ON THE MEASUREMENT OF THE ANGULAR CORRELATION BETWEEN TWO GAMMA RAYS OF NICKEL (60)*

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ABSTRACT. The angular correlation between the two cascade gamma rays of $Co^{60} \rightarrow Ni^{60}$ transitions has been measured, using Geiger Müller counters. The source was in the form of $CoCl_2$ solution. From the correlation function $W(\theta)$ of Hamilton, the curve $\frac{N(\theta)}{N(\pi/2)}$ plotted against θ, was explained with the assumption that the two radiations are octopole – octopole in nature. An alternative spin-parity scheme of $Co^{60} \rightarrow Ni^{60}$ transitions has been suggested.

INTRODUCTION

The method of determining change of angular momentum from life time of a metastable state has its natural limitations when the gamma rays have large disintegration constant, that is, half-lives shorter than 10^{-8} second. In this region, the measurement of angular correlation of the successive gamma rays has been suggested, following the work of Hamilton (1940) who showed that there is correlation between the angle of emission of gamma rays and the spin change associated with the transition. The gamma rays from excited Ni^{60} following the emission of β-rays from 5.3 years Co^{60} have been studied. Such attempts have been made previously by Brady and Deutsch (1950) which we have repeated and extended. Dunworth (1940) first suggested that there might be some angular correlation between the directions of emission of two successive gamma rays emitted by a nucleus when this passes from an excited level A to the ground level C by way of definite intermediate level B.

On Dunworth's suggestion, the problem was theoretically investigated by Hamilton (1940) according to whom the probability of the second quantum to be emitted at an angle θ with respect to the first per unit solid angle in cascade emission is given by the series,

$$W(\theta) = 1 + \sum_{1}^{l} a_k \cos^{2k}\theta$$

$$= 1 + a_1 \cos^2\theta + a_2 \cos^4\theta + a_3 \cos^6\theta + \quad \ldots \quad (1)$$

where l is the multipole order of the gamma rays present in the transitions and the coefficient a_k's are constants but are functions of J_1, J_2 and J_3, the respective spin values of the initial, intermediate and final states of the nucleus. For dipole-dipole transition, $l=1$, the equation (1) becomes

$$W(\theta) = 1 + a_1 \cos^2\theta, \quad \ldots \quad (2)$$

and for quadrupole-quadrupole transitions

$$W(\theta) = 1 + a_1 \cos^2\theta + a_2 \cos^4\theta, \quad \ldots \quad (3)$$

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and similarly for other higher poles. If, however, in the above case one of the transitions is dipole i.e. dipole-quadrupole or quadrupole-dipole, on explicit computation of a's it has been found (Hamilton 1940) that a_2 becomes zero and (3) reduces to

$$W(\theta) = 1 + a_1 \cos^2\theta$$

In general, the number of terms in $\cos\theta$ in equation (1) will be determined by the lowest order multipole present in the transitions.

J_1, J_2, J_3 take values depending on the type of radiation. For dipole-dipole transitions, $J_1 - J_2 = J_2 - J_3 = 0$ or ± 1, and a_1 may take any value. Hamilton (1940) has calculated the values of a_1 for dipole-dipole, dipole-quadrupole and those of quadrupole-quadrupole radiations for all possible values of J_1, J_2 and J_3.

The values of the coefficients for octopole and of higher multipole order radiations have not yet been worked out.

From equation (1) it will be seen that at $\theta = 90°$, $W(\theta) = 1$. Thus $W(\theta)$ in equation (1) represents also the ratio of the probability of gamma rays emitted at an angle θ to that emitted at $90°$.

The experimental verification is obtained by observing coincidence rates between successive gamma rays at different angles. Such experiments have been carried out during the last few years. The experiments have borne out Hamilton's idea of the existence of such correlation between successive gamma rays emitted by a nucleus and have given plausible numerical values for the spin changes in certain nuclei.

EXPERIMENTAL ARRANGEMENT AND DETAILS

The disintegration of Co^{60} has been thoroughly investigated by Deutsch, Elliot and Roberts (1945) and the results are shown in figure 4. We find that two gamma rays are emitted in cascade from the excited state of Ni^{60}. We have studied the angular correlation between these two gamma rays. The experimental arrangement is shown in figure 1.

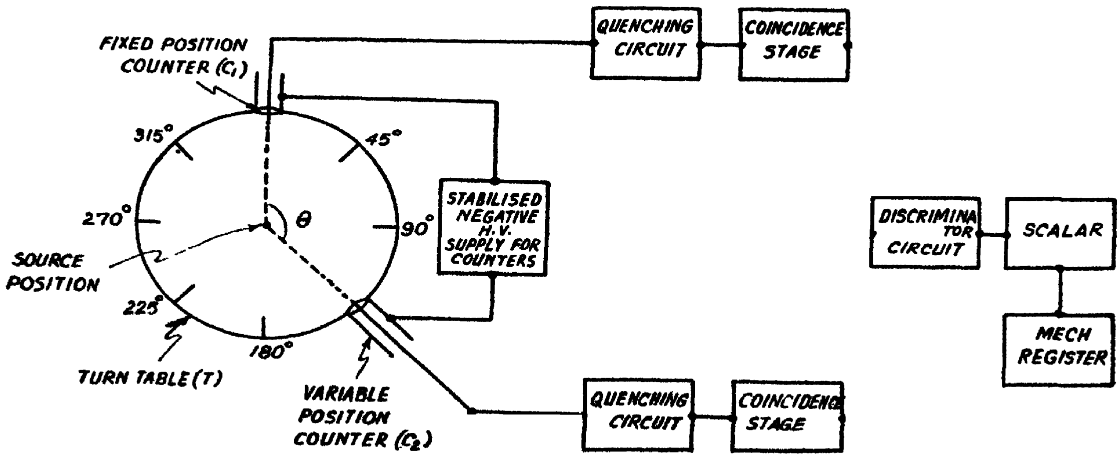

FIG. 1
Schematic diagram of the experimental arrangement

Two similar gamma counters, C_1, C_2 are placed symmetrically at their end-on positions with respect to the source on a turntable T, graduated in degrees. One of the counters, C_1, is fixed in its position while the other C_2, is free such that it can be rotated about the axis of the turntable with the source as centre and then fixed at any position on it. The source, 5.3 years Co^{60}, was in the form of cobalt chloride solution contained in a cylindrical glass capsule of 0.8 centimetre diameter and its axis coincided with that of the turntable.

The effective ends of the counters were found by coincidence experiments with a radium source and taking this into account, the counters were placed in such a way that these effective ends of both the counters were just ten centimetres away from the centre of the source. The diameter of the counters was 1.8 centimetres and the angular resolution of the arrangements was 10° 18′.

The thickness of the glass capsule containing the source and the glass thicknesses of the counters were calculated to be sufficient to cut off all primary beta rays emitted by the disintegrating nuclei.

Since the gamma rays of Ni^{60} are fairly energetic, 1.1 and 1.3 Mev, it was apprehended that Compton scattering might give rise to stray coincidence counts. To see the effect of scattering we have observed coincidence and single counts of the counters at 180 degrees and at 90 degrees under varied conditions, namely, (*a*) the counters covered with lead shield of thickness $\frac{1}{8}$ inch; (*b*) with a thick lead sheet of one centimetre thickness between the counters as partition; (*c*) with the source itself covered with thin lead sheet; (*d*) with the ends of the counters covered with thin aluminium sheet and (*e*) with no absorbers on and near about the counters. These general tests showed definitely that the presence of any material near the source or the counters increased the scattering effect. We found that except for the last case, the scattering effect had always decreased the ratio $\frac{N(\pi)}{N(\pi/2)}$

TABLE I

Case	$\frac{N(\pi)}{N(\pi/2)}$
a	1.10
b	1.31
c	1.23
d	1.30
e	1.47

The results of these experiments are given in the Table I. We used, therefore, a minimum amount of material for mounting the counters and source-holders and avoided any material in the form of absorbers. The symmetry of the moving counter about the source was assured by observing the equality in single counts at different positions on the turntable with the source at the centre.

The output pulses from the counters (figure 2) are first applied to the grids of the two cathode follower type quenching circuits and then to Rossi type coincidence circuit using two 6SJ7 valves. The output of the coincidence circuit is fed to the input of a discriminator, which is essentially an one-shot multivibrator triggered only by pulses above a pre-determined amplitude. This removes the partials, if any, from the coincidence stage. The square top negative pulse from the discriminator operates a standard laboratory 128 scaler circuit.

Highly stabilised power supplies were used for the electronic recording circuits and the counters. The A.C. mains supply was also stabilised by a magnetic stabiliser.

The resolving time of the coincidence circuit was determined from the measurements of random coincidence counts due to two uncorrelated sources such as Co^{60} and radium. The resolving time of the circuit was found to be of the order of 0.4 microsecond.

The experiment on Co^{60} consisted of taking coincidence rates between two gamma rays at different angles between the two counters and the number of individual counts in each counter at every position, both before and after each observation. Every time the random coincidence rates due to two gamma rays from two different nuclei were subtracted from the total coincidence rates to get the genuine coincidence rates.

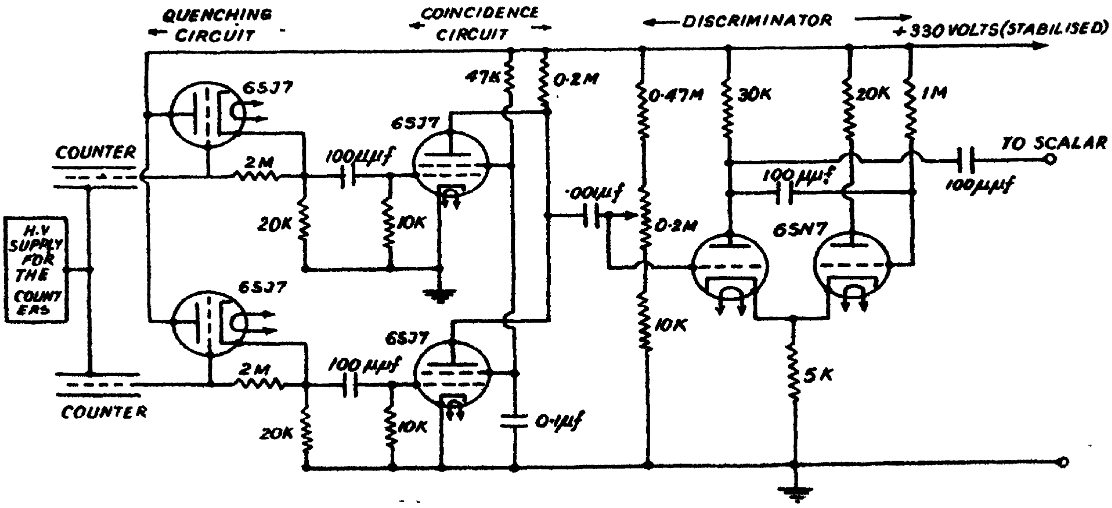

FIG. 2

Circuit diagram of the coincidence and recording unit

EXPERIMENTAL RESULTS

The experimental results are shown in figure 3. The ordinate gives the ratio of the coincidence rates at any angle θ to that at 90 degrees and the abscissa denotes the angle between the axis of the free counter and that of the fixed counter.

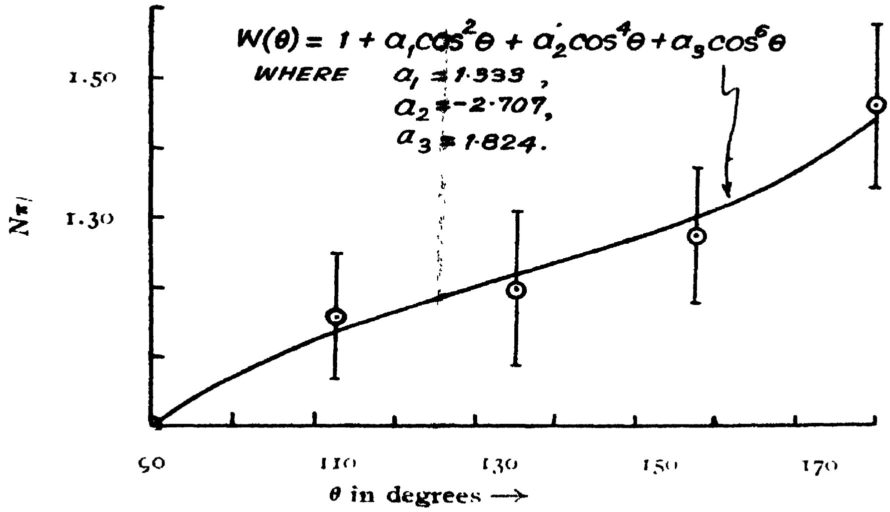

FIG. 3

Experimental curve for the angular correlation of the two gamma rays of Ni^{60}

The best fit of our experimental curve, within the statistical error, is found with the equation,

$$W(\theta) = 1 + a_1 \cos^2\theta + a_2 \cos^4\theta + a_3 \cos^6\theta, \quad (4)$$

in which the values of the coefficients are given as $a_1 = 1.333$, $a_2 = -2.707$, $a_3 = 1.824$.

This shows that the lowest multipole order present in the gamma ray transitions from Ni^{60} is octopole *i.e.* $l = 3$. Since the values of the coefficients of cos θ for octopole and higher multipole order radiations have not been calculated, we could not assign the definite spin values of Ni^{60}. But our experiments tend to prove that one of the radiations is octopole while the other is, at least, octopole or higher multipole order. From the above considerations we, however, assign the angular momenta of the states of Ni^{60} as 6, 3, 0, which accord with the spin assignment of the β^--ray transitions from Co^{60}.

DISCUSSION

It is interesting to note that contrary to previous results of other workers (Brady and Deutsch, 1950) whose results showed quadrupole-quadrupole transition in Ni^{60}, our experiment speaks in favour of octopole-octopole case. How far we are justified in this conclusion, can be understood mainly from two standpoints. The first is that the experimental points when plotted against θ yield a curve, the best fit of which can only be made out with the equation (4) and our trials with $\cos^2\theta$ and $\cos^4\theta$ only have produced curves of entirely different natures from the experimental mean curve. The appearance of $\cos^6\theta$ term in equation (4) forced us to conclude that the minimum value of l should be 3.

The other feature of our result is that the ratio $\frac{N(\pi)}{N(\pi/2)}$ is 1.45 which is rather higher than the results obtained by Brady and Deutsch whose value is 1.17.

We further lend our support of the above conclusion from the experiment of Deutsch and Siegbahn (1950) who approached the problem by an entirely different method, namely the measurement of internal conversion coefficients of the two gamma rays of Ni^{60}. In assigning the multipolarity of these gamma rays of Ni^{60}, on the evidence of their measured conversion coefficient we quote Deutsch and Siegbahn, that "both radiations are either quadrupole or possibly octopole. Thus the first excited state has probably spin 2 or possibly 3". Therefore, our results tend to agree with the findings of these authors.

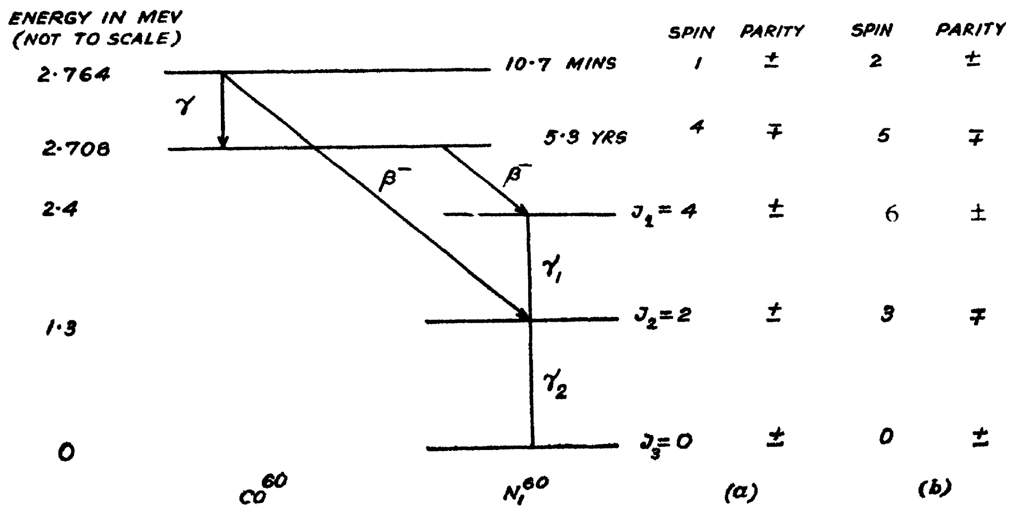

Fig. 4

Disintegration and spin-parity scheme of Co^{60}

The existing spin-parity scheme of $Co^{60} \rightarrow Ni^{60}$ transitions is reproduced in figure 4 (*a*) along with the one proposed by us in (*b*) of figure 4 for elucidation. A glance at the schemes will show that figure 4- (*b*) is a parallel mode of spin-parity changes of figure 4- (*a*).

It is also worthwhile to note that even with $\Delta J = \pm 3$ for the excited state of Ni^{60}, have half lives less than 10^{-9} seconds as calculated from Bethe's formula and explain why attempts to detect the half lives of the gamma rays by delayed coincidence method failed.

CONCLUSION

In view of our experimental results we may say that even with octopole-octopole transitions it is possible to set up an alternative but self-consistent spin-parity scheme of the levels of $Co^{60} \rightarrow Ni^{60}$ transitions. It is, of course, not very clear to us why our coincidence countings yielded such a high value of $\frac{N(\pi)}{N(\pi/2)} = 1.45$ or stating otherwise, why other workers have got such a low value as 1.17. Our experience during this experiment is that the scattering phenomenon always tends to decrease the ratio. Since all these workers have used photo-electron multipliers as their detectors of gamma rays, they had to put the whole assembly in light tight metal chambers. As such, our surmise is that perhaps scattering phenomenon was far more prominent than in our case and had pulled down the ratio to such a low value.

Further work is being carried out in this laboratory using scintillation counters to study the angular correlation of two gamma rays of Ni^{60} with arrangements eliminating all possible scattering effect.

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