

atom is, for a time comparable with the lifetime of the intermediate nuclear level, in a state with an appreciable magnetic moment. This occurs for the elements of Table I, if the atom is suitably excited (e.g., Cd  $^1P_1$ ,  $^3P_1$ ) or suitably ionized (e.g., Cd $^+$ , Cd $^{++}$ ). Therefore, it should be possible to reduce the angular correlation by exciting or ionizing the decaying atom and preventing it for a sufficiently long time from being de-excited or neutralized. Most of the nuclear events are accompanied by processes which may lead to excitation or ionization (e.g., beta-decay or  $K$ -capture with subsequent rearrangement of the shell,<sup>5</sup> internal conversion, Auger effect after  $K$ -capture or internal conversion, recoil after the decay).

We consider first the case of excitation. If the decaying atom is embedded in a metal, the transition from the excited to the ground state is very fast<sup>6</sup> compared with the lifetime of the intermediate nuclear level, and we may assume that the measured correlation is "true." But if the atom forms a lattice defect in an ionic crystal or a semiconductor, the lifetime of the excited state may be so long that its associated magnetic moment may partially destroy the angular correlation.

A similar consideration may be valid for ionized atoms. The free electrons of a metal neutralize the ion in a very short time. In an insulator, however, the time for the neutralization may be long compared with the half-life of the nuclear level.

Thus, there may be a possibility of observing an influence of the atomic shell by comparing the angular correlation of metal sources with that of ionic crystal sources.

Usually, angular correlation is measured with the radioactive element in a chemical compound. This is not very suitable for the investigation of the mentioned effects, because it is very difficult to avoid contaminations. Furthermore, it is not possible to vary the type of binding and the nature of the surroundings to a very large extent.

An excellent method for varying the environment of the atom is through the use of evaporated "double stream" sources.<sup>7,8</sup> The substance of the second vapor stream may be varied for different sources from metal to ionic and molecular crystal. Such evaporated sources would give perhaps the best approximation to the ideal arrangement of isolated atoms or ions in a homogeneous medium.

A second proposal for embedding the source in a suitable medium might be the thermal diffusion of the radioactive isotope into the medium.

Experiments of this type should also give insight into the mechanism of the rearrangement after the decay.

<sup>1</sup> G. Goertzel, *Phys. Rev.* **70**, 897 (1946).

<sup>2</sup> E. L. Brady and M. Deutch, *Phys. Rev.* **78**, 558 (1950).

<sup>3</sup> Sunyar, Alburger, Friedlander, Goldhaber, and Scharf-Goldhaber, *Phys. Rev.* **79**, 181 (1950).

<sup>4</sup> D. M. Roberts and R. M. Steffen, *Phys. Rev.* **82**, June 1 (1951).

<sup>5</sup> E. P. Cooper, *Phys. Rev.* **61**, 1 (1942).

<sup>6</sup> F. Seitz, *The Modern Theory of Solids* (1940), Chapter XVII.

<sup>7</sup> Frauenfelder, Walter, and Zünti, *Phys. Rev.* **77**, 557 (1950).

<sup>8</sup> H. Frauenfelder, *Helv. Phys. Acta* **23**, 347 (1950).

### Influence of the Atomic Shell on Nuclear Angular Correlation in Cd<sup>111</sup>

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THE previous letter<sup>1</sup> discusses possibilities of influencing the angular correlation of successive nuclear radiations. We have succeeded in establishing a definite effect upon the angular correlation of the  $\gamma$ -rays in Cd<sup>111</sup>. Cd<sup>111</sup> results from the  $K$ -capture of In<sup>111</sup>, and seemed especially promising because of the long lifetime of the intermediate state and the properties of the electron shell.<sup>1</sup>

The resolving time of the coincidence circuit† (2.2×10<sup>-7</sup> sec) was so great that practically all transitions were measured regardless of the lifetime of the intermediate level. Both crystals were shielded with lead against scattered quanta.

The sources were prepared with a "double stream" method.<sup>2</sup> The cadmium, containing the radioactive In<sup>111</sup> (from bombardment by 7-Mev protons), was placed in a carbon crucible. By slowly heating the crucible in a vacuum, all cadmium was evaporated away, most of the radioactive indium remaining in the crucible. Finally, the crucible was heated to 900°C for 1 minute and the (carrier-free) indium, accompanied by an intense vapor stream from a second crucible, was evaporated onto a thin aluminum foil. As a result of this procedure In<sup>111</sup> was embedded free from contaminations within a suitable medium. After the evaporation the foil was rolled and placed in a small tube with very thin walls, so that the scattering of the  $\gamma$ -rays in the whole source was negligible. Four to six different sources were prepared in this way from each cyclotron irradiation.

The anisotropy was determined by measuring the coincidence rate at 90° and 180° alternately. The different sources were frequently interchanged. The different measurements were always consistent statistically. All results were corrected for the finite angular resolution.

The results for Cd<sup>111</sup> are summarized in Table I. These values provide two important conclusions:

1. We have to assume that the value for "thick" metal sources (>10<sup>3</sup>Å) is the best approximation to the true angular correlation for the atom in the ground state. Therefore our new value,  $A = -0.16 \pm 0.01$ , is considerably higher than the hitherto reported values<sup>3,4</sup>  $A = -0.07 \pm 0.04$  and  $A = -0.06 \pm 0.02$ .

It seems possible that the values found for the anisotropy in several other cases (e.g., Sr<sup>88</sup>, Pd<sup>108</sup>, Te<sup>124</sup>) may similarly be in error and should be remeasured with a metallic embedding medium. In addition, several  $\beta$ - $\gamma$ -correlations (e.g., Cd<sup>115</sup>), which until now have shown an isotropic distribution, may become

TABLE I. Angular correlation of Cd<sup>111</sup> in different media.

Embedding medium	Approx. thickness in Å	$A = \frac{K(180^\circ)}{K(90^\circ)} - 1$ , in %	Mean statistical error, in %
LiF	10 <sup>3</sup>	+1.6	±2.6
AgCl	5×10 <sup>4</sup>	+0.9	±1.4
SiO 1	10 <sup>3</sup>	-1.1	±1.9
SiO 2	5×10 <sup>4</sup>	+0.3	±2.0
Se (red) <sup>a</sup>	10 <sup>3</sup>	-5.8	±2.2
Au 1	<10 <sup>3</sup>	-5.8	±2.2
Au 2	<10 <sup>3</sup>	-6.5	±1.7
Ag 1	<10 <sup>3</sup>	-5.0	±2.1
Ag 2	<10 <sup>3</sup>	-10.6	±1.9
Ag 3	<10 <sup>3</sup>	-17.6	±1.3
Ag 4	3×10 <sup>3</sup>	-16.8	±2.1
Ag 5	5×10 <sup>3</sup>	-15.7	±2.3
Ag 6	10 <sup>4</sup>	-15.6	±1.7
Ag 7	10 <sup>4</sup>	-17.0	±1.4
Ag 8	2×10 <sup>4</sup>	-14.0	±1.2
Chemical compound In(OH) <sub>3</sub> , 4 different sources		-3.0 to -7.5	±2.0

\* P. K. Weimer, *Phys. Rev.* **79**, 171 (1950).

anisotropic when the source is embedded in a suitable medium. The wide discrepancy in the measured anisotropy of Rb<sup>86</sup> may also be due to the way in which the source was prepared.

2. A variation of the correlation with the thickness of the metal film is obvious from Table I. This is not surprising, because very thin metal films show strong anomalies in their electric and magnetic behavior. One is therefore required to use relatively thick metal sources in order to obtain the "true" angular correlation. In measurements involving low energy electrons, the scattering in the source will thus necessarily be large.

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<sup>1</sup> H. Frauenfelder, *Phys. Rev.* **82**, 549 (1951).

† Each anthracene crystal was viewed by two multipliers in coincidence, in order to reduce the background. We are indebted to Mr. F. Humbel for the design and construction of the electronic equipment.

<sup>2</sup> H. Frauenfelder, *Helv. Phys. Acta* **23**, 347 (1950).

<sup>3</sup> F. Boehm and M. Walter, *Helv. Phys. Acta* **22**, 378 (1949).

<sup>4</sup> D. M. Roberts and R. M. Steffen, *Phys. Rev.* **82**, 332 (1951).