This expression is somewhat different from that of Heikes, who first suggested that Ω depends only on $\mathbf{M}(T)$. This is correct provided the pertinent assumption $t_0 \ll \tau$ is fulfilled. Now, the relaxation time t_0 is of the order of $\hbar/J_{\text{eff}}$.[31] Here $J_{\text{eff}}=b_\pi^2/U$, where U measures the Coulomb repulsion between two electrons at the same ion. From Van Vleck's relation between $T_N = 520°\text{K}$ and J_{eff}, one finds $(J_{\text{eff}})_{\text{exp}}=0.022$ eV and $t_0 \sim 3\times10^{-14}$ sec. On the other hand, it follows from Eq. (2) that the mean time-of-stay $\tau = 1/W \ll \hbar\omega_0$, so that in fact $t_0 \ll \tau$.

IV. CONCLUSION

Mobile polaron holes in NiO are localized in molecular orbitals of t_{2g} symmetry, corresponding to the high spin configuration of the trivalent cation. The transfer integral b_π between two t_{2g} orbitals centered opposite a ligand ion determines the coherence between polaron hole wave functions and is the pertinent parameter for real hopping transitions of polaron holes. The value of b_π is only $\sim\frac{1}{3}$ of the transfer integral b_σ connecting orbitals of e_g-symmetry between which virtual transitions of electrons take place, causing the superexchange mechanism proposed by Anderson. Since b_π is of the same magnitude as the phonon energy $\hbar\omega_0$, the frequency factor for nonadiabatic through-the-barrier tunneling transitions is of comparable magnitude with that for adiabatic over-the-barrier transitions; therefore, if one ignores magnetic ordering, $W_0 \approx \omega_0/2\pi$. The effect of magnetic ordering on the transition probability W is determined by the time-dependent spin-pair correlation function $\gamma_{ij}(t)$ for two neighbor cations i and j of different sublattices. Since the mean time-of-stay $\tau = 1/W \gg t_0$ (= the relaxation time for the correlation γ_{ij}), the pair correlation is given by the time-independent expression of $\gamma_{ij}(t \gg t_0)$. This merely depends on the sublattice magnetization $\mathbf{M}(T)$, and the effect of magnetic ordering is accounted for with

$$W_0 \approx \Omega\omega_0/2\pi = (\omega_0/4\pi)[1-\mathbf{M}^2(T)/\mathbf{M}^2(0)]. \quad (12)$$

At $T=300°\text{K}$, the effect of magnetic ordering leads to $\Omega=\frac{1}{10}$.

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Magnetic Structures of Field-Cooled and Stress-Cooled Chromium*

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Single crystals of chromium have been cooled through the Néel temperature in an applied magnetic field of 55 kG (field cooling) and with an applied compressive stress of 0.7 kg mm^{-2} (stress cooling). The resulting magnetic structures of both states have been determined, by neutron diffraction, at temperatures of 78 and 294°K. The results are consistent with the assumption that field cooling favors the nucleation and growth of domains in which there exists a spin-density wave (SDW) with its vector parallel to the direction of the field applied during cooling; in stress cooling the development of domains with a SDW vector parallel to the direction of compressive stress is inhibited. Data on the anisotropy of magnetic susceptibility of field-cooled chromium suggest that the susceptibility of a SDW is maximum when measured normal to the direction of spin polarization. Data on the effect of field cooling on the anomalous temperature dependence of the resistivity of chromium near the Néel temperature are also discussed.

I. INTRODUCTION

NEUTRON-diffraction investigations[1–5] have shown that high-purity chromium exists in two antiferromagnetic phases which, following Hamaguchi *et al.*,[6] are referred to below as the AF_1 and AF_2 phases. The AF_1 phase is stable in the range from the Néel temperature $T_N=311$ to about 120°K; the AF_2 phase is stable at temperatures below 120°K. The phase transformation from AF_1 to AF_2 has been characterized as a change in the direction of antiferromagnetism and the temperature at which the transformation occurs is known as the spin-flip temperature T_{sf}. Overhauser[7] has reviewed the evidence which indicates that the

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observed antiferromagnetism of chromium is a consequence of sinusoidal polarization of the d-band electron magnetic moments rather than of conventional antiparallel alignment of (localized) ionic moments. Tachiki and Nagamiya[8] have demonstrated the stability of a spin-density wave arrangement of band electrons which interact with the lattice.

The magnetic, mechanical, and electrical properties of chromium are modified by field cooling which is achieved by applying magnetic fields, of magnitude greater than a threshold value of about 15 kG, to specimens as they are cooled through the Néel temperature. Montalvo and Marcus[9] have observed the effect of field cooling on the anisotropy of magnetic susceptibility of single crystals of chromium, and these results have been discussed by Lomer and Marcus.[10] Watts[11] has observed the effect of field cooling in de Haas–van Alphen measurements of chromium. Munday, Pepper, and Street[12] have investigated field-cooling effects in measurements of the elasticity and anelasticity of polycrystalline chromium and of the magnetic susceptibility of polycrystalline and single-crystal specimens. Trego and Mackintosh[13] have reported that the anomalous temperature variation of the resistivity of chromium at temperatures near T_N is largely affected by field cooling. The modifications of the physical properties of chromium which are induced by field cooling may be entirely removed by heating a field-cooled specimen to a temperature above T_N and cooling through T_N in zero applied field. Marcus and Arko[14] have noted that the magnetic properties of chromium may also be modified by stress-cooling in which a specimen is cooled through T_N with a stress of a few kg mm^{-2} acting on it. Again, stress-induced perturbations may be removed by heating a specimen above T_N and allowing it to cool through T_N under zero stress.

Some previously reported attempts to detect the modification of the magnetic structure of chromium by field cooling have not been successful, probably because lower than threshold field intensities were applied during cooling through T_N. In the measurements of Shirane and Takei[4] no changes of neutron-diffraction line intensities due to field-cooling effects with a field of 10 kG were detected. Møller *et al.*[5] investigated a relatively large single crystal of chromium in the 1-kG field-cooled state. Field cooling apparently induced small changes in the intensities of some neutron reflections but they were difficult to systematize as the observed magnetic structures in the non-field-cooled state were highly anisotropic. This anisotropy was attributed to the effects of residual stress. Very recently, Brown *et al.*[15] have made neutron-diffraction observations, in the field-cooled state, of the chromium single-crystal specimen used in Bacon's original investigations.[3] It was found that cooling through the Néel temperature in a field of 60 kG inclined at 31° to [100] in the (010) plane considerably altered the magnetic structure in the AF_1 phase. However, these authors suggest that residual strains in the crystal may have influenced some of their results. The work reported here was carried out to investigate the modifications of the magnetic structures of AF_1 and AF_2 phase chromium produced by field and stress cooling, using single-crystal specimens as free as possible from the perturbing effects of internal stress.

II. EXPERIMENTAL

The specimens were cut from single-crystal rods grown by W. A. Rachinger, using a strain-anneal method, from high-purity chromium supplied by the Aeronautical Research Laboratories, Melbourne, Australia. Analysis of the material showed 0.008 wt. % nitrogen and 0.03 wt. % oxygen; other impurities were below the limit of spectrographic detection. A single-crystal rod was fixed to a goniometer and the crystallographic axes were suitably aligned using back-reflection x-ray techniques. The goniometer assembly was then mounted on a Servomet spark-eroding machine, and several specimens 3.2 mm diam and 3.2 mm long were

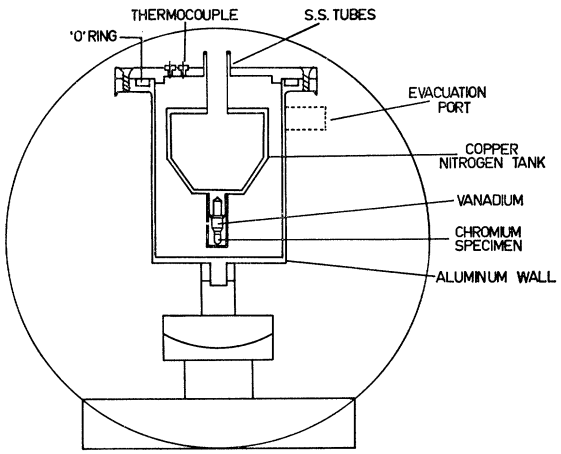

FIG. 1. Schematic diagram of cryostat mounted on full-circle goniometer.

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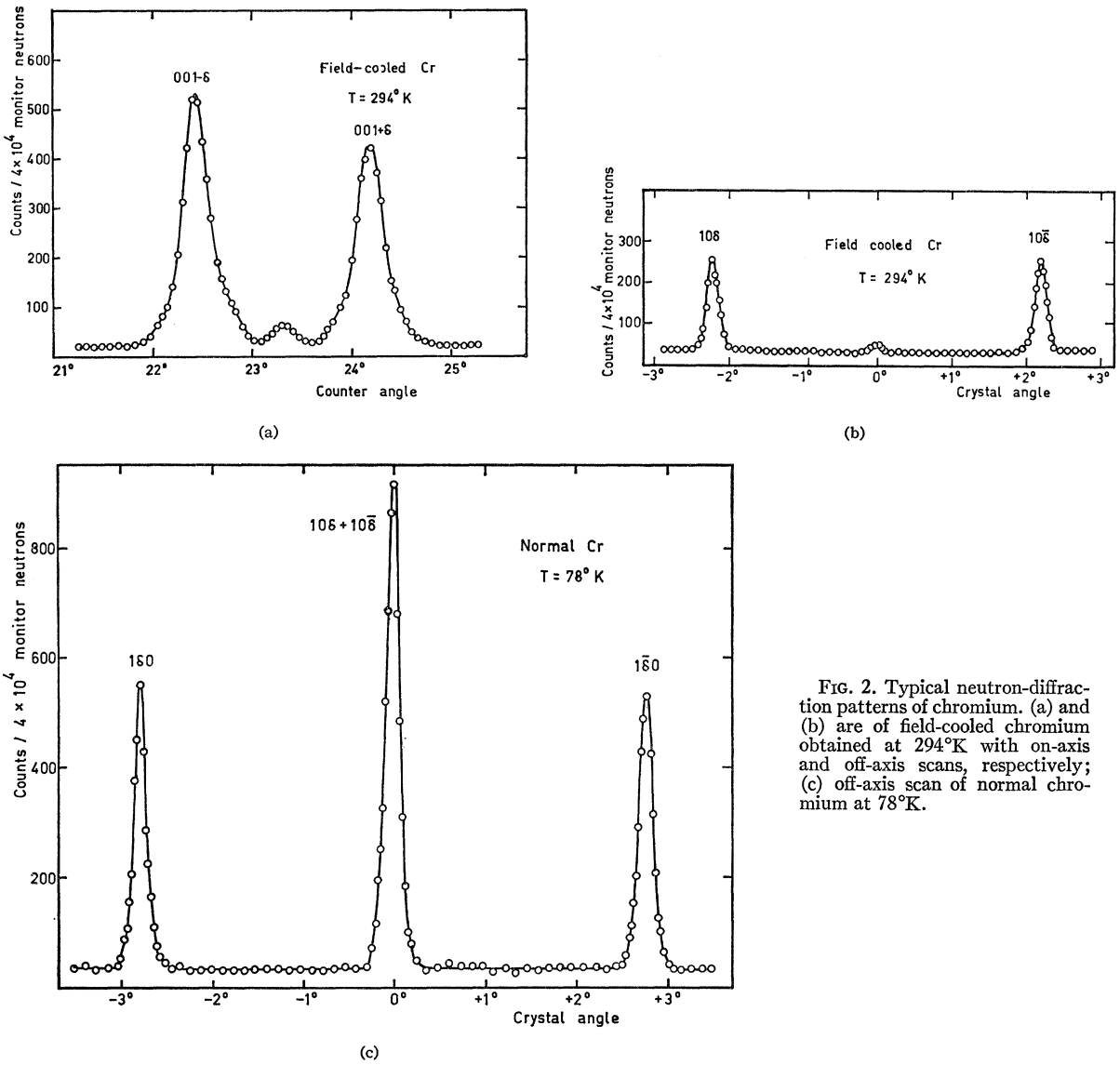

FIG. 2. Typical neutron-diffraction patterns of chromium. (a) and (b) are of field-cooled chromium obtained at 294°K with on-axis and off-axis scans, respectively; (c) off-axis scan of normal chromium at 78°K.

cut with a tubular brass cutter. A surface layer of polycrystalline material which was mainly brass about 0.001 mm thick was rapidly removed by etching in hot hydrochloric acid. It is estimated that the cylindrical axes of the specimens coincided with the [001] crystallographic axis to within $\pm\frac{1}{2}$ deg. After forming, the specimens were enclosed in a small box of high-purity chromium and annealed at 1200°C for 1 h *in vacuo*.

The magnetic fields applied during field cooling were produced by a superconducting solenoid with an inner Dewar vessel providing a working chamber isolated from the liquid helium. For field cooling, a specimen was fitted into an axial hole in a cylindrical copper block on which a heater was wound. The block was lowered into the working chamber of the solenoid and heated to about 120°C, determined by an attached thermocouple. The magnetic field of 55 kG was established and the block and specimen allowed to cool below the Néel temperature. Stress-cooled specimens were produced with a compressive stress of 0.7 kg mm^{-2} applied along the cylindrical axis of the specimen.

Neutron-diffraction measurements were carried out with monochromatic neutron beams of wavelength 1.16 Å from the HIFAR reactor of the Australian Atomic Energy Research Establishment. The magnetic structures were determined with specimens mounted in the cryostat shown in Fig. 1. AF_1 phase measurements were made at 294°K; for the AF_2 phase, measurements were made at 78°K with liquid nitrogen in the cryostat. Reflections corresponding to on-axis points in reciprocal space were scanned with conventional 2:1 coupling of counter and crystal rotations. Off-axis reflections were scanned by maintaining a fixed angular relation between the incident neutron beam and the counter and

rotating the crystal by an independent drive coupled to the crystal table of the diffractometer.

III. RESULTS

Typical neutron-diffraction patterns obtained at 294 and at 78°K are shown in Fig. 2. The results in Figs. 2 (a) and (b) were obtained at 294°K with field-cooled chromium and on-axis and off-axis scans, respectively. Figure 2 (c) was obtained using normal chromium with an off-axis scan at 78°K; no on-axis reflections were observed in the AF_2 phase. Chromium specimens in the normal (unperturbed), field-cooled and stress-cooled states were examined by neutron diffraction; the data on the AF_1 and AF_2 phases of the three states are summarized below.

A. Normal Chromium

The observed neutron-diffraction reflections are plotted for the AF_1 and AF_2 phases in the form of reciprocal space diagrams in Fig. 3, and the averaged intensities of the reflections are tabulated below these figures. (The intensities indicated in this and following figures are in arbitrary units which are consistent for all the figures). The results of Fig 3 are in agreement with those previously reported for normal chromium[1,3,4] as follows: (i) For the AF_1 phase the $\{1-\delta\,0\,0\}$ reflections have intensities approximately 20% greater than those of the $\{1+\delta\,0\,0\}$ reflections and the intensities of the off-axis reflections $\{1\delta 0\}$ are about 50% of the intensities of the on-axis reflections. (ii) at 294 and 78°K the values of δ are calculated to be 0.0380 and 0.0487, respectively, which are in agreement with Bacon's[3] 294°K value of 0.0395 and with Shirane and Takei's[4] 294°K values of 0.0370 and 0.0481. The intensities of the sets of reflections around each of the nominally equivalent {100} points were almost identical and it was inferred from this that the crystals as prepared were free from significant perturbation by residual stress.

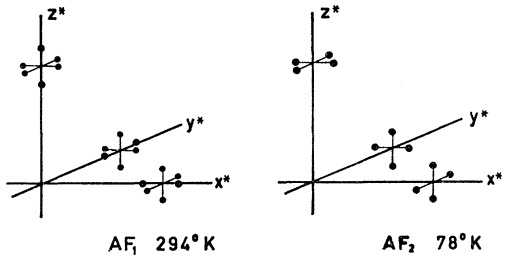

FIG. 3. Reciprocal space plots of neutron-diffraction reflections from normal chromium in the AF_1 and AF_2 phases.

Reflections		Average intensities AF_1 phase	AF_2 phase
On-axis	$(1-\delta, 0, 0)$	14	0
	$(1+\delta, 0, 0)$	12	0
Off-axis	$(1, \delta, 0)$	6.5	35

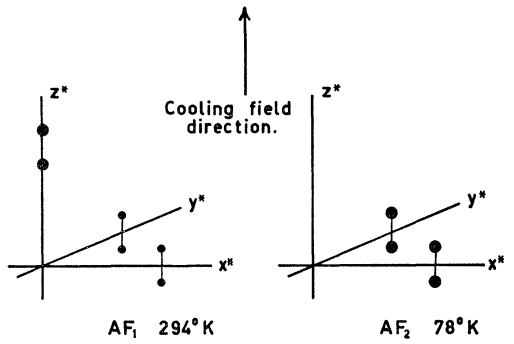

FIG. 4. Reciprocal space plots of neutron-diffraction reflections from field-cooled chromium in the AF_1 and AF_2 phases.

Reflections		Average intensities AF_1 phase	AF_2 phase
On-axis	$(0, 0, \pm(1-\delta))$	43	0
	$(0, 0, \pm(1+\delta))$	36	0
Off-axis	$(\pm 1, 0, \pm\delta)$	18	100
	$(0, \pm 1, \pm\delta)$	18	100

B. Field- and Stress-Cooled Chromium

The results obtained after the crystal had been cooled through T_N with a field of 55 kG acting along the [001] direction are shown as reciprocal space diagrams and tabulated intensities in Fig. 4.[16] In other sets of experiments in which the crystal was heated above T_N and then cooled in a field acting along either the [100] or [010] the results, with the cooling field direction as the reference direction, were very similar to those shown in Fig. 4. This provided additional evidence to show that the influence of residual strain was negligible.

After the field-cooling experiments the crystal was heated to 120°C and allowed to cool in zero magnetic field. It was confirmed that the observed neutron diffraction patterns were then identical to those described in Sec. IIIA. The crystal was then cooled through T_N with a compressive stress of 0.7 kg mm^{-2} acting along the [001] direction; the results are shown in Fig. 5.

The locations in reciprocal space of the observed reflections for both field-cooled and stress-cooled states were identical with the locations of the reflections for normal chromium at the same temperature. Thus, the quantity δ at a fixed temperature was independent of the state of the material. We note that in order to transform a field- or stress-cooled specimen completely to the normal state it was necessary to heat it to at least 20°C above T_N before allowing it to cool with zero applied stress and magnetic field.

IV. DISCUSSION

Overhauser[7] has suggested that the ordering of the magnetic moments of the *d*-band electrons in chromium

[16] After this work had been completed, A. Arrott, J. A. Werner and H. Kendrick [Phys. Rev. Letters 14, 1022 (1965)] reported neutron-diffraction data identical with those given in this figure.

TABLE I. Derivation of the resultant SDW vectors $\mathbf{Q}'$ by combining the fundamental SDW vectors $\mathbf{Q}$ and the reciprocal lattice vectors $\{\mathbf{G}\}$. Only those values of $\mathbf{Q}$ giving neutron reflections represented by points in the first octant of reciprocal space and surrounding {100} positions are included in the table.

Fundamental SDW $\mathbf{Q}$ (units of $2\pi/a$)			Polarization $\hat{\epsilon}$		Resultant SDW $\mathbf{Q}'=2\pi\mathbf{G}(hkl)+\mathbf{Q}$						
Q_x	Q_y	Q_z	AF_1 phase	AF_2 phase	(000)	(200)	(020)	(002)	(110)	(101)	(011)
$1-\delta$	0	0	$\hat{y}$ or $\hat{z}$	$\hat{x}$	(i) $(1-\delta, 0, 0)$	(iv) $(1+\delta, 0, 0)$	...	...	(vii) $(\delta, 1, 0)$	(ix) $(\delta, 0, 1)$	...
0	$1-\delta$	0	$\hat{x}$ or $\hat{z}$	$\hat{y}$	(ii) $(0, 1-\delta, 0)$	...	(v) $(0, 1+\delta, 0)$	...	(viii) $(1, \delta, 0)$	...	(xi) $(0, \delta, 1)$
0	0	$1-\delta$	$\hat{x}$ or $\hat{y}$	$\hat{z}$	(iii) $(0, 0, 1-\delta)$	...	...	(vi) $(0, 0, 1+\delta)$	...	(x) $(1, 0, \delta)$	(xii) $(0, 1, \delta)$

at temperatures below T_N results in the formation of linear static spin-density waves (SDW's). The wave vectors of the three independent SDW's are of magnitude $Q=2\pi/a(1-\delta)$ and are directed along the $\langle 100\rangle$ crystallographic directions; a is the bcc Cr lattice parameter and δ decreases monotonically with decreasing temperature from a value of about 0.04 at 300°K. In the AF_1 phase of normal chromium the fundamental polarization waves are transversely polarized triple linear SDW's of the form

$$\mathbf{P}(\mathbf{r})=P_0(\hat{\epsilon}_1\cos Qx+\hat{\epsilon}_2\cos Qy+\hat{\epsilon}_3\cos Qz), \quad (1)$$

where $\hat{\epsilon}_1=\hat{y}$ or $\hat{z}$, $\hat{\epsilon}_2=\hat{x}$ or $\hat{z}$, $\hat{\epsilon}_3=\hat{x}$ or $\hat{y}$, with $\hat{x}$, $\hat{y}$, $\hat{z}$ as unit vectors along the orthogonal $\langle 100\rangle$. Equation (1) represents eight possible states of polarization which are energetically equivalent in the absence of perturbations produced by stress or a magnetic field. A particular state is not of cubic symmetry, but a specimen in which all eight states are equally probable will exhibit overall cubic magnetic symmetry. The fundamental mode in the AF_2 phase of normal chromium is considered to be a single longitudinally polarized triple linear SDW for which

$$\mathbf{P}(\mathbf{r})=P_0'(\hat{x}\cos Qx+\hat{y}\cos Qy+\hat{z}\cos Qz), \quad (2)$$

and this has cubic symmetry.

The fundamental spin-polarization modes are modulated by the ionic lattice potential and the resultant spin-polarization waves have wave vectors

$$\mathbf{Q}'=2\pi\mathbf{G}\pm\mathbf{Q},$$

where $\{\mathbf{G}\}$ is the set of reciprocal lattice vectors of the ionic lattice. SDW's with a component of spin polarization transverse to the wave vector create transversely polarized magnetic induction waves which scatter neutrons; longitudinally polarized SDW's are not associated with magnetic induction waves and are unable to scatter neutrons. The polarization vector of a resultant SDW is the same as the polarization vector of the fundamental SDW. Thus, neutron scattering occurs for scattering vectors $\mathbf{K}$ given by

$$\mathbf{K}=2\pi\mathbf{G}\pm\mathbf{Q}, \quad (3)$$

when the polarization of the fundamental SDW of wave vector $\mathbf{Q}$ has a component of spin polarization normal to $\mathbf{K}$.

The locations of the points in reciprocal space corresponding to possible neutron reflections calculated from (3) are tabulated in Table I (only points in the first or positive octant of reciprocal space are given). The observed intensity of a reflection will be zero if the resultant SDW is polarized along its wave vector. Thus, as observed, the on-axis reflections (i)–(vi) always have zero intensity in the AF_2 phase where the SDW's are longitudinally polarized. The intensity of a particular reflection will also depend on the total volume of the domains which contain the associated fundamental SDW. It is reasonable to suppose that in normal chromium equal domain volumes are associated with each of the three fundamental SDW's. It follows from Table I that, in the AF_1 phase, the intensities of each of

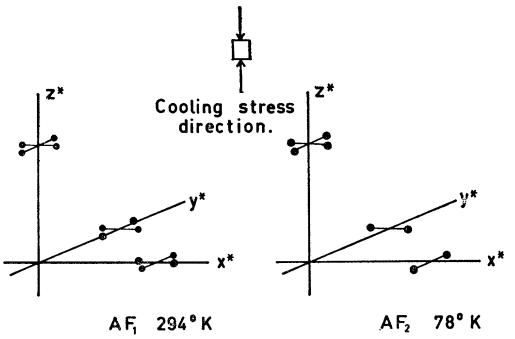

FIG. 5. Reciprocal space plots of neutron-diffraction reflections from compressive stress-cooled chromium in the AF_1 and AF_2 phases.

Reflections		Average intensities AF_1 phase	AF_2 phase
On-axis	$(\pm(1-\delta), 0, 0)$	24	0
	$(\pm(1+\delta), 0, 0)$	20	0
	$(0, \pm(1-\delta), 0)$	24	0
	$(0, \pm(1+\delta), 0)$	20	0
Off-axis	$(\pm\delta, 0, \pm1)$	10	59
	$(0, \pm\delta, \pm1)$	10	59
	$(\pm1, \pm\delta, 0)$	10	59
	$(\pm\delta, \pm1, 0)$	10	59

the reflections (vii)–(xii) should be one-half of the intensities of each of the reflections (i)–(vi), since for the latter set the resultant SDW's have two possible transverse polarizations; for the former set one possible resultant SDW has a polarization very nearly parallel to the SDW vector, and is thus invisible to neutrons. In the AF_2 phase all SDW vectors (i)–(vi) are longitudinally polarized and cannot be observed; reflections (vii)–(xii) have equal intensities. The experimental results, for example those shown in Fig. 3, are in agreement with these predictions, within the limits of experimental error and of the rigid spin approximation.[7]

The results shown in Fig. 4 for field-cooled chromium are in complete agreement with the predictions of Table I if it is assumed that field cooling favors only the growth of domains which contain SDW's with the wave vector parallel to the direction of the cooling field. Thus, for the conditions of Fig. 4 the only allowed fundamental SDW vector is $(0, 0, 1-\delta)$, since the cooling field direction was [001]. In the AF_1 phase the predicted first octant reflections are (iii) and (iv) at $(0\,0\,1\pm\delta)$ which each have twice the intensity of the only other first octant reflections (x) and (xii) at (10δ) and (01δ). In the AF_2 phase the on-axis reflections have zero intensity; i.e., in the present case both $(0\,0\,1\pm\delta)$ disappear leaving only equally intense (10δ) and (01δ) reflections.

The effects of [001] compressive stress cooling (Fig. 5) may be accounted for from Table I with the assumption that stress cooling inhibits the growth of domains with SDW vectors parallel to the applied stress direction. In the case of Fig. 5 the only domains which occur are those containing SDW's of the form $(1-\delta, 0, 0)$ and $(0, 1-\delta, 0)$. Thus, in the AF_1 phase first octant reflections (i), (ii), (iv), and (v) are predicted each with twice the intensity of each of the only other reflections (vii), (viii), (ix), and (xi). In the AF_2 phase, all on-axis reflections disappear and the remaining off-axis reflections (vii), (viii), (ix), and (xi) occur with equal intensities.

The same single crystal specimen was used for all the measurements reported here and it is, therefore, possible to apply additional tests to the model by intercomparison of the normal, field-cooled (FC) and stress-cooled (SC) data in the AF_1 and AF_2 phases. Assuming that field cooling and stress cooling affect the domain distribution in the way already described, then Table I predicts the intensities shown in Table II for the AF_1 and AF_2 phases. The agreement between the observed and predicted intensity ratios is satisfactory.

TABLE II. The predicted relative intensities of the on-axis and off-axis reflections in normal, field-cooled (FC), and stress cooled (SC) chromium. The observed relative intensities (Figs. 3, 4, and 5) are included in parentheses. For each phase the intensity of an off-axis reflection in normal chromium is taken as unity.

	AF_1 phase			AF_2 phase		
	Normal	FC	SC	Normal	FC	SC
On-axis reflections	2(2)	6(6.2)	3(3.4)	0(0)	0(0)	0(0)
Off-axis reflection	1(1)	3(2.8)	1.5(1.5)	1(1)	3(2.9)	1.5(1.7)

TABLE III. Distribution of SDW's in AF_1 and AF_2 phases of field-cooled and stress-cooled chromium.

Phase	FC Cr along [001]	Compressive SC Cr along [001]
AF_1	Equal volumes of domains with $\hat{x}\cos Qz$, $\hat{y}\cos Qz$	Equal volumes of domains with $\hat{y}\cos Qx$, $\hat{z}\cos Qx$, $\hat{x}\cos Qy$, $\hat{z}\cos Qy$
AF_2	A single domain $z\cos Qz$	Equal volumes of domains with $\hat{x}\cos Qx$, $\hat{y}\cos Qy$

The above assignments of linear SDW's for field-cooled and stress-cooled chromium are summarized in Table III. It is also possible to account for the neutron reflections in the AF_1 phases in terms of helical SDW's. For example, the magnetic state of the AF_1 phase of field-cooled chromium may be described in terms of equal volumes of domains containing the helical SDW's $(\hat{x}\cos Qz+\hat{y}\sin Qz)$ and $(\hat{x}\cos Qz-\hat{y}\sin Qz)$. Again, it is not possible unambiguously to determine from the neutron reflections whether a multiple linear SDW exists throughout the whole crystal, or whether an equivalent number of single linear SDW domains exist in separate regions. For example, the magnetic state of the AF_2 phase of stress-cooled chromium could be described as well by a double linear SDW $(\hat{x}\cos Qx+\hat{y}\cos Qy)$ which exists throughout the whole crystal, as by equal volumes of domains of two types which support SDW's $\hat{x}\cos Qx$ and $\hat{y}\cos Qy$, respectively.

In spite of these ambiguities of interpretation, there is sufficient information on the distributions of spin polarization to discuss the effects of field cooling on magnetic susceptibility (χ) and the temperature dependence of resistance near T_{sf} and T_N and the effect of stress cooling on the spontaneous deformation of chromium below T_N. The results of Montalvo and Marcus[9] showed, for example, that for a specimen cooled through T_N in a field acting along the [001], $\chi_{001}>\chi_{100}$ $(=\chi_{010})$ in the AF_1 phase but in the AF_2 phase $\chi_{001}<\chi_{100}$ $(=\chi_{010})$. The subscripts here refer to the direction in which the measuring field is applied for the determination of the susceptibility. Inspection of Fig. 4 shows that the susceptibility results are consistent with the assumption that in both AF_1 and AF_2 phases the susceptibility $\chi_\perp$ measured normal to the direction of polarization of a linear SDW is greater than $\chi_\parallel$ measured parallel to the direction of polarization. It is very likely that the susceptibility depends on the orientation of the measuring field in relation to the directions of both the polarization and the wave vectors. Since field cooling selects one of the three fundamental SDW's it follows that at a fixed temperature

$$\frac{\chi_{001}(\mathrm{FC})-\chi_{001}(\mathrm{normal})}{\chi_{001}(\mathrm{FC})-\chi_{100}(\mathrm{FC})}=\frac{2}{3}$$

in both AF_1 and AF_2 phases. Pepper and Street[17] have measured the temperature dependence of the anisotropy of magnetic susceptibility of field-cooled and normal chromium and the results are consistent with the above prediction.

The disappearance of the SDW $Q(0\,0\,1-\delta)$ on cooling through T_N with compressive stress applied along [001], as shown in Fig. 5, suggests that the lattice of chromium expands in a direction parallel to the wave vector of a transverse linear or helical SDW but contracts at right angles to it. It follows that a sufficiently strong field applied isothermally along ⟨100⟩ in the AF_1 phase will result in a magnetostrictive expansion along the field direction.

Some measurements have been made on the temperature dependence of resistivity of field-cooled chromium, particularly at temperatures around T_N and T_{sf}. The single-crystal specimen was in the form of a cylinder (8 mm long×1 mm diam) cut with a [001] along the axis of the cylinder. The measuring current was parallel to the cylinder axis and measurements were made with the chromium in the normal state and in the field-cooled state produced by cooling through the Néel temperature in a field of 55 kG applied along [001]. No anomaly in resistivity was detectable at T_{sf} for both normal and field-cooled states. However, the depth of the cusp anomaly near T_N in the resistance-versus-temperature curve is about three times greater for field-cooled chromium than for normal chromium. These observations may be accounted for in terms of the domain distribution induced by field cooling if it is assumed that the resistance of a domain measured in a direction parallel to $\mathbf{Q}$ is greater, by a factor $(1+\alpha)$, than the resistance measured in directions normal to $\mathbf{Q}(\alpha>1)$. Arrott[18] has pointed out that the absence of any anomalous variation of resistivity near T_{sf} provides some evidence for the existence of linear and not helical SDW's in the AF_1 phase. It is expected that the change from transverse to longitudinal polarization would not markedly affect either the resistivity of a single domain or, hence, the resistivity of a multidomain crystal.

V. CONCLUSIONS

It has been shown that field cooling and compressive-stress cooling profoundly alter the magnetic structure of chromium. The modifications induced by the two processes are complementary. The results may be satisfactorily interpreted by assuming that during field cooling the nucleation and growth of domains containing SDW's with wave vector parallel to the cooling field are preferred, but in stress cooling the development of domains with a SDW vector parallel to the direction of the stress is inhibited. It is considered unlikely that field and stress cooling change the amplitude of spin polarization. Such a change may be expected to shift both the Néel temperature and the magnitude of the SDW vectors. No such shifts could be detected in our measurements.

Previous observations on the effect of field cooling on the magnetic susceptibility of chromium are consistent with the assumption that the susceptibility of a SDW measured in a direction perpendicular to the direction of spin polarization is greater than the susceptibility measured along the direction of polarization. Data on the temperature variation of the resistivity of normal and field-cooled chromium may be interpreted on the assumption that a domain contains a single SDW and that the resistivity measured in a direction along the wave vector is greater than the resistivities measured in directions normal to the wave vector.

Note added in proof. We have recently completed some experiments on a crystal cooled through T_N with a tensile stress of 0.5 kg mm^{-2} applied along the [001] direction. The results are entirely similar to those described above for field-cooled chromium and thus confirm our inference about the sign of the magnetostriction.

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[17] A. R. Pepper and R. Street (to be published).
[18] A. Arrott, in *Magnetism*, edited by G. T. Rado and H. Suhl (Academic Press Inc., New York, to be published), Vol. II.