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

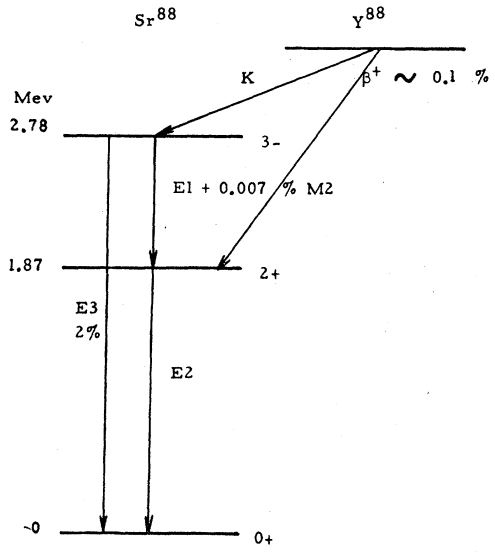

FIG. 3. Spin and parity assignments to the levels of Sr^{88}.

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.

* Supported in part by the U. S. Atomic Energy Commission.
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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

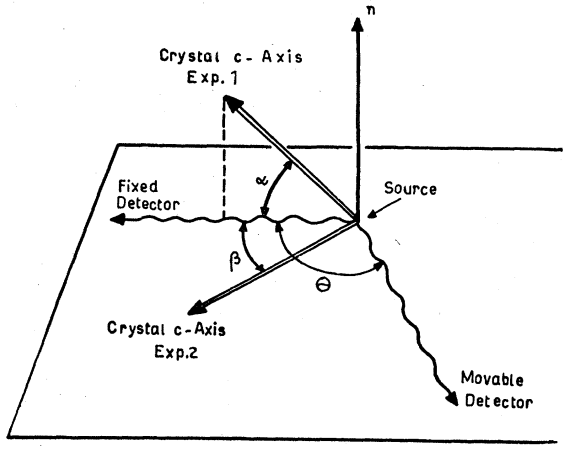

FIG. 1. Diagram of the c axis orientation of the In single crystal with respect to the detector directions.

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

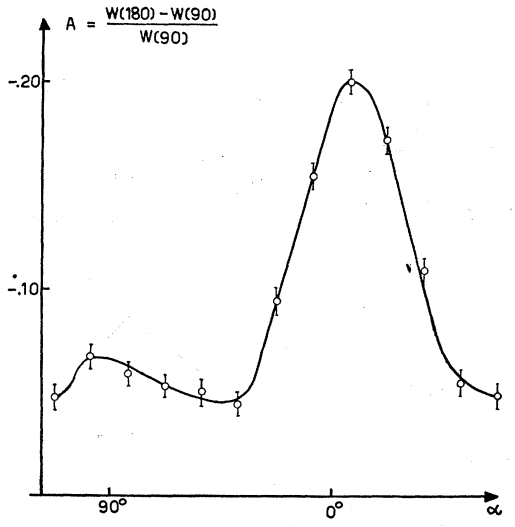

FIG. 2. Anisotropy *vs* angle α of the c axis with respect to the direction of the fixed detector (experiment 1).

strength of the field fulfills the condition that the Zeemann splitting of the atomic levels be large compared with the hyperfine splitting of the intermediate nuclear state.

In the case of Cd^{111}, calculation of the hfs from disturbed angular correlation and the known half-life of the intermediate state indicates that a field of 20 000 gauss should be sufficient to restore the undisturbed correlation. In our experimental arrangement we used a magnet with bored polefaces with which we could apply a very homogeneous field up to 20 000 gauss to the source placed in the center of the magnet gap. The detectors consisted of NaI(Tl) crystals[7] and 1P21 photomultipliers and were placed in front of the bored holes. For every source we measured the ratio $\delta = W(180°, H)/W(180°, 0)$ and in addition the anisotropy A without magnetic field (in an arrangement without magnet). Then the anisotropy B with magnetic field may be easily calculated from A and δ.

Two different groups of sources were used. One group consists of the so called "double stream" sources prepared by simultaneous evaporation of the active In^{111} atoms and the embedding material. The other group consists of chemically prepared indium compounds in solutions and in crystalline form. All the decoupling experiments with about 20 different sources gave no appreciable effect although in some cases the anisotropy was increased by a few percent. From these results we draw the conclusion that the large attenuation of the angular correlation observed in most of the sources cannot be explained with the magnetic interaction.

An analogous "electric decoupling experiment" would decide if the interaction is electric or not, but this experiment cannot be carried out because it is not possible to produce an artifical inhomogeneous electric field of sufficient strength. One can, however, make use of the high electric fields in crystals with lower symmetry than cubic. If one uses single crystals with axial symmetry one expects a dependence of the correlation function on the orientation of this axis respective to the detectors.

For this experiment we prepared metallic indium single crystals (tetragonal face centered) containing active In^{111}. The single crystals were examined by x-ray methods. The ratio of the coincidence rates in the 90° and 180° positions was measured for different orientations of the c axis (Fig. 1). Figure 2 shows the result when the c axis lies in the plane defined by the direction of the fixed counter and the normal to the plane of the two counters as a function of the angle α between the c axis and the fixed counter (experiment 1). Figure 3 shows the result when the c axis lies in the plane of the two counters as a function of the angle β between the c axis and the fixed counter (experiment 2). A phase shift in the correlation depending on α and β has also been observed.

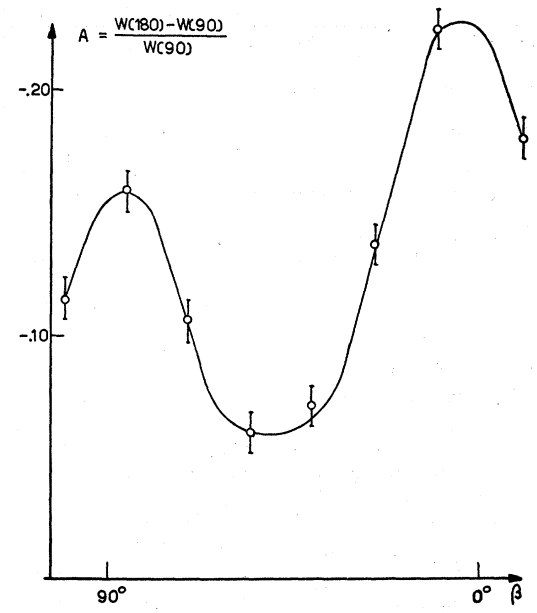

FIG. 3. Anisotropy *vs* angle β of the c axis with respect to the direction of the fixed detector (experiment 2).

We conclude from these experiments that the attenuation in this type of source is due to quadrupole interaction, with very little doubt. Further experiments are in progress, and it will be possible to obtain the quadrupole moment of the first excited state of Cd^{111} by comparing the experimental result with formulas derived by Alder,[8] if one makes reasonable assumptions for the value of grad$E$ in the crystal. In addition, we intend to make more detailed investigations of observed attenuations from the new viewpoint of the quadrupole interaction.

We thank K. Alder for the very helpful discussion of theory, Dr. W. Känzig and R. Kern for their aid with the x-ray investigations and the growth of the single crystals, the cyclotron group for the many irradiations and O. Braun for assistance during the measurements.

* National Science Foundation postdoctoral fellow, on leave from Argonne National Laboratory.

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Angular Distribution of Deuterons from $Be^9(p,d)Be^8$

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(Received March 2, 1953)

THE angular distribution of deuterons from the reaction $Be^9(p,d)Be^8$ (ground state) was measured using the internal, circulating 22-Mev proton beam of the Oak Ridge National Laboratory 86-inch cyclotron. The target assembly, which is described in detail elsewhere,[1] consists essentially of a thin beryllium target at the center of a $3\frac{1}{2}$-in. radius semicircular detector holder. The deuterons are detected both by the 3.3-hour activity they induce in lead by the reaction $Pb^{208}(d,p)Pb^{209}$ and by the 15-hour activity they induce in sodium by the reaction $Na^{23}(d,p)Na^{24}$. Both of these activities can also result from (n,γ) reactions, so that it is necessary to correct for the neutron activity by bombarding additional detectors under a thick absorber. The lead foils are processed chemically after bombardment to remove the proton-induced activities, and counted under end-window Geiger counters. The sodium detectors are made from sodium fluoride with a small amount of sodium silicate as a binder. About 36 hours after the bombardment they are counted with a scintillation spectrometer set on the 2.76-Mev photoelectric peak. Chemical checks have confirmed that the activity is due to sodium, but routine chemical processing was proved unnecessary.

All parts of the target assembly which are exposed to the cyclotron beam are covered with carbon since the (p,d) reaction in C^{12} has a very high threshold. Deuteron background, as determined by running with the beryllium target removed from the target assembly, was undetectable. The beam is stopped several inches past the target by a large slab made of carbon to minimize neutron background [the (p,n) threshold is very high for C^{12}].

In order to obtain energy discrimination and to correct for the variation of energy with angle due to center-of-mass motion, the detectors are covered by a stepped absorber which is adjusted to equalize the energy of the longest range group to below the detection threshold. The excitation function for the $Na^{23}(d,p)$