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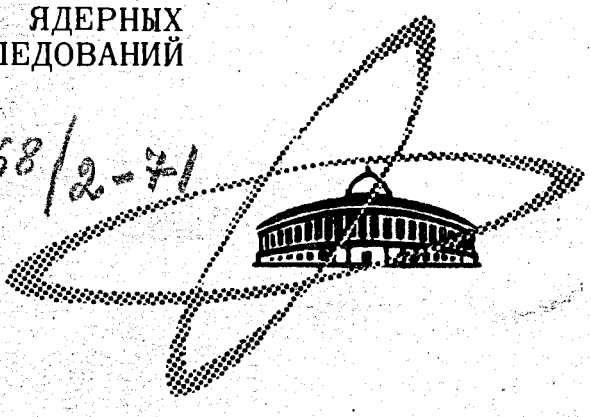

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TRIAL EXPERIMENTS ON THE MAGNON SCATTERING OF NEUTRONS AT THE IBR BEAM No. 1A

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1. Introduction

The work reported here was intended to provide some data concerning the existing situation on the beam No.1a of the IBR reactor at Dubna and to give some information as to the possibilities of performing magnetic experiments on this beam. So far mostly incoherent phonon scattering has been measured there.

We decided to use samples in which the magnon spectra had already been measured elsewhere. Two samples were chosen: a single crystal - pyrrhotite ($Fe_7 S_8$) and polycrystalline - chromium oxide ($Cr_2 O_3$). In principle the maximum information is gained on single crystals but some information can still be obtained using polycrystalline samples, which are much more easily prepared.

2. Experimental Set-Up

The Cracow-Dubna Neutron Spectrometer KD SOG-0/1/ installed at a distance of 22.3 m from the core of the IBR pulse reactor was used during the experiments. The axis of the channel *1a* looked at the angle 12° at the centre of a surface of about 22x22 cm of the water moderator

which surrounded the active zone of the reactor. There was a vacuum neutron guide tube about 19 m long placed between the spectrometer axis and the reactor. Some neutron collimators inserted into this tube and made of a mixture of paraffin and boron carbide gradually limited the cross-section of the beam to the dimensions 80 /in the horizontal direction/ x 120 mm at the end of the guide tube.

The spectrometer was used in two geometries. The first one described in/1/ utilized the principle of the *Be* -filter inverted geometry. A schematic diagram of the second geometry is shown in Fig. 1. To analyse energies of the scattered beam a single crystal of *Al* of dimensions 160x75x18 mm cut parallelly to *(111)* crystallographic planes was used and the *Be* -filter replaced by a Soller type collimator.

In the case of work with a single crystal sample a new mechanical set-up was installed above the mechanical axle of the arm by means of which the sample could be rotated about the vertical axis by remote control with a precision of 2'. A goniometer head was also mounted on the top of this table to orient the single crystal in other directions. If necessary a Soller type collimator with horizontal sheets was placed between the sample and the analyser.

Reasons for trials with the second type geometry were as follows:

1⁰/ Because of a strong dependence of magnetic form-factors on the scattering wave vector $\vec{\kappa} = \vec{k}_f - \vec{k}_o$ ($\vec{k}_{f,o}$ – respectively final and initial wave vector of neutron) all magnetic experiments should be performed at optimalized geometries with respect to $\vec{\kappa}$ vectors . This usually requires measurements at a small scattering angle ϕ_o and a region of energy analysis higher than in the case of *Be* -filter.

During the reported experiments we performed measurements with two energies of analysis: 57.3 meV and 9.8meV. The corresponding Bragg angles of the $Al(111)$ analyser were 14.8^{o} and 32.2^{o}, respectively. The collimator of 0.72^{o} in the horizontal plane was placed only between the analyser and the counter array. This collimation caused $\Delta E_{a} = 5.4$ meV and $\Delta E_{a} = 0.31$ meV, respectively. In the case of Fe_7S_8 the collimator in the vertical direction was $\approx 2^{o}$.

The results obtained with the single crystal of Fe_7S_8 ($\vec{\tau} = (00.1)$, $1/d = 176 m\text{Å}^{-1}$) are presented in Figs 4 and 5. The dimensions of the crystal (80 g) were approximately 20 x 17 x 50 mm. For $E_{a} = 57.3$ meV the angle of scattering was 8^{o}, which corresponded to about 18 meV of average transfer of neutron energy. The second geometry ($E_{a}=9.8$meV, $\phi_{a} = 10^{o}$) corresponded to about 11.2 meV average transfer of neutron energy.

The measurements with powder samples were performed at $\phi_{a} = 15^{o}$ only with $E_{a} = 57.3$ meV. Attention was paid to the optical magnon branch in Cr_2O_3 which is situated at the level of about 50 - 55 meV. The area of powder irradiated by neutrons was about 80 x 120 mm and the surface density of the sample about 1.3 g/cm^2. The plane of this parallel layer of powder always bisected the angle formed by the directions of the incoming and scattered beams. The powder holder was placed in a cryostat and measurements were done in the temperature of liquid nitrogen and in room temperature. The time-of-flight spectrum for Cr_2O_3, corrected on the background and the empty cryostat effect, is shown in Fig. 6. To obtain information on the phonon spectrum behaviour in Cr_2O_3 similar measurements were undertaken for Al_2O_3 (with the surface density 1.5 g/cm^2), which has the same crystallochemical structure as Cr_2O_3. The intensity of phonon scattering was very low and almost independent of temperature.

C/ Experiments with the Be filter. The measurements of time-of-flight spectra for Cr_2O_3 and Al_2O_3 powders with the Be filter as an analyser were performed at two scattering angles 35^0 and 90^0. The dimensions and positions of samples were the same as those described above. The results obtained for the angle 35^0 are shown in Figs 7 and 8. Positions of satellites changed in the case of Cr_2O_3 powder in comparison with other measurements because of the change of the repetition rate of the reactor pulses.

4. Estimation of the Magnon Scattering Cross-Section

For the case of Cr_2O_3 and the single crystal analysing system an attempt was made to calculate the experimental cross-section for the optic magnons of $E_m \approx 50$ meV. We took into account that at $\Delta E \approx 50$ meV there were 90 neutrons inelastically scattered and counted in one channel of 64 μsec width per 19.5 hours. The following formula was used

$$\left[\frac{d\sigma}{d\Omega}\right]_{\Delta E = E_m} = \frac{I_{sc}}{I_0 \cdot \Omega_a \cdot N \cdot S \cdot \eta},$$

where: a) spectral density of scattered and detected neutrons $I_{SC} \sim 2.8 \times 10^{-2}$ min^{-1} meV^{-1}; b) spectral density of incoming beam at $E = 107$ meV $I_0 = 0.46 \times 10^6$ cm^{-2} min^{-1} meV^{-1}; c) solid angle of the analysing system $\Omega_a = 3 \times 10^{-3}$; d) number of Cr ions per cm^2 of the sample $N = 1 \times 10^{22}$ cm^{-2}; e) active surface of the sample $S = 28$cm^2; f) efficiency of the detection system $\eta \sim 1 \times 10^{-2}$. Then roughly $\left[\frac{d\sigma}{d\Omega}\right]_{\Delta E = 50meV} \approx .0.01$ b/sterad per Cr ion. This value has the expected order of magnitude when compared with the value estimated theoretically[x/]. It is no much

[x/] A. Kowalska (private communication).

sence to make a detailed comparison between the theory and the experiment because of some very rough estimations (especially the one of η magnitude).

5. Discussions and Conclusions

The results presented in Sec. 3 are in an agreement with previously obtained information[2] and[3] about the substances used. The complicated shape of the INS peak in Fig. 4 is caused by a mixture of maxima corresponding to the acoustic and optical branches in Fe_7S_8. According to[2] the optical branch of magnon excitations should start from about 15 meV. For $E_o = 9.8$ meV and $\Delta E_{ov} = 11.2$meV we expected that the resolution would be sufficient to separate two acoustic peaks (see Fig. 5 - an additional drawing above the INS peak; the shape of expected peaks was taken by interpolation from QNS (quasi-elastic) peaks of the first and second order reflections). It seems from the comparison of anticipated and obtained INS peaks that even for $\Delta E = 11$ meV there already exists an optical peak.

The spectra given in Figs 6 and 7 exhibit the existence, in the nitrogen temperature, of magnetic peaks near the energies 45 and 52 meV, i.e. the energies of optical magnons in Cr_2O_3. Unfortunately there are also some optical phonon frequencies known in this region from the infrared spectroscopy (see Fig. 7). The difference between spectra obtained in two temperatures shows the summary effect of temperature influence on both phonon and magnon excitations. It is impossible to select exact contributions of either kind of excitation, particularly if the temperature of 288^{o}K is still below the Neel point of the substance. Some opinion concerning the effect of phonons themselves can be obtained from measurements on Al_2O_3.

As expected on the basis of κ dependence of the magnetic form-factor, the ratio of magnon to phonon scattering in the higher energy region is greater when E_o is greater and ϕ_o smaller (cf. Figs 6 and 7).

The conclusions to be drawn from our trial experiments are the following: It is possible even at the present power of the IBR reactor to perform experiments on inelastic magnetic scattering. The scientific problems which can be dealt with are, for example: investigation of the magnon dispersion relations in single crystals, determination of the top of magnon branches, determination of energies of transitions between states of paramagnetic ions in crystal fields. To perform such researches, however, it is necessary to improve the methods. Much work must be done to increase the crystal analyser efficiency, which is now no greater than 20%. One solution will be the use of pyrollytic graphite crystals. The resolution may be increased by introducing better collimation behind the crystal analyser and by work at a greater distance from the reactor. The latter condition will be provided by the new KD SOG-I spectrometer. A programme for theoretical calculations of the resolution function has nearly been completed. We propose to pay most attention to the development of that method which enables measurements at small scattering angles.

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Received by Publishing Department
on August 5, 1971.

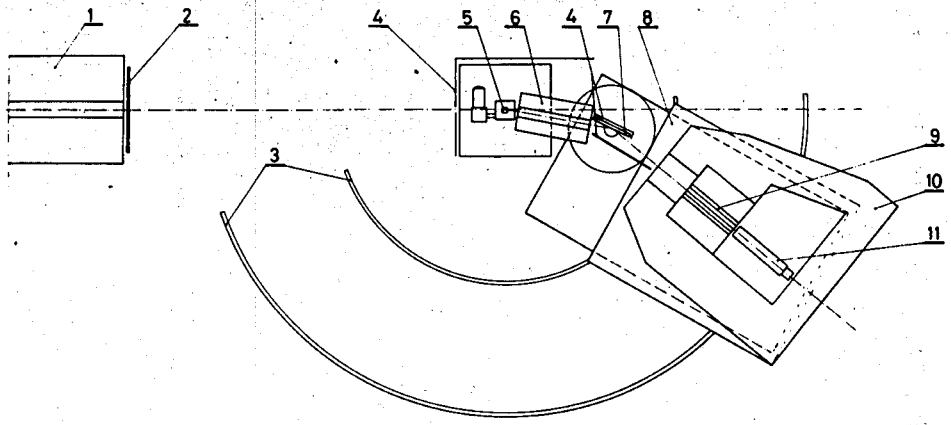

Fig. 1. A schematic diagram of the second geometry of measurements. 1 - guide tube with paraffin collimator, 2 - Cd and B_4C shielding, 3 - steel rails - trajectory of the spectrometer arm, 4 - Cd shielding, 5 - sample, 6 - Soller type collimator in the vertical direction, 7 - analyser, 8 - spectrometer arm, 9 - Soller type collimator in the vertical direction, 10 - detector shielding, 11 - neutron counters.

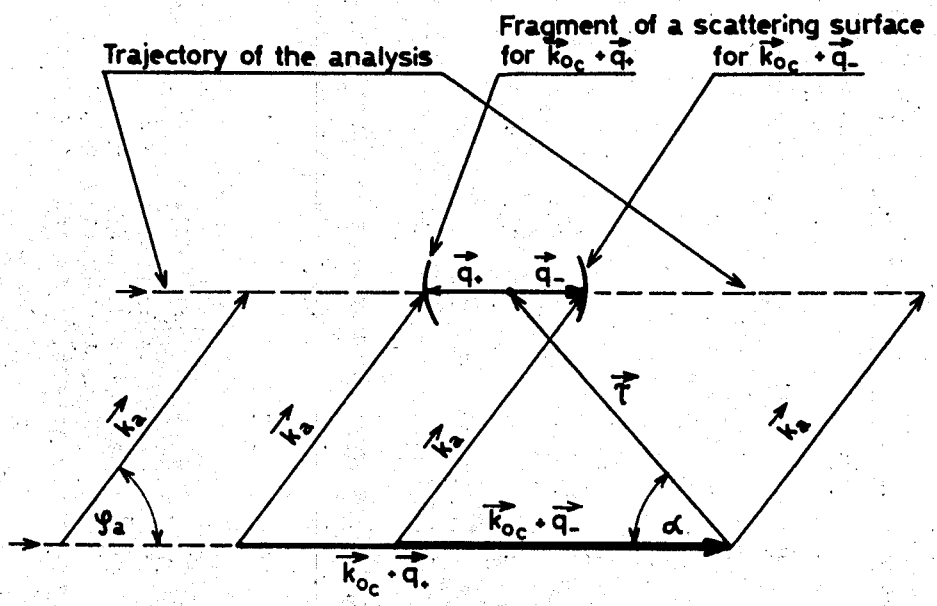

Fig. 2. A schematic diagram in the reciprocal space explaining the method of the energy analysis at pulse reactors if the energy of an analyser is constant.
$\alpha = \arcsin\left(\frac{k_a}{\tau} \sin \phi_a\right)$.

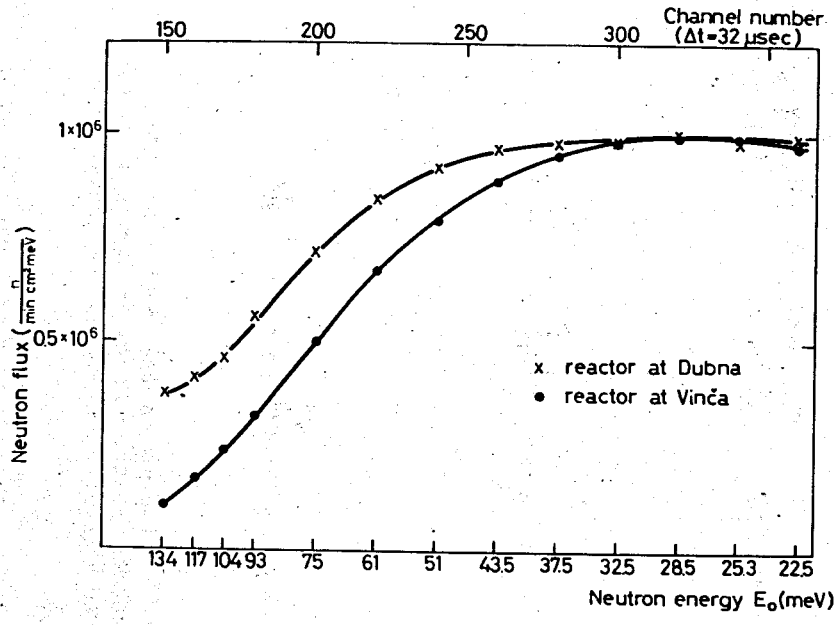

Fig. 3. The spectral density of the "white" beam at the IBR reactor and at the RA reactor at Vinca.

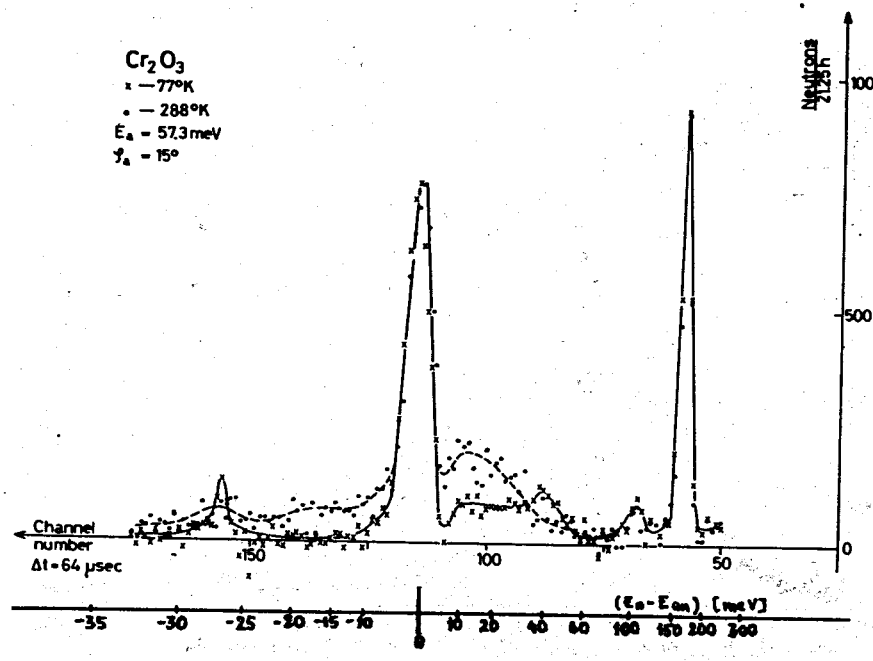

Fig. 6. The spectrum obtained for Cr_2O_3 powder in two temperatures with the use of the *Al(111)* analyser. The peak on the right side of the spectrum is connected with the second order reflection from the analyser, the trace of a peak on the left side of the spectrum is a residuum of the first satellite. A correction for the background (effect with the empty powder container) was made.

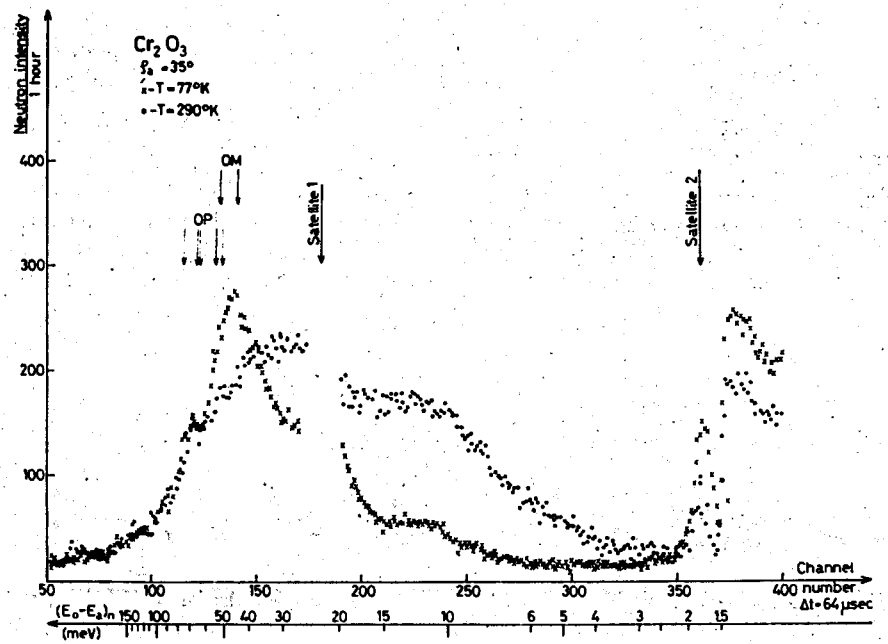

Fig. 7. The time-of-flight spectrum for Cr_2O_3 powder obtained for the inverted Be filter geometry and $\phi_a = 35^0$. OM - magnon peaks - positions of arrows calculated from the density of spin wave states given in /3/. OP - optical phonons - frequencies observed in the infrared spectroscopy/4/.

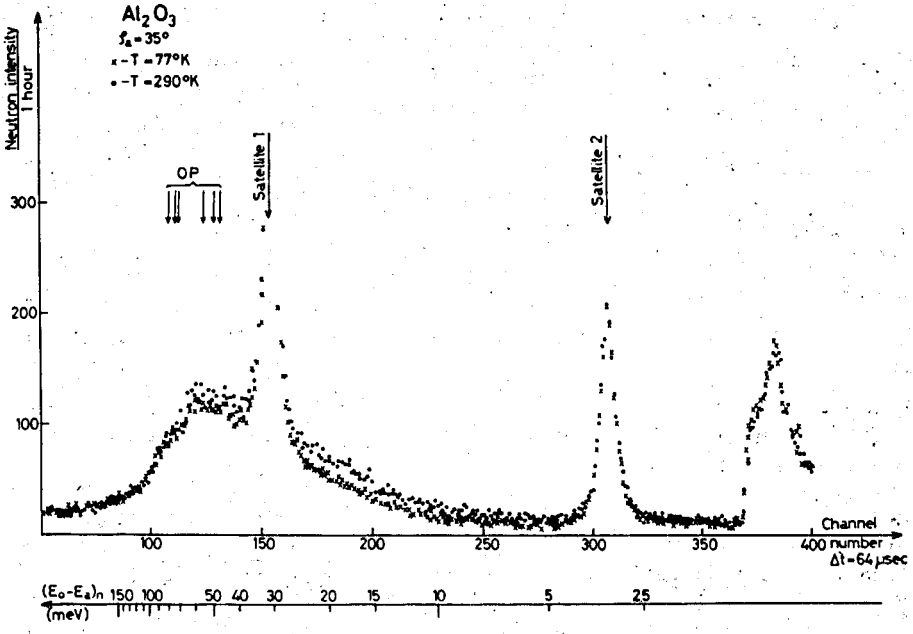

Fig. 8. The time-of-flight spectrum for Al_2O_3 powder for the inverted Be filter geometry and $\phi_a = 35^0$. OP - optical phonons -- frequencies observed in the infra-red spectroscopy/5/.