional water moderator of 4 cm thickness was applied that is preferable for shorter neutron wavelengths, later a nitrogen cooled polyethylene-beryllium moderator was used which gives higher flux in the range of longer wavelengths. Fig. 2 shows the construction of the cooled moderator. The choice of 4o mm polyethylene and 6o mm Be thickness was made on basis of earlier experiments at this reactor. [1], [4], [6]. The effective moderator surface is 4o x 4o cm². To avoid the undesirable consequences of deformation and dissociation of polyethylene due to the high neutron flux, bunched foils are applied and the gaseous products are exhausted. The liquid nitrogen container of 14 l volume is in direct heat contact with the moderator. The nitrogen level is checked by nickel resistance level indicators. For average reactor power of 6 kW the nitrogen consumption is 0,6 l/hour. The container is refilled once per day by remote control. The aluminium cryostat with lead gasket wires is vacuum insulated. With the use of carbon absorber the vacuum pressure can be kept better than 1o^{-5}mm Hg over a fortnight's operation.

B. The Spectrometer

To keep the background low, compact shielding system was developed. The water shutter built into the 2 cm thick reactor wall permits to work alternatively with 75, 2oo or 4oo mm diameter neutron beams. The collimator tube built into the reactor wall ends in a combined iron-boron carbide shutter with a 5 x 5 cm² hole in open position.

The monochromator crystal and its goniometer table are surrounded by 5 cm B_4C and 1oo cm water, the sample by 2o cm B_4C paraffin shield.

The vacuum flight tube is 64o cm long and 6o cm in diameter, both the flight tube and the detector holder are surrounded by B_4C shield of 15 cm thickness. The distances from core to monocrystal and from there to sample are 8,4o m and 1,5o m, respectively.

A natural grown monocrystal magnetite with about 3o cm² reflecting surface is used as monochromator. At $\Theta = 5o^{o}$ its (111) crystallographic plane reflects neutrons with wavelength of 4,1o Å and all those of higher order reflections. The mosaic spread of the monocrystal was measured as $\Delta\Theta = 0{,}5^{o}$ and the reflectivity as R=2o %.[7]. The rocking curve of the /111/ reflexion of the monocrystal, as measured with 2o' collimation for continuous flux from the reactor is shown in Fig. 3.

A Soller type collimator is used to decrease the intensity reflected by the monocrystal to higher angular positions. The horizontal divergence of the beam can be changed by suitable rearrangement of the cadmium sheets of the collimator.

C. Detection and electronics

Three detector sets are used for the observation of critical scattering. One of them measures the transmitted intensity, while the other two, located symmetrically at $\vartheta = 2{,}16^{o}$ to the primary beam detect the scattered neutrons. Each detector set contains three parallel coupled proportional BF_3 counter tubes, 4 cm in diameter and 13 cm in effective length, filled to 7oo mm Hg pressure with BF_3 gas enriched to 72 % in B^{10}.

The divergence of the neutron beam under the given experimental conditions is 1^{o} in the horizontal and $1{,}2^{o}$ in the vertical direction.

The electronic equipment permits to analyse 16 time-of-flight spectra simultaneously, each of them being determined by a different detector position.

All electronic units are fully transistorized. The transistorized preamplifiers of a gain of 1oo are mounted into the counter assembly.

The bias level of discriminators is fixed at 0,75 V. The gain of the main amplifiers can be continuously varied from 0,2 to 2o. The operation of the amplifier system can be qualitatively checked on signal lamps connected parallel to the discriminator outputs.

The information arriving through 16 channels is sorted by a coder unit into five channels to be passed by cable to the analysers of dividable memory, located at about 8oo m from the experimental hall.

The measurements are timed by monitor counter and preset scaler units. The block diagram of the electronics is shown in Fig. 4.

D. Sample and heating devices

The study of critical state requires high temperature stability and homogeneity. This is achieved by means of water cooled resistance furnace with vanadium neutron windows and temperature controller device.

Bifilar resistance wires wound around the sample are used for heating. To homogenize the temperature, the pitch of the winding decreases at both ends of the sample of 9 x 3,5 x 0,5 cm^3 volume. The highest temperature difference inside of the lo cm^2 sample surface exposed to the neutrons was found to be 0,2^{o} C at an average temperature of 750^{o} C. Temperatures of about looo^{o} C can be achieved with a heating power of 1 kW.

The temperature is measured and controlled by means of two chromel-alumel thermocouples. The temperature controller, type KFKI NP-248, was developed in the Central Research Institute for Physics. The temperature stability was found to be better, than 0,1^{o} C at 750^{o}C for 100 hours operation.

Neutronphysical characteristics

The most important characteristics, namely, flux at sample surface, time resolution and background depending on neutron energy were measured for both the usual 4 cm room temperature water and the cooled polyethylene beryllium moderator. The neutron spectra reflected by the (111) surface of the magnetite monocrystal, measured at the end of the flight tube, that is at a distance of 16,1 m from the reactor core, are shown in Fig. 4, while the flux and reflexion half-width data are listed in Table 1.

Table 1.

Neutron wavelength /Å/		4,1o	2,o5	1,37	1,o2
n /cm^2 sec	water moderator	3	5o	1oo	6o
	cooled moderator	3o	28	14	6
Δt /μsec/	water moderator	3oo	16o	1oo	1oo
	cooled moderator	4oo	3oo	16o	1oo

The listed data have been evaluated for 6 kW reactor power and are corrected for counter efficiency and analyser dead time. The uncertainty of the flux data was estimated as 2o %.

The half-widths at shorter wavelengths are predominantly determined by the loo μsec reactor burst.

The time resolution was evaluated from the slope of the cutoff-edge of the beryllium filter cooled to liquid nitrogen temperature. The change of time resolution with different moderators is shown in Fig. 5.

The wavelength resolution, evaluated from the half-width of the reflected beam and from the slope of the beryllium filter cutoff edge, agrees with that measured by the rocking curve of the monocrystal.

The background observed for 25o cm^2 detector surface is 0,6 neutrons/hour/16 μsec at about $\lambda = 4Å$ and 2 neutrons/hour/16 μsec at about $\lambda = 2$ Å with 6 kW reactor power. This background was found to originate from the reactor shielding and to be independent of the open or closed state of the reactor channel of the spectrometer.

As an example of the measurements performed with the spectrometer, the distribution of slow neutrons scattered by iron in critical state at $\vartheta = 2,16^{\circ}$ /solid line/ and that of the direct beam /dotted line/ are shown in Fig. 6.

Acknowledgments

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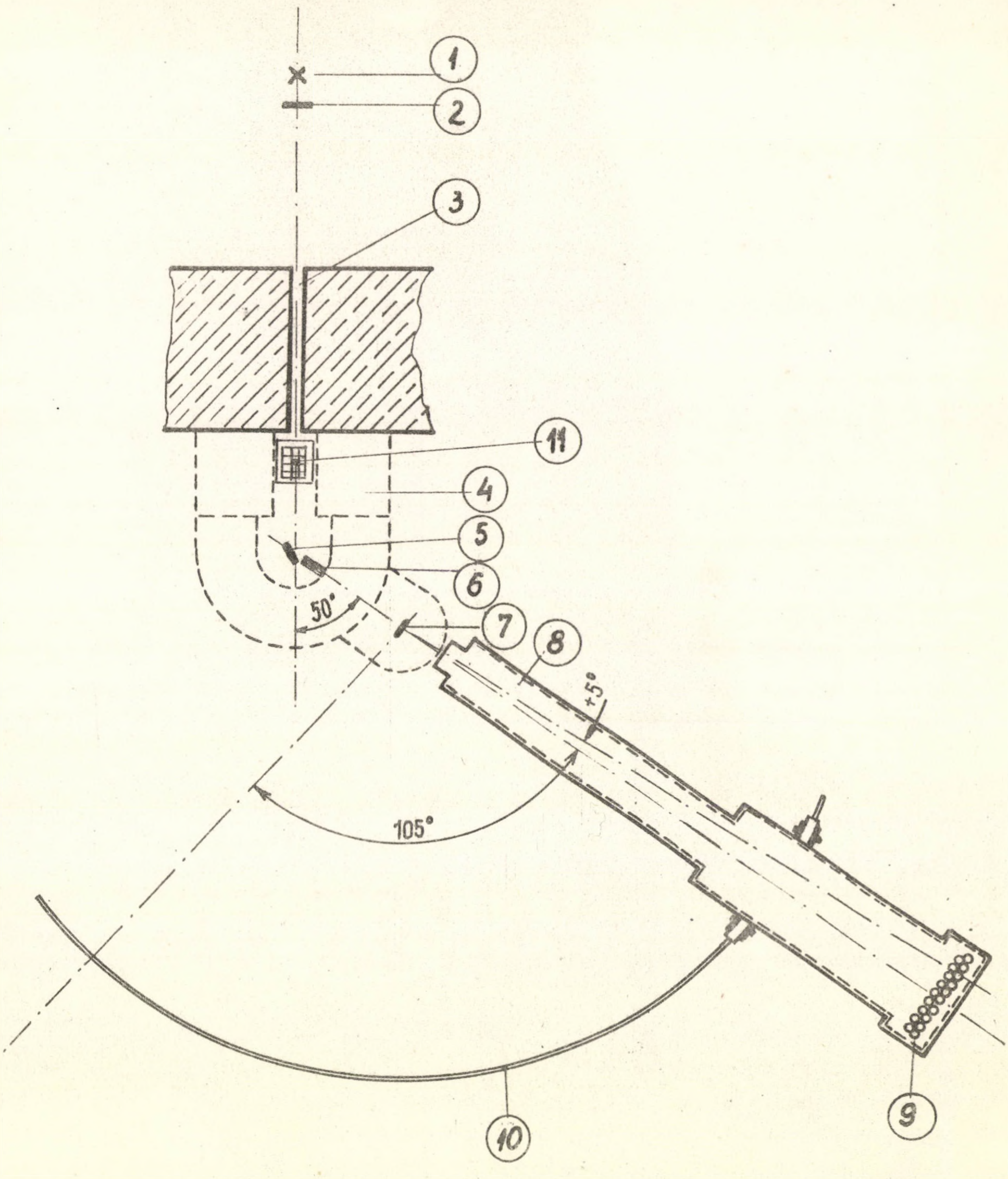

Fig. 1.

Layout of the experimental arrangement

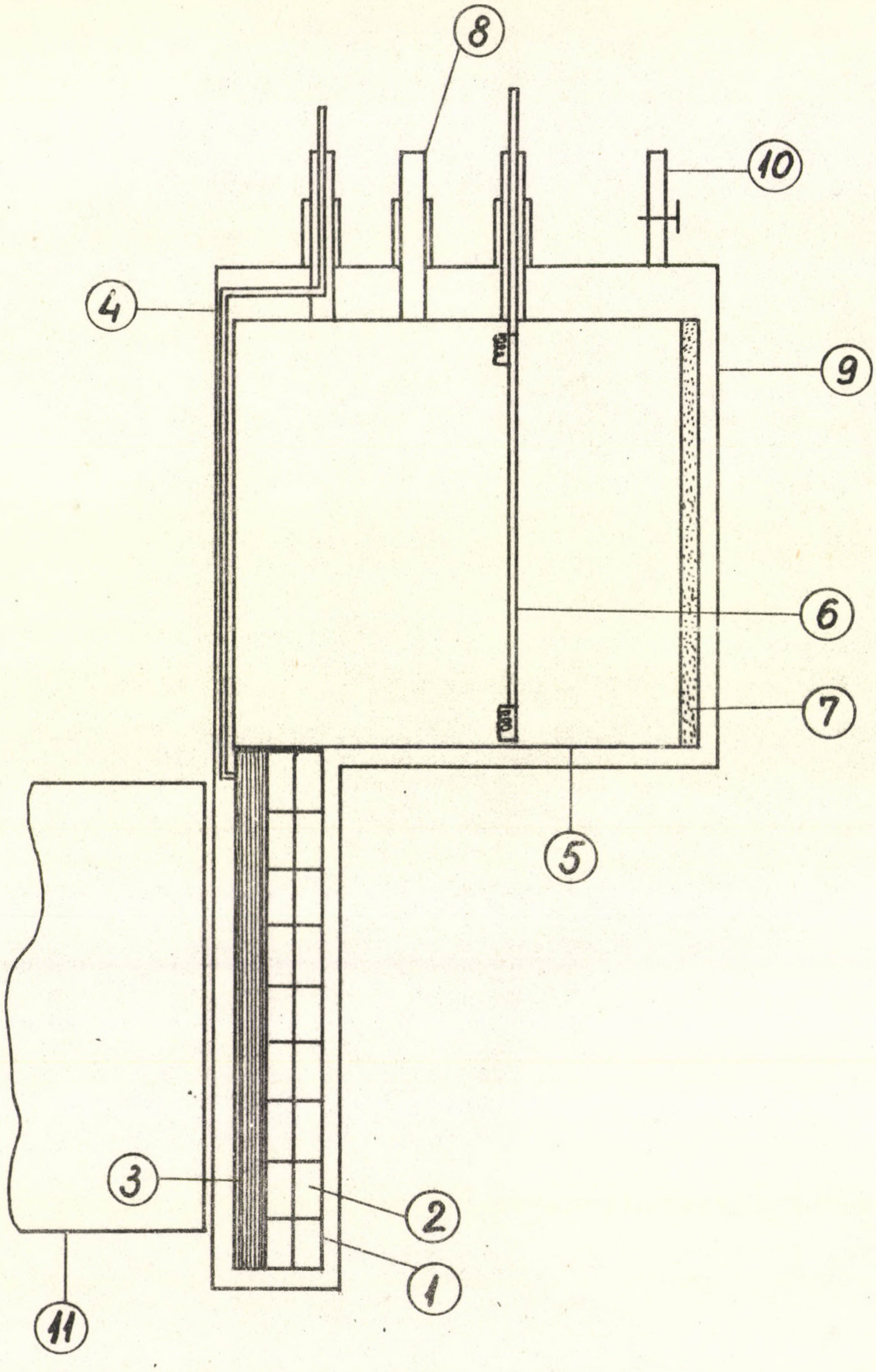

Fig. 2.

Arrangement of the cooled moderator 1/ Moderator box, 2/ Beryllium, 3/ Bunch of polyethylene foils, 4/ Pipe for gaseous dissociation products, 5/ Liquid nitrogen container, 6/ Level indicators, 7/ Carbon absorber, 8/ Inlet and exhaust pipes, 9/ Vacuum jacket, 10/ Vacuum valve, 11/ Reactor core.

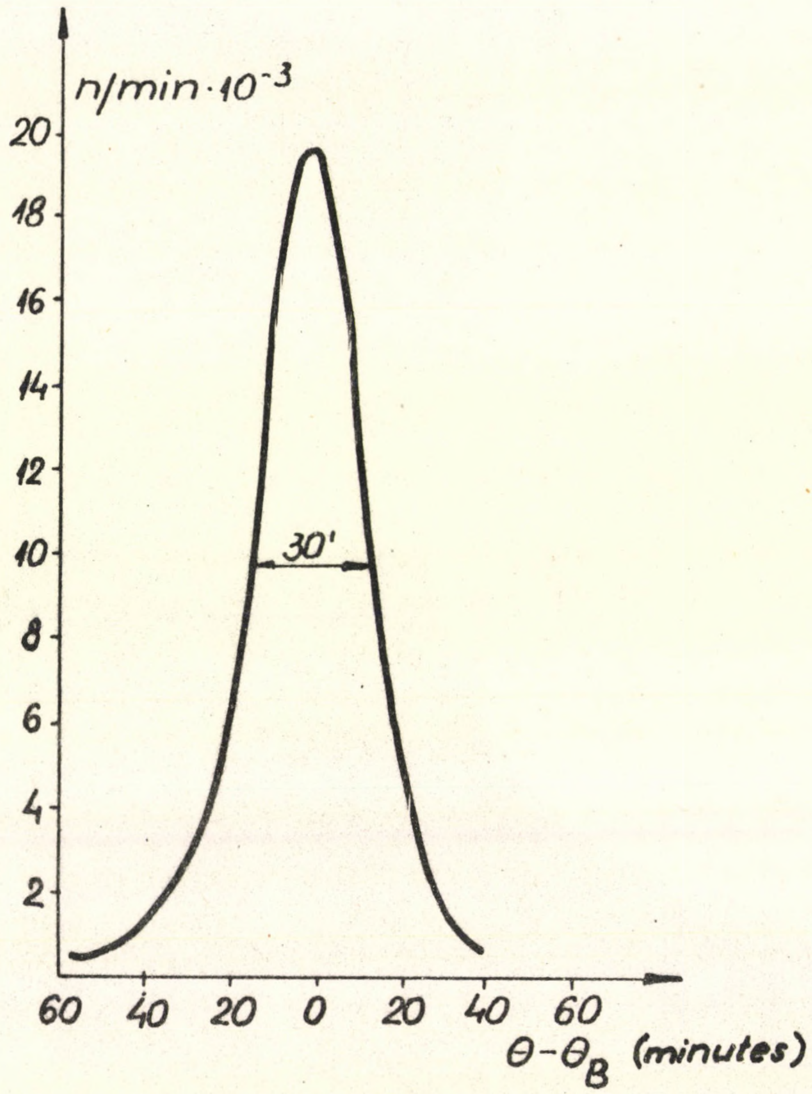

Fig. 3.

Rocking curve for the /111/ reflexion of the monocrystal.

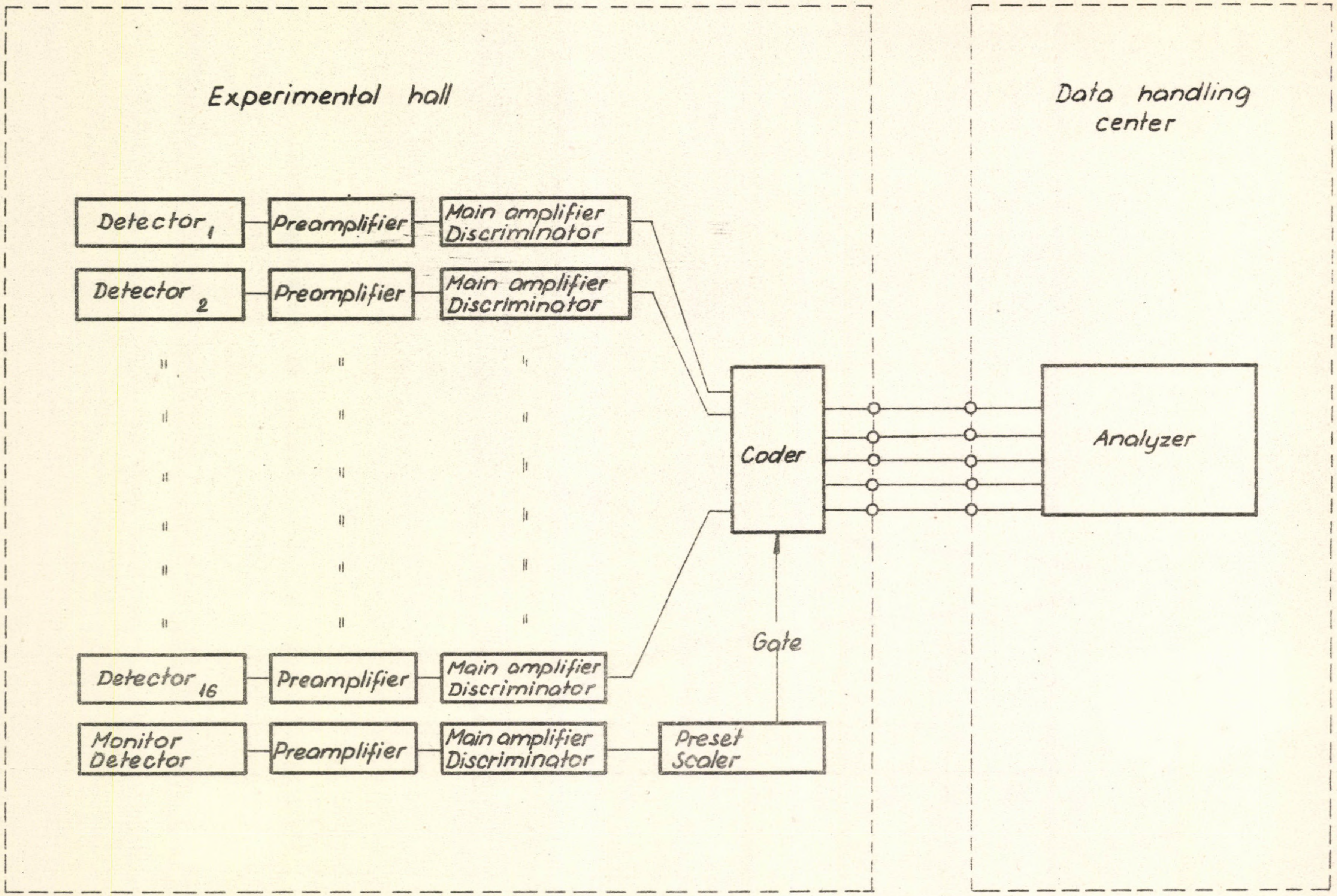

Fig.4.

Block diagram of electronics.

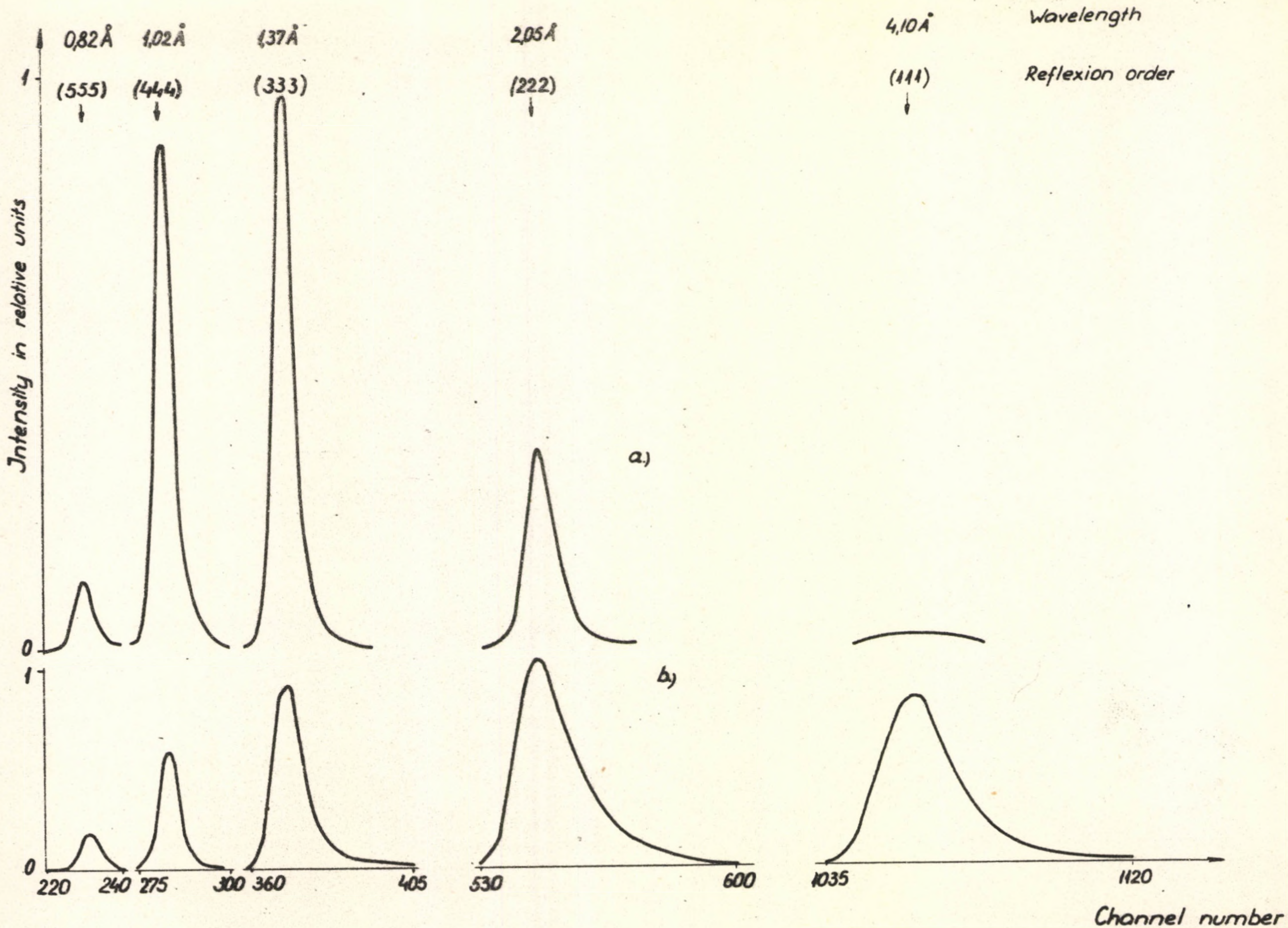

Fig.5.

Neutron spectra reflected by the /111/ surface of magnetite monocrystal
/a/ cooled polyethylene-beryllium moderatór, /b/ normal water

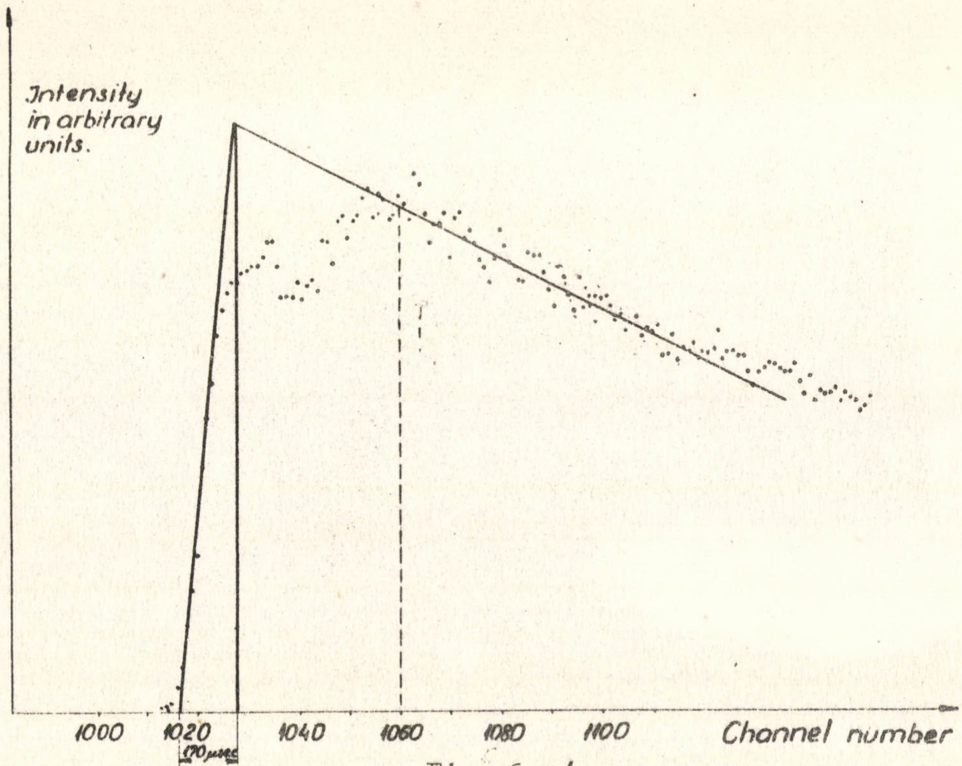

Fig. 6 a/

Fig. 6 b/

Distribution of neutrons transmitted through Be filter

a/ normal water,
b/ cooled polyethylene-beryllium moderator

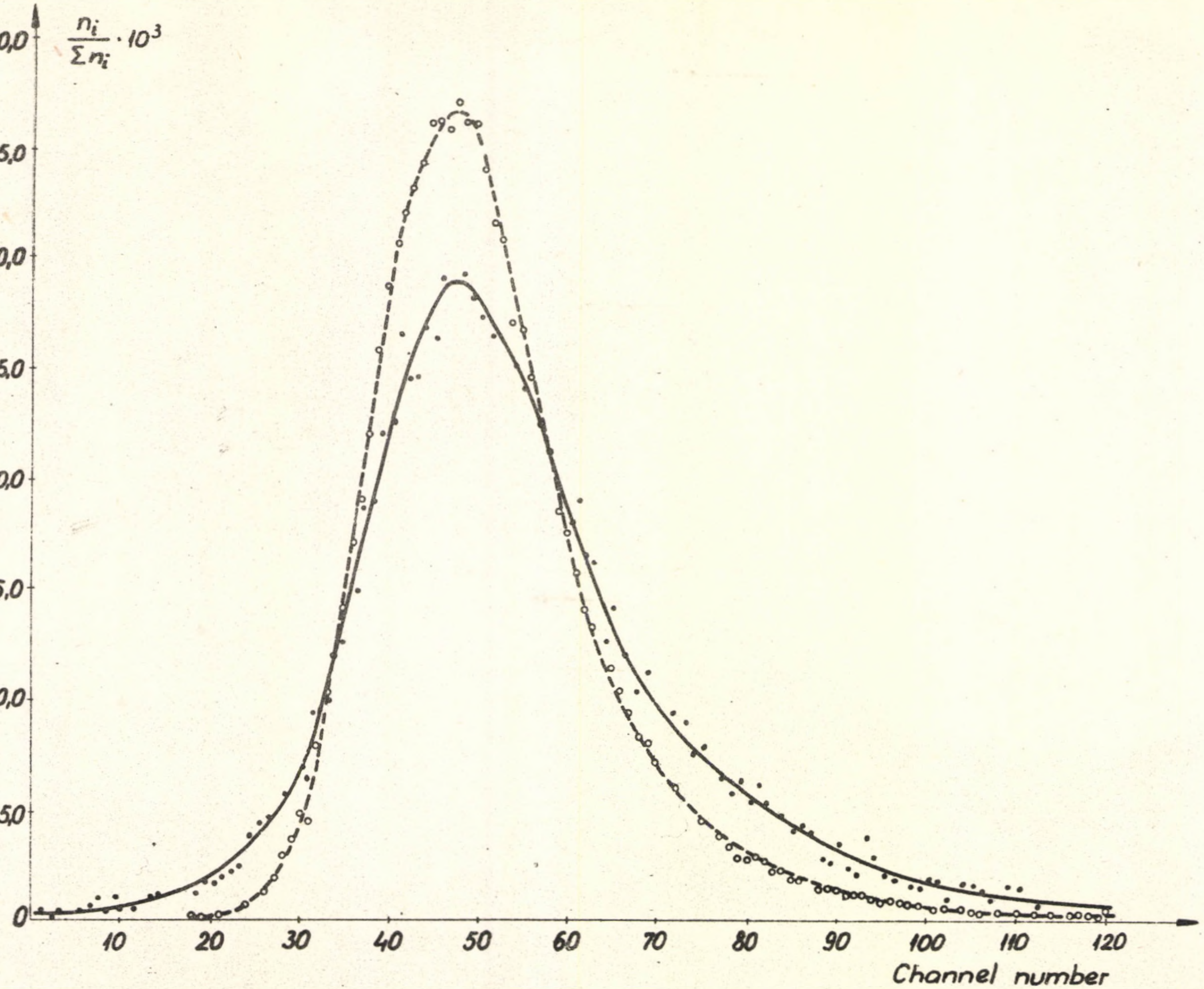

Fig. 7.

Distribution of neutrons scattered by iron of critical state /solid line/ as compared with that of the incoming beam /dotted line/.

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