DOUBLE-HYPERFRAGMENT EVENT

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(Received September 25, 1959)

Figure 1 shows a star found in Ilford G5 nuclear emulsion irradiated by 4.5-Bev/c π^- mesons from the Berkeley Bevatron. The primary particle which is seen but which does not show in the plate is presumably a π^- meson; the very small chance that it is a K^- meson does not affect the discussion.

The two particles which go due north and south in the figure have respective ranges 13.7 and 9.7 microns; the angle between them is $8.7 \pm 1.0°$; their point of origin is the main star to within 0.4 micron; their tracks are saturated and they presumably come to rest. Each particle gives a star of which one prong is a π^- meson, identified in the plate by its own terminal star. The N-bound particle is a uniquely identified ${}_\Lambda H^4$ with $B_\Lambda = 2.29 \pm 0.61$ Mev. The S-bound particle can be satisfactorily analyzed as ${}_\Lambda H^4$ or ${}_\Lambda Li^{8,9}$, with other possibilities remote.[1]

It seems unlikely that these two mesonically decaying hypernuclei are generated by the normal mechanism: the chance per star that a single mesonically decaying hypernucleus is found is about 1.5×10^{-4} (our present study comprises 260 322 stars; similar information comes from Slater[2]); the chance that any mesonically decaying hyperfragment from such a star has a range of less than 20 microns is about 4×10^{-2}.

We suggest that a natural explanation is to be found in the formation of a short-lived Ξ hypernucleus. The conversion reaction $\Xi + N \rightarrow 2\Lambda^0$ within the Ξ hypernucleus results in the formation of the two ordinary Λ^0 hypernuclei.[3] Although this reaction is technically fast it is quite likely that the lifetime of a Ξ hypernucleus is long enough to enable the hypernuclear state to be well defined. This is because:

(I) the reaction goes as $g_K^{\,4}$, and K vertices are presumed relatively weak[4];

(II) the scale of the nucleus is $\hbar/m_\pi c$ but the conversion range is $\hbar/m_K c$;

(III) selection rules are unusually restrictive.[5]

Perturbation theory, an empirical nucleon momentum distribution, pseudoscalar K-meson, and $g_K^{\,2} = 1$ give a lifetime of several times 10^{-20} sec not sensitively dependent on the Ξ-N relative parity.[6]

The immediate consequence of this speculative interpretation of our double event is that the Ξ-N interaction is attractive.[7]

Thanks are due to Dr. E. Lofgren and the staff of the Berkeley Bevatron for providing the π^- irradiation and to the William Waldorf Astor Foundation for a grant that enabled it to be carried out.

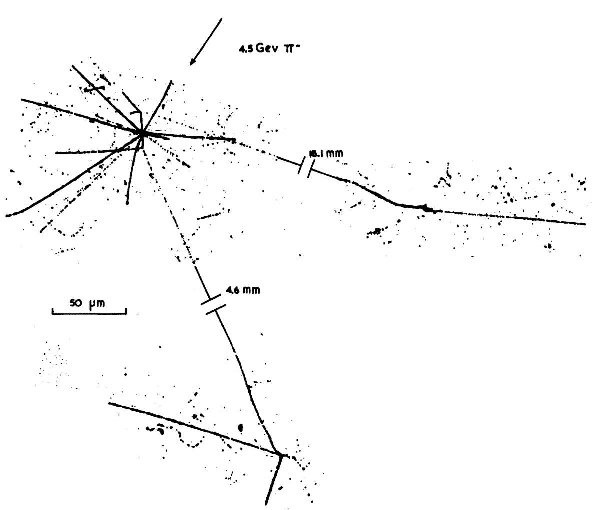

FIG. 1. Double-hyperfragment event.

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[1] ${}_\Lambda He^7$ might be admitted but is very improbable. The possibility that this particle is a K^- meson is rejected because: (I) the chance that a K^- meson of only 0.6 Mev emerges from a 4.5-Bev/c star is less than 10^{-6} as is known from this and related investigations; (II) the chance that a K^- meson gives on absorption a π^- meson of range as short as 4.6 mm is 0.01 or less; (III) the other prongs of the K^- star would have to conspire with the π^- meson to make the event acceptably analyzable as a hypernucleus decay. The possibility of a Σ^- hyperon is rejected with similar firmness. So is a large number of possibilities based on chance coincidences.

[2] W. E. Slater, Suppl. Nuovo cimento 10, 1 (1958).

[3] A possible double-hyperfragment event for which this explanation is proposed has been reported by Barkas, Biswas, DeLise, Dyer, Heckman, and Smith, Phys. Rev. Letters 2, 466 (1959).

[4] R. H. Dalitz, Reports on Progress in Physics (The Physical Society, London, 1957), Vol. 20, p. 163; 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN Scientific Information Service, Geneva, 1958), p. 187.

[5]E. g., for even relative Ξ-N parity, of the S-state Ξ-N encounters, only the ^{11}S is effective for conversion: 1/32 of the total number.

[6]We are indebted to Dr. J. Hamilton for a detailed discussion of this point.

[7]The intepretation of the event may be extended if, as seems most natural, the near-collinearity of the N-bound and S-bound hyperfragments is accepted as a reflection of the dynamical correlation between them resulting from the conversion process. Such a correlation then requires a momentum balance of the same order as the collinearity. If the S-bound hyperfragment is $_\Lambda H^4$ its momentum balances against that of the N-bound $_\Lambda H^4$ to within 15% which matches well the angle of 8.7° between the two. If the S-bound hyperfragment is $_\Lambda Li^{8,9}$ the momentum unbalance is by a factor of 3. This preference for $_\Lambda H^4$ as the S-bound hypernucleus is strengthened by its mesonic decay which is considerably more likely for $_\Lambda H$ than for $_\Lambda Li$. This use of the collinearity also implies that the Ξ hypernucleus decays effectively free of strong interaction with other residue of the large star. This in turn implies a time scale of order 10^{-20} sec or more which is consistent with the possible lifetime as estimated using perturbation theory.

If both Λ^0 hypernuclei are $_\Lambda H^4$ their measured energies reveal the binding energy of the Ξ hyperon into the various possible Ξ hypernuclei (we use the mass value $m_{\Xi^-}=1319.1\pm0.5$ Mev quoted by L. W. Alvarez at the 1959 Annual High-Energy Physics Conference in Kiev from Berkeley work of W. M. Powell and his colleagues). We find, for $_\Xi He^8$, $B_\Xi=5.9\pm1.2$ Mev and, for $_\Xi He^9$, $B_\Xi=3.6\pm1.2$ Mev. All other possibilities up to $_\Xi B^{15}$, beyond which we need not go, yield negative values of B_Ξ and so can be rejected. Of $_\Xi He$ and $_\Xi He^9$ there is a strong preference for $_\Xi He^8$ because: (I) the decay of $_\Xi He^9$ involves a neutron in an unlikely manner – of very low energy if the $_\Xi He^9$ decays when moving slowly, or accurately balancing the momentum of the $_\Xi He^9$ if the decay is at high speed; (II) the "core" – Li^7 – of $_\Xi He^8$ is on the stability line for light nuclei, viz., is of $|T_z|=0$ or $\frac{1}{2}$ while that of $_\Xi He^9$, Li^8, is off the stability line ($|T_z|=1$). The expected preference for cores of the highest symmetry properties is well seen in the systematics of ordinary Λ^0 hypernuclei.

The expected lifetime for a Ξ hypernucleus is much longer than the presumed value of the imaginary part of the Ξ-nucleus optical model potential, due to the ordinary strong interactions, and so the Ξ hyperon will convert from an S state in the Ξ hypernucleus. It is most likely that the Li^7 core will be in a state of odd parity since all low-lying states of Li^7 are p^3 (no even-parity state of Li^7 is well established; the first possibility is unstable by about 4 Mev against break-up into He^4+H^3). So the parity of $_\Xi He^8$ is most probably minus the Ξ-N relative parity. If now we made the usual assumption[4] $J=0$ for $_\Lambda H^4$ [see also the report of R. H. Dalitz to the 1959 Annual High-Energy Physics Conference in Kiev (unpublished)], we see that the Ξ-N relative parity must be odd.

THEORY OF THE HIGH-ENERGY PEAKS IN PION-NUCLEON CROSS SECTIONS*

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(Received July 6, 1959; revised manuscript received August 14, 1959)

We wish to report an investigation of whether the spectrum of high-energy peaks[1] observed at 650 Mev, 950 Mev, and 1.3 Bev in π-p scattering (and photoproduction) can be explained in terms of the conventional low-energy pseudoscalar π-N interaction. Previous investigation of this problem[2] has yielded negative results, stimulating speculation on the role of π-π interactions.[3] We suggest that the previous investigations of the π-N interaction have been inadequate. A Chew-Low[4] formalism is outlined below which predicts two isobars, or metastable states, of the nucleon that may be associated with the 950-Mev and 1.3-Bev peaks.

We consider the two-p-wave pion, one static nucleon system, and explicitly examine the effects of the low-energy $p_{3/2}$ $T=3/2$ pion-nucleon scattering resonance on this system. Loosely speaking, we consider one meson and then the next meson, etc., scattering in the 3/2, 3/2 state, with respect to the nucleon, as represented in Fig. 1.

The propagation of the 2π-N system is being examined just as a mechanism for the existence of isobars. If a certain T matrix element $\langle 2\pi\text{-}N|T|2\pi\text{-}N\rangle$ is sharply peaked, the various observable cross sections, which we do not attempt to calculate here, will also be peaked.[5] Calculation of $\langle 2\pi\text{-}N|T|2\pi\text{-}N\rangle$ offers possible advantage over calculation of the one-meson production amplitude $\langle \pi\text{-}N|T|2\pi\text{-}N\rangle$ which has been considered by others. In the latter an extremely energetic incident pion is involved and the dynamics are unfamiliar to us. Furthermore, it seems relatively difficult to consider the physical mechanism discussed above in case of the latter amplitude.