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Indications of the Interaction of Electric Field Gradients and Nuclear Electric Quadrupole Moments in Angular Correlation*

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THE influence of extranuclear fields on the angular correlation of successive nuclear radiation has been discussed by several authors.[1] It was generally assumed that the interaction between the nuclear magnetic dipole moment and magnetic fields, due to either the electron shell or the surrounding of the decaying atom, is mainly responsible for the reduction of the angular correlation. The dependence of this reduction on the source material was attributed to the difference in recovery time of the excited and ionized electron shell.

However, several directional correlations were reported recently, where the reduction of the anisotropy of the correlation could not be understood on the basis of the magnetic interaction alone, e.g., α-γ correlation of $RdTh^{228}$,[2] γ-γ correlation of Cd^{111},[3] and of Ta^{181}.[4] Abragam and Pound[5] were able to show that the coupling between the nuclear electric quadrupole moment in the intermediate state and the grad$E$ in axial crystals provides an explanation for the observed α-γ correlation of $RdTh^{228}$. It is well known that the Cd^{111} γ-directional correlation depends strongly on the chemical state[3,6] and on the environment[1] of the decaying In^{111} atom. This was explained hitherto by magnetic interaction. However, magnetic decoupling experiments with a magnetic field of 7000 gauss applied in the direction of the propagation of one γ-ray showed no tendency to restore the maximum directional correlation (Table I). This field is probably too small for a complete decoupling of I and J (complete Paschen-Back effect of the hyperfine structure or Back-Goudsmit effect), but nevertheless it is large enough to cause a partial breaking of the (I, J) coupling (incomplete Back-Goudsmit effect). An increase in the anisotropy much larger than the experimental error of the measurements should have been observed if the magnetic coupling were the predominant cause for the attenuation of the correlation in the sources investigated. Similar results with even higher fields have been obtained by Heer *et al.*[7] This result seems to indicate that the attenuation of the Cd^{111} correlation in solid sources is due to the interaction between the crystalline grad$E$ field and the electric quadrupole moment of the 0.247-Mev excited state of Cd^{111}, for which a rather large value of the quadrupole moment is expected from shell model considerations.

The largest anisotropy found for nonmetallic solids is exhibited by In_2O_3 and $In(OH)_3$. Both are cubic crystals with relatively small values of grad$E$ at the position of the In, due to the high symmetry of their space groups: T_h^7 and T_h^5, respectively. As a result of the preceding decay, however, these atoms may be displaced from the original lattice point and may be in regions of larger grad$E$ values during a time comparable with the lifetime of the intermediate state.

TABLE I. Directional correlation of Cd^{111} with different sources and with application of a magnetic decoupling field.

Source	B gauss	Anisotropy: $A=\frac{W(\pi)}{W(\pi/2)}-1$
Solid sources:		
$InCl_3$, dry (20°C)	···	-0.012 ± 0.005
$InCl_3$, dry (20°C)	7000	-0.015 ± 0.005
$InCl_3$, dry (540°C)	···	-0.022 ± 0.006
InI_3, dry (20°C)	···	-0.020 ± 0.006
InI_3, dry (20°C)	7000	-0.019 ± 0.006
InI_3, dry (200°C)	···	-0.021 ± 0.006
$In(C_9H_6OH)_3$	···	-0.020 ± 0.006
In_2O_3	···	-0.045 ± 0.004
$In(OH)_3$, dry	···	-0.035 ± 0.006
$In(OH)_3$, dry	7000	-0.036 ± 0.007
In metal, electrodeposited (20°C)	···	-0.051 ± 0.005
In metal, electrodeposited (150°C)	···	-0.048 ± 0.006
In metal, electrodeposited (20°C)	7000	-0.056 ± 0.007
Liquid sources:		
$InCl_3$, aqueous solution	···	-0.221 ± 0.005
$InCl_3$, aqueous solution $+10^{21}$ Fe^{+++} ions/cc	···	-0.215 ± 0.006
InI_3, liquid salt (220°C)	···	$-0.19\ \pm0.02$
$In(C_9H_6ON)_3$ in $CHCl_3$ dissolved	···	$-0.20\ \pm0.01$
In, liquid metal (180°C)	···	$-0.20\ \pm0.01$

A further indication that the attenuation of the Cd^{111} correlation in the solid sources is caused by crystalline grad$E$ fields stems from the fact that, without exception, liquid In^{111} sources of very different character give the maximum correlation (Table I). In the liquids used the character of the local configuration around a nucleus and thus the gradient of the electric field changes in a time much smaller than the lifetime of the intermediate nuclear state. Consequently the average perturbation on the nuclear m substates due to the quadrupole interaction is zero over the lifetime of the nuclear state.

During the progress of this work a convincing proof for the electric quadrupole interaction on the Cd^{111} correlation has been given by the beautiful experiments of the Swiss group[7] by using single crystals of indium as sources.

Attenuation effects very similar to those exhibited by the Cd^{111} correlation have recently been measured by McGowan[4] on the Ta^{181} γ-cascade. Liquid sources of Hf^{181} also show a much more pronounced anisotropy than solid sources.[4] Moreover, there is evidence that the $P_4(\cos\theta)$ term in the angular correlation function is less attenuated than is the $P_2(\cos\theta)$ term, a result which is impossible with magnetic interaction alone.[8] Both effects, however, are explained easily if electric quadrupole interaction in the intermediate state of Ta^{181} is assumed. For this nucleus a very large electric quadrupole moment in the lower excited states is to be expected from shell model considerations, the ground state of Ta^{181} having one of the largest quadrupole moments known.

A more detailed account of this investigation will be submitted for publication in the near future.

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Search for 1-Mev Gamma from N^{16} Decay*

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IN the β-decay of N^{16} to the 1^- (7.1-Mev) and 3^- (6.1-Mev) excited states of O^{16}, respectively, a discrepancy exists between the branching ratio of about 1:1 determined from absorption measurements on the β-spectrum,[1] and the ratio of