SOVIET PHYSICS JETP VOLUME 17, NUMBER 3 SEPTEMBER, 1963

INVESTIGATION OF THE PHONON SPECTRUM OF NICKEL

N. A. CHERNOPLEKOV, M. G. ZEMLYANOV, A. G. CHICHERIN, and B. G. LYASHCHENKO

Submitted to JETP editor October 13, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) 44, 858-860 (March, 1963)

A time-of-flight neutron spectrometer was used to measure the inelastic scattering of cold neutrons by a sample consisting of a mixture of nickel isotopes with an average coherent amplitude equal to zero. The phonon spectrum of nickel has been reconstructed from the results.

WHEN the scattering is completely incoherent, the study of the inelastic scattering of slow neutrons [1] by monatomic crystals of cubic symmetry allows a unique reconstruction of the phonon spectrum of the scatterer from the experimental data.

Up to now such a reconstruction has been done only for vanadium,[2] a metal with a body-centered cubic lattice, for which the coherent scattering cross section is negligibly small because of spin incoherence. The reason for this is that vanadium, like hydrogen, is an element for which the neutron scattering is almost completely incoherent. But the number of substances for which one can directly study the phonon spectrum can be extended by using those elements (Li, Ni, Sm) which have isotopes having both negative and positive scattering amplitudes for neutrons. If we use specially prepared alloys of isotopes of these elements corresponding to a zero average amplitude for coherent scattering, the scattering will be entirely incoherent and the phonon spectrum of the scatterer will be given uniquely. It will obviously be very close to the phonon spectrum for the normal mixture of isotopes of the element.

We are reporting the results of measurements of inelastic scattering of cold neutrons by an alloy of nickel isotopes which scatters neutrons incoherently, and also give the reconstruction of the phonon spectrum. The measurements are of interest primarily because nickel, like vanadium, is a transition metal, but has a face-centered cubic lattice, which makes it possible to compare the phonon spectra for two transition metals with different crystal structure.

The sample was prepared by alloying 46% of normal nickel, which has a coherent neutron scattering amplitude $a = 1.03 \times 10^{-12}$ cm, with 54% of the Ni^{62} isotope, having an amplitude $a = -0.87 \times 10^{-12}$ cm. The measurements were made on a time-of-flight neutron spectrometer [3] at room temperature over a range of energy of the scattered neutrons from 1.4×10^{-2} to 5.0×10^{-2} eV.

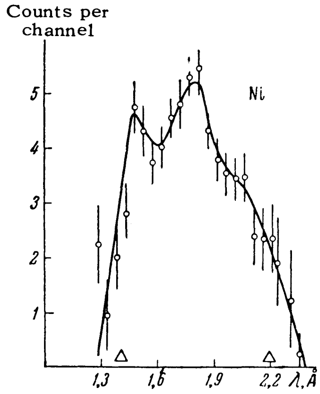

FIG. 1.

Figure 1 shows results of the measurements corrected for the transmission function of the neutron spectrometer chopper, the deviation of the detector efficiency from a 1/v law, and the attenuation of the scattered neutrons in air.

Since the contribution from multiphonon and multiple processes as well as from inelastic magnetic scattering is negligibly small, the experimental data were used directly, taking account of the overall resolution of the neutron spectrometer, to reconstruct the frequency distribution function $g(\omega)$ of the normal vibrations. The problem of reconstructing $g(\omega)$ was solved using a digital computer and writing the phonon spectrum $g(\omega)$ in the interval from $\omega_1 = 2$ to $\omega_2 = 6.84$ as a series

$$g(\omega) = \sum_{\alpha=0}^{7} g_\alpha f_\alpha(\omega)$$

with the error

$$\delta(\omega) = \left\{\sum_{\alpha=0}^{7} f_\alpha^2(\omega)\right\}^{1/2},$$

while for $\omega < \omega_1$, the function $g(\omega) = 0.019\,\omega^2$. The frequency ω is expressed in units of 10^{13} sec^{-1}, $\omega_0 = 1.09$ and $\Omega = \omega_2 - \omega_1$; $f_\alpha(\omega)$ are the basis functions, determined by the relation given in our earlier paper.[2] The expansion coefficients for the normalized spectrum are given in the Table.

Expansion coefficients of $g(\omega)$

α	g_α	$f_{\alpha 0}$	$f_{\alpha 1}$	$f_{\alpha 2}$	$f_{\alpha 3}$	$f_{\alpha 4}$	$f_{\alpha 5}$	$f_{\alpha 6}$	$f_{\alpha 7}$
0	8.0	0.0169							
1	—4.4	—0.0215	0.0410						
2	—2,6	0.0244	—0.0387	0.0397					
3	—0.4	—0.0131	0.0400	—0.0364	0.0417				
4	—0.4	0.0150	—0.0203	0.0413	—0.0367	0.0466			
5	0.6	—0.0064	0.0309	—0.0184	0.0466	—0.0387	0.0525		
6	—0.5	0.0166	—0.0084	0.0364	—0.0167	0.0544	—0.0430	—0.0626	
7	—0.7	—0,0005	0.0410	—0.0031	0.0456	—0.0016	0.0682	0.0472	0.0751

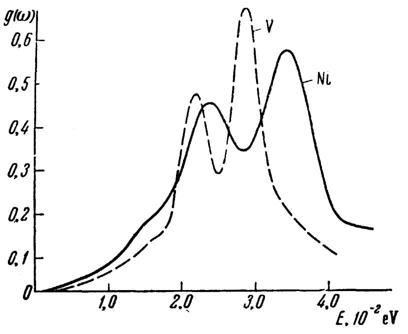

FIG. 2

In Fig. 2 we give a comparison of the nickel phonon spectrum with that for another transition metal, vanadium.[3] From this comparison we see that the maxima in the nickel spectrum are wider, are at higher energy and are separated more than those in the vanadium spectrum (24 and 35 meV for nickel and 22 and 29 meV for vanadium).

The shift of the maxima in the nickel spectrum toward higher energy shows that the force constants in nickel are considerably larger than those in vanadium.

The authors thank M. I. Pevzner for interest in the work and participation in discussions, E. Z. Vintaĭkin and A. I. Novak for help in preparing the sample, and A. E. Golovin for assistance in carrying out the experiment.

---

[1] G. Placzek and L. Van Hove, Phys. Rev. **93**, 1207 (1954).

[2] Chernoplekov, Zemlyanov, and Chicherin, JETP **43**, 2080 (1962), Soviet Phys. JETP **16**, 1472 (1963).

[3] M. G. Zemlyanov and N. A. Chernoplekov, PTÉ, #5, 1962.

Translated by M. Hamermesh
144