Striction of antiferromagnetic transition and magnetic Grüneisen parameter of α–Mn

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The temperature dependence of the efficiency of the electromagnetic excitation of elastic waves and that of the velocities of transverse and longitudinal sound in polycrystalline α–Mn have been studied. The spontaneous striction of the antiferromagnetic transition (the magnetic volume) has been determined: $W \approx 8 \times 10^{-4}$. The magnetic Grüneisen parameter in the antiferromagnetic phase has also been determined: $\Gamma_M = -47$.

The α modification of manganese is well known as a noncollinear four-sublattice antiferromagnet with a Néel temperature $T_N = 95$ K. While the magnetic structure of α–Mn has been studied in detail,[1] several important magnetoelastic properties of this metal have not been determined. In this letter we are reporting a study of the temperature dependence of the elastic moduli and that of the efficiency of the electromagnetic excitation of sound in α–Mn. Values of the compression modulus E and the shear modulus G over the interval 4–300 K were calculated from the temperature dependence of the longitudinal and transverse sound velocities, S_l and S_t, respectively, with the help of data on the temperature dependence of the density of the metal, ρ (Ref. 2).

The phase velocities of the elastic waves were measured by a contactless method involving the electromagnetic excitation of standing sound vibrations in a plane-parallel metal plate. The sound was generated in the interaction of the alternating current induced by the electromagnetic wave in the skin layer of the metal, with a static magnetic field. During antisymmetric excitation—the sample was placed inside two inductance coils, positioned parallel to each other, one used for excitation and the other for detection—resonance features of the surface impedance were observed when the thickness of the plate was equal to a half-integer number of sound wavelengths. From the frequencies of these resonance features we calculated the velocities of the elastic waves. The amplitudes and Q values of the acoustic resonances carried information about the efficiency of the electromagnetic–acoustic conversion and the attenuation of the sound. The measurements were carried out on a polycrystalline sample in magnetic fields up to 8 T at frequencies of 10^6–10^7 Hz.

Figure 1 shows the temperature dependence of the amplitude of the acoustic resonances of the transverse (A_t) and longitudinal (A_l) sound in α–Mn. The sharp decrease in the signals near T_N is due to an increase in the attenuation of sound upon the phase transition, according to measurements of the Q values of the resonances.

A sharp increase in the amplitudes of acoustic resonances has been observed previously in metals with a huge magnetostriction, Tb and Dy (Ref. 3), at the Néel points. In other words, the increase in the signals due to the increase in the conversion

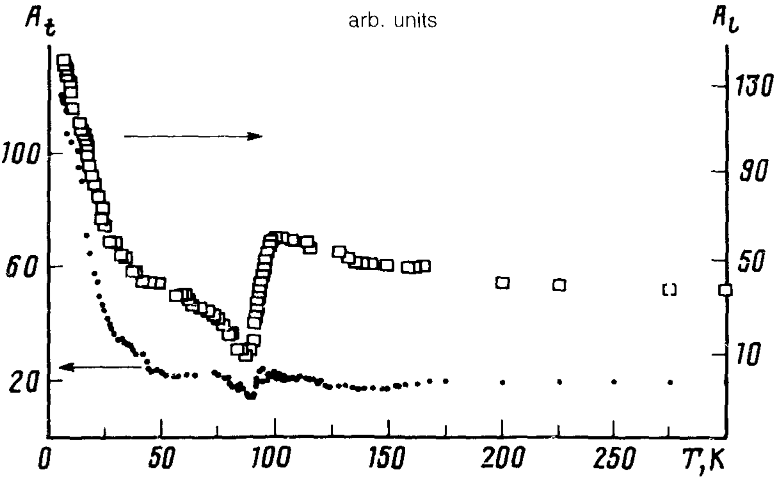

FIG. 1. Temperature dependence of the amplitudes of the acoustic resonances of the transverse (A_t) and longitudinal (A_l) sound in α–Mn.

efficiency more than made up for the decrease in the signals due to the attenuation. From this fact alone we can draw a qualitative conclusion: The magnetoelastic coupling constants in α–Mn are small.

An interesting feature of this behavior is the anomalous increase in the efficiency of the electromagnetic–acoustic interaction at low temperatures. According to some additional measurements of the magnetic and transport properties of this sample which we carried out, this behavior cannot be explained on the basis of an induction mechanism for the electromagnetic–acoustic interaction. It stems instead from the appearance of a magnetoelastic mechanism for the excitation of sound.[4] Since no magnetic conversions occur below the Néel point in α–Mn, it might be suggested that this effect stems from a transition to the magnetic state of manganese oxide, Mn_3O_4, whose Curie temperature is $T_C = 42.5$ K. The appearance of a parasitic ferromagnetism at this temperature was also pointed out in Ref. 5.

Figure 2 shows the temperature dependence of the longitudinal (S_l) and transverse (S_t) sound velocities. The jump in the compression modulus at the Néel point, $\Delta E/E = 2\times\Delta S_l/S_l$, amounts to 2.6×10^{-2}, while that in the shear modulus is $\Delta G/G = 2\cdot\Delta S_t/S_t - 6\times10^{-3}$. From these results we can calculate the temperature dependence of the bulk modulus:[5]

$$K = E - 4/3 \cdot G. \tag{1}$$

The jump in K at T_N is 5.1×10^{-2}.

It can be shown[1] that the jump in the bulk modulus at the Néel point is proportional to the square of the isotropic magnetostriction γ and inversely proportional to the uniform—exchange constant b. Using the expression[7] $b = 3NkT_N/(80M^4)$ for the exchange constant for an estimate (N is the density of atoms, k is the Boltzmann

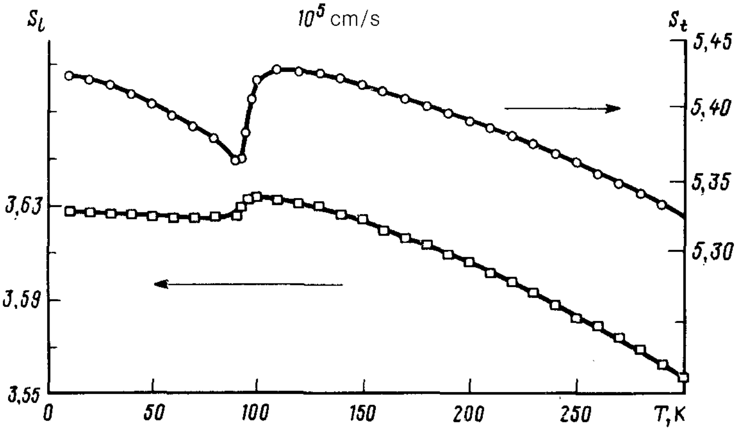

FIG. 2. Temperature dependence of the velocities of transverse (S_t) and longitudinal (S_l) sound in α–Mn.

constant, and M is the sublattice magnetization), we find the spontaneous striction of the transition (the magnetic volume) of α–Mn to be $W = \gamma M^2/K_N = 8\times 10^{-4}$, where K_N is the bulk modulus at the Néel point. This value agrees well with data found from the temperature dependence of the coefficient of thermal expansion, β (Ref. 2).

From the temperature dependence of K in the antiferromagnetic phase and the data on the temperature dependence of β (Ref. 2), we calculated the magnetic Grüneisen parameter of α–Mn. In order to determine the magnetic component $\Delta K_M(T)$ of the bulk modulus, we extrapolated the temperature dependence $K(T)$, as shown in Fig. 3, out of the paramagnetic phase into the low-temperature region. From this

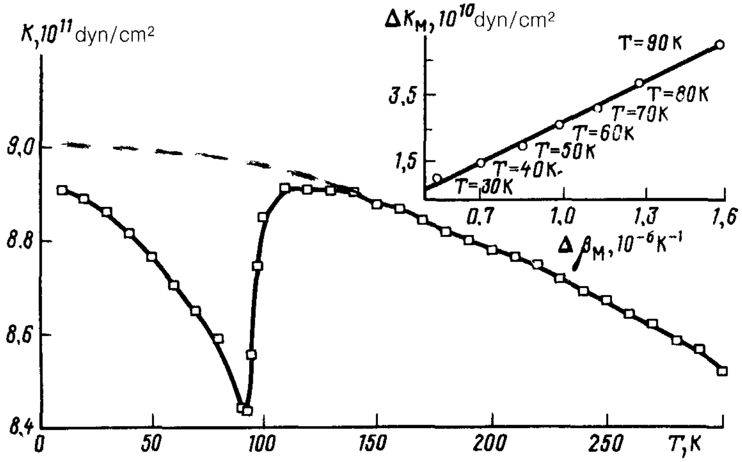

FIG. 3. Temperature dependence of the bulk modulus K in α–Mn. The dashed line is an extrapolation out of the paramagnetic phase. The inset shows the magnetic components of the bulk modulus, ΔK_M, and of the thermal expansion coefficient, $\Delta\beta_M$.

curve we subtracted the experimental temperature dependence $K(T)$ in the antiferromagnetic phase. The ratio $\Delta K_M(T)/\Delta\beta_M(T)$, where $\beta_M(T)$ is the magnetic component of the thermal expansion coefficient, turned out to be constant at $T<T_N$ (see the inset in Fig. 3). According to the procedure developed by Fawcett,[9] this result made it possible to determine the magnetic Grüneisen parameter of α–Mn in the antiferromagnetic phase:

$$\Gamma_M = (-T_N \cdot K_N)^{-1} \cdot (\Delta K_M(T/T_N)/\Delta\beta_M(T/T_N) = -47. \qquad (2)$$

The value which we found for Γ_M in α–Mn is on the same order of magnitude as the magnetic Grüneisen parameters in chromium[8] and in alloys of γ–Mn with copper, while it is substantially larger than Γ_M in other 3d transition metals.[9]

1) We intend to devote a separate report to a calculation of the behavior of the elastic moduli and that of the efficiency of the electromagnetic–acoustic conversion near the antiferromagnetic transition.

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