Nuclear Hyperfine Structure Interaction in 3.1-hr Cs^{134m}*

D. A. GILBERT AND VICTOR W. COHEN
Brookhaven National Laboratory, Upton, New York
(Received November 19, 1954)

WE have performed a magnetic resonance atomic beam experiment[1,2] on 3.1-hr Cs^{134m} to observe the transitions $\Delta F=\pm 1$. In a magnetic field in the neighborhood of 1 gauss the spectrum was split into many components. The central π component $(17/2, +1/2 \rightleftarrows 15/2, -1/2)$ and $(17/2, -1/2 \rightleftarrows 15/2, +1/2)$ is field-independent and extremely narrow compared to the others. The frequency of the center of this line is equal to $\Delta W/h$, where ΔW is the hyperfine structure interaction energy. We observe this line at several values of the magnetic field. It had a width of approximately 100 kc/sec and a center at 3684.594 Mc/sec. The principal limitation on the accuracy was noise modulation on the 2K42 Klystron used as a source. The results of four runs at differing magnetic fields gave a total spread in peak frequency of about 15 kc/sec. In view of this we feel that ± 20 kc/sec is a conservative estimate of error. This result, combined with that computed from reference 1,[3] serves to confirm the assumption of a positive sign for the nuclear magnetic moment.

The high precision in the determination of ΔW will be of interest for possible study of hyperfine structure anomaly in the 2.3-yr and the 3.1-hr states of Cs^{134}. Work toward this objective is in progress.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] V. W. Cohen and D. A. Gilbert, Phys. Rev. **95**, 569 (1954).
[2] L. Goodman and S. Wexler, Phys. Rev. **95**, 570 (1954).
[3] In computing data of reference 1 an error was made in the sign of g_I. A recomputation gives 3684.2 ± 0.6 Mc/sec.

Deuteron Stripping and the Problem of Nuclear Radii

L. N. COOPER* AND W. TOBOCMAN
Institute for Advanced Study, Princeton, New Jersey
(Received November 16, 1954)

RECENT experiments on high-energy electron scattering[1] and on the transition energies of mu mesonic atoms[2] have been interpreted[3,4] as indicating that the charged matter inside the nucleus is confined approximately within a sphere of radius $R \simeq 1.2 \times A^{\frac{1}{3}} \times 10^{-13}$ cm or smaller. On the other hand, experiments like those on 90-Mev neutron scattering[5,6] or inelastic collision cross sections[7,8] (which are sensitive to the distribution of nuclear matter as distinguished from charged matter) seem to indicate that the nuclear matter is not confined to such a small volume. Such results have suggested the possibility that protons occupy a smaller volume than neutrons in the nucleus, and an attempt to justify such a hypothesis has recently been published.[9]

The purpose of this note is to point out that the measurement of cross sections for deuteron stripping (or pick-up) reactions can provide a direct experimental measurement of the difference in the probability for finding a proton or a neutron at the surface of a nucleus. These cross sections are in fact just proportional to the probability for finding the stripped-off (picked-up) particle at the surface of the residual (target) nucleus.[10] Thus, for example, if one measured the cross sections for (d,p) and (d,n) reactions leading to similar residual nuclei, one could calculate the reduced width (which is proportional to the probability for finding the particle at the nuclear surface) for the last proton or the last neutron of each residual nucleus. If the protons are indeed confined to a smaller volume than the neutrons, one should find the proton reduced widths characteristically smaller than the neutron reduced widths.

Such an effect apparently has been noted in one case by Fujimoto, Kikuchi, and Yoshida.[11] They calculated the reduced widths for three corresponding levels in the mirror nuclei Mg^{25} and Al^{25} from measurements made on the $Mg^{24}(d,p)Mg^{25}$ and $Mg^{24}(d,n)Al^{25}$ reactions. The reduced widths for Mg^{25} were found to be about 10 times greater than the reduced widths for Al^{25}. This discrepancy appears to be too great to be accounted for by the fact that these workers neglected the Coulomb interaction and the interaction of the liberated particle with residual nucleus in their calculations.

Rough estimates of the dependence of the reduced widths on the distributions of protons and neutrons show that the ratio of reduced widths, γ_p/γ_n, is quite sensitive to differences in the distributions. If one chooses a uniform neutron density to a radius of $R=1.4A^{\frac{1}{3}}\times 10^{-13}$ cm, and a proton density with a rms value $\langle r^2\rangle^{\frac{1}{2}}=1.0A^{\frac{1}{3}}\times 10^{-13}$ cm (equivalent to a uniform density to $R=1.2A^{\frac{1}{3}}\times 10^{-13}$ cm), then choosing various shapes for the proton density results in values of γ_p/γ_n of the order of $\frac{1}{6}$, independent of A (assuming the shape to be independent of A). Thus if such a difference in distributions were the explanation of the experimental results cited above, it should easily be detected by a comparison of corresponding (d,p) and (d,n) cross sections.

The mirror nuclei are particularly well suited for the measurements suggested above because it is to be expected that the other factors affecting the reduced widths would be the same. For example, one might compare reduced widths calculated from measurements of the cross sections for the $Ca^{40}(d,p)Ca^{41}$ and $Ca^{40}(d,n)$-Sc^{41} reactions. These two reactions are (excluding Coulomb effects) symmetrical with respect to the roles played by protons and neutrons. Since at the relevant energies the Coulomb interaction can be taken into account[10] in calculating the reduced widths, a discrepancy in the reduced widths from two such reactions [especially at the higher energies where the Coulomb effects diminish] would indicate that the neutron and proton distributions were not identical. This in the case of mirror nuclei would be quite surprising.

Heavier nuclei are also of great interest because it is for them that the experiments which have suggested distribution differences are most reliable. It is not possible, however, to get complete symmetry between protons and neutrons once one leaves the region of the mirror nuclei. Instead one can choose cases in which neutron and proton shells are completed in the respective residual nuclei. These are advantageous because factors other than distribution differences which might influence the reduced widths are minimized, while at the same time the possibility of separating the ground state level from other levels so that a measurement can be made is enhanced. An example would be $Tl^{205}(d,n)Pb^{206}$ and $Pb^{207}(d,p)Pb^{208}$.

Note added in proof.—Our attention has been called to related experimental and theoretical work on pickup processes by W. N. Hess and B. J. Moyer, Phys. Rev. **96**, 859 (A) (1954); and W. N. Hess, thesis, University of California Radiation Laboratory Report UCRL-2670, 1954 (unpublished).

* National Science Foundation Post-Doctoral Fellow.

1 Hofstadter, Fechter, and McIntyre, Phys. Rev. **92**, 978 (1953); Hofstadter, Hahn, Knudsen, and McIntyre, Phys. Rev. **95**, 512 (1954); Pidd, Hammer, and Raka, Phys. Rev. **92**, 436 (1953).

2 V. L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953).

3 L. I. Schiff, Phys. Rev. **92**, 988 (1953); Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).

4 L. N. Cooper and E. M. Henley, Phys. Rev. **92**, 801 (1953).

5 Cook, Macmillan, Peterson, and Sewell, Phys. Rev. **75**, 7 (1949).

6 Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

7 Millburn, Birnbaum, Crandall, and Schecter, Phys. Rev. **95**, 1268 (1954); (see also for other references).

8 W. Heckrotte, Phys. Rev. **95**, 1279 (1954).

9 M. H. Johnson and E. Teller, Phys. Rev. **93**, 357 (1954).

10 W. Tobocman, Phys. Rev. **94**, 1655 (1954).

11 Fujimoto, Kikuchi, and Yoshida, Progr. Theoret. Phys. (Japan) **11**, 264 (1954).

Angular Correlation Effects in Unstable Particle Decay*

S. B. TREIMAN, GEO. T. REYNOLDS, AND A. L. HODSON
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

(Received November 2, 1954)

ONE line of approach in the attempt to reconcile the long lifetimes and copious production of the new unstable particles is to suppose that the particles have high spin angular momentum.[1] This view is beset with grave difficulties, but the assumption of large spin does lead to testable consequences. In particular one might expect to find strong angular correlation effects in both the production and decay processes of the high spin particles.

There is some preliminary evidence, from Brookhaven[2] as well as from cosmic-ray experiments,[3] that Λ^0 particles are produced in states of high orbital angular momentum. This is by no means conclusive proof of high spin, but it is suggestive. The purpose of the present note is to discuss an experimental method which can provide a lower-limit estimate of the spins of unstable particles which undergo two-body decay. This consists in searching for angular correlation effects in the decay processes. Quite aside from the question of whether the assumption of large spin will ultimately prove adequate to account for their metastability, it is of course a matter of considerable interest to determine the spins of the new unstable particles. Preliminary evidence reported in the following letter[4] indicates that there may be at least one species of V^0 particle which has spin greater than one-half.

Consider a particle which undergoes two-body decay. The normal to the decay plane, $\mathbf{n}$, must be perpendicular to the line of flight of the unstable particle. Let $\mathbf{N}$ be some reference vector which is normal to the line of flight and which is defined independently of the decay normal $\mathbf{n}$. For example, in the case of single V^0-particle events, one may define $\mathbf{N}$ as the normal to the plane containing the line of flight of the primary particle which produces the nuclear interaction and the line of flight of the emerging V^0 particle. In events where two unstable particles come from a common nuclear interaction, an alternate choice for $\mathbf{N}$ would be the normal to the plane containing the two unstable particles. (It is events of this kind which are discussed in the following letter.)

In either case, if the unstable particle decays isotropically in its rest frame, the angle η between $\mathbf{n}$ and $\mathbf{N}$ should take on all possible values with uniform probability. Now spin zero and spin one-half particles must in fact decay isotropically, for reasons of parity and angular momentum conservation. Thus, any statistically significant departure from a uniform distribution in η for a series of decay events would immediately imply spin greater than one-half. The converse, however, is not necessarily true: a uniform distribution in η does not rule out spin greater than one-half, since the spins may be randomly oriented with respect to the reference vector $\mathbf{N}$.

The most general form of the angular distribution in the case of a particle of spin S which undergoes two-body decay can easily be obtained by the methods of Wolfenstein.[5] In the rest system of the unstable particle, the final state wave function ψ has definite parity and is an eigenfunction of angular momentum corresponding to eigenvalue S. The outgoing intensity $|\psi|^2$ must therefore transform under rotations as a sum of spherical harmonics of even parity. After one sums over final spin states, the spherical harmonic of maximum degree which can appear in the expression for the outgoing intensity is either $2S$ or $2S-1$ (according as S is integer or half-odd integer).[5]

The angular distribution in the rest frame of the unstable particle is therefore