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NOTES ON HYPERFRAGMENTS

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NOTE ON HYPERFRAGMENTS

by

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NOTE ON HYPERFRAGMENTS

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Since the delayed disintegration of a heavy nuclear fragment with the release of a large amount of energy was first reported by Danysz and Pniewski,¹ many events have been observed which establish the fact that a Λ^0 together with a number of nucleons can form systems which are stable for times of the order of the lifetime of the free Λ^0 . If the strong interaction between the Λ^0 and the nucleon is attributed to the exchange of a heavy meson,² the interaction can be expected to have a range of about one third and a depth about three times the range and depth, respectively, of the interaction between nucleons. With such an interaction, neither the hyperdineutron ($n + \Lambda^0$) nor the hyperdeuteron ($p + \Lambda^0$), which form an i-spin doublet with spin singlet and triplet states, is stable;³ and, in fact, there is no experimental evidence for such particles. We consider some of the simple consequences of the assumption of charge independent forces between two nucleons and charge symmetric forces between a Λ^0 and a nucleon.

The hypertrineutron (Λn^3), hypertritium (ΛH^3), and hyperhelium-3 (ΛHe^3) form an i-spin singlet in spin doublet and quartet states, and an i-spin triplet in only spin doublet states, excluding orbital excitation. It seems reasonable to assume that the lowest lying state is a quartet (having three spins parallel) and hence is an i-spin singlet (ΛH^3). There are three events in which the identity of the hypertriton has been definitely established.⁴ The binding

energy of the Λ^0 is found to be less than one Mev. The small binding makes a second bound level unlikely; therefore, the hypertrineutron probably has no stable states; and, considering the additional coulomb energy, it is even less likely that the hyperhelium-3 is stable.⁵

Of the four hypersystems with three nucleons and a Λ^0 , hyperhydrogen-4 ($\Lambda^4\text{H}$) and hyperhelium-4 ($\Lambda^4\text{He}$) undoubtedly form a stable i-spin doublet differing in total binding by the coulomb energy. The binding energy of the Λ^0 can be expected to be very nearly the same in the two fragments. Observations indicate that the binding energy of the Λ^0 in $\Lambda^4\text{He}$ is about 2.4 ± 1.5 Mev;⁶ evidence for the existence of $\Lambda^4\text{H}$ is at present less convincing.⁷ Assuming that the $\Lambda^4\text{H}$ is indeed stable, one concludes that the Pauli principle causes the forces between a third neutron and the nucleons of H^3 , which do not lead to a stable system, to be weaker than the forces between a Λ^0 and the nucleons of H^3 . However, the i-spin quartet of this group of hyperfragments is certainly unstable; for, neither H^4 nor Li^4 is stable, and the two extremes of the quartet are obtained by replacing the single proton or neutron, which is unrestricted by the Pauli principle, by a Λ^0 , which is likewise unrestricted and for which the forces are somewhat weaker.

The hypersystems with four nucleons and one Λ^0 have a stable state which is an i-spin singlet, hyperhelium-5 ($\Lambda^5\text{He}$). One example of this fragment has been reported.⁸ The two components of the i-spin triplet, $\Lambda^5\text{H}$ and $\Lambda^5\text{Li}$, are probably unstable because both He^5 and Li^5 are unstable. However, it is possible that the freedom in the orientation of the spins which exists in the two hypersystems and also the fact that $\Lambda^4\text{H}$ and $\Lambda^4\text{He}$ are less stable

than He^4 might provide sufficient energy for binding. If the systems are indeed stable against nucleon emission, the binding energy of the Λ^0 in $\Lambda^5\text{H}$ must be greater than the binding energy of the Λ^0 in $\Lambda^4\text{H}$ and the binding energy of the Λ^0 in $\Lambda^5\text{Li}$ must be greater than the binding energy of the Λ^0 in $\Lambda^4\text{He}$.

These considerations can be extended to hypersystems of greater mass number.

LITERATURE CITED

- ¹ M. Danysz and J. Pniewski, Phil. Mag. 44, 348 (1953).
- ² R. G. Sachs, Phys. Rev. (in press). See also - A. Pais, Phys. Rev. 86, 663 (1952). The same coupling constant is assumed, in the present discussion, for the Λ^0 --nucleon and nucleon--nucleon interactions; one may question, of course, whether this assumption is justified.
- ³ F. Duimio, Nuovo Cimento 1, 688 (1955).
- ⁴ Bonetti, Levi Setti, Panetti, Scarsi and Tomasini, Nuovo Cimento 11, 210, 330 (1954). Debenedetti, Garelli, Tallone and Vigone, *ibid.* 12, 466 (1954). Baldo, Belliboni, Ceccarelli, Grilli, Sechi, Vitale and Zorn, *ibid.* 1, 1180 (1955). The binding energy of the Λ^0 as obtained by each of these three groups, is 0.7 ± 1 Mev, 0.3 ± 4 Mev, and -0.2 ± 1 Mev, respectively. H. Yagoda, Phys. Rev. 98, 153 (1955), has observed an event which he interprets as being the disintegration of a hypertriton in which the Λ^0 is bound with 3.1 ± 1 Mev. One should note, however, that the event of this reference may possibly be an example of a $\Lambda^4\text{H}$ rather than a $\Lambda^3\text{H}$. The

mode of disintegration could be either (a) $\Lambda^H \rightarrow H^2 + p + n + \pi^-$ $\sim 30.9 \pm 1$ Mev, or (b) $\Lambda^H \rightarrow H^3 + p + \pi^-$ 31.0 ± 1 Mev. In both modes, the H^2 and H^3 are to be identified with the track which Yagoda designates by A. (The kinetic energy of the H^3 is about 2.01 ± 0.06 Mev.) The two possible modes lead to a binding of the Λ^0 in Λ^H of about -0.3 ± 1 Mev and 5.9 ± 1 Mev, respectively.

⁵An event, which may be the disintegration of either a Λ^{He3} or a Λ^{He4} , has been observed by Fry, Schneps and Swami, "The Disintegration of Hyperfragments" (Univ. of Wis. preprint, Jan. 1955). Because the total binding energy found for Λ^{He3} (5.9 ± 1 Mev) is almost twice that of Λ^{H3} , the event is probably an example of a Λ^{He4} .

If one assumes that the Λ^{n3} is indeed stable, one can examine its possible modes of disintegration. For example, the mode, (a) $\Lambda^{n3} \rightarrow 2n + p + \pi^- + Q_a$, is especially interesting because the charged secondaries are the same as those of the decay of the free Λ^0 . However, the apparent Q-value, i.e., the Q-value calculated from the observed kinetic energies of the p and π^- , would not have a unique value for all events of this mode of disintegration of the Λ^{n3} . One may ask whether mode (a) could possibly account for the low, anomalous Q-values which have been observed for the decay of the free Λ^0 . [See, for example, Castagnoli, Friedlander, Merlin, and Teucher, Nuovo Cimento 12, Supplement 2 (1954), especially p. 461.] For the mode, (b) $\Lambda^{n3} \rightarrow t + \pi^- + Q_b$, both secondary particles are charged and could be observed; in this case the Q-value plus the binding energy of the Λ^0 would be 45.4 Mev.

⁶Hill, Salant, Wigdoff, Osborne, Pevsner, Ritson, Crussard and Walker, Phys. Rev. 94, 797 (1954), who find 3.1 Mev. Naugle, Ney, Freier and Cheston, Phys. Rev. 96, 1383 (1954), who find 2.7 ± 0.9 Mev. Fry, Schneps and Swami, loc. cit., who find 3.9 ± 1 Mev. J. Crussard and D. Morellet, C. R. Acad. Sci. (Paris) 236, 64 (1953); this event is interpreted as the disintegration of either a Λ^0 He⁴ or a Λ^0 Li⁷. (in each case, the Q-value is slightly ambiguous because the kinetic energy of the recoil nucleus (He³ or Li⁶) is not stated.) If the event is an example of a Λ^0 He⁴, the binding energy of the Λ^0 ($\sim 9 \pm 4$ Mev) is somewhat higher than that of the other events quoted. See also Baldo et al., loc. cit. The event of the latter reference is interpreted as the disintegration of either a Λ^0 He⁴ or a Λ^0 He⁶, with the binding energy of the Λ^0 equal to 1.7 ± 1.2 or 1.5 ± 1.2 Mev, respectively. B. Stiller, N. Seeman, M. M. Shapiro, Bull. A.P.S. 30, no. 5, 13 (1955), who find 1.9 ± 2.9 Mev. W. F. Fry, private communication, who finds 0.9 ± 0.5 Mev.

⁷A preliminary estimate, based on a single event, reported in Nature 175, 972 (1955) gives a 1.2 ± 0.8 Mev for the binding energy of the Λ^0 in Λ^0 H⁴.

⁸See reference 7. No estimate of the binding energy of the Λ^0 in the Λ^0 He⁵ is given.