The relation between proton pulse height and channel number was found to be correct within 2 percent by ascertaining the positions of the photoproton peaks produced by the 2.618-Mev γ-line of RdTh and the 2.758-Mev γ-line of Na^{24}.

Three measurements were made in consecutive weeks with sources of Na_2CO_3 and NaF irradiated to about 100 mC in the pile at AERE Harwell. First, with the source far away from the counter the 2.76-Mev line was recorded; then the source was brought close to measure the high energy γ-line. Known attenuation was introduced to bring the pulse height into the kicksorter range. Bringing the source close to the counter increases the average ionization current due to γ-rays, and it was necessary to check the validity of extrapolating the energy calibration from the low energy region to the expected photoproton energy. This was done by examination of the deuteron recoil spectrum produced by a RdTh-γ-Be source with successive increases of the γ-ray background. No significant shift with γ-ray intensity was observed, and the position of the end point of the recoil spectrum agreed with the expected maximum energy (848 kev) to within 3 percent.

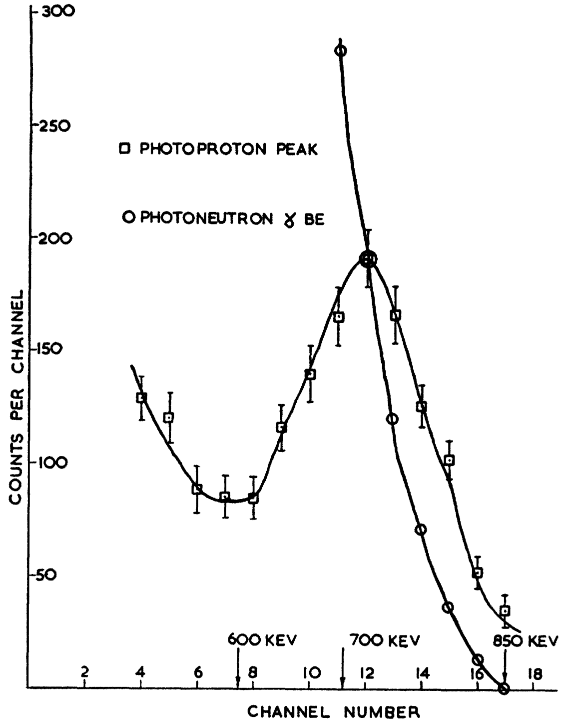

FIG. 1. Photoproton distribution from Na^{24} γ-rays disintegrating deuterium in ion chamber; and deuterium recoils from RdTh-γ-Be neutrons.

It is difficult to reconcile the correct position of the recoil spectrum end point with an instrumental shift of the photoproton peak. The possibility of positive ion effects in the chamber has been considered carefully, and calculation showed that the worst possible case of reduction of pulse height would produce a loss of 10 percent. Taking the extreme case of 10 percent and adding the calibration errors, etc., the photoproton energy might be as high as 790 kev and the energy of the γ-ray accordingly 3.81 Mev.

It is unlikely that the line is due to impurities in the irradiated material, since the same results were obtained with Na_2CO_3 and NaF, and the counting at the peak decreased with the period of Na^{24}.

It is interesting to compare the upper limit for the 4.14-Mev cross-over line (2×10^{-6}) with the theoretical predictions by Blatt and Weisskopf.[4] Assuming the well-known 4^+, 2^+, 0^+ assignment for the 4.14-Mev, 1.37-Mev, and ground-state level of Mg^{24}, the probability of the 4.14-Mev $(2)^4$-pole relative to the 2.76-Mev $(2)^2$-pole becomes 10^{-6}.

As to the new line (the energy of which as stated, lies between 3.6 and 3.8 Mev) it has to be decided whether it is due to a transition from the 4.14 Mev level to a new level at (400 ± 100) kev or to a transition from a new (3.7 ± 0.1)-Mev level to the ground state. The first alternative can be excluded by considering the various transition probabilities concerned in such a scheme (again using the calculations of Blatt and Weisskopf). The only possible transition probability would need an assignment of 7^+ to the (400 ± 100)-kev level. Similarly, for the second alternative we can exclude all spin and parity assignments for the 3.7-Mev level other than 2^+ or 2^-, or values above 7 for the spin.

We are indebted to Lord Cherwell for his interest in this work and for extending to us the facilities of this laboratory.

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Continuous γ-Radiation of β-Emitters*

L. MADANSKY AND F. RASETTI
The Johns Hopkins University, Baltimore, Maryland

(Received May 5, 1951)

It has long been known that a weak continuous γ-radiation is emitted in the β-decay of nuclei.[1] The theory of the effect was first given by Knipp and Uhlenbeck[2] and Bloch,[3] and later extended to include forbidden β-transitions and different kinds of β-interactions by Chang and Falkoff.[4]

The increased efficiency of detection of γ-radiation allowed by the use of scintillation counters suggested a new and more quantitative investigation of the phenomenon. Sources of P^{32} and RaE of the order of 0.1 millicurie were used. The γ-radiation was measured by means of NaI(Tl) crystals (about $1\times 1\times 0.5$ cm), a 5819 phototube, a linear amplifier, and a one-channel discriminator. The γ-continuum to be investigated and γ-ray lines for energy calibration were also observed and photographed on an oscilloscope screen. Both the total intensity and the spectral distribution of the continuum were studied.

To avoid admixture of ordinary bremsstrahlung produced in the stopping of the β-rays, the following arrangement was used. The sources were deposited on relatively thin supports (3 mg/cm^2 Cellophane for P^{32} and 3 mg/cm^2 Ni for RaE) and placed at about 15 cm from the lead-shielded detector. A beam from the source was allowed through a $\frac{1}{2}$-inch hole placed at half the distance between source and detector. This diaphragm was covered with a $\frac{1}{2}$-inch Lucite plate to absorb the β-rays completely. Various tests have satisfied us that with this geometry ordinary bremsstrahlung produced in the support and other materials near the source did not exceed a few percent of the total measured γ-intensity.

Energy calibration of the pulse size was obtained by measuring the position of the peaks due to the 87-kev line of Cd^{109}, the 47-kev line of RaD, and the annihilation radiation. In the low energy region investigated (30–300 kev) it was assumed that the pulse represented the energy dissipated in the crystal by photoelectric absorption, as the photoelectric cross section in NaI at these energies is much larger than the scattering cross section. Corrections were applied to the measured pulse-size distribution to allow for the following factors: (1) absorption in the Lucite plate, (2) efficiency of the crystal (this was calculated by means of the known absorption coefficients in I and Na); and (3) lack of resolution of the detecting system. For the last purpose, the shape of the peaks due to monochromatic lines was measured and found to be approximately represented by gaussian curves with a width at half-maximum $2w(\ln 2)^{\frac{1}{2}}=38$ kev. For the purpose of comparing the experimental spectra with the theory, the theoretical spectral distribution $S(k)$, $(k=h\nu/mc^2)$, corrected for absorption and crystal efficiency, was transformed by numerical integration into the distribution

$$F(k)=\int_0^{w_0-1} S(k')\exp[-(k-k')^2/w^2]dk',$$

which should directly correspond to the measured one.

Figure 1 shows the theoretical curves of $F(k)$ and the experimental points for both P^{32} and RaE. In the latter case, the use of the function $S(k)$ for allowed transitions is questionable, since RaE is a heavy nucleus and exhibits a forbidden β-spectrum. The agreement of the low energy continuum with the theory seems to indicate lack of sensitivity of the γ-spectrum to the forbiddenness of the β-transition in this energy region.

Within the measured energy range, the theoretical and experimental spectra agree closely (Fig. 1), and we shall assume that they also agree in the higher and lower energy regions. The theoretical curve of $S(k)$ and a curve corrected for absorption and crystal efficiency are shown in Fig. 2. To determine the absolute intensity of the continuum of P^{32}, all pulses above 90 kev ($0.175\ mc^2$) were counted, and referred to the number of β-decays from the same source. The number of β-rays was measured with a Geiger counter and corrected for absorption in air and counter window. We found 2.4×10^{-3} γ-quanta above 90 kev per β. The ordinates of the $S(k)$ curves in Fig. 2 are normalized according to this figure. From the normalized curve of $S(k)$ we plotted a curve of $kS(k)$ and by graphical integration from zero to the upper energy limit, we found that the energy emitted by P^{32} in the form of γ-radiation is $3.2\times10^{-3}\ mc^2$ per β. For RaE, the number of γ-quanta above 90 kev was 1.6×10^{-3} per β.

The theoretical value for the total intensity in P^{32} can be found by integrating the exact expression for $kS(k)$ neglecting Z-dependence and assuming an allowed β-transition. This number is $2.4\times10^{-3}\ mc^2$ per β.

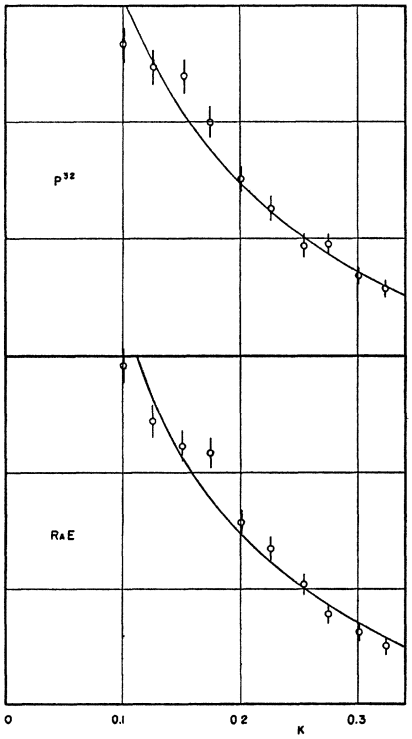

FIG. 1. Continuous γ-ray spectra. Curves represent the theoretical function $F(k)$, circles experimental points. Ordinate scale is arbitrary.

We conclude that both the total intensity and the spectral distribution show no significant discrepancy with the theory. The total intensity in P^{32} had been measured by Wu[1] with essentially the same result. No evidence was obtained for the emission of characteristic x-radiation from RaE reported by Bramson.[5]

Preliminary experiments on $\beta-\gamma$ angular correlation by discriminating the energies of both radiations, show a strong forward-backward asymmetry for high energy β-rays. This effect and the shape of continua emitted in highly forbidden β-transitions are being investigated.

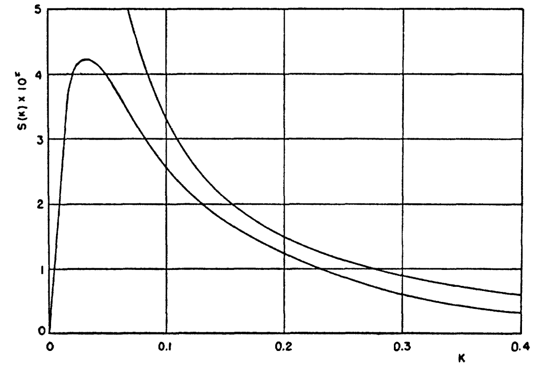

FIG. 2. Continuous γ-ray spectra. Upper curve represents the theoretical function $S(k)$ normalized according to the experimental value of the integrated intensity. Lower curve corrected for absorption and crystal efficiency.

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* Research carried out under contract with the AEC.

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An Equivalence Theorem in Meson Theory

K. V. ROBERTS
King's College, Cambridge, and H. H. Wills Physical Laboratory, University of Bristol, England

(Received May 7, 1951)

THE following equivalence theorem may be of interest; it arose during a discussion with Dr. N. Kemmer.

It is well known that the lagrangian for the charged scalar meson field, for example, interacting with the electromagnetic field, may be written in either of the two equivalent forms

$$\mathcal{L}_a=\chi(\chi^2U^\dagger U-U_i{}^\dagger U^i)-ie\chi(A_iU^\dagger U^i-A^iU_i{}^\dagger U)-e^2\chi A_iA^iU^\dagger U, \quad (1)$$

$$\mathcal{L}_b=\tfrac{1}{2}i(\psi^*\beta^i\partial_i-(\partial_i\psi^*)\beta^i\psi)+\chi\psi^*\psi+e\psi^*\beta^iA_i\psi, \quad (2)$$

where

$$U^i=\partial^iU,\quad U_i{}^\dagger=\partial_iU^\dagger, \quad (3)$$

and

$$\begin{aligned}\Gamma_k{}^*\beta_l\psi&=i\chi g_{kl}U, & \psi^*\beta_l\daleth_k&=-i\chi g_{kl}U^\dagger,\\ \Gamma_k{}^*\psi&=U_k-ieA_kU, & \psi^*\daleth_k&=U_k{}^\dagger+ieA_kU^\dagger.\end{aligned} \quad (4)$$

(The notation of Harish-Chandra[1] is used throughout.)

The different types of vertex which can occur in a Feynman-Dyson graph are known[2] to correspond to the different terms in the interaction lagrangian $\mathcal{L}^i$. It is therefore remarkable that the two interaction lagrangians, $\mathcal{L}_a{}^i$ and $\mathcal{L}_b{}^i$, are not the same, so that while only 3-vertices occur in case (b), both 3-vertices and 4-vertices occur in case (a). The purpose of this note is to show that this