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PERFORMANCE FEATURE OF CRYSTAL ANALYSER MIRROR TYPE SPECTROMETERS USING COLD AND THERMAL PULSED NEUTRON SOURCES

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Abstract

We have been engaged in developing the crystal analyser mirror type spectrometers combined with the KENS cold and thermal neutron sources. Our studies have revealed that the crystal analyser mirror(LAM type mirror) is the simplest but most suitable device for the spectrometers using pulsed sources. Performance feature of the LAM type quasielastic and inelastic spectrometers is described.

In order to carry out neutron spectroscopy using the pulsed source, it is most desirable that the neutron pulse emitted from the source be utilized directly for energy analysis using the time-of-flight technique without any auxiliary device for narrowing the pulse width. As to accompanying secondary energy analysing devices, there are several options. Our crystal analyser mirror is the most suitable one. Therefore, we adopted the arrangement of devices shown in Fig. 1.

In the case of time-of-flight measurements, the energy resolution required is attained by selecting an appropriate length of neutron flight path to the width of the neutron pulse. Of course, in the case of cold neutron scattering for a long flight path, the neutron guide tube must be used. Next, a wide range energy resolution of the crystal analyser is

appropriately selected by adjusting the Bragg angle. This combination of devices enabled us to design a set of quasielastic and inelastic spectrometers with large flexibility of performance.

If the design parameters of the spectrometers are appropriately selected, the time spectrum of the scattered neutrons from the sample at a scattering angle θ is simply expressed as follows [1].

$$n(t;\theta)=\text{const.}\int\int\phi(E_1,t-t_2)\sigma(E_1\rightarrow E_2,\theta)R(E_2)dE_1dE_2, \tag{1}$$

where $\phi(E_1,t_1)$ is the incident neutron flux at time t_1 into the sample, $\sigma(E_1\rightarrow E_2,\theta)$ is the incoherenet differential scattering cross section, $R(E_2)$ is the energy resolution function of the crystal analyser mirrors, m is the neutron mass, ℓ_1 and ℓ_2 are the average flight path lengths of the incident and scattered neutrons, t_1 and t_2 are given by the followings,

$$t_1=\ell_1/\sqrt{2E_1/m}\ , \tag{2}$$

$$t_2=\ell_2/\sqrt{2E_2/m}\ . \tag{3}$$

The quantities measured is the energy transfer, ε, defined by

$$\varepsilon=E_1-E_2\ . \tag{4}$$

The overall energy resolution of the spectrometers, $\Delta\varepsilon$, is approximately given by the following expression,

$$\Delta\varepsilon=(\Delta E_1^{\,2}+\Delta E_2^{\,2})^{1/2}. \tag{5}$$

The energy resolution, ΔE_1, in the time-of-flight experiments is given by

$$\Delta E_1=2E_1(\Delta t_z^{\,2}+\Delta t_1^{\,2}+\Delta t_2^{\,2})^{1/2}/t_1\ , \tag{6}$$

where Δt_z is the pulse width of the neutrons emitted from the source, Δt_1 is the variance of the flight time due to the variance of ℓ_1, and Δt_2 is the variance of the flight time due to the scattered neutrons from the sample to the counters.

To decide the dimensions of the analyser mirror, many factors are involved. We designated the position inside the medium of the sample as $\mathbf{r}$, the position on the mirror as Σ and the position on the assumed plane of the diaphragm of the counter as S. The Bragg angle spread of the analyser mirror is calculated by the following equation [1].

$$\hat{R}(\theta_B)=\iiint p(\mathbf{r},\Sigma,S)|\mathbf{r}-\Sigma|^{-2}|\Sigma-S|^{-2}\delta[\theta_B-\hat{\theta}_B(\mathbf{r},\Sigma,S)]d\mathbf{r}d\Sigma dS \ , \qquad (7)$$

where $\theta_B(\mathbf{r},\Sigma,S)$ is the Bragg angle determined by the positions $\mathbf{r}$, Σ and S, and $p(\mathbf{r},\Sigma,S)$ is a factor representing efficiency due to the projection of each plane and the mosaicness of the crystals.

The energy resolution of the analyser mirror is estimated by the following expression,

$$\Delta E_2=2E_2[(\cot\theta_B\Delta\theta_B)^2+(\Delta\tau/\tau)^2]^{1/2} \ . \qquad (8)$$

Here $\Delta\tau$ is the variance of the reciprocal lattice vector, τ, due to the limitation of the number of lattice planes contributing to the reflection. In our case, the second term in the brackets in the right hand side of Eq. (8) may be small enough to neglect as compared with the first term.

Quasielastic spectrometers (LAM-40 and LAM-80)

To attain the optimum condition for quasielastic measurements, that is, the desired resolution and high efficiency, it is necessary to match the energy resolution in time-of-flight measurement, ΔE_1, for the energy resolution of the analyser mirror, ΔE_2, according to Eqs. (1) and (4).

For the case of flight path lengths 6, 30 and 150 m, the variances of incident and scattered neutron energies, ΔE_1 and ΔE_2, as functions of the Bragg angle calculated by Eqs. (6) and (8) are depicted in Fig. 2. Of course, ΔE_1 depends on the Bragg angle, but ΔE_2 does not depend on the flight path length. An optimal condition is achieved by matching ΔE_1 to ΔE_2. Thus, the optimal condition for the desired performance can be found around the points where the two curves cross, as shown in Fig. 2.

The two spectrometers, the LAM-40 and the LAM-80 (Fig. 3-a,b), utilize two sets of LAM-type analyser mirrors(lattice-$\frac{d}{\Lambda}$-crystal analyser mirror), of which the structural frames supporting the crystal pieces were fabricated according to the same design method described in the previous chapter. The main difference between them is in the Bragg angles, 39° for the LAM-40, and 80° for the LAM-80, respectively. Next, for the LAM-40, small beryllium filters of 6 cm thickness were used. The average distance from the sample to the counter diaphragm via the mirror crystals is 120 cm for both sets of mirrors.

Currently we are working on the design of a LAM-type analyser mirror having a Bragg angle of 86° to 88° in the hope of developing a quasielastic spectrometer having a few μeV resolution.

The energy resolution of the LAM-40 has a special feature in its shape, that is, it shows a sudden steep rise on only one side of the resolution function, and this shape enebles clear observation of a faint spectrum existing in the energy transfer range about 0.3 meV to 1 meV. Then, the LAM-40 has been used to investigate the non-Markovian random process in the motion of polymer chains. A typical example of the measured spectra is shown in Fig. 4. The central peaks of spectra in the figure are the elastically scattered components, which are broadened by the resolution function of the spectrometer. The down-scattering

quasielastic spectrum exists in the time-of-flight region from about 160 channel to 230 channel. We do not utilize the up-scattering quasielastic spectrum existing in the channels above 230 channel because it was distorted by the undesirable tail of the resolution function. Expanded quasielastic spectra on the scattering angle of 88° at various temperatures are shown in the figure.

The LAM-80 is an intermediate resolution spectrometer with a wide energy window. Fig. 5 shows some preliminary data obtained by using the LAM-80. In this case the sample was poly(butadiene) at a temperature between melting and glass-transition points. The wide energy window covered by the LAM-80 is shown in the insert in Fig. 5. The upper limit of energy transfer is due to the transmission of the guide tube.

Down-scattering spectrometer (LAM-D)

Arrangement of the LAM-D is illustrated in Fig. 3-c. A beryllium filter, which has a length of 20 cm, is used at liquid nitrogen temperature. Fig. 6 shows the energy transfer resolution devided by the incident neutron energy for several cases of the incident flight path length. This figure reveals that the LAM-type mirror is also very useful for the inelastic scattering. The resolution in the range 100-3000 cm^{-1} is estimated to be 2-3 % for 10 m incident path length. In this region, the resolution is approximately proportional to the reciprocal of incident path length. Then, better resolution (1 % or less) will be easily attained by using longer incident path length, if we use more intense source.

Fig. 7 is the observed spectra for PMMA(h_8), in which S/N is excellent. But present LAM-D has only one analyser mirror and data acquisition rate is not high. We have begun a design of new improved

version of present LAM-D, which has four analyser mirrors.

Reference

[1] K. Inoue, et al.: Nucl. Instr. and Meth., 178(1980)459.

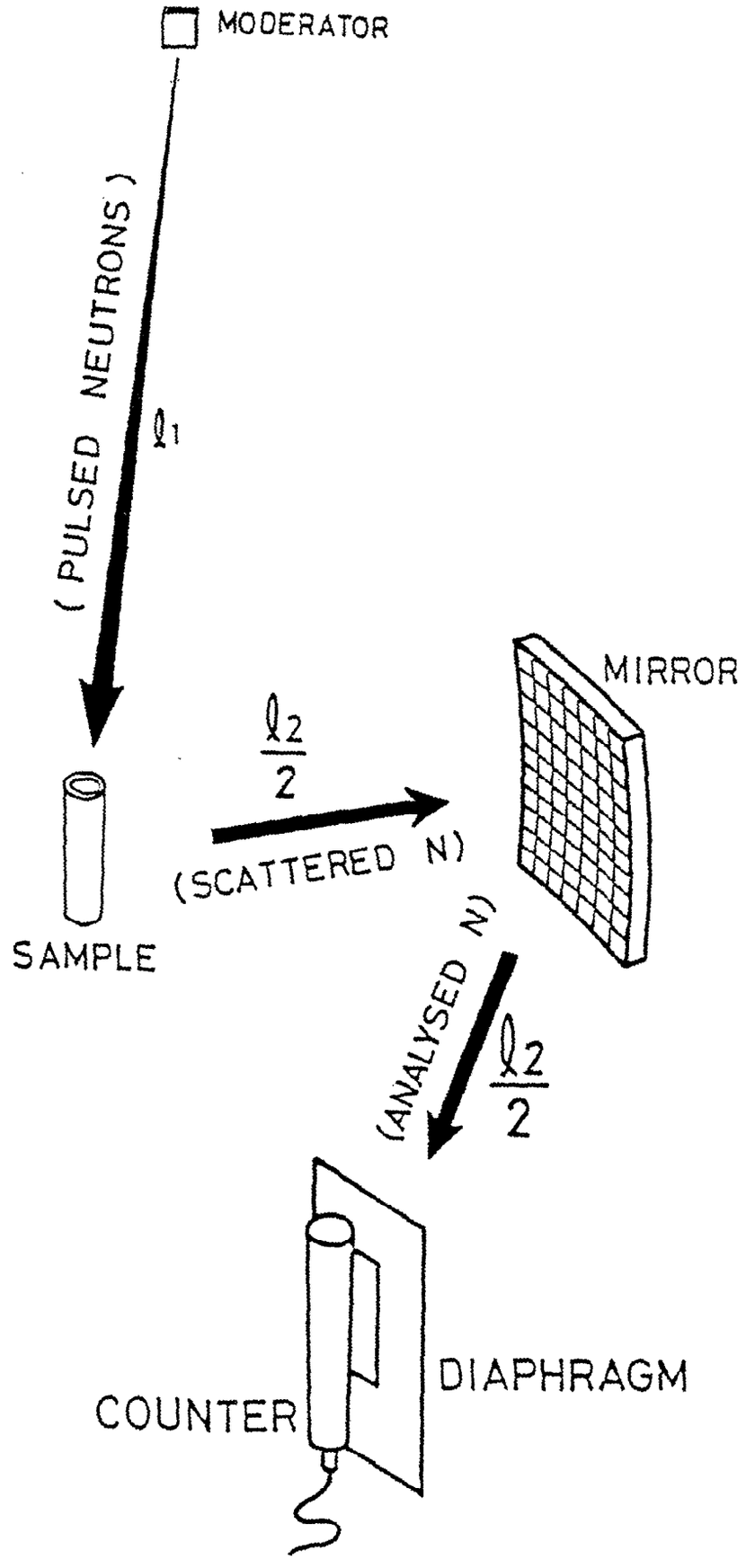

Fig. 1 General layout of the inverted geometry spectrometer using a pulsed neutron source and the LAM-type analyser mirror.

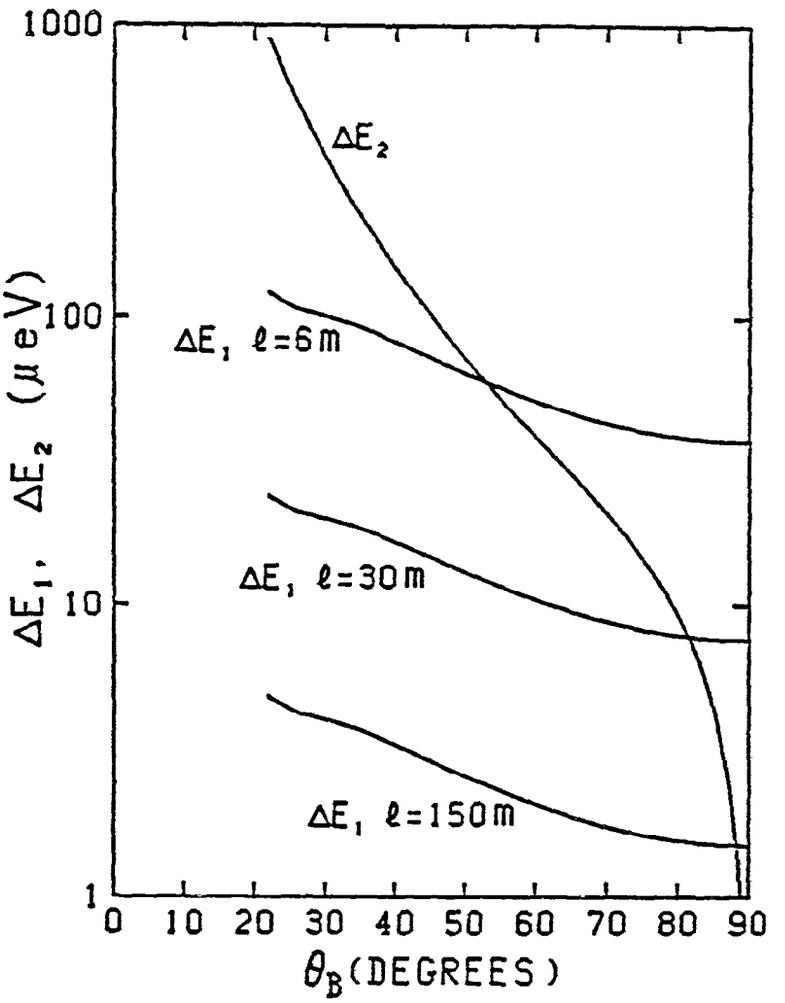

Fig. 2 Partical energy resolutions, ΔE_1 and ΔE_2, plotted as functions of the Bragg angle for three cases of flight path length in the time-of-flight measurement using the pulsed cold source.

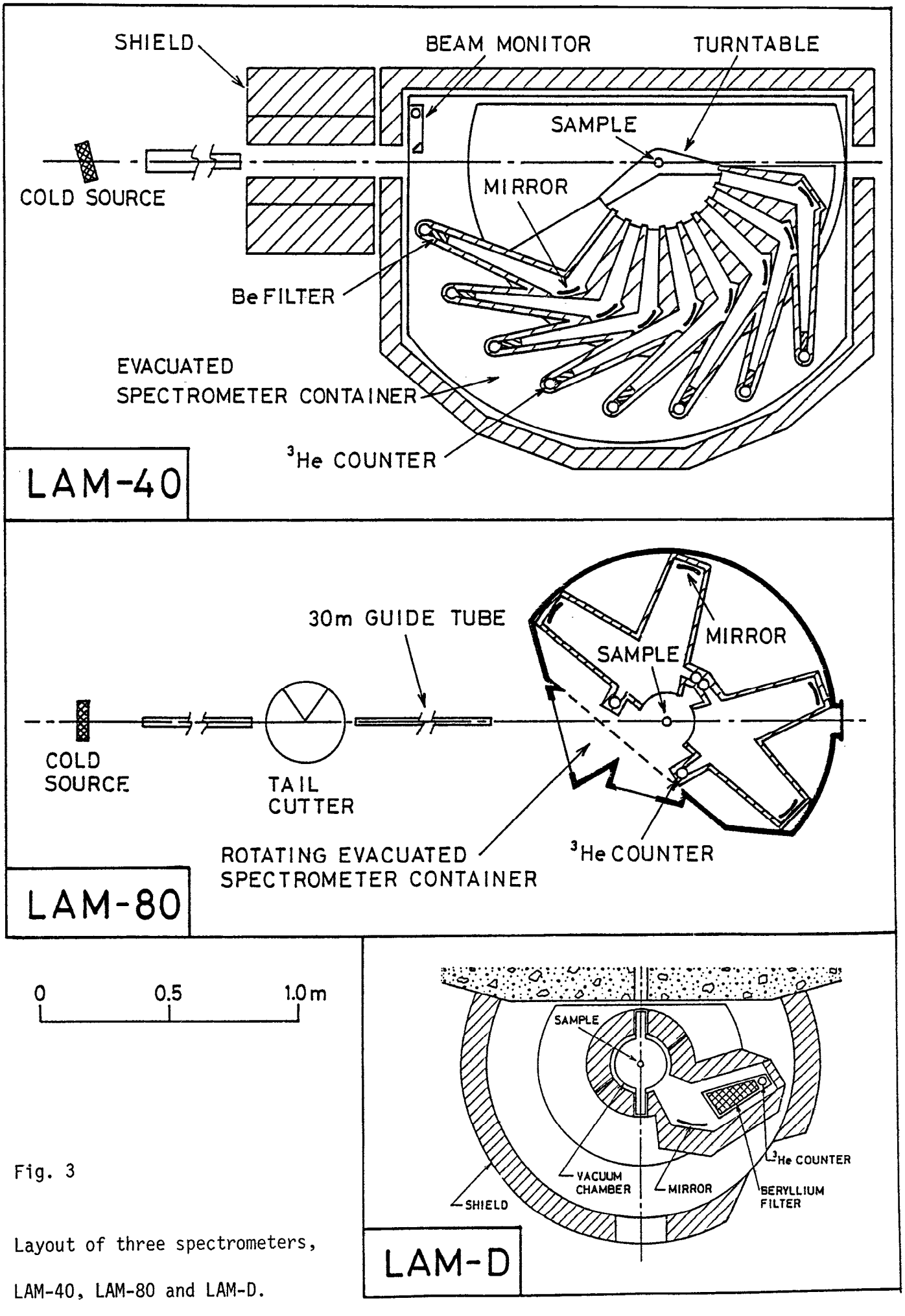

Fig. 3

Layout of three spectrometers, LAM-40, LAM-80 and LAM-D.

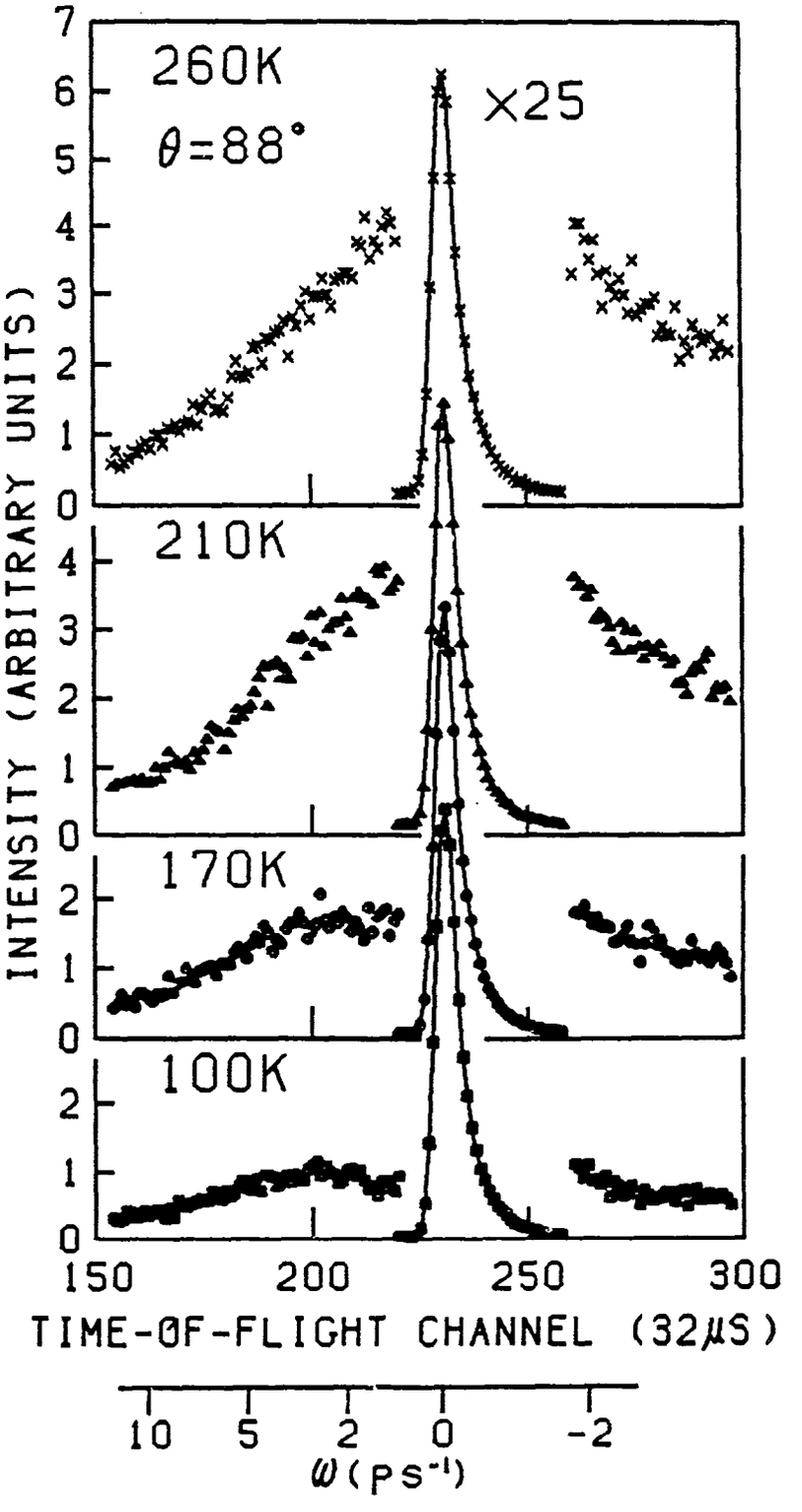

Fig. 4 Time-of-flight spectra from poly(butadiene) at various temperatures, measured by the LAM-40.

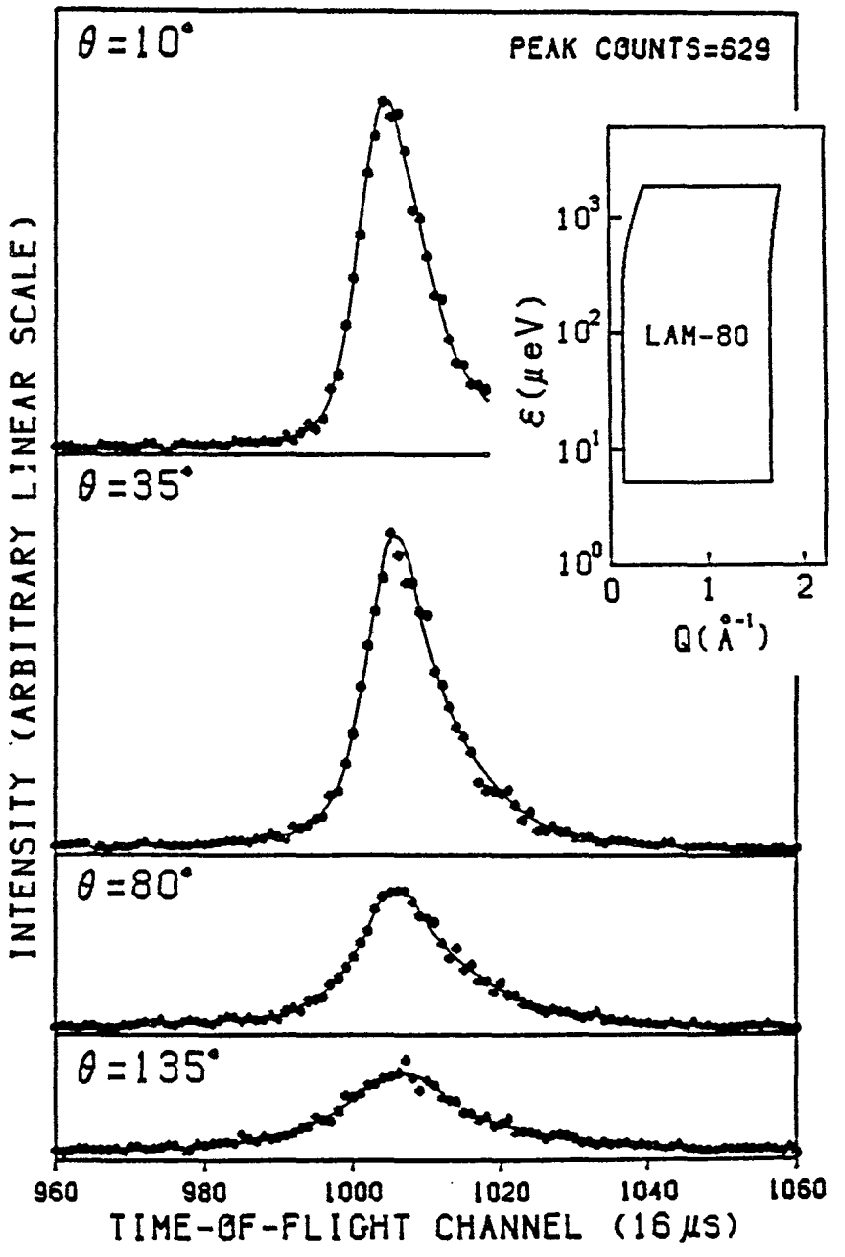

Fig. 5 Time-of-flight spectra from poly(butadiene) at a temperature below melting point, measured by the LAM-80.

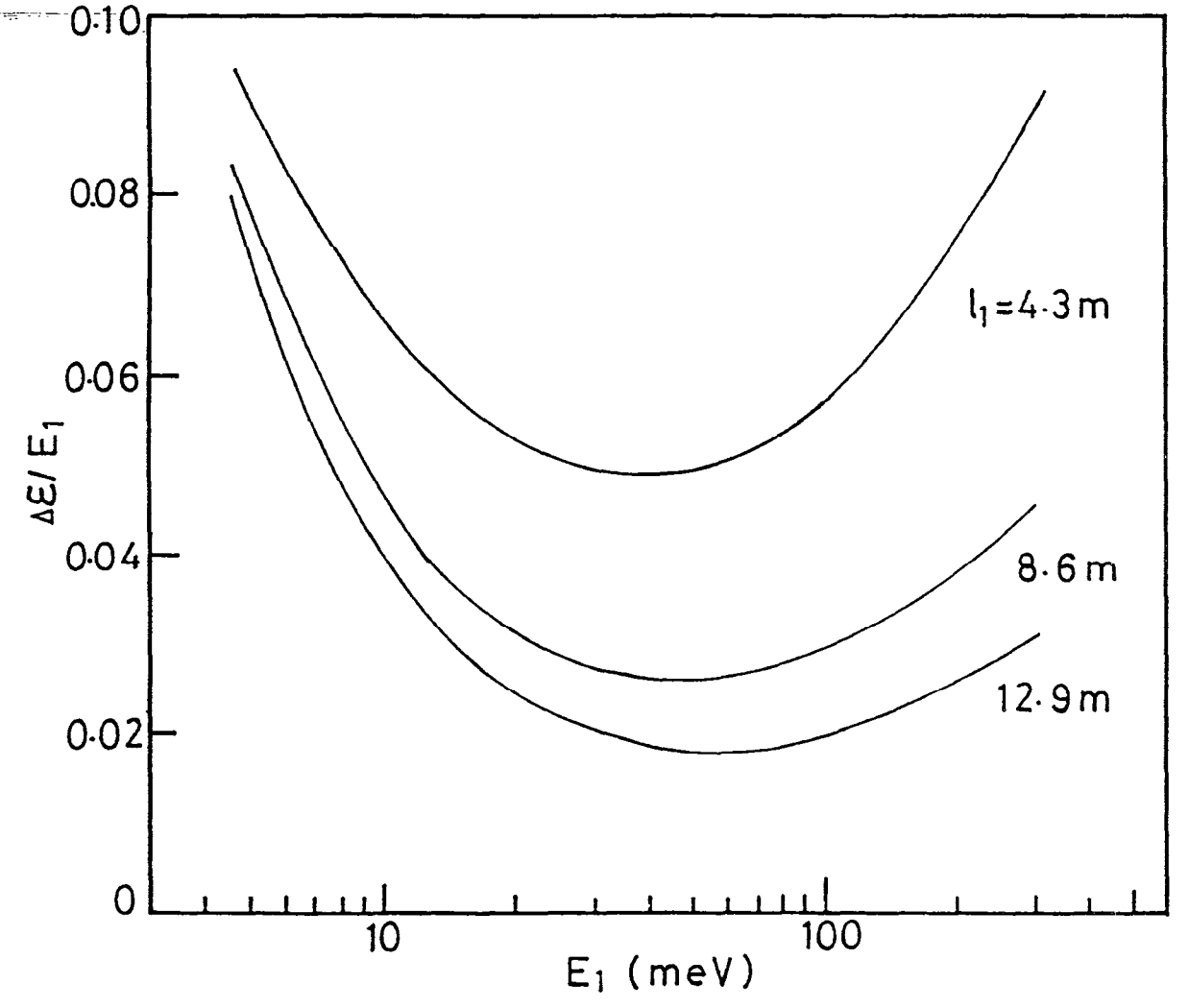

Fig. 6 Overall energy resolution devided by the incident neutron energy, E_1, as a function of E_1 for three cases of incident flight path length in the time-of-flight measurement using the pulsed thermal source.

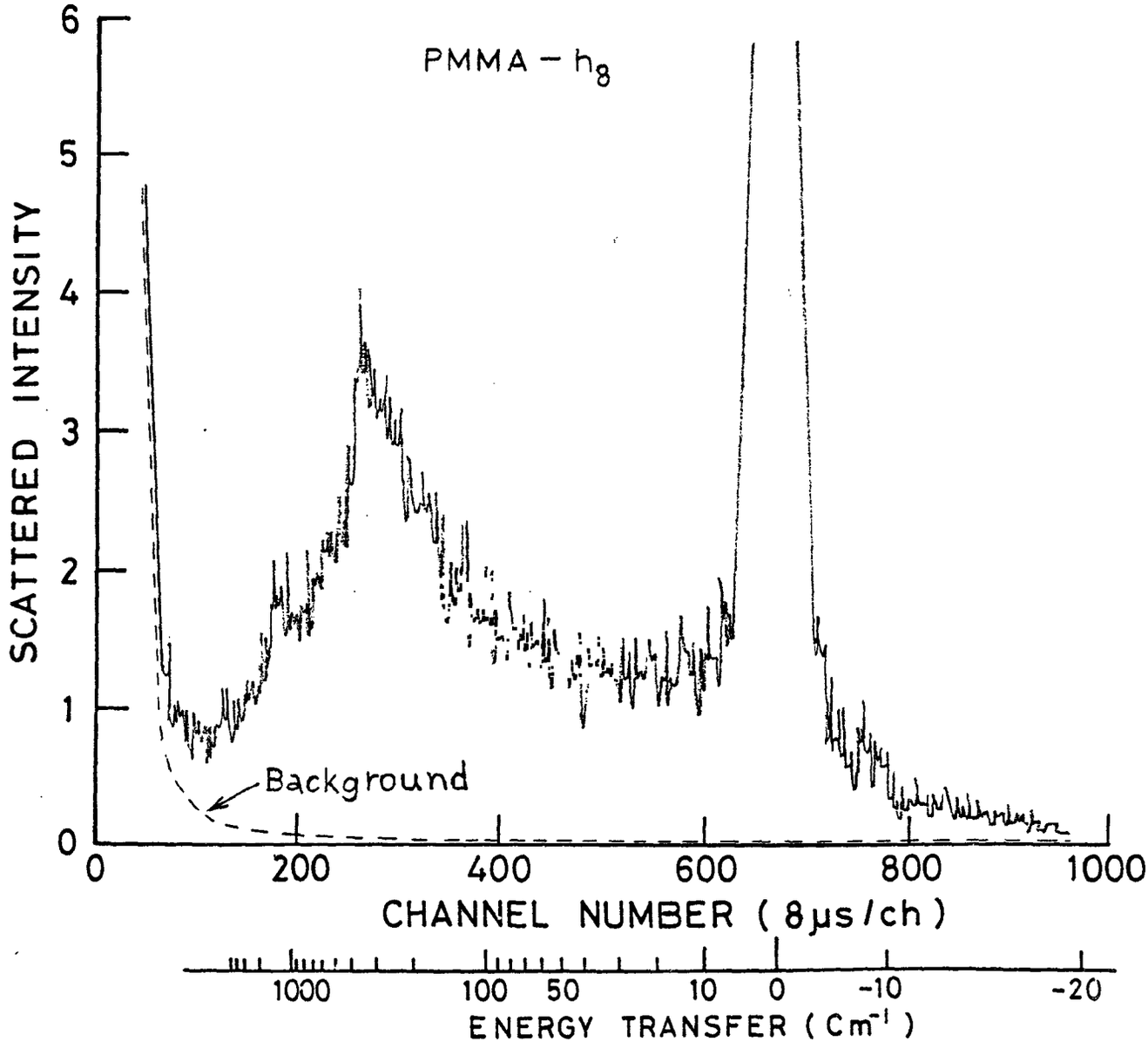

Fig. 7 Time-of-flight spectra from poly(methyl methacrylate) measured by the LAM-D.