to prevail. If calculations are made assuming the entire interaction to be due to one nucleus alone, it is possible to place maximum values on the interactions present from the separate nuclei. This leads to values of 3 Mc and 4 Mc as the maximum possible values of the interaction constant, $|eqQ/h|$, for Cl and Cs, respectively.

* Supported in part by the ONR.
[1] H. K. Hughes, Phys. Rev. **72**, 614 (1947).
[2] J. W. Trischka, Phys. Rev. **74**, 718 (1948).
[3] E. S. Rittner, to be published.
[4] Maxwell, Hendricks, and Mosley, Phys. Rev. **52**, 968 (1937).

The Positron to γ-Ray Ratio in Zn^{65}

GEORGE M. GRIFFITHS
Department of Physics, University of British Columbia, Vancouver, Canada
(Received June 27, 1951)

IN connection with the calibration of Zn^{65} and Co^{60} sources, the following measurements were made which indicate a ratio of 1 positron to 65 ± 5 γ-rays for 250-day Zn^{65}.

Two scintillation counters were placed at equal distances from, and on opposite sides of, a small zinc source, and coincidence and single channel counting rates were obtained. The source was surrounded by aluminum foil, so that for each positron there were two annihilation quanta emitted in very nearly opposite directions. If the source produced N_+ positrons and N_γ γ-rays per unit time and the plane angles subtended by the counters at the source were large compared with the small departure from collinearity of the annihilation quanta,[1] then the positron to γ-ray ratio is approximately given by

$$N_+/N_\gamma = N_c{}^+\epsilon_1{}^\gamma/2\epsilon_1{}^+\epsilon_2{}^+(N_1{}^\gamma+N_1{}^+) = N_c{}^+\epsilon_2{}^\gamma/2\epsilon_1{}^+\epsilon_2{}^+(N_2{}^\gamma+N_2{}^+),$$

where N is a counting rate, ϵ a counter efficiency, superscripts $+$ and γ refer to annihilation radiation and nuclear γ-rays, respectively, and subscripts 1, 2, and c refer to counters 1, 2 and the coincidence counter, respectively. This approximate formula holds for the case when the ratio N_+/N_γ is small, as it is for Zn^{65}. Note that the solid angle factor does not appear. Thus, with the above-mentioned measurements, corrected for background, dead time, and accidental coincidences, we require only the counter efficiencies[2] at 0.51 and 1.11 Mev in order to calculate N_+/N_γ.

The efficiency for the Zn^{65} γ-ray (1.11 Mev) was assumed to be the same as that for the Co^{60} γ-rays (1.17 and 1.33 Mev). By means of a standard coincidence method (applicable for a source giving cascaded radiations of about the same energy) the efficiency for Co^{60} γ-rays was found to be 17 percent when the quanta traversed one inch of a clear anthracene block ($1''\times1''\times\frac{1}{2}''$) mounted on the end of an RCA 5819 photomultiplier. Within experimental errors this is equal to the efficiency as calculated using the Klein-Nishina formula. When the geometry was such that 180° backscattered quanta (0.2 Mev) from one counter could enter the second counter, the coincidence rate increased because of single quanta producing pulses in both counters. From the amount of the increase we calculated that the counter efficiencies for the 0.2-Mev backscattered quanta were about 30 percent, close to the theoretically expected value of 38 percent. The experimental value is low, owing to absorption of some of the backscattered quanta in the scattering crystal and to the smaller number of photons excited in the crystal by the low energy quanta. Since these measurements agree reasonably well with the theory, we assumed that the efficiency for the annihilation radiation was 25 percent as given by the Klein-Nishina formula.

Owing to the small departure from collinearity of annihilation quanta, the ratio N_+/N_γ increased as the counters were moved closer to the source, and angular correlation curves at the larger distances showed the characteristic tails.[1] These effects were not detectable with the counters closer than 40 cm to the source. The result of 1 positron in 65 ± 5 γ-rays is the average of 4 measurements with the counters 35 cm from the source (the ±5 includes an estimate of the error involved in the efficiency figures). This result is not in agreement with the decay scheme presented in *Nuclear Data*[3] but is in rough agreement with the results in the *Trilinear Chart of Nuclear Species*.[4] The data for Zn^{65} in the latter publication was based primarily on unpublished work of Dr. W. C. Peacock.[5] Taking his value of 50 percent K-capture to the 1.11-Mev level of Cu^{65}, one finds that 0.8 percent of the Zn^{65} disintegrations are by positron emission.

I wish to express my thanks to Dr. K. C. Mann for providing the Zn^{65} and to the Ontario Research Council for a scholarship.

[1] P. E. Argyle and J. B. Warren, Can. J. Phys. **29**, 32 (1951).
[2] Mann, Rankin, and Daykin, Phys. Rev. **76**, 1719 (1949).
[3] National Bureau of Standards, *Nuclear Data* (U. S. Government Printing Office, Washington, 1950), Circ. 499.
[4] *Trilinear Chart of Nuclear Species*, edited by W. H. Sullivan (John Wiley and Sons, Inc., New York, 1949).
[5] Private communication from W. H. Sullivan.

Paramagnetic Resonance Absorption in Three Chlorides of Copper

J. ITOH, M. FUJIMOTO, AND H. IBAMOTO
Faculty of Science and Institute of Scientific and Industrial Research, Osaka University, Osaka, Japan
(Received June 4, 1951)

WE have measured the microwave paramagnetic resonance absorption in single crystals[1] of $CuCl_2\cdot2H_2O$, $K_2CuCl_4\cdot2H_2O$, and $(NH_4)_2CuCl_4\cdot2H_2O$ at 3100 Mc/sec and at

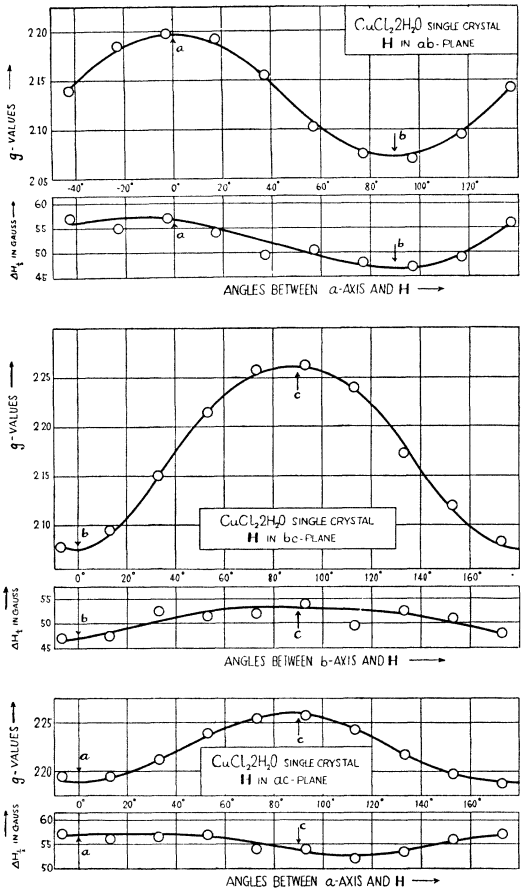

FIG. 1. Variation of g-values and half-widths ($\Delta H_{\frac{1}{2}}$) with angle between the static field **H** and the crystal axis in $CuCl_4\cdot2H_2O$, at 3100 Mc/sec. The figures indicate these angular dependences for the cases in which **H** rotates about the c axis, the a axis, and the l axis, respectively.

room temperature. Also, we calculated g-values for these crystals and compared them with the experimental results.

The measurements were made by the usual standing wave method. The crystal structure of $CuCl_2 \cdot 2H_2O$ is orthorhombic, while the other two are tetragonal. The unit cell of these crystals contains two molecules. In the case of copper chloride, one of the molecules is derived from the other by a translation from the point $(0, 0, 0)$ to $(\frac{1}{2}, \frac{1}{2}, 0)$ followed by a reflection in the $b-c$ plane. In the case of potassium and ammonium salts, one is derived from the other by a translation from the point $(0, 0, 0)$ to $(\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$ followed by a reflection in the $(1, 0, 0)$ plane. Therefore, one may generally expect two resonance peaks. Actually, however, we obtained only one resonance maximum for all directions of the static magnetic field, which means that exchange coupling between copper ions is sufficiently strong that one resonance maximum occurs at the arithmetical mean of the two expected resonance fields.

Angular dependences of g-values and half-width values obtained experimentally for copper chloride and for the potassium salt are

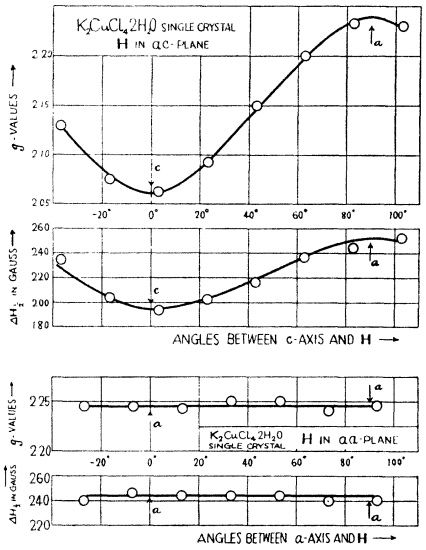

FIG. 2. Variation of g-values and half-widths ($\Delta H_{\frac{1}{2}}$) with angle between the static field **H** and the crystal axis in $K_2CuCl_4 \cdot 2H_2O$, at 3100 Mc/sec. Figures indicate these angular dependences for the cases in which **H** rotates about the a axis and the c axis, respectively.

shown in Fig. 1 and Fig. 2. Those for the ammonium salt are almost the same as those for the potassium salt.

Since in these crystals the crystalline electric field at the position of the copper ion is of rhombic symmetry, we extended the calculation of Polder,[2] who treated the case of a tetragonal field, to the case of a rhombic field. Also, we have calculated self-consistent values for the induced moments of water molecules and chlorine ions; and then the expansion coefficients of the crystalline field at the position of copper ions were computed up to the fourth-order terms. Here, we assumed each ion or each water molecule to be a point charge and/or a point dipole at the position predicted by the x-ray analysis of Harker[3] and Chrobak.[4] The g-values thus calculated, and also the experimental g-values, are shown in Table I. As mentioned above, by the effect of exchange coupling, only the value $\frac{1}{2}(g_a+g_b)$ can be obtained experimentally for the potassium and ammonium salts; these values are shown also in the table. The agreement is satisfactory for all of these salts.

TABLE I. Calculated and experimental g-values.

	$CuCl_2 \cdot 2H_2O$		$K_2CuCl_4 \cdot 2H_2O$		$(NH_4)_2CuCl_4 \cdot 2H_2O$	
	Exp.	Calc.	Exp.	Calc.	Exp.	Calc.
g_a*	2.195	2.248		2.290		2.122
$(g_a+g_b)/2$			2.24	2.28	2.25	2.23
g_b*	2.075	2.052		2.278		2.336
g_c	2.26	2.278	2.06	2.04	2.05	2.01

* g_a and g_b for the potassium and ammonium salts mean the g-values for the molecule at (0, 0, 0) in the direction (1, 1, 0) and (1, 1, 0), respectively.

The shapes of the absorption curves are not gaussian, but lie between gaussian and Lorentz-type absorption curves. Those for the potassium and ammonium salts almost coincide with the latter. Therefore, the experimental half-width $\Delta H_{\frac{1}{2}}$ may not be compared directly with the theoretical value of $(\langle \Delta H^2 \rangle_{Av})^{\frac{1}{2}}$ calculated by Van Vleck's formula.[5] $\Delta H_{\frac{1}{2}}$ is much smaller than 2.36 $(\langle \Delta H^2 \rangle_{Av})^{\frac{1}{2}}$, which corresponds to the theoretical half-width in the case of a gaussian-type absorption curve. Moreover, the angular dependance of $(\langle \Delta H^2 \rangle_{Av})^{\frac{1}{2}}$ is not similar to the experimental results. The width for copper chloride is still narrower than that for copper sulfate pentahydrate, suggesting still stronger exchange coupling.

The details of the experiment and the calculations will be published elsewhere.

[1] These single crystals were made available by the courtesy of Dr. R. Kiriyama of the Department of Chemistry, to whom we express our gratitude.
[2] D. Polder, Physica **9**, 709 (1942).
[3] D. Harker, Z. Krist. **93**, 136 (1936).
[4] L. Chrobak, Z. Krist. **88**, 35 (1934).
[5] J. H. Van Vleck, Phys. Rev. **74**, 1168 (1948).

Production of Neutral Mesons by γ-Rays Incident on Hydrogen*

A. SILVERMAN AND M. STEARNS
Cornell University, Ithaca, New York
(Received July 5, 1951)

THE reaction $\gamma+H^1 \rightarrow \pi^0+H^1$ has been investigated by bombarding thin polyethylene and carbon targets with bremsstrahlung radiation from the 310-Mev Cornell synchrotron. The experimental arrangement is shown schematically in Fig. 1.

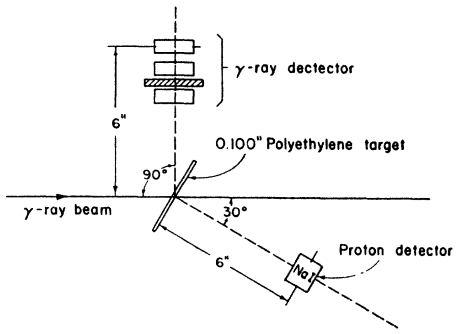

FIG. 1. Experimental arrangement (schematic).

The reaction is observed by detecting coincidences between the recoil proton and one of the decay γ-rays from the neutral meson. The energy and angle of the recoil proton are measured, and these two quantities, combined with the conservation equations, uniquely determine the energy of the incident γ-ray and the energy and angle of the neutral meson. In this manner it is possible to get the cross section for the production of neutral mesons as a function of γ-ray energy despite the continuous spectrum of the incident radiation. The technique of detecting the two decay γ-rays used by Steinberger, Panofsky, and Steller[1] does not give the meson energy directly, since a measurement of the angle between the two γ-rays does not uniquely determine the meson energy.