thin targets fit the calculated curve to within the statistical errors, which are similar to those in Fig. 1. However, the shape of the cutoff is measurably altered by spreading the beam in time. With a beam pulse 2.5 milliseconds long, the measured energy spread is about 2 percent, in agreement with the spread predicted from the time variation of the 30-cycle magnetic field.

Some experimental data on the energy sharing between members of electron pairs have also been obtained. Preliminary results were affected by scattering by the walls of the spectrometer vacuum chamber,[6] but after this effect was eliminated, the results shown in Fig. 2 were obtained for 270-Mev photons and a ½-mil gold pair former. The experimental points represent relative true coincidence rates for various pairs of counter groups representing the same total momentum of the electron pairs. The errors are the standard statistical errors. The curve is the Bethe-Heitler differential cross section;[3] the agreement is well within the statistics.

* Supported by the joint program of the ONR and AEC.
[1] DeWire, Ashkin, and Beach, Phys. Rev. **82**, 447 (1951).
[2] L. I. Schiff, Phys. Rev. **70**, 87 (1946).
[3] H. A. Bethe and W. Heitler, Proc. Roy. Soc. (London) **146**, 83 (1934).
[4] Powell, Hartsough, and Hill, Phys. Rev. **81**, 213 (1951).
[5] M. Camac (private communication).
[6] J. W. DeWire and L. A. Beach, Bull. Am. Phys. Soc. **26**, No. 3, 42 (1951).

Gamma-Radiation from I^{132}

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THE decay of the photoneutron activity created by neutron-irradiated U^{235} as measured by Bernstein and Talbot[1] has recently been analyzed by Ergen[2] and yielded tentative evidence for the existence of a gamma-ray above the photoneutron threshold of Be in the spectrum of I^{132}. This gamma-ray has been confirmed by Parker[2] using photoneutron methods and separated I^{132}. Since earlier absorption measurements[3] indicated no gamma-ray energies above 1.4 Mev, the present investigation was carried out to find this gamma-ray energy. Further interest may be evidenced in the I^{132} spectrum, since the Brookhaven National Laboratory has recently announced[4] the production of this isotope for medical purposes.

Numerous sources of I^{132} were distilled from separated Te in a 4 *M* HNO_3 solution with the addition of 7 percent H_2O_2. The iodine was collected as NaI in a dilute NaOH solution. The source, in all cases, was allowed to stand a sufficient time so that iodine activities from short-lived tellurium isotopes were not present. The measured half-life was 2.4 hr. For the preparation of the many sources used, the authors are indebted to Dr. George W. Parker of Oak Ridge National Laboratory.

Energy measurements were made by three methods, all using NaI crystals. In the first method, a single NaI crystal was used to obtain the spectrum shown in Fig. 1, curve A. This spectrum was run several times and was observed to decay with a half-life of 2.3 to 2.4 hr. Energies of the three gamma-rays listed in Table I were determined, using Cs^{137}, Co^{60}, and ThC″ gamma-rays as standards. The intensities in Table I were estimated by correcting the heights of the photoelectric peaks above background by the photoelectric cross section of NaI. A similar estimate with a Na^{24} source indicated equal intensities of the two gamma-rays within 14 percent.

TABLE I. Gamma-rays in I^{132}.

	Gamma-ray energy		Relative intensity
	From single-crystal spectrometer	From Hofstadter-type two-crystal spectrometer	from single-crystal spectrometer
1	0.67	0.69 (0.80)	37
2	1.41	1.41	4
3	1.99	2.02	1

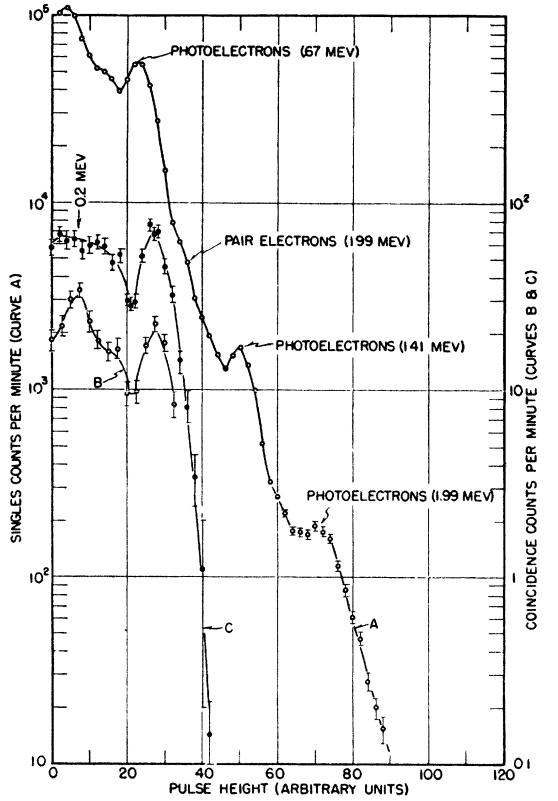

FIG. 1. Single-crystal and coincidence spectra of I^{132}.

Further measurements were made using two complete single-crystal spectrometers connected in coincidence, the source being placed midway between the two 1½-in. crystals which were about ¾-in. apart. For curve B, Fig. 1, one channel was fixed at the photoelectron peak of the 1.4-Mev gamma-ray with a window width of 15 units. The other channel, with a 2-unit window width, was varied to give the spectrum shown. A broad low energy peak was found at about 0.2 Mev. It seemed probable that this peak was due to backscattered secondary Compton gamma-rays. In order to reduce this effect, a ½-in. lead shield was placed between the crystals with a hole drilled in it so the source could see both crystals. Measurements made with a stronger source with this arrangement are shown in curve C, and the low energy peak had now disappeared. This curve was corrected by subtracting the chance coincidence rate as determined with a Cs^{137} source. The background rate amounted to about 25 percent of the total counting rate at the higher energy peak.

Since a peak occurs in the coincidence curves at 0.7 Mev (note that the gain had shifted slightly since the single run which was made two weeks earlier), the 0.7-Mev gamma-ray is in coincidence with either the 1.4- or the 2.0-Mev gamma-ray. The latter possibility was eliminated by another coincidence run in which the fixed channel was placed at 0.7 Mev. Since no coincidences were observed at 2 Mev, the 0.7-Mev gamma-ray must be in coincidence with the 1.4-Mev gamma-ray. The marked inequality of the intensities of these gamma-rays is in general agreement with earlier indications that the beta-spectrum is complex.[3] The 2.0-Mev gamma-ray presumably represents the cross-over transition.

A final set of energy measurements was made with a Hofstadter-type two-crystal spectrometer.[5] Since the coincidence counting

rates at the high energy gamma-ray were quite low, it proved expedient to record the data by photographing the oscilloscope screen. The oscilloscope was made to operate as a gate by modulating the intensity with the pulse from the degraded-gamma-counting crystal. Figure 2 shows a reproduction of such a photo-

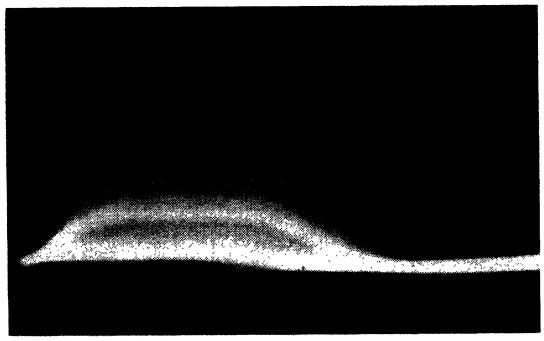

FIG. 2. I^{132} spectrum with Hofstadter-type two-crystal spectrometer.

graph. The original negative shows lines corresponding to the three gamma-rays at energies listed in Table I, together with the pair line from the high energy gamma-ray and an indication of a weak line at 0.8 Mev.

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[1] Bernstein and Talbot, AECD-1833 (unpublished).
[2] W. K. Ergen, private communication.
[3] K. Way, *Nuclear Data*, NBS Circular No. 499, 152 (U. S. Government Printing Office, Washington, D. C., 1950).
[4] Winsche, Stang, and Tucker, Nucleonics **8**, 14 (1951).
[5] R. Hofstadter, Phys. Rev. **78**, 617 (1950); and Bair, Maienschein, and Baker, Phys. Rev. **81**, 283 (1951).

On the Hyperfine Structure of Hydrogen and Deuterium

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BREIT *et al.*[1] have shown that, if the Breit hamiltonian is used, the ratio of the hyperfine structure in deuterium and hydrogen is given, except for correction terms of relative order of magnitude of $\alpha^2(m/M)$, by

$$(\nu_D/\nu_H)_{\text{theor}}=(3/4)(m_D/m_H)^3(\mu_D/\mu_P). \tag{1}$$

Very accurate measurements of the ratios of the hyperfine structure[2] and of the magnetic moments[3] of deuterium and hydrogen have been carried out recently. These give

$$\Delta\equiv 1-\left[\frac{(\nu_D/\nu_H)_{\text{exp}}}{(\nu_D/\nu_H)_{\text{theor}}}\right]=(1.702\pm 0.008)\times 10^{-4}. \tag{2}$$

Low[4] has discussed in detail the effect of the structure of the deuteron on the ratio (ν_D/ν_H). The largest source of error in his result was the uncertainty in the expectation value $\langle 2\gamma R\rangle_S$ for the S-state part of the wave function for the deuteron ground state, γ^{-1} being the "radius" of the deuteron. The accuracy of low energy measurements on the neutron-proton forces has been improved greatly in the last few years, and the present value[5] for the effective triplet range $\rho_t(0,-\epsilon)$ is now $(1.704\pm 0.030)\times 10^{-13}$ cm and for the deuteron binding energy (2.226 ± 0.003) Mev. From the above value for $\rho_t(0,-\epsilon)$ a value for $\rho_t(-\epsilon,-\epsilon)$, the effective range defined in terms of the deuteron ground-state wave function, can be calculated separately for each shape of the neutron-proton potential.[5] Approximate deuteron ground-state wave functions for each potential shape were used, accurate at small distances as well as asymptotically and containing one arbitrary parameter each. This parameter was fixed so as to give exactly the appropriate value for $\rho_t(-\epsilon,-\epsilon)$. Using these wave functions $\langle 2\gamma R\rangle_S$ was then calculated for each potential shape. Due to some fortuitous cancellation $\langle 2\gamma R\rangle_S$ does not depend strongly on potential shape. For a Yukawa and square well potential $\langle 2\gamma R\rangle_S$ was found to be 1.44 and 1.47 respectively, with intermediate values for an exponential and gaussian potential. We shall use a value of

$$\langle 2\gamma R\rangle_S=(1.45_5\pm 0.03). \tag{3}$$

Using this value the numerical result of Low's[4] calculation becomes

$$\Delta=(1.98\pm 0.10)\times 10^{-4}. \tag{4}$$

The value (4) obtained for Δ was based on the assumption that (a) the Breit hamiltonian is completely correct and (b) each nucleon behaves as a point-particle with both its electric charge and magnetic moment concentrated in a point and fixed. In the derivation of the Breit hamiltonian from quantum electrodynamics by means of second-order perturbation theory, the recoil energy of the nucleus has to be neglected compared with the energy of the virtual photon which is interchanged. No completely consistent alternative for the Breit hamiltonian has, as yet, been applied to this problem. The correction to the Breit term due to the nuclear recoil can, however, be estimated by a simple nonrelativistic calculation. The integral obtained for this correction from the nonrelativistic region (photons of energy much less than the rest energy of the nucleus) involves a logarithm whose numerical value is about 10. A relativistic treatment would, presumably, result in the addition to this logarithm of some term of the order of magnitude of unity.

For a nucleus of unit charge and mass AM this nonrelativistic calculation results in a factor, multiplying the expression for the hyperfine structure, of

$$1-(4/\pi A)(\hbar/Mca_0)\log(a_0/r_0), \tag{5}$$

where a_0 is the Bohr-radius and r_0 is a cut-off radius of the order of the nuclear Compton wavelength. For the case of deuterium the range of integration for distances smaller than the range of nuclear forces should really be treated separately. However, to the accuracy of a nonrelativistic treatment, it suffices to replace r_0 by $(\hbar/Mc)$. This leads to a value of Δ larger by $(0.3\pm 0.1)\times 10^{-4}$ than the value given in (4). Relativistic effects for the electron cannot contribute to the ratio (ν_D/ν_H), and there seem to be no other relativistic terms for the nuclei which could alter Δ by as much as the error $(\pm 10^{-5})$ quoted above.

We therefore conclude that the rather large difference between the values (4), plus the recoil correction term, and (2) for Δ, obtained from the calculation and experiments, respectively,

$$(+0.58\pm 0.20)\times 10^{-4} \tag{6}$$

is a result of the structure of the nucleons themselves. One possible effect would be a dependence of the magnetic moment of one nucleon on the proximity of another. This would mean that the value of 4 percent, assumed for the percentage D-state of the deuteron in the above calculation,[4] is incorrect. Another possibility[6] is that the magnetic moment of a nucleon is spread over a certain finite radius. If all of the discrepancy in Δ mentioned above were due to, say, only the anomalous part of the magnetic moment of a nucleon being spread out uniformly up to a certain radius, this radius would have to be rather large, of the order of magnitude of at least 2×10^{-13} cm.

[1] G. Breit and R. E. Meyerott, Phys. Rev. **72**, 1023 (1947); Breit, Brown, and Arfken, Phys. Rev. **76**, 1299 (1949).
[2] A. G. Prodell and P. Kusch, Phys. Rev. **79**, 1009 (1950).
[3] Smaller, Yasaitis, and Anderson, Phys. Rev. **81**, 896 (1951).
[4] F. Low, Phys. Rev. **77**, 361 (1950).
[5] E. E. Salpeter, Phys. Rev. **82**, 60 (1951).
[6] A. Bohr, Phys. Rev. **73**, 1109 (1948).

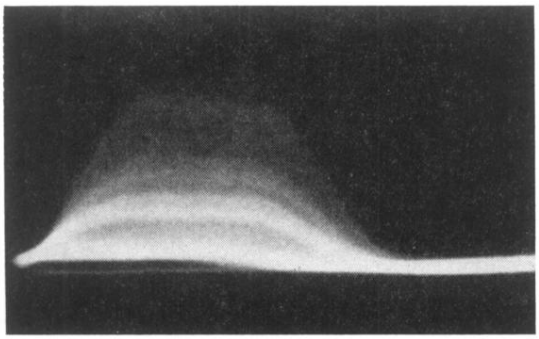

FIG. 2. I^{132} spectrum with Hofstadter-type two-crystal spectrometer.