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TIME OF FLIGHT SPECTROMETER WITH BERYLLIUM FILTER AND CRYSTAL MONOCHROMATOR IN FRONT OF COUNTER

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The application of a beryllium filter and single crystal arrangement as the analyser of the energy of scattered neutrons has made it possible to construct a spectrometer with a resolution of $\Delta T/T=2.3$ per cent, with satisfactory neutron intensity. The effect of various factors on the resolution is discussed. The results are compared with measured spectra of neutrons scattered by ammonium chloride cooled to the temperature of liquid nitrogen.

General Discription of the Spectrometer

The solution of problems of physics by means of inelastic scattering of neutrons requires spectrometers with high resolution. In spectrometers with choppers monochromatizing the neutrons and in crystal spectrometers the resolution is increased correspondingly by altering the chopper speed or increasing the collimation of the beam. At the same time this brings about a loss in intensity. The resolution of spectrometers with a filter /e. g. Be or BeO/as the analyser of scattered neutron energy can be increased by the use of reflecting single crystals.

A time of flight spectrometer with the filter placed in front of the detector without the monocrystal is installed at I.B.R.

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It is used in incoherent neutron scattering measurments. The details of this spectrometer have been described earlier /1/.

The neutrons, leaving the moderator placed at the core, travel over a distance of 20.2 m or 30 m and hit the sample /Fig.1/. The energy of the incident neutrons is determined by measuring the flight time from the moderator to the counter by means of multi-chanel time analyser. Some of the scattered neutrons pass through a beryllium filter /24 cm thick/ and impinge upon a large zinc crystal. The surfaces of the single crystal are made from three zinc single crystal cut parallelly to the (002) plane, each with the dimensions 20x6.7x1.5 cm^3. Set together and appriopriately oriented, they constitute a crystal plane with an area of 20x20 cm^2. The mosaic structure of the single crystal was increased artficially during breeding and now equals $\pm 1.6^{\circ}$.

When a filtered neutron of a given energy impinges upon the crystal at the Bragg angle it is then reflected. A tray of BF_3 counters is placed in a such a way that only neutrons reflected from the the single crystal are detected. Thus, the gate analysing the scattered neutron energy is limited on the one side by the transmission of the beryllium filter and on the other by the reflectivity of the crystal. These two distributions can be shifted with respect to each other by altering the setting angle of the single crystal.

The application of the beryllium filter is connected with the necessity of removing all the reflections higher then the first order. That is very important when the energy of the Bragg reflection is much lower then the temperature of the moderator.

The number of neutrons reflected from the single crystal depends on the collimation of the incident beam. The collimator is inside the

beryllium filter; the beryllium is sandwiched with vertical sheets of cadmium foil which collimate the beam to $\pm 9^{\circ}30'$.

Zinc is hexagonal in structure. Cut parallelly to the (002) plane it can reflect neutrons /coheretly and elastically/ of a wave-length not exeeding 4.94 Å /E=3.37 meV/. Neutron impingment and reflection then occur at a right angle to the (002) plane. In practice the single crystal must be set at a smaller angle and, therefore, the mean wave-length of the reflected neutrons is decreased. At the grazing angle of $53^{\circ}15'$ the mean energy of the reflected neutrons is equal to the beryllium energy cut-off. Hence, we have at our disposal a range of angles from 53° to 90°. The energy spread of the neutrons reflected from the single crystal depends on the collimation of the incident beam /$\pm 9^{\circ}30'$/ and the mosaic structure of the crystal.

Determination of the Spectrometer Resolution

The resolution of the spectrometer was calculated theoretically and all the most important factors affecting it were taken into account.

Neutrons of an energy E_o, leaving the moderator at time t hit the sample / after travelling over the flight path L_1 / at time $t + \frac{\alpha L_1}{E_o^{1/2}}$ /where $\alpha = 2285.2\,(\text{meV})^{1/2}\,\mu\text{sec/m}$ /. In the scattering process a neutron loses the energy $\varepsilon = E_o - E$. If the energy of scattered neutron E is smaller than the beryllium cut-off E_{Be} it can then pass through the filter

be reflected from the single crystal, and detected by the counters. Finally, the time of detection can be written as

$$T = t + \frac{\alpha L_1}{E_0^{1/2}} + \frac{\alpha L_2}{E^{1/2}} , \qquad /1/$$

where L_2 is the mean total distance between the sample, single crystal and detector.

The distribution function of the neutron detection time, measured by a time analyser, can be written in quite good approximation as

$$\alpha T N(T) = \alpha T \int_0^\infty \alpha E_0 \int_0^\infty \alpha E \int_0^\infty \alpha t \, \rho(t) n(E_0) \sigma(E_0, E, \varphi) \times$$
$$\times \Phi(E) \rho(E) \delta\left(T - t - \frac{\alpha L_1}{E_0^{1/2}} - \frac{\alpha L_2}{E^{1/2}}\right) \qquad /2/$$

where:

$$\rho(t) = \begin{cases} \exp\{(t_m - t)/\tau\} & t > t_m \\ t/t_m & 0 < t < t_m \\ 0 & t < 0 \end{cases}$$

is the approximate time distribution of the neutrons leaving the moderator /2/. τ, t_m are distribution constants.

$n(E_0) \sim E_0 \exp(-E_0/T_{max})$ is the energy distribution of the neutron flux leaving the moderator. T_{max} is the temperature of the neutrons in the moderator.

$\sigma(E_0, E, \varphi) \sim \sqrt{\frac{E}{E_0}} (2E_0 - \varepsilon) \delta(E_0 - E - \varepsilon)$ is the one-phonon cross-section for inelastic and incoherent neutron scattering from the crystal at an angle of 90°. It was assumed that the sample alters the energy of a neutron by a constant value ε. The cross-section is a peak of infinitesimal width.

$\Phi(E) \sim \left(1 - \exp\left(-\frac{4E}{E_{Be}}\right)\right) \Theta(E_{Be} - E)$ is the empirical formula for the for the beryllium filter transmission. The thickness and temperature are 24 cm and 78°K respectively. E_{Be} is the energy cut-off.

$\eta(E) \sim \exp\left\{-\left(\frac{b}{r}\right)^2\left(\frac{1}{E^{1/2}} - \frac{1}{E_r^{1/2}}\right)^2\right\}$ is the energy spread of the neutrons reflected from the single crystal.

E_r is the energy of the neutrons reflected coherently at the setting angle of the single crystal with the assumption of ideal collimation and zero mosaic structure, i. e. energy of the distribution maximum.

r is the angular spread of the incident beam, and

b is a constant. The crystal thickness effect is negligible /3 /.

$\delta(T - t - \alpha L_1/E_0^{1/2} - \alpha L_2/E^{1/2})$ is a function ensuring that a neutron will be recorded in channel of the time analyser which is open at time T .

Its width is neglected.

In Eq. /2/ the uncertainty of the flight path L_1 and L_2 are not taken into account. These factors have but a small effect on resolution.

The results of numerical calculation of the relative resolution as a function of energy change ε are presented in Figs 2 and 3. The parameters of the curves are the flight path L_1 and L_2 and the energy E_r of the position of the maximum of the crystal reflectivity curve. In all curves the half-width /duration/ of the neutron pulse leaving the moderator /half-width $\varphi(t)$/ is assumed to be the same throughout and equal to 150 μsec.

We see immediately that $\Delta T/T$ is not constant within the entire range of changes ε but reaches minimum value at approx. 30–40 meV. It follows from the presented calculations that

for the collimation used of the scattered beam the best resolution attainable is of the order of $\Delta T/T \sim 2.3$ per cent. An increase in the second flighth path from $L_2 = 0.8$ m to $L_2 = 1.2$ m changes the resolution by about 0.2 per cent, which is relatively little.

In the region of small energy changes ε the most important role is played by the energy E_r. The higher its value, the better the resolution. The use of energies $E_r > E_{Be}$ is aimless for the increase in resolution is small whereas losses in intensity are large. A further improvement of resolution, therefore, should be sought not in increases of the energy $E_r > E_{Be}$ but by increasing the collimation of the beam imping upon the single crystal.

In the region of large changes ε an improvement in the resolution can be achieved by increasing the flight path L_1. There is no sense, however, in increasing the energy E_r.

Fig. 4 presents the calculated resolution curves for various values of energy change ε. Their shape is non-symmetrical.

Experimental Data of the Spectrometer

A convinient substance for testing the resolution is ammonium chloride at the temperature of liquid nitrogen. In the inelastic part of its spectrum there is a very sharp peak. Its natural width is of the order of 0.5 meV and its area is equal to 1/3 of that of the entire frequency spectrum /4/.

The distribution of neutrons scattered by ammonium chloride cooled to $-160^{\circ}C$ and $-75^{\circ}C$ are presented in Figs 5 and 6.

The filtered neutrons impinge upon the zinc single crystal at an angle of $55^{\circ}30'$. The energy maximum of the elastic peak corresponds to 4.94 meV. Its half-width in both cases is $\Delta T/T = 0.062$. On the side of the short detection times there is a hump which is due to the aluminium placed in the path of the neutrons.

The width of the inelastic hindered rotation peak amounts to $\Delta T/T = 0.039$ and $\Delta T/T = 0.052$ at the temperature $-160^{\circ}C$ and $-75^{\circ}C$, respectively. The peak width for low temperature is somewhat greater than the value $\Delta T/T = 0.031$ calculated theoretically for the experimental conditions, that is, $L_1 = 20.2$ m, $L_2 = 1.2$ m and $E_r = 4.94$ meV. This inconsistency should be ascribed to the spread to the L_1 and L_2 flight paths linked with the finite dimensions of the sample and the neglect of the natural width of the line in ammonium chloride.

Under identical conditions with the beryllium filter but without the single crystal the peak width at the temperature of liquid nitrogen increase to $\Delta T/T = 0.072$ /1/, i. e. it is almost doubled.

The intensity of the detected neutrons drops when the single crystal is used. This decrease is due to the reflectivity of the crystal. A five-fold decrease in intensity in the elastic part and an almost ten-fold decrease in the inelastic part were observed experimentally. The use of the counter tray, better matched to the dimensions of the beam,can double the luminosity. The present counting rate with the use of the monochromator depends on the type and thickness of the sample, but for samples

of negligible neutron absorbtion it is generally of the order of 100 pulses/hour into an analyser channel with a width of 64 μsec at a flight path L_1 = 20.2 m /the I.B.R. power of 6 kW/.

Conclusion

The use of a monocrystal in a spectrometer with a beryllium filter in reversed geometry improves resolution about twofold. This arrangement makes it possible to alter the resolution easily. In contrast to the crystal spectrometers, there is no problem of higher order reflections, these being eliminated by the beryllium filter.

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Refereces

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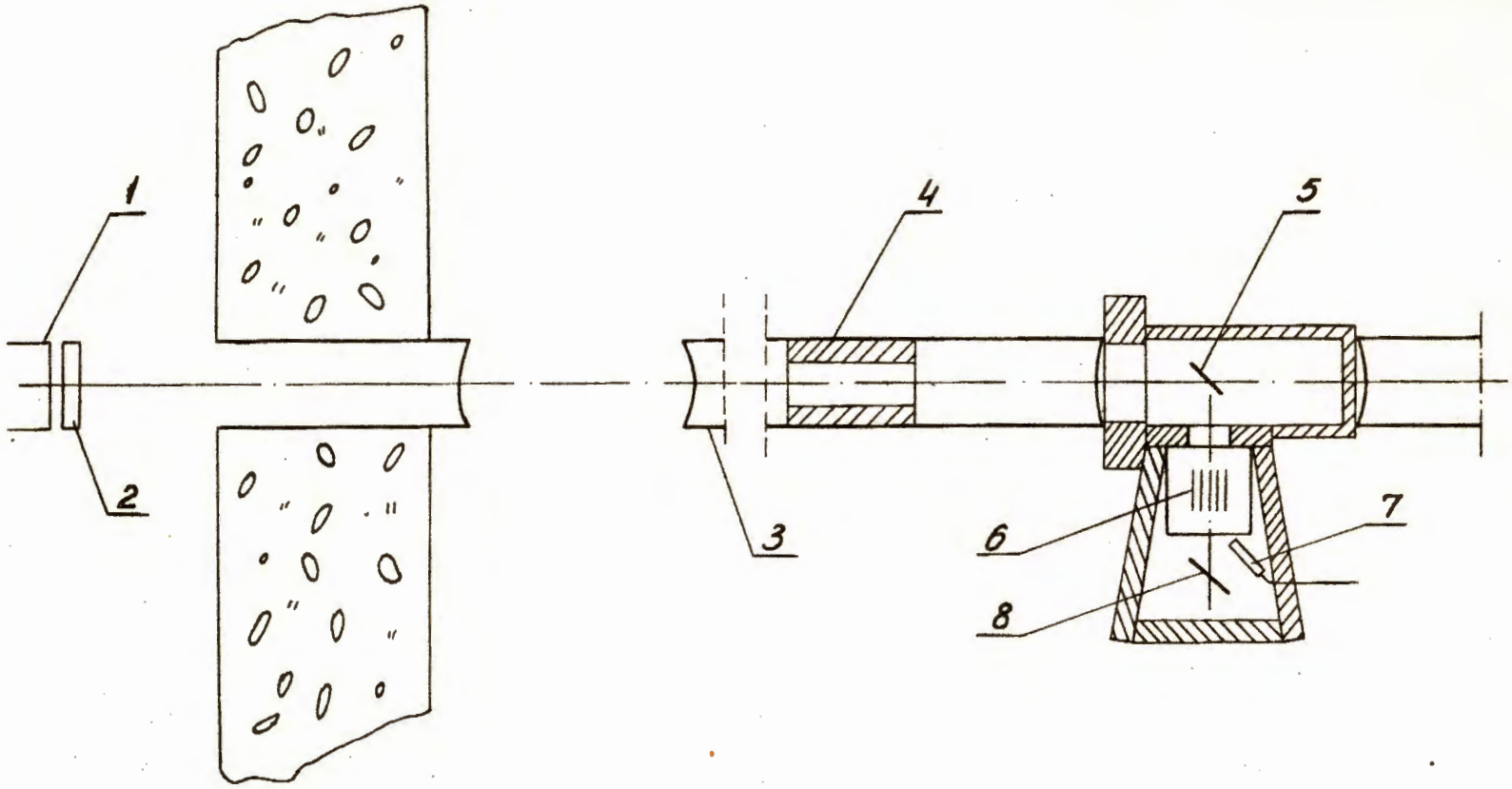

Fig. 1. Diagram of spectrometer. 1 - reactor core, 2 - moderator, 3 - vacuum tube, 4 - collimator, 5 - sample, 6 - beryllium filter with collimating cadmium inserts, 7 - tray of BF_3 counters, 8 - monocrystal

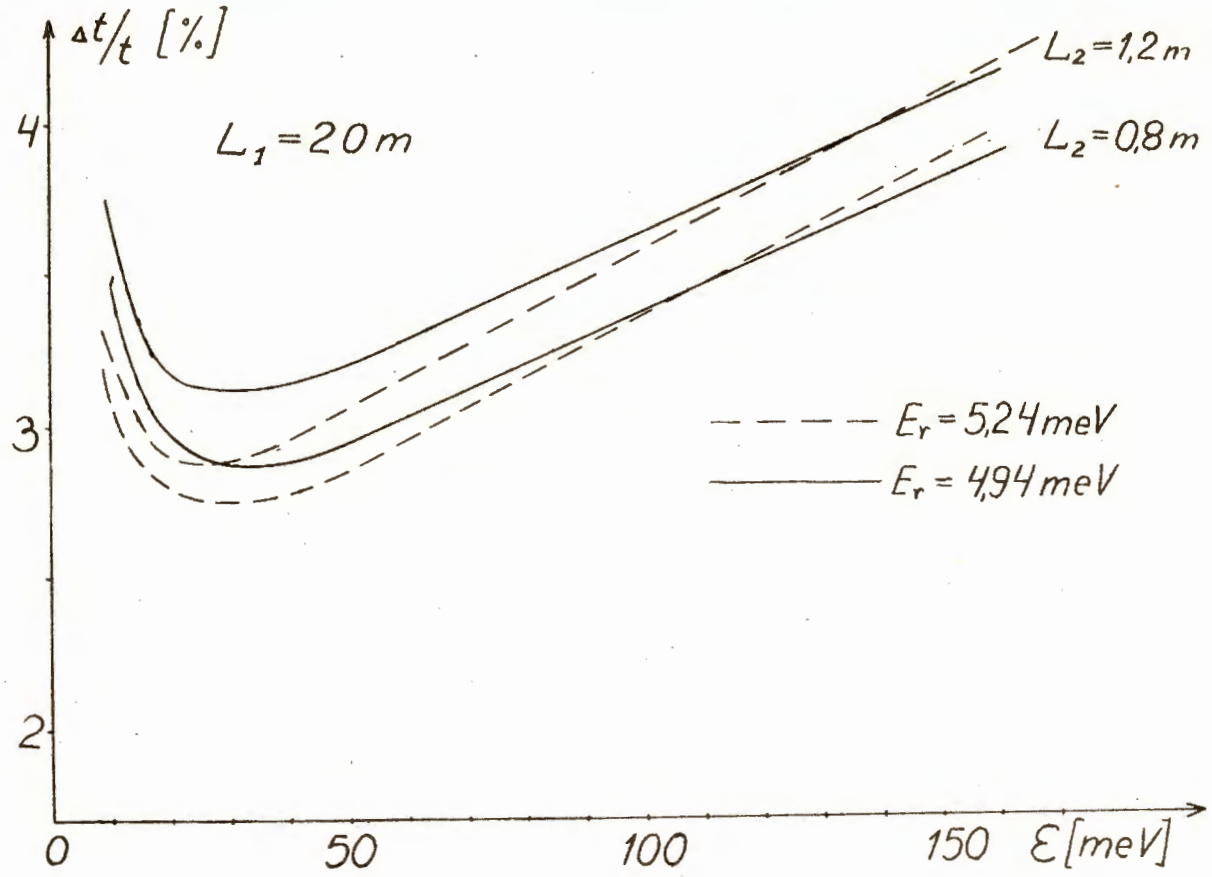

Fig. 2. Relative half-width of resolution curves as function of energy change for flight path L_1=20.2 m

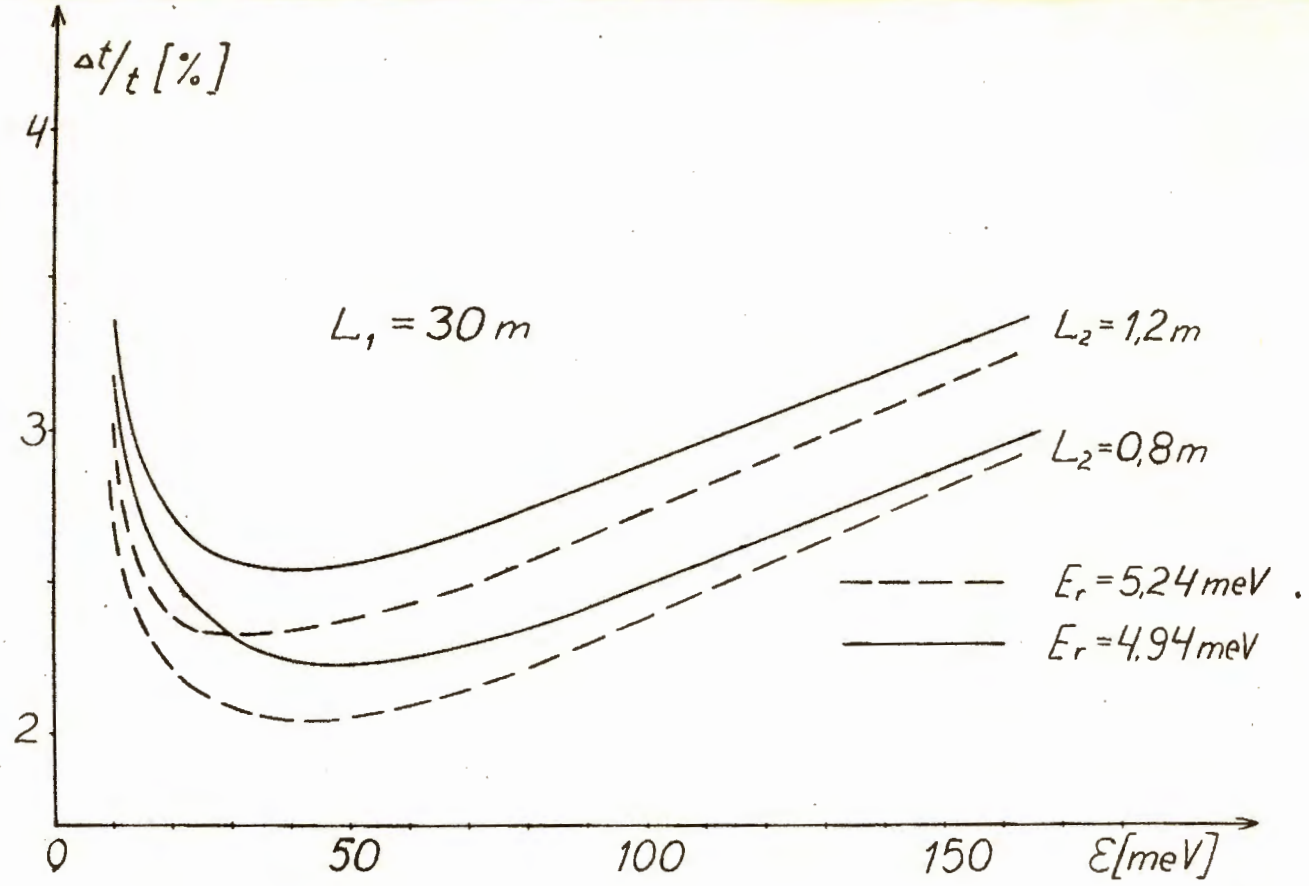

Fig. 3. Relative half-width of resolution curves as a function of energy change for flight path L_1=30.0 m

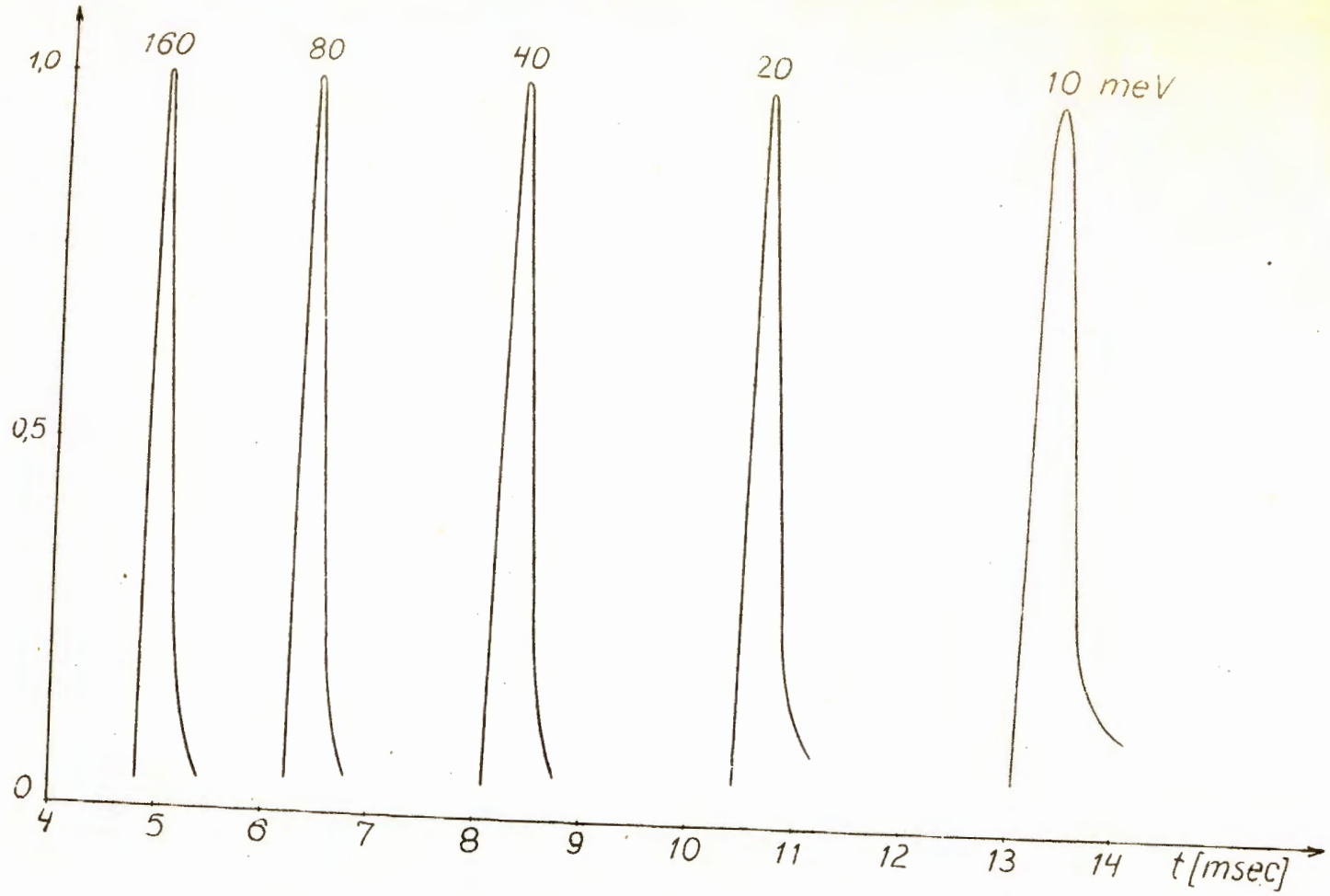

Fig. 4. Shape of resolution curves for various values of changes in energy for flight path L_1 = 20.2 m, L_2 = 1.2 m, and energy E_r = 4.94 meV

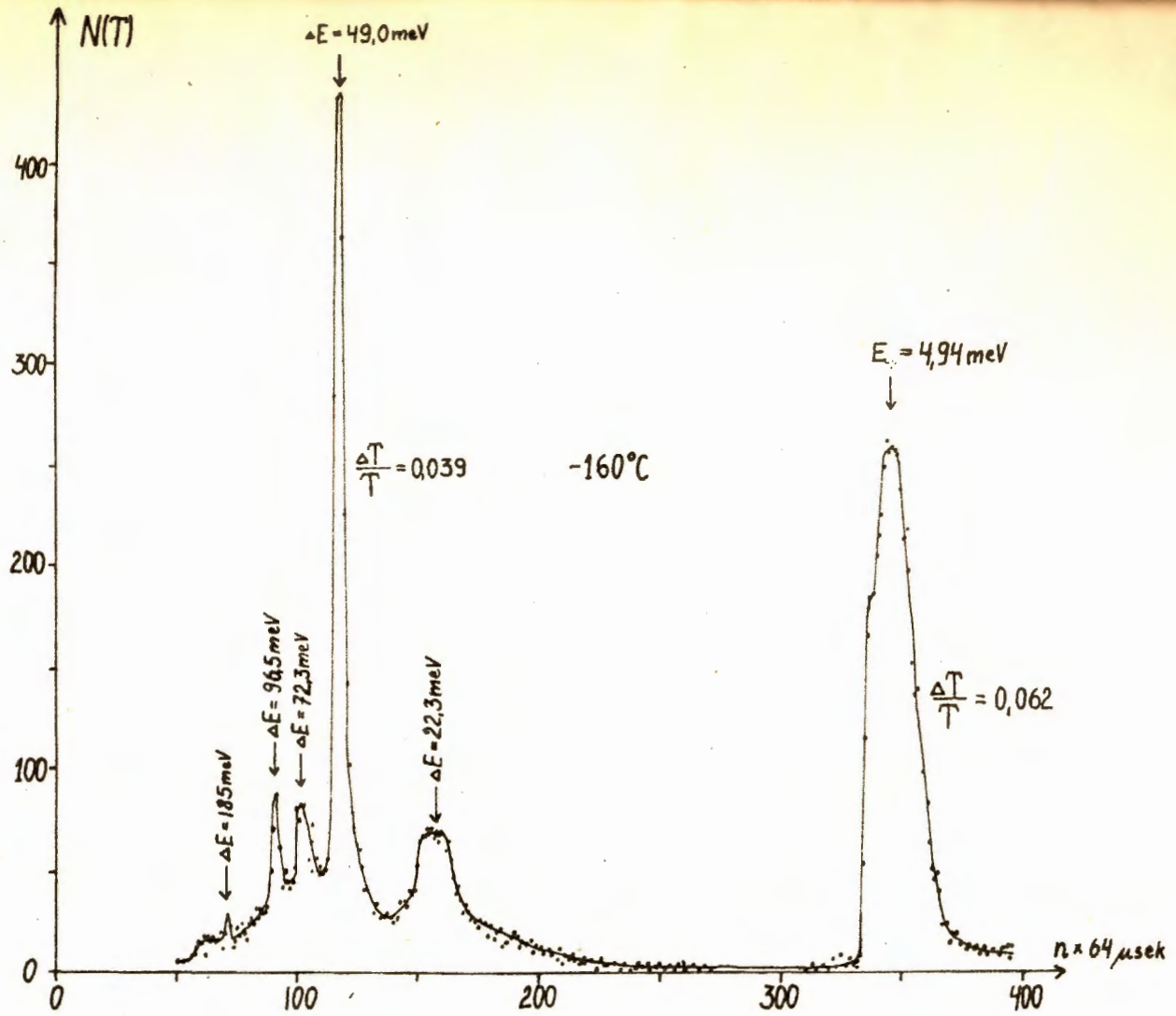

Fig. 5. Spectrum of neutrons scattered from polycrystalline ammonium chloride at a temperature of -160°C

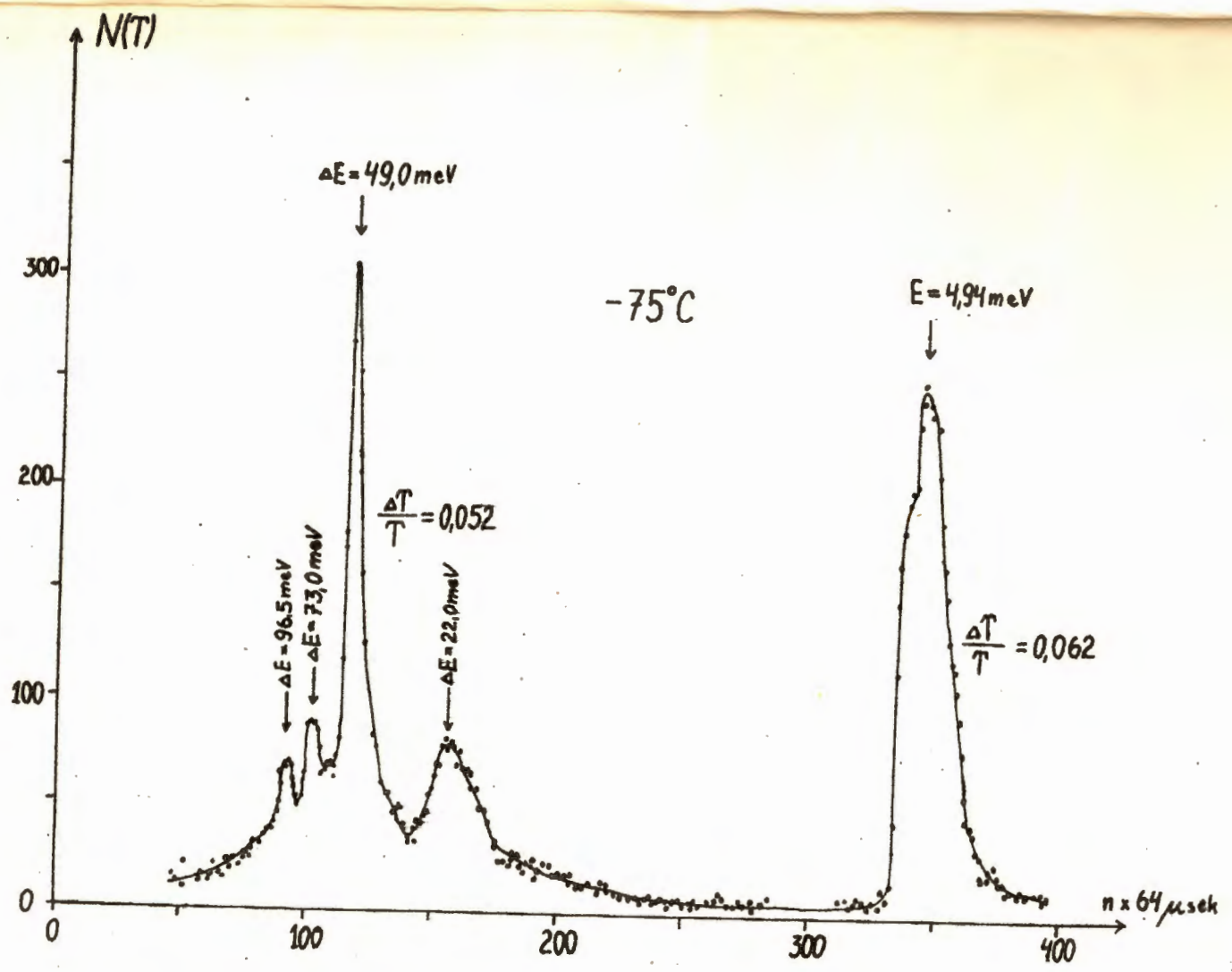

Fig. 6. Spectrum of neutrons scattered by polycrystalline ammonium chloride at a temperature of -75°C.