Gamma-Ray Spectrum from the Deuteron Bombardment of C^{13}*

L. M. BAGGETT† AND S. J. BAME, JR.†
Rice Institute, Houston, Texas
(Received August 6, 1951)

THE gamma-ray spectrum from the deuteron bombardment of C^{13} has been measured by Thomas and Lauritsen.[1] Using a magnetic lens spectrometer, they observed the Compton electrons produced in a beryllium converter by gamma-rays from a 50 percent enriched C^{13} target bombarded with 1.58-Mev deuterons. The gamma-ray energies thus measured are listed in Table I.

TABLE I. Gamma-ray energies and yields from $C^{13}+d$.

Energy[a] (Mev)	Yield[a] per 10^6 deuterons	Energy[b] (Mev)	Yield[b] per 10^6 deuterons
0.729 ± 0.022	1.3		
1.643 ± 0.004	1.4		
2.318 ± 0.008	4.5		
		3.05 ± 0.09[c]	30
3.390 ± 0.010	1.6	3.40 ± 0.15	1.7
3.9(?)			
5.056 ± 0.025	1.2	5.04 ± 0.09	1.2
$5.69\ \pm0.050$	0.6		
6.115 ± 0.030	2.0	6.10 ± 0.10	1.5

[a] Results of Thomas and Lauritsen using a 50 percent enriched C^{13} target, $E_d=1.58$ Mev.
[b] Results from pair spectrometer using a 35 percent enriched C^{13} target, $E_d=1.65$ Mev, uncorrected for relative abundance of the isotopes.
[c] Line from $C^{12}(d, p)C^{13}$, uncorrected for relative abundance of the isotopes.

Since the cross section for production of Compton electrons is decreasing at higher energies, it was thought worthwhile to measure this spectrum with a pair spectrometer.

A 180° magnetic pair spectrometer designed and constructed by Terrell[2] was used. A thick target of carbon enriched to 35 percent C^{13} (kindly presented to us by Professor H. C. Urey) was bombarded with 1.65-Mev deuterons from the Rice Van de Graaff accelerator, and the gamma-rays were observed at 90° to the beam. A 31 mg/cm² tin radiator was used. Figure 1 shows the spectrum

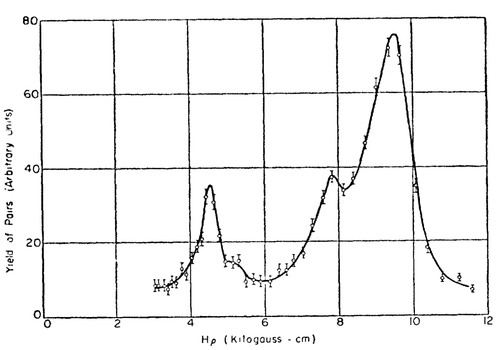

FIG. 1. Gamma-ray spectrum from $C^{13}+d$, obtained with a 180° magnetic pair spectrometer.

obtained with a no radiator background subtracted. Three strong lines appear at 4550, 7850, and 9570 gauss-cm, and a weak line appears at about 5150 gauss-cm. The line at 4550 is due to $C^{12}(d, p)C^{13}$. Applying peak shift corrections, the line energies were calculated and are listed in Table I. The lower energy lines found by Thomas and Lauritsen were not detected in the present experiment due to the low efficiency of a pair spectrometer below 3 Mev. The 5.69-Mev line was not resolved; however, the broadness of the upper energy lines suggests that this line may be present. The counting efficiency of the spectrometer was calibrated[2] at 2.62 Mev using a Th C″ source, and at 4.5 Mev using a Po—Be source. Using these efficiencies along with a calculated efficiency at 9.0 Mev, the yields for the different lines were calculated and are shown in Table I. These yields are for a 35 percent enriched C^{13} target and are uncorrected for relative abundance. The 6.10-Mev line has been assigned[1] to $C^{13}(d, p)C^{14}$ because it is also observed at $E_d\sim0.6$ Mev where only this assignment is energetically possible, while the 3.40- and 5.04-Mev lines have been assigned to $C^{13}(d, n)N^{14}$.

* Assisted by the joint program of the ONR and AEC.
† Now at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
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Applicability of the Renormalization Theory and the Structure of Elementary Particles*

SHOICHI SAKATA, HIROOMI UMEZAWA, AND SUSUMU KAMEFUCHI
Institute of Theoretical Physics, Nagoya University, Nagoya, Japan
(Received July 23, 1951)

SOME of the fundamental difficulties in the theory of elementary particles have been circumvented by the development of the renormalization theory. As we have pointed out in previous papers,[1] this theory should be regarded as an abstract formalism, behind which the concrete structures of the elementary particles lie hidden. So long as the renormalization procedure is successful, it is unnecessary to know the detailed features of the structures; but, as soon as defects of the renormalization theory become obvious, we must seriously consider the structures of the elementary particles.

As is well known, one of the most striking defects of the renormalization theory is found in the problem of the anomalous magnetic moment of the nucleon. In fact, none of the four types of the meson theory has yet been able to explain this anomaly. However, it seems to us that it is still too early to accept this as conclusive, since it is always possible to add a magnetic moment of Pauli type having finite or infinite value in accordance with the idea of renormalization. If such an addition were made, the great success of the renormalization theory in quantum electrodynamics would also be regarded as merely accidental. In the philosophy of renormalization, there is no reason why we should exclude the possible existence of a magnetic moment of Pauli type in the case of the electron.

If the structure of the elementary particles were known, the qualitative differences among the various types of interactions would surely be clarified. However, in the present stage, we must content ourselves with a more formal or phenomenological classification of the interactions. Although the renormalization theory treats all kinds of interactions in the same manner, it has become clear[2–4] recently that they may be classified into two groups, which give rise, respectively, to different situations: (a) those interactions which can be renormalized by assuming the coexistence of a finite number of interactions belonging to the same group and (b) those interactions which require the further introduction of infinitely many interaction terms having successively higher derivatives of the field quantities. The electromagnetic interaction of the electron and the scalar interaction of the scalar meson with a nucleon are examples of the former group, while the electromagnetic interaction of the vector meson[2] and the direct interaction between spinor particles[3] belong to the latter.

If there were only interactions belonging to the first group, the renormalization theory would form a closed system in the frame of the present quantum field theory. However, as the existence of the direct interaction between spinor particles is indispensable for interpreting beta-decay experiments, it seems premature to content ourselves with the success of the renormalization theory in quantum electrodynamics. The assembly of the infinite number of interactions having successively higher derivatives is equivalent to a nonlocal interaction, which is intimately connected with the structure of the elementary particles.

In order to classify all the interactions in this way, we have investigated the condition for the "closing" in the renormalization theory as applied to the most general type of interaction. Let the number of field quantities U^α of the field (α), and the maximum number of the derivation operators which operate on the $U^\alpha(\alpha=1, 2, \cdots)$ in the interaction hamiltonian $H_l(l=1, 2, \cdots)$ be k_l^α and a_l, respectively, and let the asymptotic form of the fourier amplitude $\Delta^\alpha(p)$ of the propagation function of the field (α) be $p^{b^\alpha-2}$ for large p. Then, the condition for the closing is given by

$$K_l \equiv -\Sigma_\alpha \tfrac{1}{2}(b^\alpha+2)k_l^\alpha+4-a_l \geqslant 0 \quad (l=1, 2, \cdots). \qquad (1)$$

The results so far obtained for various cases by actual calculations[4] are found to be compatible with the conclusions from condition (1).

Now, in connection with the requirement (1) concerning the limit of applicability of the renormalization theory, it is of interest to recall Heisenberg's[5] classification of interaction types into first and second kinds. According to his considerations, when the coupling constant is of the dimension l^n with $n>0$, the present quantum field theory cannot give correct results for phenomena relating to a wavelength shorter than l (in this case the series expanded in powers of the coupling constant does not converge).[6] Such phenomena are regarded as being closely connected with the so-called "universal length r_0,"[7] and so with the structure of elementary particles.

Now, it can be verified that n is equal to $-K_l$, whose value is the criterion for the applicability of the renormalization procedure. This important fact gives the physical basis for condition (1) and also clarifies the reason that the renormalization theory has succeeded in the electrodynamics of the electron.

In view of condition (1), we may classify the interaction types as follows: (a) the case in which the renormalization procedure gives a consistent closed theory, i.e., interaction of the first kind of Heisenberg with $n=-K=0$, (b) the case in which the renormalization procedure gives a consistent closed theory, i.e., interaction with $n=-K<0$, (c) the case in which the renormalization fails, i.e., interaction of the second kind of Heisenberg with $n=-K>0$.

For the closing of the theory type (a) occasionally requires the further introduction of type (b). As an example of such cases, we may mention the interaction between a nucleon and a scalar meson via scalar coupling, where a $\lambda\phi^3$-term is required. Type (c) corresponds to the case in which the perturbation expansion does not converge.

* Read at the Nagoya meeting of REKS (the Kansai Branch of the Elementary Particle Theory Group), held on February 6, 1951.

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The α−γ Angular Correlation in the Decay of Radiothorium*

J. K. Beling,† B. T. Feld, and I. Halpern
Laboratory for Nuclear Science and Engineering, and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received August 7, 1951)

THE most reasonable energy level diagram for those levels in RdTh and ThX that are displayed in the α-decay of RdTh is given in Fig. 1. This arrangement of levels is based on a number of measurements of the various radiations involved in the α-decay. The α fine structure was measured by Rosenblum and co-workers.[1]

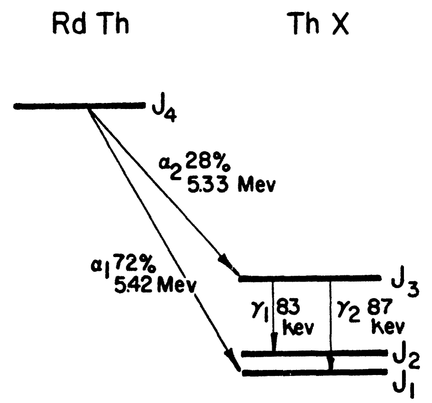

Fig. 1. Energy levels in the decay of RdTh.

They found only the two α-lines shown, except that the line α_1 showed a broadening that would be consistent with the existence of the close doublet at the ground state of ThX. This doublet is suggested by the observations of two gamma-rays (of energies 83.3 and 86.8 kev) by Surugue and Tsien[2] and by Riou.[3] The conversion coefficients for the γ's can be computed from their data and they both correspond to electric quadrupole transitions. It is likely that the spins J_1 and J_4 are equal to zero because the nuclei involved are even-even. All these data together imply that all the levels have the same parity.

The measurement of angular correlations between successive nuclear decay radiations is a means of checking a given set of assumptions concerning the spins and parities of the levels involved. In the case of the natural radioactivities, e.g., RdTh, many data have been accumulated. It was felt that an $\alpha-\gamma$ angular correlation in this case, would have the property of confirming or denying the validity of the accumulated picture (Fig. 1) in all of its details. The results of a previous attempt[4] to measure this correlation were not sufficiently reliable for this purpose.

In the present experiment scintillation counters were used for both the α- and γ-detectors. A large number of runs, each lasting several hours and including angles in all four quadrants, were made

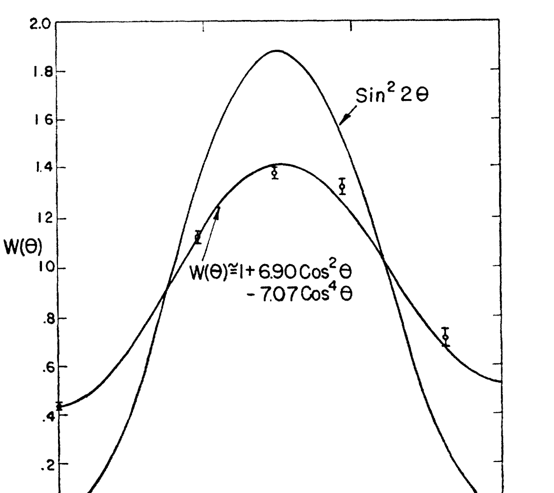

Fig. 2. The observed correlation with both γ-rays. $W(\theta)$ is the least squares fit to the data. $\sin^2 2\theta$ is the theoretical correlation corresponding to the spin sequence $0 \xrightarrow{\alpha} 2 \xrightarrow{\gamma} 0$. The two curves are normalized to the same total coincidence rate.