

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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² A. S. Nowick, *Phys. Rev.* **82**, 340 (A) (1951).

³ 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.⁵ A simple extension of the phenomenological treatment of Neél,⁶ Bitter,⁷ and Van Vleck¹ 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*.

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

³ N. Poulis, *Leiden Comm.* 283a.

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

⁵ 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.

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

⁷ 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's¹ theoretical prediction and Stout's² results on 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 character³ from that observed in the paramagnetic $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ crystals⁴ 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 Ag^{111} to a 0.1-Microsecond Excited State of Cd^{111}

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IN the decay scheme of Ag^{111} proposed by Johansson¹ (Fig. 1) 8 percent of the disintegrations lead to a 340-kev level and one percent to a 243-kev level of Cd^{111} . Johansson postulates that

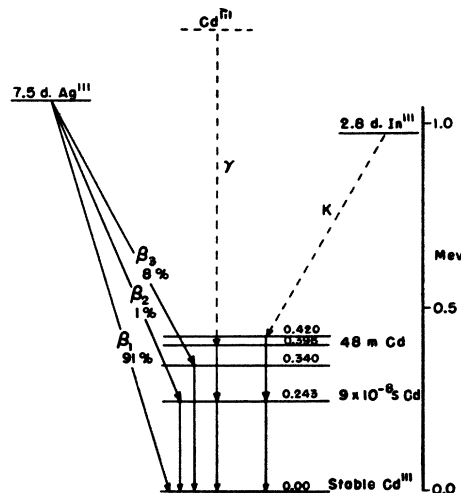


FIG. 1. Disintegration schemes of Ag^{111} , Cd^{111*} , and In^{111} .

the 243-kev level is identical with the 0.09- μ sec level observed in the K -capture decay of In^{111} and in the 48-min isomeric transition^{2,3} of Cd^{111*} . McGowan³ did not observe the 0.09- μ sec level of Cd^{111} in the beta-decay of Ag^{111} .

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

Stilbene scintillation counters with 1P21 photomultipliers cooled

with liquid nitrogen were employed to detect the radiations. The beta-crystal was so thin (*ca* 20 mg/cm²) that its efficiency for gamma-rays was negligible. The coincidence circuit employed blocking oscillator pulse shaping and a 6BN6 mixing stage. Various lengths of terminated RG 65/U cable were used to introduce the delays.

A plot of the coincidence rate *versus* delay time is shown in Fig. 2. The dotted curve is that of Co⁶⁰ and is typical of substances

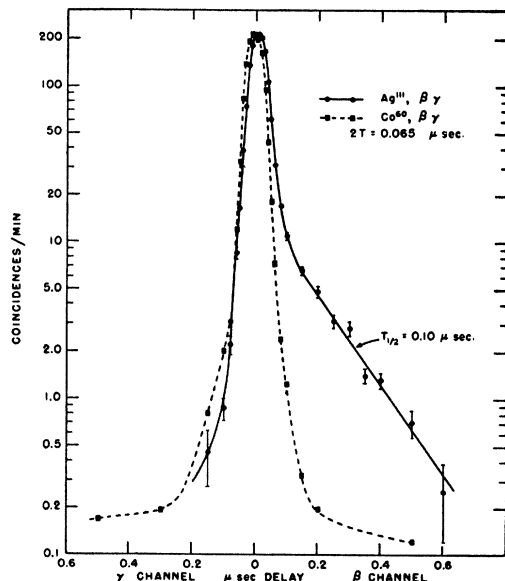


FIG. 2. Delayed coincidences in 7.5-day Ag¹¹¹.

showing no measurable gamma-delay. The solid curve is that observed with a purified source⁴ of Ag¹¹¹. The main body of the transitions shows no delay greater than 0.02 μsec. A small fraction of the transitions are delayed with a half-life of 0.10±0.02 μsec. Since nearly equal counting efficiencies for the two gammas are expected, it may be calculated that the ratio of the undelayed to delayed transitions is about 6:1. This agrees well with the ratio of 8:1 for the 340-keV to 243-keV transitions found by Johansson.

The identification of the 243-keV level in Cd¹¹¹ formed by beta-decay of Ag¹¹¹ with the 0.09-μsec level observed in the K-capture decay of In¹¹¹ and in the 48-min isomeric transition of Cd¹¹¹* thus appears to be justified.

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³ F. K. McGowan, ORNL-366, 34 (August 12, 1949) (unpublished).

⁴ Obtained through the courtesy of the Isotopes Division of the Oak Ridge National Laboratory.

The Thermal Neutron Capture Cross Section of Co⁵⁹

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A DISCREPANCY has existed in the values published for the thermal neutron capture cross section of Co⁵⁹. The activation method used by Seren, Friedlander, and Turkel¹ yielded a value of 21.7±4.3 barns. The "pile oscillator" or "danger coefficient" method gave values of 34.3±0.7 barns,² 34.2±3.4 barns,³ and 38.2±3.0 barns.⁴ This discrepancy suggested either an error in the pile activation determination or possibly a short-lived isomer of Co⁶⁰ that had not been detected.

We have determined the activation cross section of Co⁵⁹ for thermal neutrons, using the NRX heavy-water reactor. The

thermal neutron cross section of Au—93 barns—was used as a standard.³ The Au and Co were irradiated simultaneously in a position where the neutron distribution was known to be predominantly thermal. The contribution of epi-cadmium neutrons was determined by an irradiation under cadmium and small corrections were made for this (2.2 percent for Au and 0.2 percent for Co).

The Co metal (99.92 percent pure) was irradiated as a weighed disk 0.3 mm thick. A disk was cut out of a sheet of gold leaf of known weight and area, floated on water, and lifted onto an aluminum backing. The water was then evaporated, and the area of the disk, and hence its weight, was determined under a microscope.

After a measured irradiation period of about 20 hours the Co and Au samples were dissolved in *aqua regia* and made up to standard volumes. From these solutions known aliquots were withdrawn and activity measurements made several hours later. The absolute disintegration rates of these aliquots were measured by 4π proportional counting and by coincidence counting techniques. The relative values were confirmed by an end window counter.

Half-lives of 5.26 years⁵ and 2.69 days⁶ for Co⁶⁰ and Au¹⁹⁸, respectively, were used in making corrections for decay and for lack of saturation of bombardment.

The thermal neutron capture cross section for Co⁵⁹ leading to the formation of Co⁶⁰ was found to be 34.2±1.4 barns. This result is the mean of 6 activations. A large proportion of the probable error is introduced by variations in the thickness of the gold leaf used. The cross section leading to the formation of the 10.7-minute isomer is 0.66 barns,¹ and thus only about 2 percent of the thermal neutron captures lead to the short-lived isomer. Of this, less than 10 percent⁷ decays independently to Ni⁶⁰, leaving a maximum of only 0.2 percent not included in the ultimate production of 5.26 year Co⁶⁰. The cross section as measured can then be taken equal to the total absorption cross section of Co⁵⁹, with an error of less than 0.07 barns.

It will be noted that the activation cross section is now in excellent agreement with the results obtained by the "pile oscillator" method.

When this work was completed Dr. B. W. Sargent kindly drew our attention to an unpublished report by Jones, *et al.*,⁸ which gives a value of 33 barns for Co⁵⁹ obtained by the activation method. Agreement with our value is satisfactory.

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⁵ G. L. Brownell and C. J. Maletskoss, Phys. Rev. **80**, 1102 (1950).

⁶ Nuclear Data, National Bureau of Standards Circular No. 499.

⁷ Deutsch, Elliott, and Roberts, Phys. Rev. **68**, 193 (1945).

⁸ Jones, Clark, and Overman, MonC 398 (unpublished).

The Excitation Functions for B¹⁰(d, α)Be⁸

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THE excitation functions for the ground-state group and the first excited state group for B¹⁰(d, α)Be⁸ have been determined by bombarding thin targets (375 μg/cm²) of isotopically enriched boron (96 percent B¹⁰) and of normal boron with deuterons from the Bartol van de graaff generator, and observing the reaction α-particles with an argon-filled proportional counter, biased to count the α's at the end of their range, at 90° to the incident beam. The isotopic assignment of groups was first made by observing the α-particle groups from the target of 96 percent B¹⁰ (Fig. 1) and from a normal boron target (Fig. 2) bombarded with 1.20-MeV deuterons and noting the change in intensity with change in isotopic ratio. As seen in the curves, groups 1, 2, and 3 are due to the B¹⁰ reaction, and group 4 is due to B¹¹. This confirms