In general, two-body effects are important when the nuclear recoil is of the same order or smaller than the momenta occurring in the zero point motion of the deuteron. This means that if information on the nucleon spin dependence of the matrix elements is to be derived from a comparison of deuteron and proton cross sections, the measurement must be carried out at small angles of meson emission and not too high an incident photon energy.

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Close communication with H. Feshbach and M. Lax, who are also publishing a paper on this subject, was of great assistance to the authors. Much of the contents of the two papers is similar, and indeed an effort was made to employ the same notation. However, the Feshbach-Lax paper will be seen to emphasize different distribution variables than are here employed. For example they give the differential meson energy distribution, but do not obtain the total intensity at a given angle in a closed form. Also, since the validity of the different approximations made in the two papers is not entirely clear, it was felt worthwhile to publish the two separately.

APPENDIX

The Hulthèn Wave Function for the Ground State of the Deuteron

A convenient representation of the deuteron ground state is given by the Hulthèn function,

$$u_i(\rho)=\left[\frac{\alpha}{2\pi(1-\alpha\rho_1)}\right]^{\frac{1}{2}}\frac{(e^{-\alpha\rho}-e^{-\beta\rho})}{\rho}, \tag{A1}$$

where ρ_1 is the triplet neutron-proton effective range (1.74×10^{-13} cm), connected to the parameter, β, by the relation $\rho_1=4/(\alpha+\beta)-1/\beta$. The corresponding momentum space wave function is

$$c(\mathbf{k})=\left[\frac{\alpha}{\pi^2(1-\alpha\rho_1)}\right]^{\frac{1}{2}}\frac{(\beta^2-\alpha^2)}{(\alpha^2+k^2)(\beta^2+k^2)}. \tag{A2}$$

The Integral $F(k)$

From (15) and (A1), one easily finds

$$F(k)=\int\exp(i\mathbf{k}\cdot\boldsymbol{\varrho})u_i^2(\rho)d\boldsymbol{\varrho}=\frac{1}{1-\alpha\rho_1}\left(\frac{2\alpha}{k}\right)\times\left\{\tan^{-1}\left(\frac{k}{2\alpha}\right)+\tan^{-1}\left(\frac{k}{2\beta}\right)-2\tan^{-1}\left(\frac{k}{\alpha+\beta}\right)\right\} \tag{A3}$$

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Half-Life and Alpha-Particle Energy of U^{236}

A. H. JAFFEY, H. DIAMOND, A. HIRSCH, AND J. MECH
Argonne National Laboratory, Chicago, Illinois

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Several samples containing U^{236} were examined for measurement of the specific activity and the alpha-particle energy. The samples contained U^{234}, U^{235}, U^{236}, and U^{238}, the isotopic composition being known from mass spectrometer data. The samples were "weighed" through fission counting comparison with standards containing known amounts of pure U^{235}. The alpha-activity due to U^{236} was determined by ionization chamber energy analysis. The same instrument was used for the energy determination.

The half-life of U^{236} was found to be 2.46×10^7 years and the alpha-particle energy 4.499 Mev.

WORK at Los Alamos[1] in 1943 showed that some of the neutrons absorbed by U^{235} led to capture rather than to fission, with the presumable formation of the isotope U^{236}. It was later observed in highly irradiated U^{235} both mass-spectrographically[2] and with the alpha-energy pulse analyzer.[3] From the alpha-activity detected with the latter instrument, from the U^{235} capture cross section, and from the estimated neutron flux, the half-life was calculated to be approximately 2×10^7 years. The measured alpha-particle energy was 4.5 Mev.

U^{236} has been prepared recently in a more concentrated form by extensive neutron-irradiation of U^{235} followed by electromagnetic separation. Several of these samples have been made available,[4] which has made it possible for us to make more accurate measurements of both the half-life and alpha-particle energy of U^{236}.

The determination of the U^{236} specific activity involved the measurement of the weight of U^{236} in each sample and the alpha-particle disintegration rate due

TABLE I. Composition of U^{236} samples (mole percent).

Sample no.	U^{234}	U^{235}	U^{236}	U^{238}
I	0.3	59.0±0.20	22.15±0.25	18.55±0.25
II	0.4	54.5±0.24	22.0±0.30	23.1±0.30
III	0.65±0.02	58.58±0.19	37.62±0.18	3.17±0.03

[1] Unpublished Los Alamos work.
[2] D. Williams and P. Yuster, Los Alamos Report LAMS-195 (1945) (unpublished).
[3] Ghiorso, Brittain, Manning, and Seaborg, Phys. Rev. **82**, 558 (1951).
[4] We are indebted for these samples to Dr. R. S. Livingston of the Electromagnetic Research Laboratory, Carbide and Carbon Chemicals Division, Oak Ridge, Tennessee.

TABLE II. Half-life values from three samples containing U^{236}.

Sample	Half-life value
I	$(2.43_7 \pm 0.03_6) \times 10^7$ years
II	$2.45_3 \pm 0.02_8$
III	$2.48_0 \pm 0.04_5$
Average	$2.45_7 \times 10^7$ years

to it. To determine the weight of U^{236}, relative concentrations of the uranium isotopes were measured by mass-spectrometric analysis[5] (Table I), and the absolute weight of uranium in each sample was determined indirectly by counting neutron-induced fissions. Although the sample weight could be determined, in principle, by weighing techniques, the samples were too small for good purification and accurate weighing to be done conveniently, and fission counting was used instead. Since the U^{235} concentrations were known, the total uranium weight could be determined by comparing the fission rates with that of a sample containing a known amount of U^{235}. The comparisons were made in a 2π ion chamber imbedded in paraffin using a one-gram Ra—Be sample as neutron source. To minimize effects of sample thickness, the fission counting rates were determined as a function of pulse height and extrapolated to zero pulse height. In addition, small corrections were made for the fission fragments totally absorbed in the sample.

To determine the U^{236} alpha-activity, collimated samples were measured in a grid-type ionization chamber associated with a 48-channel pulse height analyzer.[6] The pulse analysis results determined the fraction of the total alpha-activity which was due to U^{236}. The total alpha-activity was measured in a 2π argon-CO_2 pulse ionization chamber, and the counting rate determined by extrapolating the counting-rate curve to zero pulse-height. The counting efficiency of 51.3 percent was evaluated by measuring several alpha-emitting samples in the argon-CO_2 counter and also in a calibrated low geometry counter (geometry calculated from dimensions), where effects of sample backscattering were negligible.[7]

TABLE III. Alpha-energy standards.

Nuclide	Energy, Mev	Nuclide	Energy, Mev
Po^{210}	5.298[a]	Pu^{238}	5.493[b]
Pu^{239}	5.140[b]	U^{234}	4.763[c, d]

[a] G. T. Seaborg and I. Perlman, Revs. Modern Phys. **20**, 633 (1948).
[b] W. P. Jesse and H. Forstat, Phys. Rev. **73**, 926 (1948).
[c] Clark, Spencer-Palmer, and Woodward, British Report-522, October 10, 1944 (unpublished).
[d] See reference 8.

The results from the three samples are shown in Table II. The errors include standard deviations of the mass spectrometric measurements and pulse analyses, and estimated errors in extrapolating alpha and fission counting plateaus to zero pulse height and in the use of 51.3 percent counting efficiency.

The energy of the U^{236} alpha-particle was measured in the grid-type ionization chamber (with pulse-analyzer)[6] relative to standard samples containing alpha-emitters of known energy. Pu^{238}, Pu^{239}, Po^{210}, and U^{234} were used as the reference standards, the U^{234} being present in the U^{236}-containing sample. The samples were collimated to reduce effects of sample self-absorption and alpha-backscattering. The energies used are given in Table III. It was assumed that the energy-ionization curve was linear over the region considered. This assumption has been shown to be true in argon (the gas used in this chamber).[8,9] Since no attempt was made to measure the position of zero pulse height, the U^{236} energy was really determined relative to that of U^{234}, the other standards being used to determine the slope of the pulse height *versus* energy curve. Thus, an error in the U^{234} energy used will be reflected in an almost equal systematic error in the U^{236} alpha-energy. However, errors due to peak shifts from sample self-absorption are almost canceled, since the U^{234} peak is shifted by almost the same amount as the U^{236} peak. The average of nine measurements resulted in an alpha-particle energy value of 4.499 ± 0.004 Mev (mean deviation).

[5] We wish to thank M. G. Inghram and D. C. Hess (Argonne National Laboratory) and R. F. Hibbs (Y-12 Chemical Division Assay Laboratory, Carbide and Carbon Chemicals Corporation, Oak Ridge, Tennessee) for mass spectrographic analyses of the uranium samples.

[6] Ghiorso, Jaffey, Robinson, and Weissbourd, *The Transuranium Elements* (McGraw-Hill Book Company, Inc., New York, 1949), Paper No. 16.8, National Nuclear Energy Series, Vol. 14B, Division IV.

[7] A. H. Jaffey, "Radiochemical assay by alpha and fission measurements," National Nuclear Energy Series, Vol. 14A, Division IV, Chapter 16 (to be published).

[8] W. P. Jesse and J. Sadauskis, Phys. Rev. **78**, 1 (1950).

[9] Jesse, Forstat, and Sadauskis, Phys. Rev. **77**, 782 (1950).