CERTAIN ANOMALIES IN THE TEMPERATURE DEPENDENCE OF THE THERMAL DIFFUSE SCATTERING OF X-RAYS BY NICKEL

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Figure 1: Fig. 1. Temperature dependence of the intensity of diffuse scattering of X-rays by nickel at $|\mathbf{K}| = 0.1$ Å^{-1}. 1—in the direction from the node 220 to the node 440 of the reciprocal lattice; 2—in the direction from the node 220 to the node 400 of the reciprocal lattice.

Abstract

Full Text

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PHYSICS

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CERTAIN ANOMALIES IN THE TEMPERATURE DEPENDENCE OF THE THERMAL DIFFUSE SCATTERING OF X-RAYS BY NICKEL

(Presented by Academician V. L. Ginzburg, 9 X 1967)

Near the ferromagnetic Curie point, fluctuations of the magnetization are sharply increased ([1–3]), which leads to anomalous magnetic scattering of neutrons in the region of the transition temperature. X-rays are not scattered directly by magnetic moments. However, fluctuations of the magnetic moments, owing to the magnetostriction effect, lead to deformation of the crystal lattice, which in turn gives additional incoherent scattering of X-rays. On approaching the ferromagnetic Curie point, at which the long-wavelength fluctuations of the magnetic moment tend to infinity, the indicated deformation effect can lead to anomalous scattering of X-rays.

The theory of X-ray scattering by deformations of the crystal lattice associated with fluctuations of the thermodynamic parameter by which the phase transformation occurs was developed in ([4]). However, in ([4]) only those cases were considered in which the deformations depend linearly on the magnitude of the fluctuating parameter. In the case of ferromagnetism, the striction effect depends on the square of the magnetization ([5]). This should lead to a complication of the dependence of the intensity of the anomalous scattering on the wave vector, but it does not qualitatively change the conclusions of ([4]).

Fig. 2

Figure 2: Fig. 2

Fig. 1. Temperature dependence of the intensity of diffuse scattering of X-rays by nickel at $|\mathbf{K}| = 0.1$ Å^{-1}. 1—in the direction from the node 220 to the node 440 of the reciprocal lattice; 2—in the direction from the node 220 to the node 400 of the reciprocal lattice

In the present work, diffuse scattering of X-rays by a single crystal of nickel was investigated in a temperature interval encompassing the Curie point (T_{K} about 630°K), at 300, 500, 600, 630, 660, and 690°K. The measurements were made in a high-temperature vacuum attachment to a GUR-4 goniometer. In all other respects, the procedure for treating the sample and for taking the diffraction pattern repeats that described in ([6]). The intensity was measured at points lying on straight lines connecting the nodes 220 and 440, and also 220 and 400, of the reciprocal lattice, within the limits of the first Brillouin zone.

The obtained curves of the dependence of intensity on temperature for one of the reciprocal-lattice points at which the measurements were made, located at a distance $|\mathbf{K}| = 0.1$ Å^{-1} from the node 220, are given in Fig. 1. The curves show a regular course of the intensity of the diffuse scattering. Because of the small number of points on the curve, anomalies of the intens—

are indicated by arrows. It is clear from the figure that, at a temperature close to the transition point, in both cases an increase in the intensity of diffuse scattering was observed, and for the transverse direction the increase is greater than for the longitudinal one. Curves of the dependence of the intensity of anomalous scattering I_{anom} on $|\mathbf{K}|$ for the same directions are given in Figs. 2 and 3. In both cases I_{anom} decreases sharply with distance from the reciprocal-lattice point, which agrees with the conclusions of ([4]).

Fig. 2. Dependence of the anomalous scattering of X-rays by nickel near the Curie point ($T \simeq 630$°K) in the direction from the 220 reciprocal-lattice point to the 400 point

Near a temperature of 500°K, a certain increase in the intensity of diffuse scattering was also noted. The dependence of the phase velocity of normal waves $c(\mathbf{K})$ ($c(\mathbf{K}) = \nu(\mathbf{K})/|\mathbf{K}|$, where $\nu(\mathbf{K})$ are the frequencies of normal vibrations with wave vector $\mathbf{K}$) on temperature in this case has the form shown in Fig. 4. In ([7]) an analogous anomaly of the elastic modulus (sound velocity) below the Curie temperature was obtained, associated with the magnetostriction of nickel (the ΔE-effect) and disappearing upon application of a saturating magnetic field.

To verify the magnetostrictive nature of the anomalies obtained, the same intensity curves were recorded by us in a magnetic field of strength 1000 Oe (exceeding the saturation field of nickel). Indeed, in the magnetic field no anomalies exceeding the experimental errors were found either at 500°K or near the Curie

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

point.

The intensity of diffuse scattering of X-rays on the displacement wave $u(\mathbf{K})$ at a point of reciprocal space separated by a distance–

Fig. 3. Dependence of the anomalous scattering of X-rays by nickel near the Curie point ($T \simeq 630°$K) in the direction from the 220 reciprocal-lattice point to the 440 point

Fig. 4. Temperature dependence of the propagation velocity of normal waves in nickel.
1 –polarization vector $\varepsilon \parallel \mathbf{K} \parallel [110]$;
2 –polarization vector $\varepsilon \parallel [110]$; $\mathbf{K} \parallel [110]$

of $\mathbf{q}$ from the origin, is proportional to $(\mathbf{u}(\mathbf{K}) \cdot \mathbf{q})^2$. If the entire change in intensity at the Curie point is expressed through the frequencies of the normal vibrations by the known formula ([8]), then the additional anomalous scattering corresponds to a decrease in the frequencies and, consequently, at a definite value of $\mathbf{K}$, to a decrease in the phase velocity of the normal waves $c(\mathbf{K})$. The values obtained for $c(\mathbf{K})$ at $|\mathbf{K}| = 0.1$ Å^{-1} near the Curie point are shown in Fig. 4 by arrows.

The results of the present work are consistent with the idea of an anomalous increase in the fluctuations of the order parameters near a second-order phase-transition point.

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Note: Figure translations are in progress. See original paper for figures.