urements for films whose thicknesses are equal to or less than the penetration depth. Furthermore, this interaction does not represent just a power loss at resonance resulting from an increase in the refractive index in the polyethylene, and thus upsetting the condition of total internal reflection at the germanium-polyethylene interface. If this were the case, the reflected radiation would always penetrate the whole of the polyethylene film and any radiation not absorbed would be reflected from the polyethylene-air interface and the signal strength would always increase with film thickness. Near the critical angle such an effect could undoubtedly be observed.

Our results indicate that through the use of a more sensitive spectrometer and more reflections this technique should indeed work in the study of surface chemistry and we expect that it should be possible to detect one to ten atomic layers. Furthermore, such a technique should be valuable in the study of thin films.

---

[1] Discussion by N. J. Harrick following paper by R. P. Eischens at Second Conference on Semiconductor Surfaces, Naval Ordnance Laboratories, White Oak, Maryland, December, 1959 [J. Phys. Chem. Solids (to be published).] It was brought to the author's attention after the work described here was completed that Dr. J. Fahrenfort of the Royal Dutch Shell Laboratories, Amsterdam, has described what appears to be a similar technique to observe the spectra of organic materials on silver chloride at the Fourth International Congress on Molecular Spectroscopy, Bologna, September, 1959 (unpublished).

[2] Julius A. Stratton, Electromagnetic Theory (McGraw-Hill Book Company, Inc., New York, 1941).

[3] F. Goos and H. Hänchen, Ann. Phys. 1, 333 (1947).

[4] Semiconductor samples similar to these have been used in the study of other properties of semiconductor surfaces. N. J. Harrick, J. Phys. Chem. Solids 8, 106 (1959). N. J. Harrick, J. Opt. Soc. Am. 49, 376 (1959).

MECHANISM OF ANTIFERROMAGNETISM IN CHROMIUM

A. W. Overhauser and A. Arrott
Scientific Laboratory, Ford Motor Company, Dearborn, Michigan
(Received January 6, 1960)

An experiment is proposed which may in principle distinguish between three mechanisms of antiferromagnetism, one of which may obtain in chromium. Corliss, Hastings, and Weiss[1] have observed that each magnetic superstructure reflection in the neutron diffraction of a Cr single crystal is split into six spots equidistant from the reciprocal lattice point and which lie along [100] type directions from that point. This result can be interpreted in several ways:

A. Cr has basically a Néel type antiferromagnetic structure, but with periodic antiphase domains.[1]

B. The localized spins lie in a (100) plane and spiral with a fixed period in the direction perpendicular to the plane.[2]

C. The localized spins are oriented by their interaction with a static spin density wave in the conduction electron gas.[3]

Each antiferromagnetic domain (or group of antiphase domains for case A) contributes to two of the six magnetic reflection spots associated with a given reciprocal lattice point. That all six spots occur [and, for example, have equal intensity at the (1, 1, 1) point] indicates that the unit vector $\vec{\lambda}$ characteristic of a given domain (as defined below) is parallel or antiparallel to one or the other of the three [100] type axes on a statistically equal basis. For the three models under consideration, $\vec{\lambda}$ is:

A. perpendicular to the antiphase domain boundaries;

B. parallel to the axis of the spiral;

C. parallel to the wave vector of the spin density wave.

An experiment of potentially great interest it to cool a single crystal of Cr through the Néel point to low temperature in a large magnetic field parallel to a [100] crystal axis, and then to study the relative intensities of the six magnetic reflection spots. If the applied field is sufficient to upset the statistical equality of the three [100] axes with regard to $\vec{\lambda}$, the relative intensities of the spots will be modified, and should allow one to distinguish between mechanisms A, B, and C, or at least between C and A or B. Such field-cooling effects may reasonably be anticipated.

Magnetic dipole-dipole interactions contribute an energy dependent on the angle between $\vec{\lambda}$ and the axis $\vec{s}$ of spin alignment. Usually the most favorable orientation is $\vec{\lambda}$ perpendicular to $\vec{s}$, as is observed to be the case for Cr.[1] The spin axis $\vec{s}$ will in turn be correlated with a magnetic field $\vec{H}$ if the sample is cooled through the Néel point with $\vec{H}$ applied. (It is helpful to recall that magnetocrystalline anisotropy is zero at the Néel point, so that $\vec{s}$ is free to adjust according to the direction of $\vec{H}$.)

Consider now an antiferromagnet conforming to model A or B. It is well known that the magnetic susceptibility of such a system is a maximum when $\vec{s}$ is perpendicular to $\vec{H}$. Consequently $\vec{s}$ will align parallel to one of the two [100] axes perpendicular to $\vec{H}$. Subsequently, for case A, $\vec{\lambda}$ will be formed either parallel to $\vec{H}$ or parallel to the other [100] axis perpendicular to $\vec{H}$. For case B, $\vec{\lambda}$ will be parallel to $\vec{H}$ since the spiral rotation of $\vec{s}$ sweeps through the plane perpendicular to $\vec{H}$. For mechanism C, however, the susceptibility is a maximum when $\vec{s}$ is parallel to $\vec{H}$.[4] A brief explanation is as follows. The axis of quantization of the static spin density wave is free to precess around the applied field direction. This precession gives rise to a large rotating effective (exchange) field H_1 (in the sense of a magnetic resonance experiment) which depolarizes the localized magnetic moments (similar to the effect of resonance saturation). As a result, the maximum susceptibility occurs when $\vec{s}$ is parallel to $\vec{H}$. Subsequently, magnetic dipole-dipole interactions favor $\vec{\lambda}$ being perpendicular to $\vec{H}$. The relative intensity of the two neutron reflection spots parallel to $\vec{H}$ from, say, the (1, 1, 1) reciprocal lattice point compared to that of the four spots perpendicular to $\vec{H}$ are:

No field, 1:1;
field-cooled, A. 2:1,
B. 1:0,
C. 0:1.

The foregoing intensity ratios would allow one to distinguish between the three mechanisms considered. However, these ratios apply only if domain orientation adjustment resulting from the field-cooling effect is complete. Very likely, magneto-elastic effects associated with domain formation will permit only partial correlations between $\vec{\lambda}$ and $\vec{H}$. In such an event it would be difficult to distinguish between A and B. However, one should still be able to distinguish between C and A or B since the intensity ratio becomes smaller than unity in the former case and larger than unity in the latter.

Whether or not mechanism C operates in Cr is of particular interest because some remarkable properties of Cr, in addition to the splitting of the neutron reflections, can be explained by this model. Shull and Wilkinson[5] have observed that the Néel point of a powdered Cr sample is 45% higher than that of bulk Cr. This result has been confirmed by Corliss, Hastings, and Weiss.[1] Such an effect can be explained as follows. It must be remembered that the wavelength of the static spin density wave (as determined by the splitting of the neutron reflections) differs by about 7% from the lattice constant. Consequently a significant fraction of the localized spins in an antiferromagnetic domain will lie near nodes of the wave and will contribute little to the condensation energy of the antiferromagnetic state. If it were possible for a domain to terminate spatially whenever the nodes of the wave begin to fall near lattice sites, and for a new domain to begin having a more propitious correlation between the phase of its wave and the lattice sites, the condensation energy and the Néel temperature could be increased by as much as a factor of two (neglecting domain wall energies, etc.). Consequently the observed effect is easily accounted for, provided one assumes that mechanical imperfections present in the powdered specimens provided a mechanism for nucleating (and stabilizing) appropriately small antiferromagnetic domains. This explanation seems all the more likely since Hastings[6] has pointed out that the neutron reflections would not be split if the domain size were small enough to explain the appreciably higher Néel temperature. Indeed, the magnetic reflections from his powdered specimens were not split.[6] The behavior of a particular sample may well be a function of its metallurgical history.

---

[1] L. M. Corliss, J. M. Hastings, and R. J. Weiss, Phys. Rev. Letters 3, 211 (1959).

[2] T. A. Kaplan, Phys. Rev. 116, 888 (1959).

[3] A. W. Overhauser, Phys. Rev. Letters 3, 414 (1959); J. Phys. Chem. Solids (to be published).

[4] A. W. Overhauser (to be published).

[5] C. G. Shull and M. K. Wilkinson, Revs. Modern Phys. 25, 100 (1953).

[6] J. M. Hastings (private communication).