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INELASTIC SCATTERING OF SLOW NEUTRONS IN TIN

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The time-of-flight spectra of inelastically scattered cold neutrons on tin were investigated at 163, 225, 293, 468, 523 and 543 K. A typical temperature dependence of the phonon population has been found, as well as the spreading of the phonon peaks in the liquid phase. The phonon spectrum of tin shows typical features of metal spectra.

1. Introduction

Several papers have been published so far about the dynamics of the tin atoms, dealing mainly with the determination of the dispersion curves. Only one of them, however, discusses the phonon frequency distribution of tin, but only for energies up to about 20 meV[1]. So, the main part of the spectrum, which spreads up to about 200 meV, has remained unexplored. Therefore, we have measured the phonon spectra of tin in the wide energy interval from 8 to 500 meV.

2. Experimental method

Measurements of the phonon spectra have been done on the time-of-flight spectrometer, mounted on the *RA* reactor in Vinča[2]. Slow neutrons have been obtained from the reactor channel equiped with the Be filter, which was cooled by liquid nitrogen. Therefore, the maximum energy of incident neutrons was 5 meV.

The tin sample was in a container of dimensions $4 \times 6 \times 0.2$ cm. The stainless steel wall around the beam was 0.02 cm. The sample thickness was chosen thus that the transmission was 60%. The sample was placed at a 30° angle in the apparatus used both as a cryostat and a furnace. The apparatus was evacuated both during cooling and heating. The scattering angle was 60°. The measurements were performed on an empty container, and the results used for the correction of the measured spectra to the background scattering.

The time-of-flight velocity spectra were measured at 163, 225, 293, 468, 523 and 543 K. In all measurements, the number of neutrons, shown on the monitor counter placed in the incident beam, was equal.

3. *Results and discussion*

The results of these measurements are shown in Figs. 1, 2, 3 and 4. The ordinate (*number neutrons*) are the experimental counts per number channel of the 256 channel analyser after correction for counter background, $\frac{1}{v}$ efficiency, and scattering from the container. The detectors were placed in one level, vertically to the incident scattered beam. The space between the detectors and the chopper was evacuated, so that no correction for the neutrons scattered through air was made. The correction was also made for the permeation through the chopper — the chopper function. For the multiple scattering, the correction was not made, for its participation in the whole number of neutrons is small.

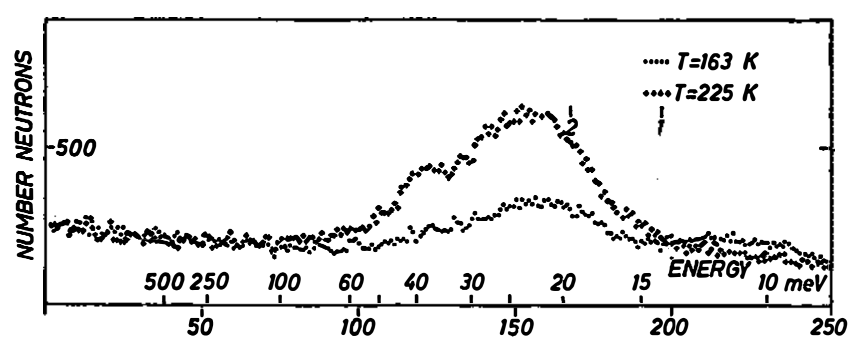

Fig. 1. Scattered neutron spectra of tin at 163 and 225 K.

It is known that the differential incoherent scattering cross section for the one-phonon energy gain process is proportional to the intensity of the incoherently scattered neutros, i. e. to the frequency-energy distribution

$$\frac{d^2 \delta}{d\Omega d\omega} \sim f(\omega) \sim I_{incoherent}.$$

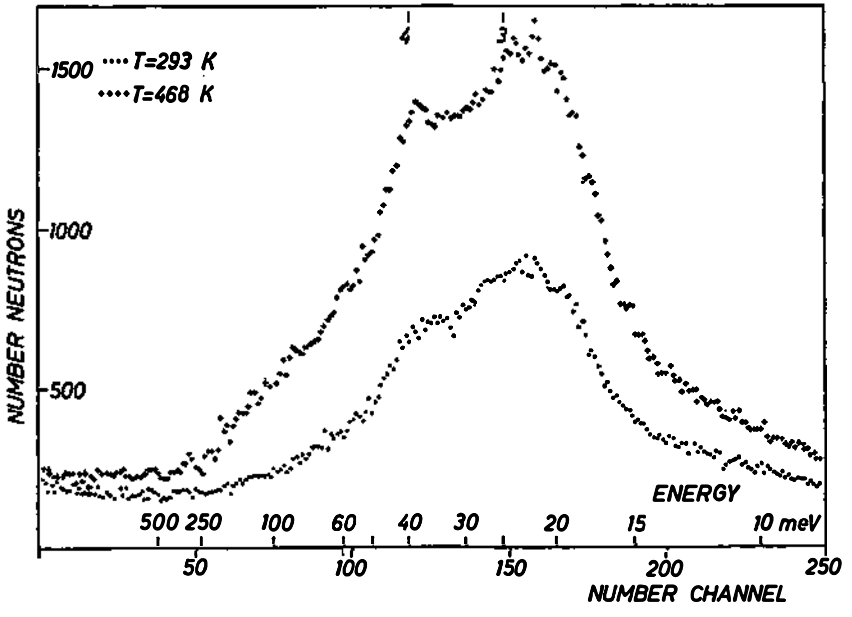

Fig. 2. Scattered neutron spectra of tin at 293 and 468 K.

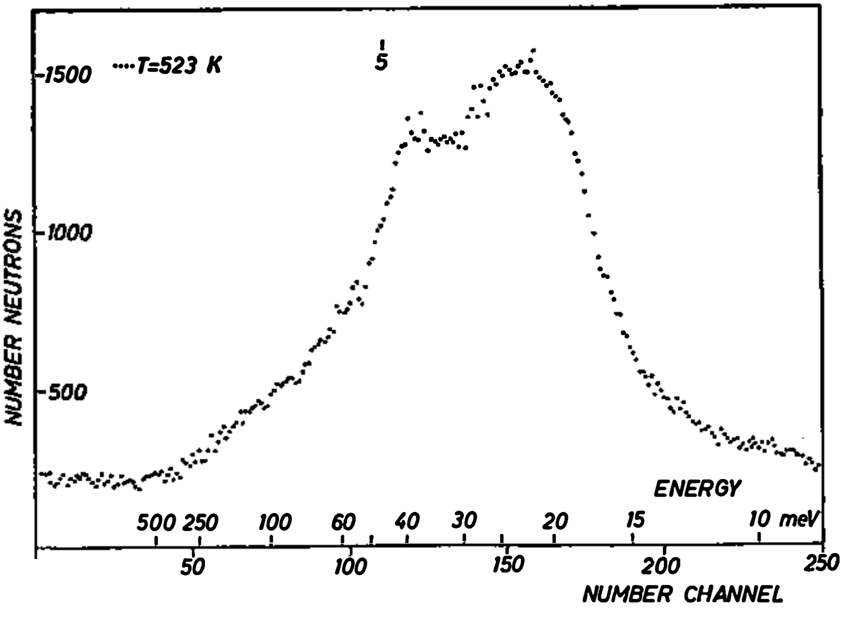

Fig. 3. Scattered neutron spectra of tin at 523 K.

So, the intensity (I) of incoherently scattered neutrons stands for the phonon energy distribution $f(\omega)$, i. e. the lattice vibration spectrum.

Figures 1-4 show the phonon energy distribution in tin at temperatures from 163—543 K. All spectra were for the same number of incident neutrons. The intensity of neutron scattering is lowest at 160 K, and increases with raising temperature. It is highest in the spectrum measured at 468 K, and then slowly decreases as the temperature raises. Fig. 1 shows the spectra for temperatures 163 K (dots) and 225 K (crosses). Above the spectra, there are two lines, marked as 1

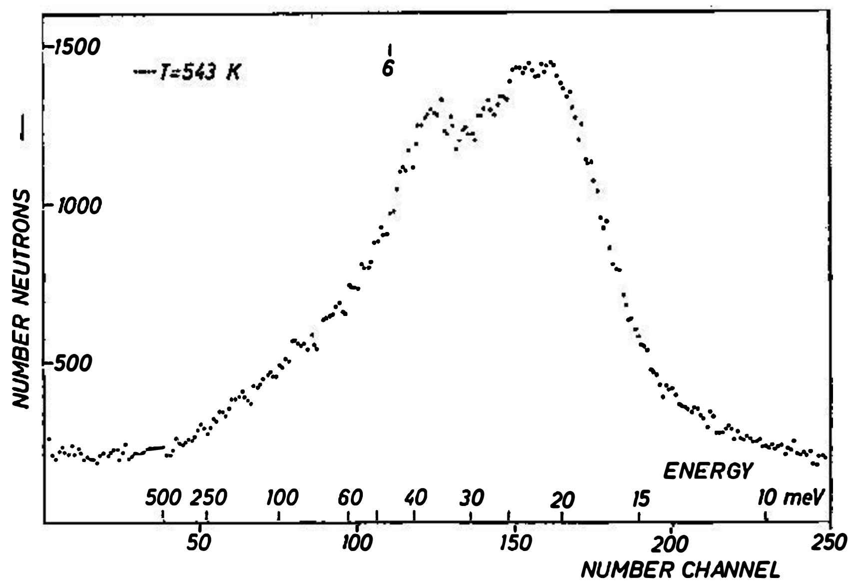

Fig. 4. Scattered neutron spectra of tin at 543 K.

and 2, representing sample energies $E = kT$, at corresponding temperatures. At 163 K, the sample energy is 14 meV, at 225 K it is about 19 meV. These energies are lower than the spectrum maximum for tin, so the higher energy phonons are weakly excited, because of which the intensity of scattered neutrons is smaller. With the raise of temperature, the sample energies become 25 and 40 meV (Fig. 2, hyphens 3 and 4) and the higher energy phonons are strongly excited. This is especially reflected in the intensity of the spectrum measured at 468 K, which is close to the temperature at which tin melts (505 K). The spectra from Figs. 3 and 4 were measured at temperatures at which tin is liquid. Hyphens 5 and 6 represent the energies of about 46 and 47 meV, and they are at energies higher than the main peak of tin. Chaotic movement of the tin atoms in the liquid causes a small spectrum spreading, but the neutrons, because of a short time of interaction, still see the single phonons, so that the tin spectrum contour at these temperatures remains the same as in solid tin.

The phase transitions in tin occur at 286.2 K and 434 K. The system is cubic up to the lower temperature, and tetragonal between those points. Above the higher transition temperature, the system is rhombic. It is interesting that these temperatures, when calculated through $E = kT$, give energies of 24.7 meV and 37.4 meV, which coincide with the lower and higher pronounced peaks in the spectrum.

The phonon energy spectra of tin show a typical picture of the phonon spectra of other metals measured so far.

4. Conclusions

In this paper, the whole phonon spectrum of tin in a wide energy and temperature interval has been studied. The spectrum intensity increases with raising temperature, up to the melting point, and then it decreases. It is possible that the phase transitions in tin agree with the highest, and somewhat lower, well pronounced phonons in the spectrum. This spectrum shows a typical picture of the metal spectra, so it could certainly be compared with some of the simple non--central force models and for the model assumed[3–5].

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NEELASTIČNO RASEJANJE SPORIH NEUTRONA NA KALAJU

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Istraživani su neutronski spektri, metodom vremena preleta neelastično rasejanih hladnih neutrona na kalaju, na temperaturama od 163, 225, 293, 468, 523 i 543 K. Preko spektra, ustanovljeno je tipično ponašanje populacije fonona sa porastom temperature i razmazivanje fononskih pikova kod spektra merenih u tečnoj fazi. Fononski spektar kalaja pokazuje tipičnu sliku spektra metala.