both (9) and (10) allow several resonances below ω_p. For large q values the spacing of the resonances according to Eqs. (9) and (10) is much larger than given by (11), as is also the case with the experimental results. It is therefore felt that the phenomenon of resonance oscillations can be fairly well explained on the basis of the present theory, although much needs to be done on calculations using a realistic density variation and an appropriate geometry before numerical comparison with experiment is possible. The unrealistic density variation we have chosen gives a too low value for the density in the oscillating region. This fact may explain why Eq. (10) gives unreasonably large values for ω_p/ω at resonance.

---

[1]P. Weissglas, J. Nucl. Energy 4, 5 (1962), part C.

[2]R. W. Gould, Proceedings of the Linde Conference on Plasma Oscillations, 1959 (unpublished).

[3]Adam Dattner, preceding Letter [Phys. Rev. Letters 10, 205 (1963)].

[4]E. Jahnke, F. Emde, and F. Lösch, Tables of Higher Functions (McGraw-Hill Book Company, Inc., New York, 1960).

NONELASTIC TRANSITIONS IN CHROMIUM

M. E. de Morton*
Metallurgy Department, Manchester University, Manchester, England
(Received 7 December 1962)

Neutron diffraction measurements[1] have established that the second-order transition in Cr observed on cooling below 40°C occurs through the onset of antiferromagnetic ordering with magnetic moments parallel to antiphase-domain boundaries. A further change in the reflected neutron intensity found in Cr single crystals at lower temperatures, i.e., -120°C[1,2] and -160°C,[3] and termed the spin-flip transition $T_{S\text{-}F}$, occurs when the direction of magnetic moments spontaneously rotates through 90°.

The transition at ~40°C, the Néel temperature T_N, is accompanied by a sharp peak ($\delta = 3\times10^{-3}$) in internal friction and a precipitous trough in the dynamic Young's modulus E when measured at resonant frequencies.[4,5] A small trough in E is also observed at -150°C. On the other hand, low-frequency (1 cps) internal friction measurements[6] on polycrystalline Cr to -70°C show contrasting results in that below T_N a marked, continuous increase in logarithmic decrement δ occurs; moreover, damping in this region is strongly amplitude dependent. Dislocation damping was absent in these measurements due to strong impurity atom interaction.

Recent internal friction measurements continued down to -196°C are shown in Fig. 1 and indicate the magnetomechanical damping referred to above disappears below about -150°C, the spin-flip transition temperature. Vibration frequency measurements f made concurrently with δ and shown in Fig. 2 indicate that the dynamic shear modulus G, which is proportional to f^2, goes through a peak at T_N and below $T_{S\text{-}F}$ increases very rapidly. These measurements, which show hysteresis, were made on annealed polycrystalline Cr of 99.98 % purity and grain size of ~130 μ in a torsional pendulum at 0.1-mm pressure of helium. The magnitude of the magnetomechanical damping was found to increase with increasing grain size.

The nonelastic behavior of Cr below T_N has been interpreted on the basis of an antiferromag-

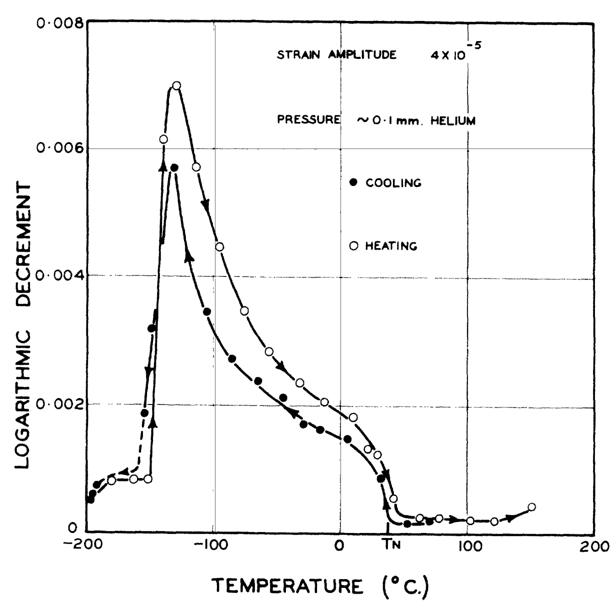

FIG. 1. Damping of chromium as a function of temperature (frequency—1 cps).

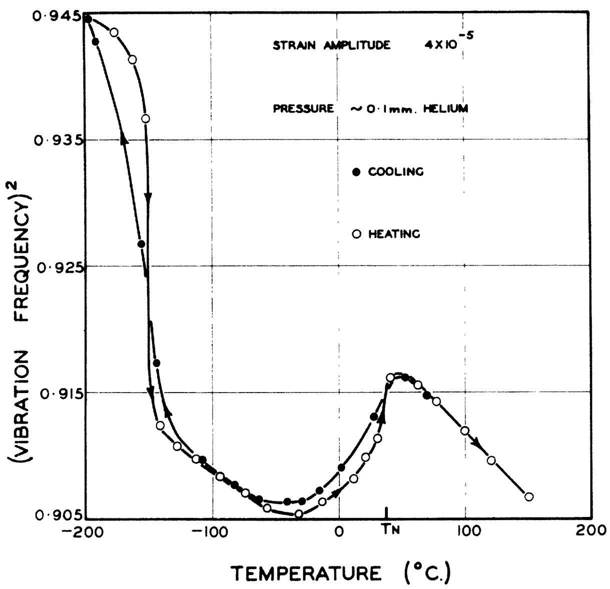

FIG. 2. Change of shear modulus of chromium (proportional to f^2) with temperature.

netic domain structure, the damping arising from the stress-induced, irreversible movement of domain boundaries.[6] An alternative explanation suggested by Overhauser[7] is based on spin-density-wave theory and holds that the damping in Cr below T_N arises from the transverse polarization of linear spin density waves by the oscillating strain of the measurement. This model implies that magnetomechanical damping will disappear below T_{S-F}, since neutron diffraction measurements[3] have shown that the magnetic state below this temperature is one where the spin density waves are longitudinally polarized. The results shown in Figs. 1 and 2 show that this prediction is indeed confirmed.

The present results obtained at low frequencies, which comply with a static hysteresis mechanism,[8] imply that on cooling below T_N the total strain will have both a magnetic and elastic component which will effectively reduce G and increase δ as the degree of magnetic ordering increases. Above T_N, a normal decrease in G due to increasing thermal motions will result in the peak at T_N observed in Fig. 2. The striking recovery of G below -150°C to the expected value on extrapolation from the paramagnetic region, together with the simultaneous reduction of δ, establishes the disappearance of the magnetic component of the strain below T_{S-F}.

On the other hand, the shape maxima and minima observed in δ and E at resonant frequencies[4,5] near T_N are very suggestive of a relaxation process similar to that observed in other antiferromagnetic and ferromagnetic materials[9] where, accordingly, T_N is strongly frequency dependent. No frequency dependence of T_N for Cr over the range 16×10^3 to 5×10^6 cps has, however, been observed.[5,10] Further measurements of δ and G in the frequency range 1-16 000 cps should give a better understanding of the interaction kinetics between the lattice and spin system.

This work was completed at Defence Standards Laboratories, Victoria, Australia, and the author would like to thank Mr. J. I. Nish for his encouragement throughout. The paper is published by permission of the Chief Scientist, Australian Defence Scientific Service, Department of Supply, Melbourne, Australia.

---

*On leave from Defence Standards Laboratories, Victoria, Australia.

[1]G. E. Bacon, Acta Cryst. 14, 823 (1961).

[2]V. N. Bykov, V. S. Golovkin, N. V. Ageev, V. A. Levdik, and S. I. Vinogradov, Dokl. Akad. Nauk S.S.S.R. 128, 1153 (1959) [translation: Soviet Phys.— "Doklady" 4, 1070 (1960)].

[3]J. M. Hastings, Bull. Am. Phys. Soc. 5, 455 (1960).

[4]M. E. Fine, E. S. Greiner, and W. C. Ellis, J. Metals 191, 56 (1951).

[5]J. M. Marin, Armed Services Technical Information Agency Report AD 270886, 1962 (unpublished).

[6]M. E. de Morton, Phil. Mag. 6, 825 (1961).

[7]A. W. Overhauser, Phys. Rev. 128, 1437 (1962).

[8]A. S. Nowick, Progr. Metal Phys. 4, 1 (1953).

[9]K. P. Belov, G. I. Katayev, and R. Z. Levitin, Suppl. J. Appl. Phys. 31, 153S (1960).

[10]H. Pursey, J. Inst. Metals 86, 362 (1958).