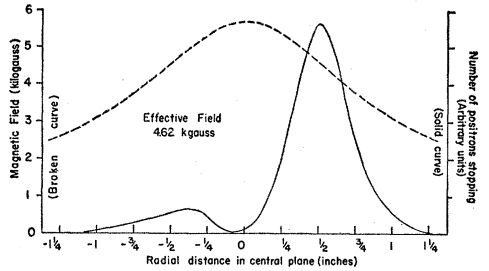

FIG. 1. Distribution of stopped positrons and radial variation of magnetic field in central plane.

photon decays from the former occur. The probability of such an event is approximately

$$[1+(\tau_1/\tau_3)(\Delta/2\hbar\omega_0)^2]^{-1}, \quad (1)$$

when $\Delta \gg 2\hbar\omega_0 = 2\hbar eH/mc$. The quantities, with their theoretical values, are $\tau_1/\tau_3 = 8.96\times10^{-4}$, the ratio of singlet and triplet half-lives;[1] and $\Delta = 0.845\times10^{-3}$ ev, the fine structure splitting.[2] The field does not alter the character of the 1^1S decays because $\tau_1/\tau_3 \ll 1$. By studying the three-photon annihilation of positronium as a function of magnetic field, $\Delta^2\tau_1/\tau_3$ can be determined. With methods similar to those described below, Deutsch has studied this effect.[3]

In the apparatus already described,[4] the positron-trapping field has been used also as the perturbing field. At six magnet currents, the coincidence rates in N_2 at 760 mm with and without 3 percent of NO were compared, and the percentage of positrons annihilating with three photons determined. The magnetic field is necessarily inhomogeneous; hence, the positions in the field where the positrons annihilate must be determined to interpret the data. A piece of aluminum foil $\frac{1}{4}$ in. $\times$ $\frac{1}{4}$ in. $\times$ 0.0006 in. supported from below by a wire was placed on the axis of the volume seen by the counters, and the coincidence rate with one atmosphere of air in the chamber measured at various distances from the center. These measurements were repeated with only the wire in position. The difference between these coincidence rates is taken to be proportional to the number of slow positrons which stop in each particular region. This interpretation is supported by the observation that the difference varies linearly with the thickness of the foil up to 0.0015 in., and is independent of the orientation of the foil. The radial variation of the field in this region was measured with a small search coil and an electronic fluxmeter.[5] Typical position and field data are shown in Fig. 1.

With these data and the calculated values of τ_1/τ_3 and Δ, the three-photon annihilation probability for the $m_j=0$ substate at the various currents can be calculated. If this probability is substituted back into Eq. (1), the effective field for each current is determined. These points are shown in Fig. 2, together with results

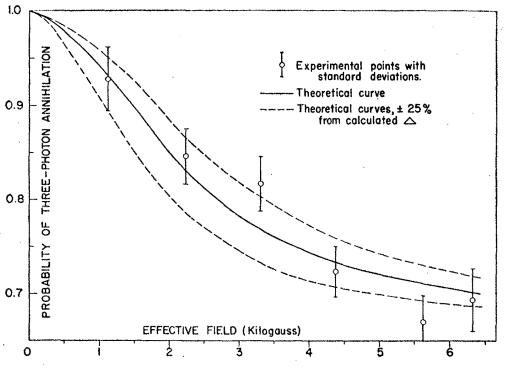

FIG. 2. Three-photon annihilation as a function of magnetic field.

of similar calculations with variations of ±25 percent from the calculated value of Δ. The probability varies between 1 and $\frac{2}{3}$ because it is assumed that the triplet substates are equally populated.

Experiment shows that at all fields the number of positrons that annihilate on the windows over the collimators is negligible. Other possible mechanisms for spurious coincidences have been investigated experimentally. Of these, random time coincidences predominate. The data have been corrected for this effect. The correction amounts to less than 1 percent of the total coincidence rate at all fields.

The experimental data show that the number of positrons decaying with three photons decreases from 15.8 percent at 1.12 kg effective field to 11.8 percent at 6.32 kgauss In order to normalize these data to the calculated points, the average of the six points is set equal to the average of the corresponding theoretical values. The result is shown in Fig. 2. Within experimental error, the points lie on the curve calculated for the theoretical value of $\Delta^2\tau_1/\tau_3$. The assumption of equal populations is justified. These results are in agreement with those of Deutsch.[3] Deutsch[6] has also measured τ_3 and finds it in agreement with the calculation of Ore and Powell.[1] Thus it seems likely that the theoretical value of τ_1/τ_3 is substantially correct. Therefore, the data in Fig. 2 can be considered a measurement of Δ^2.

* Supported by the AEC and the Higgins Scientific Trust Fund.
† AEC Predoctoral Fellow, 1949–1951. This material is part of a thesis to be submitted to Princeton University.

[1] A. Ore and J. L. Powell, Phys. Rev. **75**, 1696 (1949).
[2] R. A. Ferrell, Phys. Rev. **84**, 858 (1951).
[3] M. Deutsch and E. Dulit, Phys. Rev. **84**, 601 (1951).
[4] T. A. Pond, Phys. Rev. **85**, 489 (1952).
[5] R. H. Dicke, Rev. Sci. Instr. **19**, 533 (1948).
[6] M. Deutsch, Phys. Rev. **83**, 866 (1951).

Photoproduction of Neutral Mesons from Deuterium*

W. HECKROTTE, L. R. HENRICH, AND J. V. LEPORE
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
(Received December 17, 1951)

THE manner in which neutral mesons are coupled to nuclear matter may be determined by an experimental study of the photoproduction of neutral mesons from deuterium. This follows from the fact that the radiated meson waves may differ in phase depending on whether they arise from neutron or proton. The relative phase of this radiation is clearly controlled by the algebraic sign of the coupling. Thus, for meson wavelengths comparable to the separation of the particles in the deuteron, large interference effects may be expected.

Near threshold, meson production may be expected to lead to deuteron formation. For this case interference effects will be large. At higher energies, continuum states will be favored and the interference will be less.

We have calculated the cross section for neutral meson production when a deuteron is formed in the final state. The pseudoscalar meson theory with pseudovector coupling has been assumed, and we have treated the process according to perturbation theory. Although there is no straightforward way to do this, we have attempted to incorporate higher order meson processes by using the anomalous moments of the nucleons. Specifically, effects caused by exchange currents have been neglected but by using the anomalous moments we have, in a sense, included those virtual mesic effects not caused by the presence of a second nucleon. The nucleons have been treated nonrelativistically, and for simplicity the deuteron wave function has been taken as a Gaussian. In addition to this we have used plane waves in the intermediate states. The results are given in Fig. 1. It is found, as one might expect, that the principal contribution to the cross section is

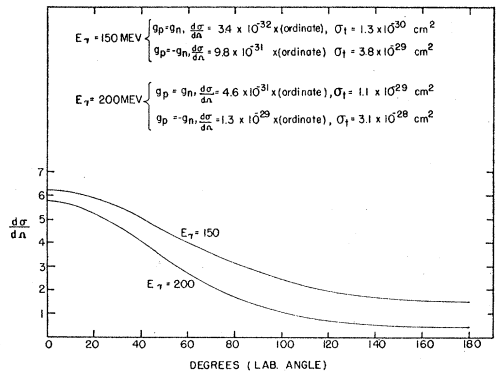

FIG. 1. The differential cross section in the laboratory system for photoproduction of neutral mesons in deuterium.

proportional to $(g_p\mu_p+g_n\mu_n)^2$, the square of the interaction energy. If g_n and g_p are of opposite sign, this term is larger than when they are the same. For $|g_n|=|g_p|$ the ratio between the two cases is 30. There is a difference in angular distribution but it is slight. We can expect our total cross section to be smaller than the correct value[1,2] if the coupling constant is chosen to be $\frac{1}{2}$ (either $g_p^2/\hbar c$ or $g_n^2/\hbar c$). However, the ratio of the cross sections for the two cases should be correctly given.

This experiment would have interesting implications regarding the charge independence of nuclear forces since the symmetrical meson theory, the most elegant designed to yield this result, requires $g_n=-g_p$.

* This work was performed under the auspices of the AEC.
[1] M. F. Kaplon, Phys. Rev. **83**, 712 (1951).
[2] K. Brueckner and K. Case, Phys. Rev. **83**, 1141 (1951).

The Coherent Neutron Scattering Cross Section of C^{13}

W. C. KOEHLER AND E. O. WOLLAN
Oak Ridge National Laboratory, Oak Ridge, Tennessee
(Received December 17, 1951)

NORMAL carbon has been used as a standard scatterer in connection with coherent neutron cross-section measurements,[1] because it nearly fulfills the condition of being a single zero spin nuclide for which the coherent scattering amplitude can be calculated directly from the results of transmission measurements because of the absence of isotope and spin incoherent scattering. The presence of 1.1 percent of C^{13} in normal carbon could, however, have an appreciable effect on the results if the scattering amplitude of C^{13} were much different than that of C^{12}, and especially if the scattering phases were opposite for the two nuclides. For this reason a direct measurement of the scattering amplitude of C^{13} has been made by neutron diffraction studies on samples of $BaCO_3$ enriched in C^{13}.

Two isotopically enriched samples, 53 and 40 atom percent C^{13}, originally prepared by the Eastman Kodak Company, were kindly loaned to us by Dr. S. F. Carson of the ORNL Biology Division. Neutron diffraction patterns of these samples, and also of normal $BaCO_3$, were obtained.

Barium carbonate (witherite) is orthorhombic, with four molecules per unit cell. It is isomorphous with KNO_3 and with several divalent metal carbonates, the prototype of which is aragonite ($CaCO_3$). Wyckoff[2] gives the space group as $V_h^{16}=P(b, n, m)$ with $a_0=8.8345$A, $b_0=6.5490$A, and $c_0=5.2556$A. The barium, carbon, and four of the oxygen atoms are in special positions of the space group, while the remaining eight oxygens occupy general positions. Barium parameters were reported by Zachariasen,[3] and Colby and LaCoste[4] have described the complete structure. On the basis of their parameters, structure factors have been calculated and are listed for a number of reflections in the second column of Table I. The corresponding F^2 values listed in the last column have been evaluated in terms of the carbon amplitudes only by using the previously measured coherent scattering amplitudes of 0.580×10^{-12} cm for oxygen and 0.528×10^{-12} cm for barium. In spite of the fact that the symmetry is low, it is possible in this case to obtain a quantitative measure of the carbon scattering amplitude. In the diffraction patterns of all three samples, the first three reflections (110), (101), and (200) appear as a single peak which is well resolved from the remainder of the pattern. Of these first three lines, the first is very weak and the other two show a strong carbon contribution.

The intensity of this first composite peak in each of the three samples was evaluated in terms of the coherent scattering cross section of 13.4 barns for nickel. A rough estimate of the characteristic temperature of $BaCO_3$ was made, and the intensities were corrected upward by two percent to take account of the effects of lattice vibrations. From the observed intensities the effective scattering amplitude of carbon in each of the three isotopic mixtures was evaluated. Since the intensity of the scattered beam depends upon the square of the structure factor, and hence, is quadratic in f_c, two roots, one positive and one negative, were obtained from each sample. An estimate of the errors involved in the experimental determination of intensities and in the sensitivity of the structure factors to the light atom positions was made, and the results are shown in Fig. 1. The lines in the figure correspond only to the positive root for $f_c=(p_1f_{12}+p_2f_{13})$, where p_1 is the fraction of carbon 12, p_2 of carbon 13, and f_{12} and f_{13} are the scattering amplitudes of the two isotopes. The negative roots are excluded because the scattering amplitude of normal carbon is known to be positive.[5] The coherent scattering amplitude of C^{13} is thus determined to be positive and to have a magnitude of 0.60 $\pm0.04\times10^{-12}$ cm, which is nearly equal to the value of 0.66×10^{-12} cm for normal carbon.

On the basis of these coherent amplitude values, one finds that the isotopic incoherence because of the presence of 1.1 percent C^{13} in normal carbon cannot be greater than about one millibarn. There is, however, also the possibility of incoherence arising from spin dependence in the C^{13} scattering. Information on this can be obtained from the total scattering cross section of C^{13}. From measurements of the transmission of neutrons by the normal and

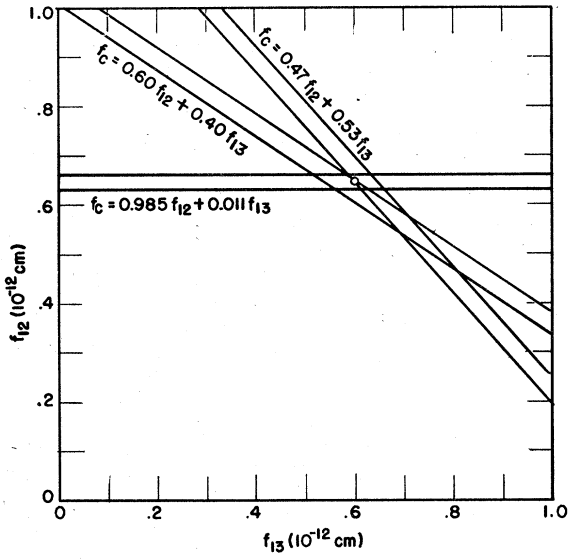

FIG. 1. The effective coherent scattering amplitudes of carbon, as determined from samples of $BaCO_3$ (normal and enriched in C^{13}), plotted as a function of the amplitudes f_{12} and f_{13} of C^{12} and C^{13}.