

disappearance of the effects at 50°C, this explanation is unlikely. By way of more positive verification, however, a specimen containing 14 atomic percent Zn was similarly studied. The pair-reorientation effect in such a specimen has been found to be 6 times smaller than that for the above specimen; the plastic properties of the two specimens should be approximately the same. The quenching experiments on these specimens show effects considerably smaller than on the original specimens. It therefore seems as if this alternate explanation has been discounted.

In terms of the vacancy mechanism, the heat of activation in diffusion or pair-reorientation experiments should be  $H = H_1 + H_2$ , where  $H_1$  is the heat of activation for the formation of a vacancy and  $H_2$  for its movement. In the present alloy,  $H = 32.9$  kcal/mole. Inasmuch as the concentration of vacancies responsible for the relaxation in the quenched specimen is that which would be in equilibrium at 400°C or a lower temperature, it is readily calculated, as a preliminary estimate, that  $H_1 \cong 12.5$  and  $H_2 \cong 20.4$  kcal/mole. Further results will be reported in a forthcoming publication.

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<sup>1</sup> C. Zener, *Trans. A.I.M.E.* **152**, 122 (1943).

<sup>2</sup> A. S. Nowick, *Phys. Rev.* **82**, 340 (A) (1951).

<sup>3</sup> C. Zener, *Phys. Rev.* **71**, 34 (1947).

temperature is lowered. They are of unequal polarization and the dispersion in their neighborhood is of opposite sign. In the  $y$ -direction a band is observed in low external fields which vanishes rapidly when the temperature decreases.

In the threshold region the orientation of the two systems of antiparallel spins is apparently decoupled from the preferred  $x$ -axis in such a way that it places itself perpendicular to an external field above the threshold value.<sup>5</sup> A simple extension of the phenomenological treatment of Neél,<sup>6</sup> Bitter,<sup>7</sup> and Van Vleck<sup>1</sup> to high field strengths in an anisotropic crystal leads to the expectation of such a decoupling. In particular, the results on the proton magnetic resonance follow the decoupling in detail.

The symmetry of the resonance diagram appears to suggest the existence of two spin systems with antiparallel orientations which interchange their directions only slowly.

Though the general picture seems clear, it is, however, not yet possible to explain in detail the many data collected. They will be published and discussed in *Physica* and in the *Leiden Communications*.

<sup>1</sup> J. H. Van Vleck, *J. Chem. Phys.* **9**, 85 (1941).

<sup>2</sup> J. W. Stout and M. Griffel, *Phys. Rev.* **76**, 144 (1949).

<sup>3</sup> N. Poulis, *Leiden Comm.* 283a.

<sup>4</sup> N. Bloembergen, *Leiden Comm.* 280c; *Physica* **16**, 95 (1950).

<sup>5</sup> C. G. B. Garrett, *Proc. Phys. Soc. (London)* **63**, 1042 (1950), observed somewhat similar phenomena in a crystal of cobalt ammonium Tuttonsalt at still lower temperatures.

<sup>6</sup> L. Neél, *Ann. de Phys.* **X** **18**, 5 (1932); **XI** **5**, 232 (1936).

<sup>7</sup> F. Bitter, *Phys. Rev.* **54**, 97 (1938).

### On Antiferromagnetism in a Single Crystal

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HYDRATED copper chloride  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  apparently becomes antiferromagnetic at a temperature slightly above the boiling point of liquid helium. Single crystals of this substance have been investigated by three different magnetic methods at a number of liquid helium temperatures. The magnetic moment of the crystal was measured as a function of the external magnetic field. The nuclear magnetic resonance of the protons was studied at frequencies between 8 and 38 Mc/sec. And finally, electronic magnetic resonance of the copper ions was observed at a frequency of 9400 Mc/sec. In each investigation the external field was orientated in various directions in the plane perpendicular to the  $c$ -axis.

The study of the magnetic moment in small external fields revealed that, in agreement with Van Vleck's<sup>1</sup> theoretical prediction and Stout's<sup>2</sup> results on  $\text{MnF}_2$ , the susceptibility in one direction (the  $x$ -direction) vanishes gradually with decreasing temperature, while in the direction perpendicular to that (the  $y$ -direction) the susceptibility remains constant at a normal value. At the lower temperatures the  $x$ -susceptibility rises rather abruptly at a threshold field of about 7000 oersteds to a normal value, while at the higher temperatures the threshold region extends from about 7000 to about 8500 oersteds. The  $y$ -susceptibility is very little influenced by the magnitude of the field.

In the investigations on nuclear magnetic resonance the contribution of the copper ions to the average local magnetic field acting on the different protons is directly detected. In the antiferromagnetic state the dependence of this field on the temperature and on the external field has a very different character<sup>3</sup> from that observed in the paramagnetic  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  crystals<sup>4</sup> and in  $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$  at liquid hydrogen temperatures. A striking symmetry of the resonance diagram indicates that, in each orientation of the external field, to every contribution to the field at one proton there occurs an exactly opposite contribution at another proton. The threshold region is also quite marked.

When the external field is orientated in the  $x$ -direction two electronic resonance bands have been observed at 9400 Mc/sec. near the threshold region. They approach each other when the

### Beta-Decay of 7.5-Day $\text{Ag}^{111}$ to a 0.1-Microsecond Excited State of $\text{Cd}^{111}$

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IN the decay scheme of  $\text{Ag}^{111}$  proposed by Johansson<sup>1</sup> (Fig. 1) 8 percent of the disintegrations lead to a 340-kev level and one percent to a 243-kev level of  $\text{Cd}^{111}$ . Johansson postulates that

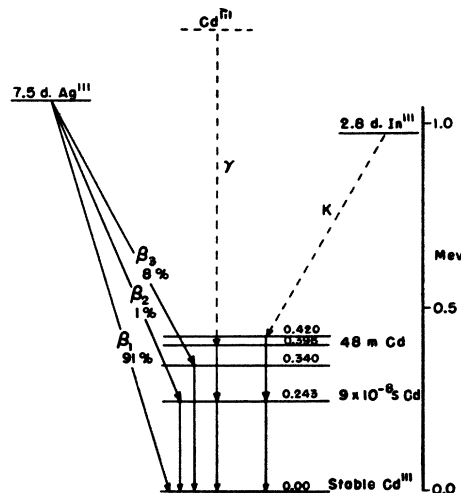


FIG. 1. Disintegration schemes of  $\text{Ag}^{111}$ ,  $\text{Cd}^{111*}$ , and  $\text{In}^{111}$ .

the 243-kev level is identical with the 0.09- $\mu\text{sec}$  level observed in the  $K$ -capture decay of  $\text{In}^{111}$  and in the 48-min isomeric transition<sup>2,3</sup> of  $\text{Cd}^{111*}$ . McGowan<sup>3</sup> did not observe the 0.09- $\mu\text{sec}$  level of  $\text{Cd}^{111}$  in the beta-decay of  $\text{Ag}^{111}$ .

Since it was felt that McGowan may have missed the 0.09- $\mu\text{sec}$  level because of its low occurrence in the beta-decay of  $\text{Ag}^{111}$ , a careful search for delayed coincidences in  $\text{Ag}^{111}$  was made at this laboratory.

Stilbene scintillation counters with 1P21 photomultipliers cooled