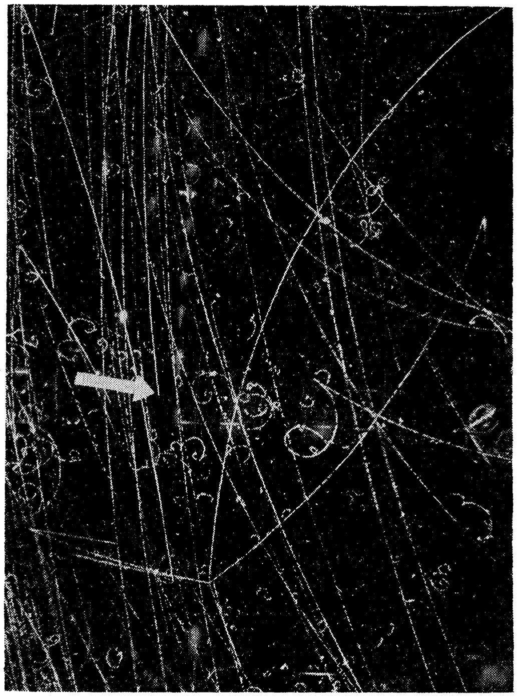

FIG. 3. An antiproton charge exchange. The antiproton is incident from the top and to the left of center, and the antiproton ending is indicated by an arrow. The antineutron from the charge-exchange process annihilates in the lower center of the picture. Five pions are produced in the annihilation with an energy release >1500 Mev.

butions differ markedly from the n-p which is also plotted for comparison. The total $\bar{p}$-p elastic cross section for scattering between 15° and 165° (center of mass) is 41_{-7}^{+10} mb. This should be compared to Fulco's value of 68 mb for the same angular interval.

The charge-exchange process $\bar{p}+p \rightarrow \bar{n}+n$ can be observed in the bubble chamber. One event has been identified and it is shown in Fig. 3 because of its inherent interest. The angle between the antiproton direction and the line connecting the antiproton ending with the vertex of the star is 30° in the lab system. The visible energy release in the star is >1500 Mev with the tentative identification of the annihilation products as $3\pi^+$ and $2\pi^-$. Thus the star is consistent with the process $\bar{n}+p \rightarrow 3\pi^+ + 2\pi^-$. The energy of the antiproton at the point of disappearance is estimated as 50 ± 30 Mev.

Other results such as the carbon annihilation and scattering cross sections and details of the annihilation process must await completion of the analysis.

[1] Five additional $\bar{p}$-p scattering events have been observed in nuclear emulsions by Chamberlain, Goldhaber, Jauneau, Kalogeropoulos, Segrè, and Silberberg. These are reported in the *Proceedings of the Padua-Venice Conference on Fundamental Particles, 1957* (Suppl. Nuovo cimento, to be published).

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9.51-Mev Level in N^{14}

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IT was pointed out recently[1] that the radiative decay angular distributions from the 9.51-Mev state in N^{14} were inconsistent with the spin assignment of $J=3$ reported in a paper on a $C^{13}(p,p)C^{13}$ experiment done previously,[2] but were consistent with a $J=2$ assignment. Because of this discrepancy, the analysis of the elastic scattering data was redone with the result that the assignment of $J^\pi=2^-$ does give a better fit than $J^\pi=3^-$. The resonance is fit well with a mixture of forty percent $S=1$ and sixty percent $S=0$ states and a level width of 40 kev. It is interesting to note that this mixture corresponds to $j=\frac{5}{2}$ with essentially no contribution from $j=\frac{3}{2}$, where j is the sum of the orbital angular momentum and one of the spins; j is then combined with the other spin to give J. An assignment of $J^\pi=1^-$ for the level gives a very poor fit, as do any other assignments with the possible exception of $J^\pi=3^-$ mentioned previously.

Because of the interference between the 9.39- and 9.51-Mev levels, the width of the 9.39-Mev level changed to about 20 kev; the assignment is still 1^-.

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Hyperfine Structure of Deuterium and Nucleon-Nucleon Spin-Orbit Potentials*

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THE original suggestion[1] that nucleon-nucleon forces include a spin-orbit term has recently been reconsidered by a number of authors.[2] The inclusion of such forces leads to a modification of the magnetic properties of the deuteron[3] and in particular modifies the magnetic moment, as has been emphasized in a recent paper by Feshbach.[4] It is the purpose of this note to point out that the hyperfine structure (hfs) of deuterium is a very sensitive indicator of the amount of spin-orbit forces in the deuteron; and that even with the present theoretical uncertainty in the interpretation of the hfs, it affords a limitation on the amount of magnetic moment arising from spin-orbit forces which proves to be more severe than that afforded by mere examination of the magnetic moment of the deuteron.[4]

The magnetic moment μ_{SL} arising from spin-orbit forces will contribute to the hfs anomaly,[5] namely that part of the hyperfine separation beyond the amount calculated on the basis of a point nucleus, using the experimental magnetic moment of the deuteron. Since μ_{SL} arises from proton motion in the presence of a magnetic field, the moment is "orbital" in nature[5,6]; that is, the electron moving rapidly inside a radius R will be able to follow the proton motion with a consequent relative change in the hfs,

$$\Delta_{SL}=-\frac{\mu_{SL}}{\mu_d}\left(\frac{2R}{a_0}\right), \tag{1}$$

where μ_d is the magnetic moment of the deuteron, and a_0 is the Bohr radius of hydrogen. An approximate formula for R is[7]

$$R=k\frac{mc^2}{|W_0|}\alpha a_0, \tag{2}$$

where mc^2 is the rest energy of the electron, W_0 is the binding energy of the deuteron, and α is the fine structure constant. For magnetic moments which are distributed over a distance of the size of the deuteron, $k=1.9$,[7] but for the short-range spin-orbit force, explicit evaluation indicates that k is close to unity. Thus one obtains with $k=1$, for the deuteron,

$$\Delta_{SL}/\mu_{SL}=-0.0039\ (\text{nm})^{-1}. \tag{3}$$

The comparison between theory and experiment for the hfs of the deuteron has recently been reviewed.[8,9] When nucleon size effects are included,[9] one finds

$$\frac{\Delta\nu_{\text{D}}}{\Delta\nu_{\text{H}}}=\frac{3}{4}\frac{M_{\text{D}}}{M_{\text{H}}}\frac{\mu_d}{\mu_p}(1-\Delta), \tag{4}$$

where $\Delta_{\text{exp}}=170.3\pm0.5$ ppm, and $\Delta_{\text{theor}}=210\pm50$ ppm. The theoretical value for Δ [Eq. (4)] does not include relativistic and mesonic effects; these have been studied most recently by Sugawara,[10] who estimates on the basis of field theory that the effects are of the order of one to two percent of the deuteron magnetic moment. The uncertainty in Δ does not include this possibility, but simply refers to computational uncertainties in the terms included.[9] The noncovariant result of Greifinger[8] may also not contain all the important terms of a fully covariant treatment.

As a typical example, the Gammel-Thaler potential[2,4] yields $\mu_{SL}=-0.036$ nm and $\Delta_{SL}=140$ ppm. While one cannot exclude the possibility of interaction moments which would compensate this large term, this appears unlikely. It should be noted that even if the interaction moments and/or the percentage of D state are adjusted to compensate μ_{SL} and give the correct deuteron magnetic moment, it is *still unlikely* that Δ_{SL} will also be compensated. This is because the spin-orbit moment makes its contribution as an "orbital" term and hence contributes more than the usual "Bohr" term.[6] The latter, which comes from distributed magnetism of moment μ and average radius d, contributes a relative correction to the hfs,

$$\Delta_B=-(\mu/\mu_d)(2d/a_0). \tag{5}$$

For most interaction moments one would expect a "Bohr" term with d rather less than the deuteron radius, so that for the same magnetic moment Δ_{SL} will be approximately 20 times as large as Δ_B. The contribution of the D state of the deuteron, although an "orbital" effect, gives an anomalously small contribution[7] so that for the same magnetic moment, Δ_{SL} will be approximately 7 times as large as the D-state contribution.

It is of course possible that there are no spin-orbit forces present in the ground state of the deuteron.[11] In any case it is clear that the hfs of deuterium is an experimental datum distinct from the magnetic moment of the deuteron, and the requirement that both of these numbers be predicted correctly will be useful in determining the nature of the spin-orbit force in the deuteron.

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Consequences of a Pseudovector Pion-Nucleon Coupling and the Universal β Decay

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On the assumption of the usual[1,2] (V-A) weak coupling it is well known that the $\pi\rightarrow\mu+\nu$ decay proceeds only through the axial vector current $\sqrt{G}\bar{\psi}\gamma_\mu\gamma_5\tau_+\psi$. Apart from the coupling constant factors, the divergence of this current is identical to the nucleon source current of a PV-coupled pion field; i.e.,

$$(4\pi)^{\frac{1}{2}}f\partial_\mu(\bar{\psi}\gamma_\mu\gamma_5\tau_i\psi)=(\Box^2-\mu^2)\varphi_i+\delta\mu^2\varphi_i.$$