analysis gives $\nu = 2.9 \pm 0.6$ with the uncertainty arising mainly from the loss correction. The wide dispersion in the present set of total radiation widths is in marked contrast with the almost constant values which have been found in neutron studies of the heavy nuclei.[5] According to the Porter-Thomas theory[4] these almost constant values are a consequence of the large number ($\sim 100$) of partial radiation widths. In the present case the derived value of $\nu$ indicates that if the theory is correct, about three partial widths on the average make up the bulk of the total radiation width. For these radioactive measurements the total radiation width includes only those gamma-ray transitions from the capturing state which are not followed by particle emission. Thus, primary transitions, which leave the nucleus with more than $\sim 4$ Mev of residual excitation, are excluded since these would most likely be followed by proton re-emission. The high-energy primary gamma-ray transitions are further enhanced by the energy dependence of the radiative probability which may either be taken to follow an $\epsilon^3$ law or inferred from photodisintegration data. A calculation, using the measured $Cu^{59}$ level density, suggests that for excitations of the capturing state of 4.5-7.5 Mev, 80-65 % of the transitions populate the seven known $Cu^{59}$ levels below 2.4 Mev. This is qualitatively in agreement with the result $\nu \approx 3$ since spin factors will further reduce the effective number of partial widths. A direct check can be obtained by observing the gamma-ray spectra from the resonances and a preliminary study indicates that on the average less than five partial widths are important. It appears, therefore, that the Porter-Thomas theory[4] accounts satisfactorily for the distribution of these total radiation widths.

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## SEARCH FOR HIGHER-ORDER EFFECTS IN ALLOWED BETA DECAY*

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The ordinary theory of beta decay predicts an isotropic beta-gamma directional correlation for allowed beta transitions, since only $s$-wave leptons contribute to the decay. Under certain conditions, however, the relative contributions of $p$ and $d$ waves by virtue of their interference with $s$ waves may become large enough to lead to measurable effects, e.g., to a small anisotropy in an allowed beta-gamma directional correlation. These higher-order effects are characterized by the presence of cross terms of the allowed matrix elements with second forbidden matrix elements. The dominant contributions are expected to arise from cross terms of $\int \vec{\sigma}$ with the relativistic momentum type second forbidden matrix elements $\int \vec{\alpha} \times \vec{r}$ and $i\int \gamma_5 \vec{r}$. The latter were estimated by Morita[1] to be of the order $M^{-1}\int \vec{\sigma}$ ($M$ = nucleon mass in units of the electron mass $m$). Recently, Gell-Mann[2] proposed a beta-decay theory which, as compared to the old theory, involves an additional term caused by the beta decay through the meson cloud of the nucleon. In Gell-Mann's theory $\int \vec{\alpha} \times \vec{r}$ is estimated to be of the order $M^{-1}(\mu_p - \mu_n)\int \vec{\sigma}$.

The anisotropy $a = [W(180°) - W(90°)]/W(90°)$ of the beta-gamma directional correlation is proportional to $p^2/W$ in both theories.[1,3] Thus these higher order effects should be noticeable at very large beta energies ($W \gtrsim 10$). Such a measurement has been reported.[4] A different situation in which the effects may be enhanced is encountered in the case of allowed beta transitions with large $ft$ values, where the magnitude of the allowed matrix elements are considerably reduced and thus the influence of $\int \vec{\alpha} \times \vec{r}$ and $i\int \gamma_5 \vec{r}$ may be relatively more pronounced.[3]

The anisotropy values to be expected for some beta-gamma cascades were computed using

Table I. Anisotropies $a=[W(180°)-W(90°)]/W(90°)$ of allowed $\beta-\gamma$ directional correlations.

| $\beta-\gamma$ cascade | Theoretical anisotropy (%) with $\int\vec{\sigma}$ nominal Morita | Gell-Mann | with $\int\vec{\sigma}$ reduced Morita | | Experimental anisotropy (%) |
|---|---|---|---|---|---|
| $Na^{24}$ $4^+(\beta^-)4^+(\gamma)2^+(\gamma)0^+$ $\log ft=6.1$ ($E_\beta=1.1$ Mev) | +0.04 | +0.11 | +0.25 | | +0.02 ± 0.04 |
| $Sc^{46}$ $4^+(\beta^-)4^+(\gamma)2^+(\gamma)0^+$ $\log ft=6.2$ ($E_\beta=0.2$ Mev) | +0.01 | +0.03 | 0.07 | | +0.02 ± 0.04 |
| $Co^{60}$ $5^+(\beta^-)4^+(\gamma)2^+(\gamma)0^+$ $\log ft=7.3$ ($E_\beta=0.2$ Mev) | -0.003 | -0.01 | -0.07 | | -0.03 ± 0.04 |
| $Na^{22}$ $3^+(\beta^+)2^+(\gamma)0^+$ $\log ft=7.4$ ($E_\beta=0.35$ Mev) | -0.0008 (-0.005) | +0.013 | -0.02 (-0.12) | (a)<br>(b)<br>(c)<br>(d)<br>Average | -0.27 ± 0.05<br>-0.25 ± 0.08<br>-0.30 ± 0.08<br>-0.18 ± 0.04<br>-0.27 ± 0.04 |

Morita's formulas,[1] and are listed in columns two and three of Table I. The values in column four were calculated by taking into account the reduction of $\int\vec{\sigma}$ which was estimated on the basis of a nominal log$ft$ value for an allowed transition of 4.5. The contribution of the Fermi component in the beta transitions of $Na^{24}$ and $Sc^{46}$ were taken from a previous paper.[5]

The anisotropies in Gell-Mann's theory for the cases of large $ft$ values are much more difficult to estimate. In Gell-Mann's theory

$$\int\vec{\alpha}\times\vec{r}\sim\frac{\mu_p-\mu_n}{M}\int\vec{\sigma}+\frac{1}{M}\int\vec{1}\tau_+ + \text{possible other terms.}$$

If the main matrix element $\int\vec{\sigma}$ is reduced, the first term is presumably also reduced and the second term may become important. It is difficult to estimate the contribution of this latter term and so no attempt will be made to do so.

The pronounced difference of the $Na^{22}$ anisotropy in Gell-Mann's and Morita's theory arises from a partial cancellation of the contributions of $\int\vec{\alpha}\times\vec{r}$ and $i\int\gamma_5\vec{r}$ in the latter. If one assumes that only $i\int\gamma_5\vec{r}$ contributes in this particular case, one obtains the values indicated in parentheses.

Measurements of the beta-gamma directional correlations were performed on the nuclides listed in Table I with the vacuum chamber and the scintillation counter arrangement shown in Fig. 1. The concidence spectrometer was of the usual fast-slow type. The beta sources were less than 30 $\mu$g/cm$^2$ thick and were mounted on 0.9-mg/cm$^2$ Mylar films. The data were carefully corrected for the presence of gamma-gamma coincidences.

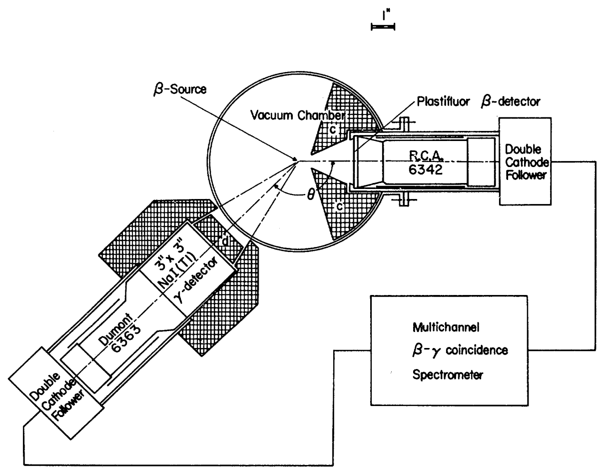


FIG. 1. Vacuum chamber and counter arrangement for beta-gamma directional correlation measurements. The lead shields (c) and the lead absorber (d) were only used in the $Na^{22}$ measurements (c) and (d), respectively.

The execution of the beta-gamma directional correlation measurements on the positron emitter $Na^{22}$ required special precautions. The annihilation radiation resulting from the positrons stopped in the beta detector, if accepted by the gamma detector, gives rise to a beta-gamma coincidence rate, which is dependent on the relative positions of the beta and the gamma detector. Although the energy window of the gamma detector accepts only the photopeak of the 1.28-Mev gamma radiation which follows the positron decay, the aforementioned effect must be considered because a fraction of the annihilation radiation reaches the gamma detector simultaneously with the 1.28-Mev gamma ray and may be detected by virtue of superposition of the annihilation photopeak on the Compton distribution of the 1.28-Mev gamma ray. This effect adds, in general, more genuine coincidences to the beta-gamma coincidence rate, if the beta and gamma detector axes are at 90° or 270°, than if they are at 180°. In other words, the effect gives rise to an apparent negative anisotropy, which is of the order of $\sim 0.1\,\%$. In order to take this superposition effect into consideration and also in order to test for possible instrumental distortions the beta-gamma correlation of $Na^{22}$ was measured under various experimental conditions. In measurement (a) the effect was eliminated by arranging the counters in such a way that the effective solid angle subtended by the gamma counter at the beta scintillator was the same at $\theta = 90°$ (or 270°) and at $\theta = 180°$. Measurements (b), (c), and (d) were performed in a different counter arrangement and corrections were applied for the presence of the superposition effect. Furthermore in measurements (c) and (d) the superposition effect was considerably reduced by placing lead wedges between the counters (c), or by placing a $\frac{1}{2}$-inch lead absorber in front of the gamma detector (d) (see Fig. 1).

The results of the beta-gamma anisotropy measurements are summarized in Table I. The errors quoted in Table I can be considered as maximum errors. The statistical errors are three times smaller.

Within experimental errors there is no indication of an anisotropy in $Na^{24}$, $Sc^{46}$, and $Co^{60}$. The disagreement between the experimental anisotropy result of $Na^{24}$ and the values calculated in columns three and four of Table I may indicate that not only the $\int \vec{\sigma}$ matrix elements, but also the momentum type matrix elements $\int \vec{\alpha} \times \vec{r}$ and $i \int \gamma_5 \vec{r}$ are reduced considerably in this beta transition. Thus these data are inconclusive as far as the Gell-Mann theory is concerned.

The small anisotropy measured in $Na^{22}$ is of the opposite sign to that predicted by the Gell-Mann theory. Thus the effect cannot be attributed to the Gell-Mann term. It rather seems likely that the anisotropy is caused by cross terms of the allowed matrix elements with other second forbidden matrix elements which are unusually large in this particular case. The presence of an anisotropy in the $Na^{22}$ beta-gamma correlation may be related to the fact that the $Na^{22}$ positron spectrum shows deviations from the allowed shape.[6]

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