MAGNETIC HYSTERESIS IN CHROMIUM

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The field dependence of the magnetic susceptibility of chromium is investigated in fields up to 20 kOe in the temperature interval from 77 to 400°K. Magnetic hysteresis is detected at temperatures below the Néel temperature. A theoretical estimate is made of the order of magnitude of the critical field above which irreversible displacement of domain boundaries is possible.

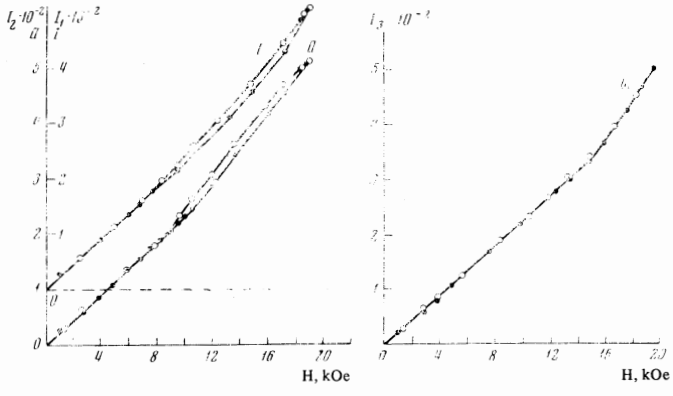
IN an investigation of the magnetic susceptibility of chromium[1], we detected a break on the curve that describes the field dependence of the magnetic susceptibility. It has been shown[2,3] that the magnetostriction of magnetically ordered chromium in fields of 10^4 Oe approaches in order of magnitude the magnetostriction of iron, although the magnetization of chromium in these fields amounts to only hundredths of a gauss. These results can be explained by assuming a domain structure in chromium[4-6] [1)]. If in the original state the vectors **Q** and η of neighboring domains are oriented along different directions, then under the influence of a field **H** there occurs not only a rotation of η toward the direction of **H**, but also a displacement of the boundaries between the domains. Since the phases AF_1 and AF_2 do not possess cubic symmetry[8], displacement of the domain boundaries is accompanied by magnetostriction, which can be appreciable even for very small rotation η from the axis of easy magnetization toward the field; that is, for weak magnetization. The break on the magnetic susceptibility curve indicates, in our opinion, the beginning of irreversible displacements; consequently, in fields near the break point there can be magnetic hysteresis.

To verify this hypothesis, we measured the magnetic susceptibility of polycrystalline specimens of chromium. The magnetic susceptibility was measured on a magnetic balance, described in[9]. The degree of purity of the specimens was the same as in[2].

The figure (curves I and II) shows the dependence of the magnetization of a polycrystalline specimen of chromium on the field (at temperatures 77 and 293°K). It is clearly evident that both in the AF_1-phase and in the AF_2-phase, hysteresis is observed in the high-field region, although the remanent moment is zero. In order to clarify whether the observed effect might be due to the presence of ferromagnetic impurities, measurements were made above the Néel point, T_N = 310°K (curve III). It was found that at temperatures above T_N, the hysteresis is absent.

The small bend on curve III of the figure is due, in our opinion, to the presence of short-range order above the Néel temperature. It is known that similar bends have been observed in ferromagnetic metals above the Curie point. From these measurements it is difficult to deduce whether the occurrence of hysteresis is due to a rotation of the vector η or of the vector **Q**. But the fact that the critical field, above which hysteresis is observed, is approximately the same for both phases seems to indicate a relation of the hysteresis to rotation of the vector **Q**. In the contrary case, the critical field H_c should be appreciably smaller in the AF_1-phase than in the AF_2-phase, since the magnetostriction in the AF_2-phase is appreciably larger than the magnetostriction in the AF_1-phase.

The mechanism by which nonuniformities of the crystalline structure affect the irreversible displacement of domain boundaries was considered theoretically in papers by one of the authors[10] for the case of ferromagnetic substances. The results obtained are easily carried over to the case of domains in an antiferromagnet. The chief difference lies in the fact that in antiferromagnetic domains the spontaneous magnetization is zero, and in consequence of the small value of the magnetic susceptibility, the magnetic interaction between the domains will be practically without influence either on their shape or on the magnetization process. In the boundary-displacement process, there is an increase of volume of a domain in which the vector η makes a larger angle with the external field, since the magnetic susceptibility κ is a maximum in a direction perpendicular to η and is zero along this



Field dependence of the magnetization of polycrystalline chromium: I, T = 77°K; II, T = 293°K; III, T = 370°K. The dark points were obtained on increase of the field, the open circles on decrease of the field.

[1)] According to neutronographic data [6,7], the magnetic structure in chromium takes the form of a standing spin wave with a wave vector $\underset{\sim}{Q}$ and a polarization vector $\underset{\sim}{\eta}$. At temperatures below the Néel temperature, T_N = 310°K, and above the spin-flop temperature, T_{SF} = 120°K, $\underset{\sim}{\eta} \perp \underset{\sim}{Q}$ (AF_1-phase), whereas for $T < T_{SF}$, $\underset{\sim}{\eta} \parallel \underset{\sim}{Q}$ (AF_2-phase).

direction up to fields comparable with the effective molecular field.

Irreversible displacement of a boundary, just as in the ferromagnetic case, sets in at a critical field H_c, at which the change of free energy ΔF on displacement of the boundary becomes and remains negative; that is,

$$\Delta F = \Delta(S\gamma + E_k + E_l + E_m) \leqslant 0, \quad (1)$$

where $S\gamma$, E_k, and E_l are, respectively, the surface energy of the domain boundary, the magnetocrystalline and magnetoelastic energies, and the energy $E_m = -(\kappa_1 V_1 + \kappa_2 V_2)H^2$ in the external magnetic field of domains with magnetic susceptibilities κ_1 and κ_2 in the field direction and with volumes V_1 and V_2. Over a wide range of magnetic fields, $\kappa_i = \kappa_\perp \sin^2\theta_i$, where θ_i is the angle between the polarization vector of a domain and the external field.

In estimating the magnitude of H_c, the critical field of chromium, it is reasonable to assume that for identical heat treatments of chemically pure iron and chromium, the orders of magnitude of the increments of energy $\Delta(S\gamma + E_k + E_l)$, referred to unit volume at $\Delta F = 0$, that is at the beginning of irreversible displacements of a wall, are the same. Then according to (1), under the same conditions, the orders of magnitude of ΔE_m are also the same; that is,

$$\Delta E_m = \varkappa H_c^2 \approx I_s(H_c)_{Fe}, \quad (2)$$

where κ is the magnetic susceptibility of chromium, whereas I_S is the spontaneous magnetization of iron. On taking for annealed iron $I_S(H_c)_{Fe} \approx 10^{-2}$ to 10^{-3} erg/cm^3, $\kappa \approx 10^{-6}$ to 10^{-7}, we get from (2) the value $H_c \approx 10^4$ to 10^5 Oe, which agrees with the order of magnitude of our observed values of H_c (see the figure).

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