Evidence of a Mixed $E1+M2$ Transition and the Angular Momenta of the Sr^{88} Levels*

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IN their pioneer work on directional correlation of successively emitted gamma-radiation, Brady and Deutsch[1] suggested as an interpretation of their measurements on the Sr^{88} gamma-gamma correlation a mixed dipole-quadrupole transition from an excited state of $I=2$ to an intermediate state of $I=1$, followed by a dipole transition to the zero-spin ground state of the Sr^{88} nucleus.

Recently reported internal conversion data[2] of the Sr^{88} gamma-rays indicate that these directional correlation data can be interpreted only if an $E1$ and $M2$ mixture is assumed.[2] Moreover, Sr^{88} would be the only even-even nucleus not having spin 2 and even parity in the first excited state (Goldhaber and Sunyar rule[3]). In view of these unusual facts it was decided to reinvestigate the Sr^{88} directional correlation.

The source used was the 105-day Y^{88} obtained by deuteron bombardment of $Sr(NO_3)_2$ in the Washington University cyclotron.[4] After a careful chemical separation the Y^{88} was used in the form of a dilute aqueous YCl_3 solution and as solid YCl_3. Both sources gave the same results.

The directional correlation of the Sr^{88} gamma-rays was measured by using four different arrangements, A, B, C, D, requiring different corrections for the finite angular resolution of the instruments. In arrangements A and B (Fig. 1) the NaI crystals used as detectors were shielded by lead in such a way that the exposed part of the crystals had almost uniform local quantum efficiency $\epsilon(\vartheta)$. In arrangements C and D, in which the whole area of the NaI crystals was used for detection, $\epsilon(\vartheta)$ varied considerably over the crystal. For A and C scattered radiation was eliminated from detection by 1.0-cm Pb absorbers in front of the crystals, for B and D by pulse-height discrimination, allowing only radiation of energies larger than 0.6 Mev to be detected.

The experimental directional correlation data (Fig. 2) were fitted by least squares to an expansion in Legendre polynomials:

$$W'(\theta)=A_0'+A_2'P_2(\cos\theta)+A_4'P_4(\cos\theta).$$

The true directional correlation coefficients A_i were then obtained

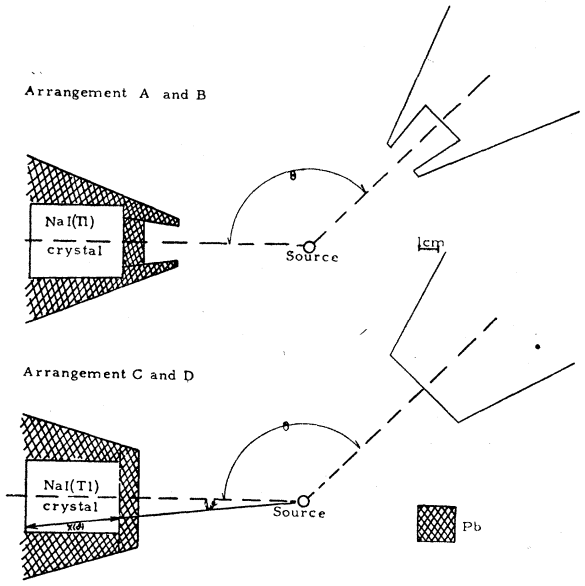

FIG. 1. Detector arrangements of the instruments for measuring gamma-gamma directional correlation.

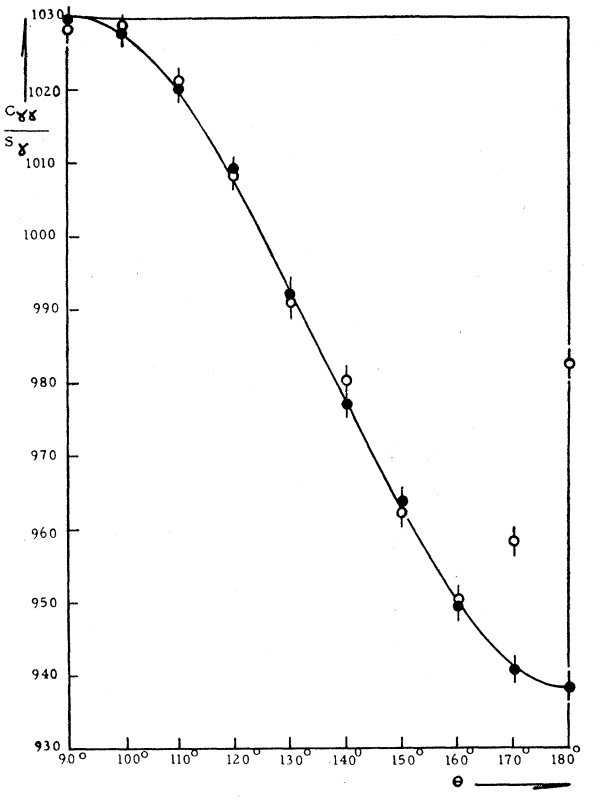

FIG. 2. Directional correlation of the Sr^{88} gamma-rays. Open circles represent measurements with arrangement C (effect of positrons observable at $\theta=170°$ and $\theta=180°$). Full circles represent measurements with arrangement D (pulse-height discrimination).

by applying the following correction for the finite angular resolution of the instruments:[5]

$$A_i'=A_i\left[\int_0^{\vartheta_{\max}}\epsilon(\vartheta)P_i(\cos\vartheta)\sin\vartheta d\vartheta\right]^2;\quad i=0,2,4,$$

where $\epsilon(\vartheta)$ is the (local) quantum efficiency of the detectors. The generally used approximation for this efficiency,[5]

$$\epsilon(\vartheta)=1-\exp[-\mu x(\vartheta)],$$

seems to be unreliable, since it was recently found by Lawson and Frauenfelder[6] that $\epsilon(\vartheta)$ varies considerably with the energy discrimination level and the NaI crystal used. Therefore, $\epsilon(\vartheta)$ was determined experimentally for all four arrangements by using a well-collimated Co^{60} gamma-ray beam whose mean energy (1.25 Mev) is not too far from the mean energy of the Sr^{88} gamma-rays (1.39 Mev).

The results are summarized in Table I. The errors given for the experimental data are the statistical errors only. To account for the limitations of the geometrical corrections applied, the errors indicated for the corrected data are slightly larger.

TABLE I. Directional correlation coefficients for the Sr^{88} gamma-cascade.

Detectors	Experimental data A_2'	$(A_0'=1)$ A_4'	Corrected data A_2	$(A_0=1)$ A_4
A	-0.0665 ± 0.0042	-0.003 ± 0.005	-0.0680 ± 0.005	-0.003 ± 0.006
B	-0.0603 ± 0.0051	-0.001 ± 0.004	-0.0617 ± 0.006	$+0.001\pm0.005$
C	-0.0635 ± 0.0033	-0.002 ± 0.004	-0.0660 ± 0.004	-0.002 ± 0.005
D	-0.0622 ± 0.0034	-0.001 ± 0.004	-0.0641 ± 0.004	-0.001 ± 0.005
Weighted mean values:			$-0.065\ \pm0.003$	-0.002 ± 0.003

These directional correlation coefficients,[7,8] together with the conversion data and the cross-over intensity, suggest an angular momentum assignment of 3, 2, and 0 to the states of the Sr^{88} nucleus (Fig. 3) and characterize the first (3→2) transition as an

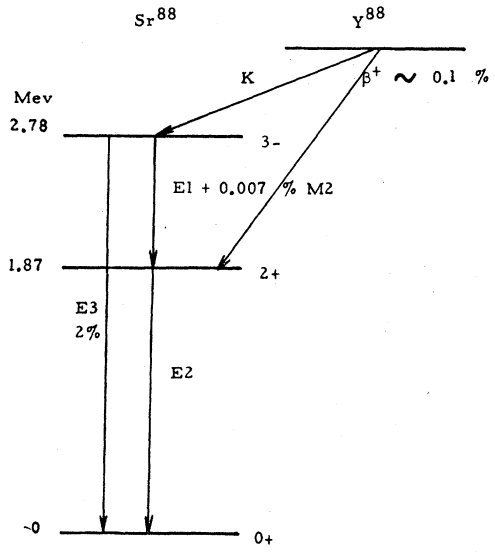

FIG. 3. Spin and parity assignments to the levels of Sr^{88}.

electric dipole transition with 0.015 percent to 0.002 percent magnetic quadrupole admixture, the two radiations being in phase. The second (2→0) transition is by pure electric quadrupole radiation. These results are in good agreement with the internal conversion data and also remove the last exception to the Goldhaber-Sunyar rule.

From an accurate determination of the magnetic quadrupole admixture information can be obtained about the reduction of the electric dipole matrix element. In view of the importance of this particular mixing ratio, extensive studies are in progress to determine the Sr^{88} gamma-gamma angular correlation with even higher precision.

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[4] The bombardment was obtained from the Isotopes Division of the U. S. Atomic Energy Commission.
[5] M. E. Rose (to be published).
[6] J. S. Lawson and H. Frauenfelder (to be published).
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[8] D. S. Ling and D. L. Falkoff, Phys. Rev. **76**, 1639 (1949).

Effect of the Electric Quadrupole Interaction on the Gamma-Gamma Directional Correlation in Cd^{111}

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ACCORDING to Goertzel[1] and Alder[2,3] the angular correlation of successive nuclear radiation can be disturbed by extranuclear fields. In the case of the Cd^{111} γ-γ cascade, such a disturbing effect has been established by Aeppli *et al.*[4,5] The dependence of the anisotropy $A=[W(180°)-W(90°)]/W(90°)$ on an externally applied magnetic field allowed the determination of the magnetic moment of the first excited state of this nucleus. Furthermore the anisotropy was found to depend strongly on the source

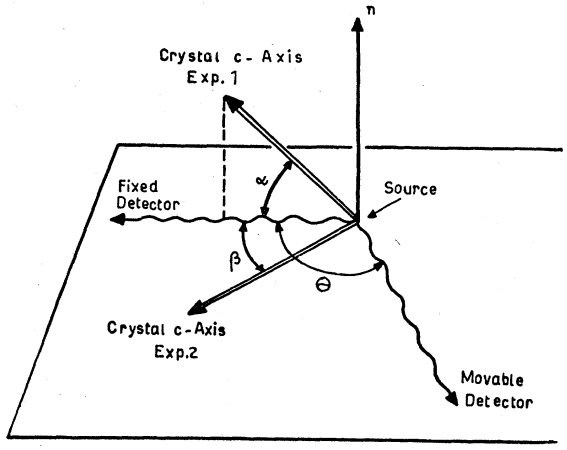

FIG. 1. Diagram of the c axis orientation of the In single crystal with respect to the detector directions.

material, metallic sources showing values for A varying from -5 percent up to the maximum value of -20 percent whereas ionic crystal sources show nearly isotropic correlations.

The question arose as to whether the source effects are due to the magnetic field of the electron shell (magnetic interaction) or to an inhomogeneous electric crystalline field (quadrupole interaction). Frauenfelder[6] has discussed the first possibility. The difference between metallic and ionic crystal sources would be explained on the assumption that after the K capture the electron shell remains excited during a time comparable with the lifetimes of the excited nuclear states in the case of the ionic crystals, whereas in the case of metallic sources the excited states would decay more rapidly. A series of experiments have been made to test this and further the possibility of the presence of an electric quadrupole interaction.

If the interaction were magnetic in origin a "magnetic decoupling experiment" should be possible. If the attenuation of the anisotropy is the result of the coupling between the angular momenta I of the nucleus and J of the shell, then it is possible to obtain the "true" correlation by applying an external magnetic field H in the direction defined by the source and one of the two detectors. The coupling between I and J will be broken if the

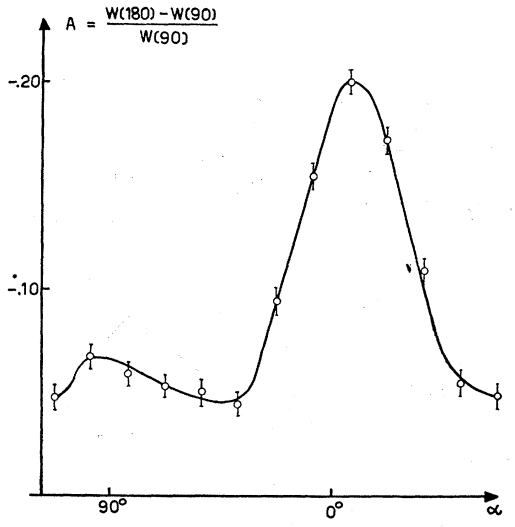

FIG. 2. Anisotropy *vs* angle α of the c axis with respect to the direction of the fixed detector (experiment 1).