Beta-Gamma Directional Correlation in the Decay of Co^{60} and Na^{22}†

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(Received October 8, 1959)

The differential and integral beta-gamma directional correlations in the decay of Co^{60} and Na^{22} have been measured with scintillation counters. Both beta transitions are allowed but have high ft values. Therefore, small anisotropies are not excluded. In the case of Co^{60} the anisotropy was found to be zero for all beta energies above 0.06 Mev; the integral anisotropy was measured to be $A=-0.0003\pm0.0017$ (standard deviation). In the case of Na^{22} the results seem to indicate an energy dependence of the anisotropy; the value is uncertain because of coincidences between positrons and annihilation quanta.

I. INTRODUCTION

IT is well-known that the beta-gamma directional correlation is isotropic in the allowed approximation.[1,2] This has been verified experimentally in a number of cases.[2–5] There are, however, small order effects which may give rise to an anisotropy even for allowed beta transitions. These effects are essentially due to forbidden matrix elements[4,6,7] neglected in the allowed approximation and, if the Gell-Mann modification[8] of the law of beta-decay is correct, to terms arising from mesonic corrections.[4,5,7] Both kinds of anisotropic terms usually are more pronounced at higher energies.

It was the purpose of the present investigation to look for small order effects in allowed beta-decays with high ft values. In such cases, the ordinary allowed type decay is strongly slowed down and the forbidden contributions might be expected to become important. For this reason, Co^{60} and Na^{22} were chosen. The decay schemes of these isotopes are given as inserts in Figs. 2 and 3. The values for $\log ft$ of the main beta groups are 7.5 and 7.42, respectively.

The question of an anisotropic beta-gamma directional correlation is to some extent[6] related to the shape of the beta spectrum. The shape of the Co^{60} beta spectrum has been measured to be allowed.[9] Na^{22} has been found to have an allowed spectral shape between 0.16 and 0.47 Mev[10]; on the other hand, an excess of low-energy electrons has been reported.[11]

There have been several determinations of the beta-gamma directional correlations in the decay of Co^{60} and Na^{22}. Early work[2] resulted in correlations isotropic within a few percent. Recently, Steffen found the correlation in the decay of Co^{60} to be isotropic[3,4] and the correlation in the decay of Na^{22} to be anisotropic[4]: $A=(-0.03\pm0.04)$ percent at 0.2-Mev β energy (Co^{60}) and $A=(-0.27\pm0.04)$ percent at 0.35-Mev β energy (Na^{22}).

II. EXPERIMENTAL TECHNIQUES

The Co^{60} source was prepared by evaporating in vacuo high specific activity material on an Al-film of 1.7 mg/cm². The source strength was 8 μC. The Na^{22} source was prepared by evaporating carrier-free solution to dryness on a Mylar film of 0.85 mg/cm²; the insulin technique was applied. The source strength was about 15 μC. Each source was about 6 mm in diameter. The source-holding frames were made from thin Al foil.

Figure 1 shows the geometry of the counter arrangement used in the present experiments. Part of the equipment has already been described.[12] The vacuum chamber wall is made of Al. The chamber was evacuated to better than 10^{-2} mm Hg. The beta rays were detected either by an anthracene crystal of $1\frac{1}{8}$ in. diameter and 4 mm thickness or by a Pilot B plastic scintillator of 1 in. diameter and 0.45 mm thickness. The anthracene scintillator was used for the differential correlation while the plastic scintillator was used for the integral correlation. Both scintillators were covered with 150 μg/cm² of Al. The energy resolution of the anthracene beta counter

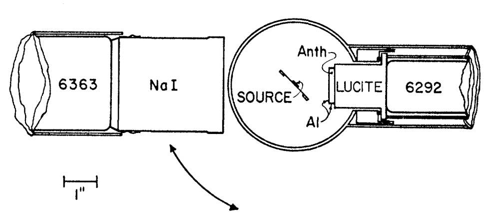

FIG. 1. Counter arrangement. For integral correlations the anthracene crystal (Anth) was replaced by a thin Pilot B plastic scintillator.

† Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
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[1] See, for example, H. Frauenfelder, *Beta- and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers Inc., New York, 1955), Chapter XIX.
[2] See: H. Frauenfelder, Annual Reviews of Nuclear Science (Annual Reviews, Inc., Palo Alto, 1953), Vol. 2, p. 129.
[3] R. M. Steffen, *Proceedings of the Rehovoth Conference on Nuclear Structure*, edited by H. J. Lipkin (Interscience Publishers Inc., New York, 1958).
[4] R. M. Steffen, Phys. Rev. Letters **3**, 277 (1959).
[5] Boehm, Soergel, and Stech, Phys. Rev. Letters **1**, 77 (1958).
[6] I. Hauser, Ph.D. thesis, State University of Iowa, 1956 (unpublished).
[7] J. Bernstein and R. R. Lewis, Phys. Rev. **112**, 232 (1958); M. Morita, Phys. Rev. **113**, 1584 (1959).
[8] M. Gell-Mann, Phys. Rev. **111**, 362 (1958).
[9] F. Bonhoeffer, Z. Physik **154**, 62 (1959).
[10] H. Daniel, Nuclear Phys. **8**, 191 (1958).
[11] Hamilton, Langer, and Smith, Phys. Rev. **112**, 2010 (1958).
[12] R. C. Waddell, Ph.D. thesis, Iowa State University, 1955 (unpublished). For the present experiments the set up has been greatly modified.

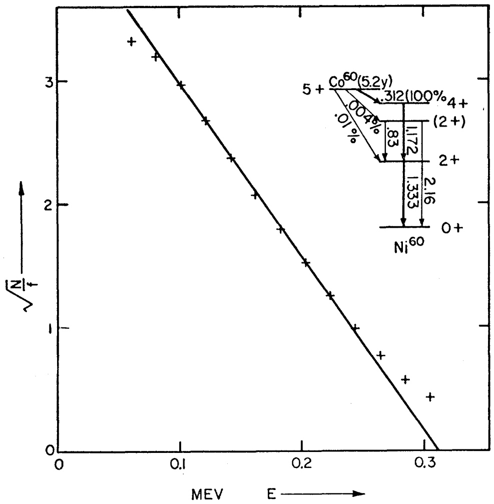

FIG. 2. Fermi plot of the Co^{60} beta spectrum. No corrections have been applied. The insert shows the disintegration scheme as given by [Strominger, Hollander, and Seaborg, Revs. Modern Phys. **30**, 585 (1958)]; energies in Mev.

was 14% at 0.624 Mev. Figures 2 and 3 show the Fermi plots of the Co^{60} and Na^{22} β spectra, respectively; no corrections have been applied. These data were obtained with an *RCL* 256 channel pulse-height analyzer and were treated in groups of ten channels. The gamma rays were detected by a 3 in.×3 in. Harshaw NaI crystal which was not shielded by lead. The energy resolution of the gamma counter was 5.3% at 1.275 Mev. The source could be adjusted by screws from outside. The gamma counter was moved by means of an electric motor device.

The fast coincidence circuit was operated at $2\tau = 0.16$ μsec. For taking the differential correlation, beta pulses in coincidence with a gamma pulse were fed into the 256 channel analyzer. The gamma pulses were selected with a single channel analyzer. For Co^{60} and

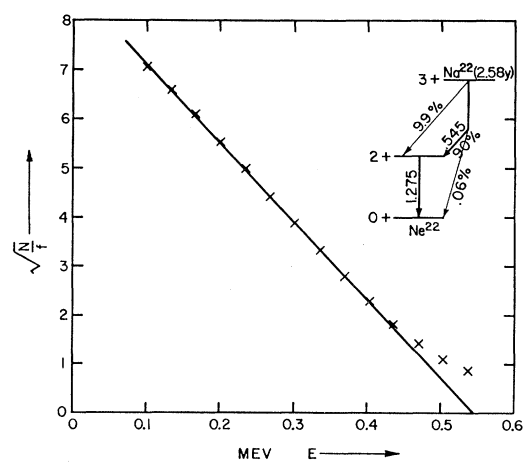

FIG. 3. Fermi plot of the Na^{22} beta spectrum. No corrections have been applied. The insert shows the disintegration scheme as given by reference 10; energies in Mev.

Na^{22}, gamma pulses corresponding to energies above 0.54 and 1.05 Mev, respectively, were admitted. In taking the integral correlation, the 256 channel analyzer was used only for control purposes. Out of the total gamma pulse-height spectrum, only the photopeaks of the two Co^{60} gamma rays or the photopeak of the Na^{22} gamma ray, respectively, were admitted. Points were taken in the 90° and in the 180° positions. The length of time for an individual point was 10 min (differential correlation) or 2 min (integral correlation).

The Co^{60} data were corrected for gamma-gamma coincidences. In the case of the differential correlation, the pulse-height distribution well above the end point of the beta spectrum was extrapolated to the lower energies. This extrapolated distribution was then subtracted from the total intensity distribution to get approximately the distribution due to the beta rays only. In the case of the integral correlation, the gamma-gamma contribution to the total coincidence rate was obtained with the help of the calculated detection proba-

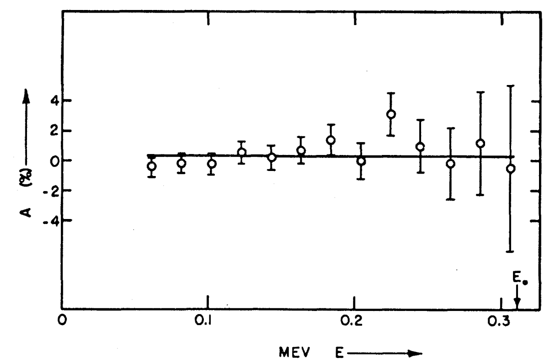

FIG. 4. Differential correlation for Co^{60}. The indicated errors are the standard deviations. The horizontal line represents the average of all points.

bility of the Pilot *B* scintillator for Co^{60} gamma rays. This detection probability was estimated to be about 0.27% of the detection probability for Co^{60} beta rays. Thus the correction due to gamma-gamma coincidences is almost negligible in the case of the integral correlation.

The Na^{22} data were distorted by coincidences between positrons and annihilation quanta. These coincidences were more intense in the 90° position because of the larger solid angle subtended by the gamma detector at the beta detector. Their intensity depended strongly on the pulse-height selection in the gamma branch. The influence of these coincidences was noticeable, even with the high discrimination actually used in the gamma branch, because of summing effects in the gamma crystal. Since the magnitude of this effect was unknown, no correction has been applied. However, an approximate correction for the summing of beta pulses and annihilation quanta pulses in the beta crystal has been applied. For this purpose the pulse height distribution well above the beta endpoint was extrapolated to lower

energies. This extrapolated distribution was then subtracted from the total intensity distribution in the beta branch.

All the angular correlation data have been corrected for the finite angular resolution.

III. RESULTS AND DISCUSSION

Co^{60}

The anisotropy of the integral Co^{60} beta-gamma directional correlation for $E_\beta \gtrsim 0.06$ Mev was found to be

$$A=-0.0003\pm 0.0017.$$

The stated error is the standard deviation.

Figure 4 shows the differential correlation. Obviously, the correlation is not a function of the beta energy. Summing the counts in the beta spectrum range leads to an integral anisotropy of $A=0.0034\pm 0.0026$ (standard deviation). This is, within statistics, completely compatible with no integral correlation, but, nevertheless, must be considered to be less certain because the correction for gamma-gamma coincidences is less certain in the case of a thick beta crystal.

The present results on Co^{60} are in complete agreement with earlier work.[2-4] They do not permit any conclusion on the Gell-Mann terms.[4,5,7]

Na^{22}

For the anisotropy of the integral Na^{22} beta-gamma directional correlation with $E_\beta \gtrsim 0.1$ Mev the value $A=-0.020\pm 0.002$ (standard deviation) was obtained. As stated in Sec. II, no correction for coincidences between positrons and annihilation quanta has been applied. Therefore, the value for A given above must not be considered as correct. It can be used only to get a lower limit of A:

$$A>-0.026.$$

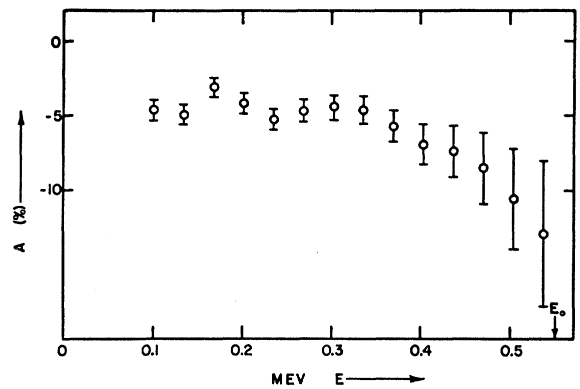

FIG. 5. Differential correlation for Na^{22}. The indicated errors are the standard deviations. The data have not been corrected for coincidences between positrons and annihilation quanta. See text.

Figure 5 shows the measured differential correlation. It is estimated that the coincidences between positrons and annihilation quanta will essentially shift the value of A independently of the beta energy. Hence, the result on the differential correlation seems to indicate an energy dependence, although it does not exclude an energy-independent correlation.

The present results on Na^{22} are not in disagreement with earlier work[2] because the statistical errors of the latter are large. The results are also not in disagreement with the work of Steffen.[4]

ACKNOWLEDGMENT

It is a pleasure to thank Dr. E. N. Jensen for his kind interest and Dr. R. M. Steffen for interesting discussions and for communicating his results prior to publication. Thanks are also due Mr. B. McDaniel for his help in taking and evaluating the data.