JOINT INSTITUTE FOR NUCLEAR RESEARCH

Laboratory of Neutron Physics

V.V.Golikov, Zh.A.Kozlov, F.L.Shapiro

E-2832

COHERENT SCATTERING OF SLOW NEUTRONS IN SOLID AND LIQUID METALS AT SMALL MOMENTUM TRANSFER

Prepared for the IAEA Panel on Research
Applications of Repetitively-Pulsed Reactors
and Boosters, July 18-22, 1966, Dubna

Рукопись поступила
в издательский отдел
„14" VII 1966г.

As known [1,2] the spectrum of the Rayleigh light scattering by liquids contains three lines, in particular, an undisplaced peak and two components of the so-called Mandelstam-Brillouin doublet disposed symmetrically with respect to the undisplaced line at a distance $\Delta\omega$ proportional to the velocity of sound u ($\Delta\omega = \pm u|\vec{q}|$), where $\vec{q}$ is a photon momentum variation in scattering). The undisplaced peak is due to light scattering on density fluctuations resultant from temperature isobaric fluctuations. Temperature fluctuations are damping due to heat conductivity and are not propagated as traveling waves. The width of the undisplaced peak is defined by the value $\Gamma = 2\chi q^2$...(1), where χ is a thermal conductivity coefficient. The Mandelstam - Brillouin doublet results from the light scattering on pressure fluctuations propagating in the form of longitudinal sound waves.

For single-atom substances, the ratio of the J_o undisplaced line intensity to the total intensity of the Mandelstam-Brillouin doublet lines ($2J_{\text{МБ}}$) is defined by Landau-Placzek relation[3]

$$\frac{J_o}{2J_{\text{МБ}}} = \frac{C_p - C_v}{C_v} \tag{2}$$

where C_p and C_v are specific heats at a constant pressure and volume respectively. Since the ratio $\frac{C_p - C_v}{C_v}$ for liquids is much greater than that for solids, the undisplaced line intensity is small in solids.

An analogous intensity spectral distribution should be also observed in neutron coherent scattering in case it occurs at a rather small momentum transfer. The studies of this quasi-elastic scattering may provide valuable information about the dynamics of liquids. For instance, one can obtain some information on the frequency dependence of sound velocity, viscosity and heat conductivity at frequencies by 2-3 orders exceeding the limiting one ($\sim 10^{10}$ Hz) that manifests itself in the Rayleigh light scattering. Though the quasi-elastic coherent scattering of neutrons has been studied in a number of papers[4/], the obtained results are poor and their interpretation is doubtful. To a considerable extent this is due to the insufficient energy resolution used. Therefore we have undertaken some measurements of quasi-elastic scattering of neutrons in lead and zinc using the reactor IBR. The present paper reports the preliminary results obtained from experiments with lead.

The scheme of the experimental arrangement is shown in fig.1. The energy of neutrons incident upon the sample (5) was determined using the times-of-flight for the distances between the moderator (1) and sample, and between the sample and detector (9) that were 10 and 2.4 meters respectively. The energy of scattered neutrons that were recorded by the detector was given alternatively by a crystalline monochromator (8) or a coolant beryllium filter. Fig.2 presents the results obtained for lead with the beryllium filter. The background measured with an empty container at a temperature equal to that at which the effect was measured has been subtracted from the curves. The angle of scatter was 6 ± 3^0. The sample was 5 mm thick. Measurements with a 1 cm thick sample have indicated that multiple scattering does not make essential contribution. The curve for solid lead at 20°C exhibits an elastic peak that seems to be due to incoherent and multiple Bragg scattering in a poly-crystalline sample, as well as a wide inelastic peak corresponding to an energy transfer of 9 meV. The latter may be interpreted as a component of the Mandelstam-Brillouin doublet or as an excitation of a longitudinal acoustic phonon. Fig.3 shows the dispersion curves $\omega(q)$ for lead[5/] with the curves $\omega(q)$ determined from energy and momentum conversation law in neutron scattering. In the given experiment (curve 1), the neutron momentum transfer corresponds to the first Brillouin zone. In view of this fact, for a cubic crystal the excitation probability for quasi-transverse phonons is very small (which essentially simplifies the analysis of scattered neutron spectrum compared to the second and following zones) and only one peak is available in the scattered neutron spectrum that corresponds to the intersection of curve 1 with the dispersion curves for longitudinal waves ($q \sim 1\,\mathring{A}^{-1}$, $\hbar\omega \simeq 9$ meV). The same peak is seen also in the curves for solid lead at T = 280°C and liquid lead at T = 350°C and 520°C.

The most interesting peculiarity of the three last curves is the presence of quasi-elastic scattering peaks whose intensity increases with temperature and at melting. Interpreting these peaks as the considered above central line associated with temperature fluctuations, will lead to the following contradictions:

1. The peak widths determined from the beryllium cutoff inclination (~ 0.5 meV and ~ 1 meV at 280°C) and 350°C respectively) are very small compared with those expected according to formula (1) ($q = 0.24 \pm 0.08\ \mathring{A}^{-1}$, $\Gamma\ (280^{o}C) > 50$ meV, $\Gamma\ (350^{o}C) >$ 25 meV).

2. Turberfield[6/] has obtained a 1 meV broadening for liquid lead at $q = 2.2\ \mathring{A}^{-1}$. Thus, no expected line broadening proportional to q^2 is observed . Turberfield associates the broadening observed by him with the diffusion motion of liquid atoms. In this case at $q = 0.24\ \mathring{A}^{-1}$ the broadening should have been tens times less than that we observed.

Possibly, these facts point out to that electrons are not involved in flattening the lattice temperature inhomogeneities characterized by a small "wavelength " $\Lambda = \frac{2\pi}{q} \leq 25\ \mathring{A}$ and short life time $\hbar/\Gamma \leq 10^{-12}$ sec.

A further discussion of the undisplaced peak nature should be delayed up to the time when there will be clear the causes of the discrepancy between the results listed in table 2 and those obtained by Cocking and Egelstaff 7/. These authors have observed no undisplaced peak at $q < 1\ \mathring{A}^{-1}$ in lead at all, but they have observed two inelastic peaks, namely, one at $\Delta E \sim 11$ meV and the second at $\Delta E \sim 3$ meV. The first one corresponds to longitudinal phonon excitation, while the origin of the second remains unclear.

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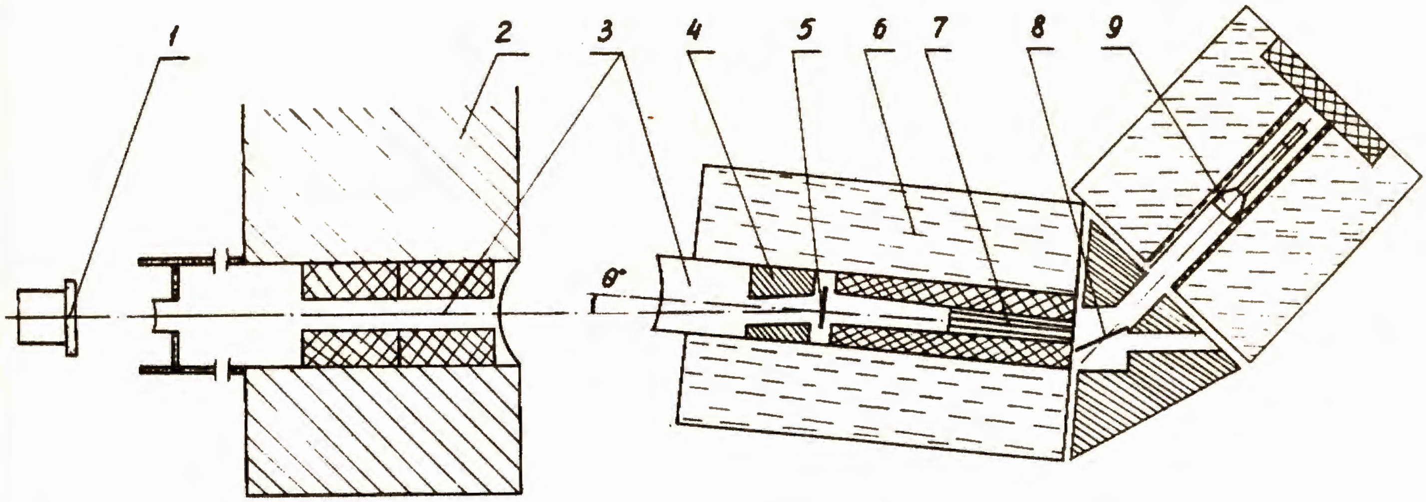

Fig.1. The experimental arrangement for small angle neutron scattering:

1 = active zone with moderator,

2 = biological shielding of the reactor,

3 = vacuum neutron guides,

4 = paraffin boron shielding,

5 = sample, 6 = water shielding,

7 = slit collimator,

8 = crystalline monochromator (or beryllium filter with detector),

9 = detector.

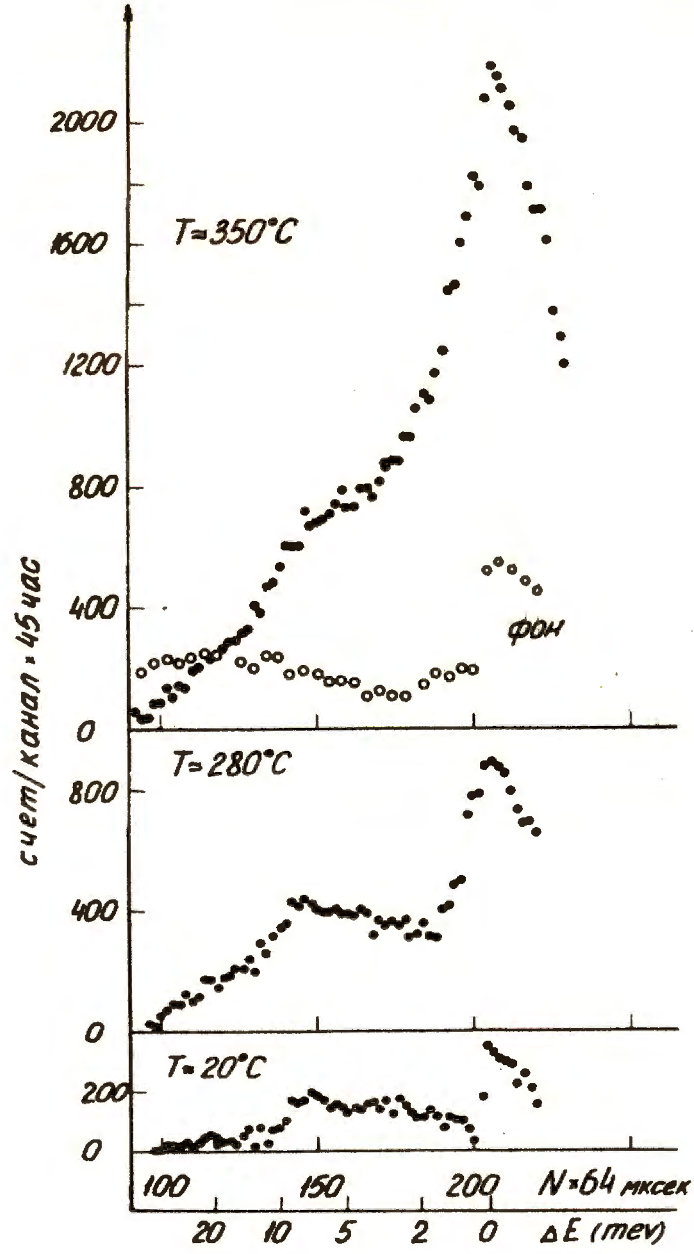

Fig.2The spectra of inelastically scattered neutrons from solid (polycrystalline) and liquid lead at temperatures 20°C, 280°C and 350°C, obtained with the aid of the beryllium filter. The angle of scatter $\Theta = 6^{\circ}$. In the upper part of the figure the background measured with an empty container is shown.

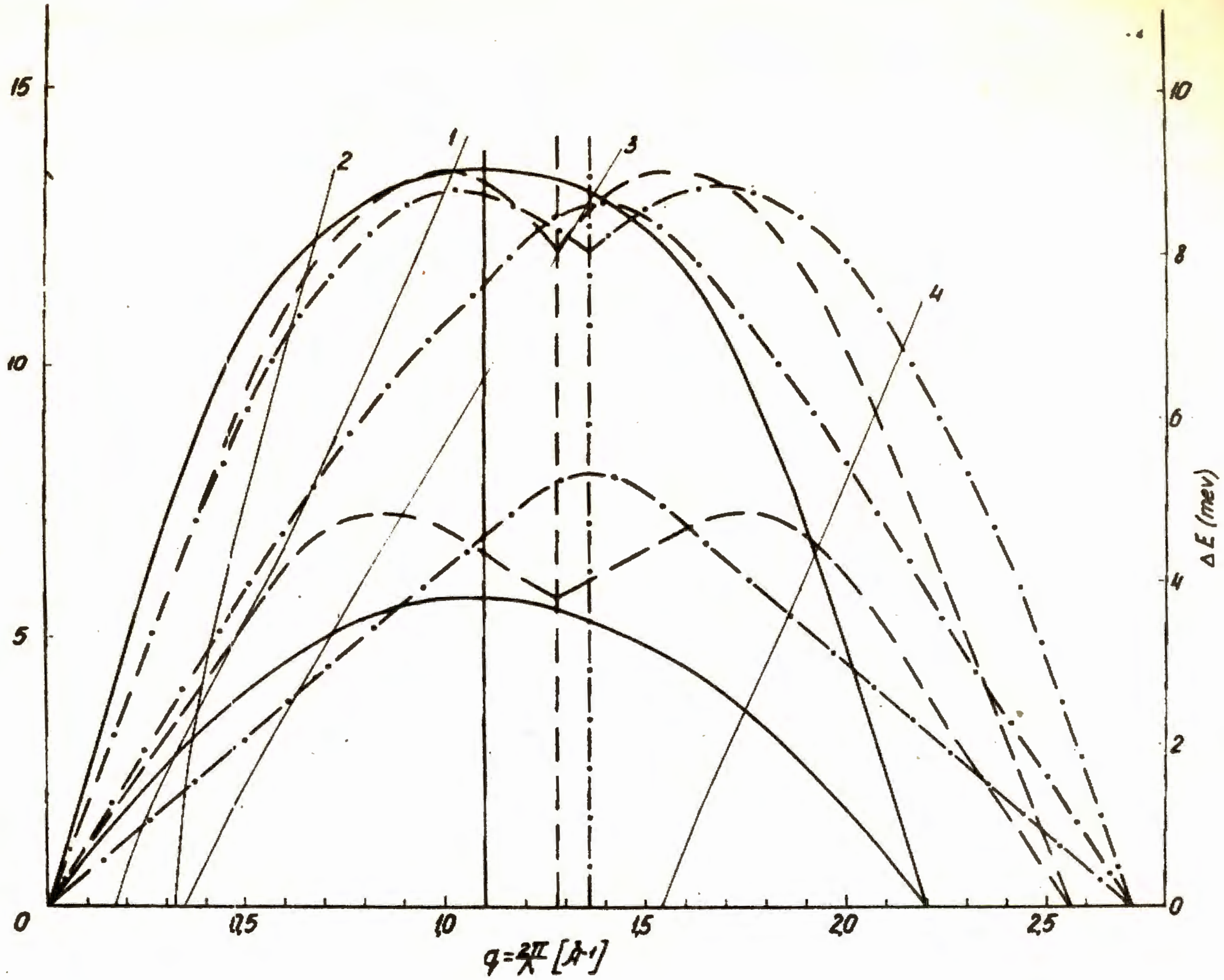

Fig. 3. Dispersion curves for three directions in lead (- [III], -.-.- [110] , - - - [100]). The vertical lines indicate the first Brillouin zone boundaries for corresponding directions. Curves 1–4 show the laws of momentum and energy conservation that are realized in the given experiment (1–2) and in paper[7/] (curves 3–4).

(1 - E_0 = 5 meV, Θ = 6°; 2 - E_0 = 20 meV, Θ = 6°; 3 - E_0 = 2.2 meV, Θ = 20°; 4 - E_0 = 5 meV, Θ = 60°)