A possible case of production and decay of a supernucleus

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An event, which is interpreted as the $\sim(2–5)\times 10^{-14}$-sec decay of a supernucleus, was detected as a result of scanning 125 000 interactions of 250-GeV protons with nuclei in photographic emulsions. A fork due to a possible decay of a $\bar{D}^0$ meson was detected. The background of this event amounts to $\sim 3\times 10^{-5}$.

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The existence of charmed particles, including the lightest baryon Λ_c^+, has now been reliably established.[1] However, the question whether the supernuclei, i.e., bound states of Λ_c^+ with nucleons that are analogous to hypernuclei, can be produced remains open.[2] According to theoretical estimates,[3–7] their existence is highly probable.

Five candidates for the decay of supernuclei were identified at the Institute of High Energy Physics and Fermi National Accelerator Laboratory as a result of scanning a photographic emulsion irradiated by 70- and 250-GeV protons.[8] Their characteristics and preliminary analysis were given in Refs. 8 and 9. As the analysis of the possible background sources showed,[10] four events can be explained by the inelastic interaction of shower particles, and the only background source for the fifth event (250-GeV proton energy) is the annihilation of a slow $\bar{p}$. The predicted number of such events is $\sim 3\times 10^{-2}$, if the fraction of the annihilation stars with an apparent energy release of $\sim$0.3–1.3 GeV (Ref. 11) is taken into account. After repeated scanning of the primary stars within $\sim$3-mm range, this even revealed a fork with a geometrically restored center at a distance of 6.3 ± 2.8 μm[1)] from the primary star and with an aperoture angle $(1.23\pm 0.03)\times 10^{-2}$ rad. The photomicrograph and the scheme ←f this event are shown in Fig. 1 (A is the center of the primary star, B is the center of the secondary star with the track numbers 1–6, and C are the forks with the tracks $V1$ and $V2$). The characteristics of the event are given in Table I and the characteristics of the tracks of the secondary star and of the fork are given in Table II.

According to the measurements of multiple scattering and ionization, the $V1$ track probably belongs to a K meson. The fork can therefore be interpreted as the $\sim 0.3\times 10^{-14}$-sec decay of a D^0 meson (which is produced in a pair with Λ_c^+ that decays in the supernucleus at the point B) into $K^+\pi^-$—the invariant mass is $M_{K\pi} = 1.62^{+0.13}_{-0.12}$ GeV–or into $K^+\pi^-\pi^0$.

The probability that the fork is a e^+e^- pair is negligible, 6×10^{-10}. The background due to K_s^0 and Λ^0 decays as well as that due to diffractive dissociation $n\to p\pi^-(n\to n\pi^+\pi^-)$ (Ref. 12) does not exceed $\sim 9\times 10^{-4}$. Therefore, the predicted

TABLE I.

Primary star	Connecting track			Secondary star		
Type of splitting	Mean free path R, μm	Immersion angle $\theta°$	Azimuthal angle $\phi°$	Apparent energy release E_{app}, MeV	Total longitudinal momentum of charged particles $P_{ch_{\parallel}}$, MeV/c	Total transverse momentum of charged particles, MeV/c
6 + 12p	1.8 ± 0.5	0 ± 18,0	192 ± 8.9	998 ± 21	190 ± 122	532 ± 42

TABLE II.

№	R, μm	$\theta°$	$\phi°$	Ionization I/I_o	$p\beta$, MeV/c	Identification	Energy T_{kin}, MeV
1	> 74620	18.5 ± 1.0	63.6 ± 0.5	0.94 ± 0.08	362 ± 18	π	270 ± 16
2	32560 ± 650	14.2 ± 1.0	102.3 ± 0.5	1.47 ± 0.12	74 ± 6	π^+	48.0 ± 1.1
3	291 ± 5	−43.3 ± 1.5	109.8 ± 1.0	–	–	p	6.9 ± 0.4
4	8790 ± 120	−43.7 ± 1.0	110.0 ± 0.5	–	79 ± 11	p	49.0 ± 1.5
5	> 65200	58.0 ± 1.0	201.1 ± 0.5	1.08 ± 0.07	160 ± 15	π	101 ± 11
6	20710 ± 320	−32.6 ± 1.0	322.8 ± 0.5	3.76 ± 0.31	115 ± 9	p	79.8 ± 1.8
$V1$	> 54000	−6.0 ± 1.0	358.8 ± 0.2	0.94 ± 0.01	840 ± 70	K	576 ± 58
$V2$	> 54000	−6.0 ± 1.0	359.5 ± 0.2	1.00 ± 0.03	9760 ±1670	π	9630 ± 1670

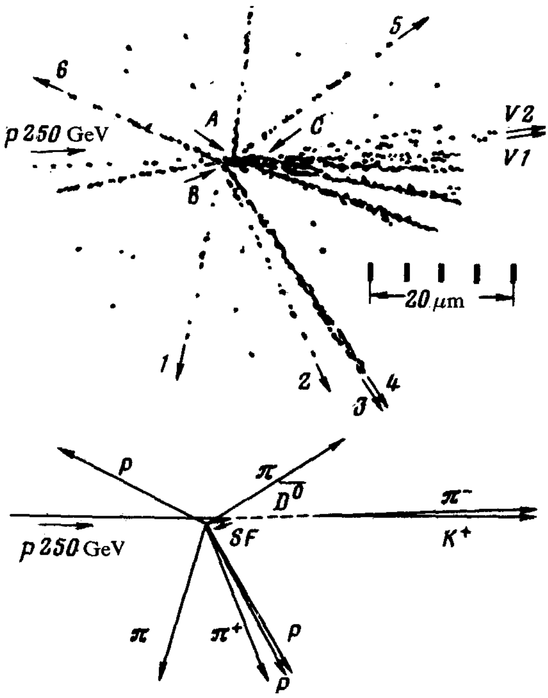

FIG. 1.

number of events, which simulate the decays of a supernucleus and of a neutral charmed particle, does not exceed $\sim 3\times 10^{-5}$.

If the secondary star is attributable to a supernuclear decay, then the products of this decay must contain a strange particle that may be nuetral-Λ^0 or $\bar{K}^0$. The experimental data are consistent with the fact that this event is a decay of a supernucleus in which Λ^0 is released (if we assume that $\bar{K}^0$ escapes, then the energy released in the second star will be larger than the difference in the masses of Λ_c^+ and the nucleon). We analyzed the secondary star kinematically, assuming that Λ^0 is the only invisible decay product of the supernucleus and estimated the binding energy of Λ_c^+ in the supernucleus $B_c(B_c = M_{\rm NC} + M_{\Lambda_c^+} - M_{\rm SF}$, where $M_{\rm NC}$ is the mass of the nuclear core, $M_{\Lambda_c^+} \sim 2.27$ GeV is the mass of Λ_c^+, and $M_{\rm SF}$ is the invariant mass of the decay products, which depends on the momentum $P_{\rm SF}$ of the supernucleus) and the time of flight $t_{\rm SF}$ of the supernucleus before its decay.

An analysis showed that the supernucleus is determined by the signs of the charges of pions that are not stopped in the chamber (track numbers 1 and 5), but the positive values of B_c-the condition for the existence of a supernucleus-are obtained independently of them. There are only three possibilities:

1) $\pi^+\pi^-$. The decay of a supernucleus ${}^4_c\mathrm{Be}\to\Lambda^0\pi^+\pi^+\pi^- ppp$ in this case occurs due to the decay $\Lambda_c^+\to\Lambda^0\pi^+\pi^+\pi^-$. The dependence of B_c on $P_{\rm SF}$ is shown in Fig. 2. According to the estimates,[4–7] the quantity B_c is of the same order of magnitude as the binding energy of Λ^0 in hypernuclei with identical nuclear cores; therefore, we assumed that the possible values of B_c are in the range 0–10 MeV (the crosshatched

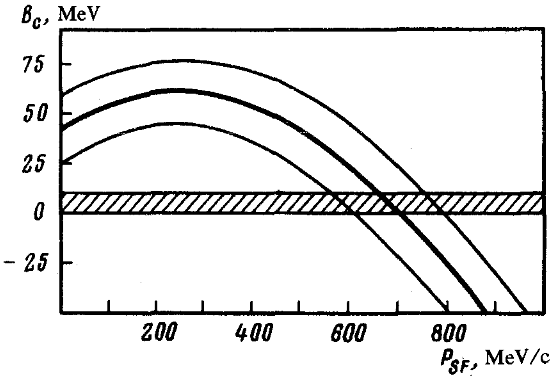

FIG. 2

region in Fig. 2). These values of B_c correspond to the values $t_{SF} \sim (2.4\text{–}5.3)\times 10^{-1/4}$ sec. Since the nuclear core $(3p)$ is unstable, the most probable interpretation presupposes an emission of k neutrons $(k \geqslant 1)$: ${}^{4+k}_{c}\mathrm{Be} \to \Lambda^0 \pi^+\pi^+\pi^- ppp + kn$.

2) $\pi^-\pi^-$. The interpretation of this event ${}^4_c\mathrm{He} \to \Lambda^0\pi^+\pi^-\pi^- ppp$ presupposes a decay of the supernucleus due to a weak interaction of Λ_c^+ with a neutron $\Lambda_c^+ n \to \Lambda^0 p \pi^+\pi^-\pi^0$ with a subsequent charge exchange $\pi^0 n \to \pi^- p$. The invariant mass $M_{\pi p}$ (track numbers 5 and 6) is equal to 1224.5 ± 12.2 MeV. Quantitatively, if the values are the same $P_{SF} B_c({}^4_c\mathrm{He}) = B_c({}^4_c\mathrm{Be}) - 5.92$ MeV. The interval $B_c = 0\text{–}10$ MeV corresponds to $t_{SF} \sim (2.9\text{–}4.4)\times 10^{-14}$ sec.

3) $\pi^+\pi^+$. The decay of a supernucleus ${}^{6+k}_{c}C \to \Lambda^0\pi^+\pi^+\pi^+ pppnn + kn (k \geqslant 1)$ occurs due to a weak interaction of Λ_c^+ with a proton $\Lambda_c^+ p \to \Lambda^0 n \pi^+\pi^+\pi^0$ with a subsequent charge exchange $\pi^0 p \to \pi^+ n$. The presence of at least two neutrons and Λ^0 makes it impossible to estimate B_c and t_{SF} quantitatively, but does not contradict the fact that B_c may be positive. An addition of k neutrons is attributable to the same reasons as in case 1. The cases 2 and 3 presuppose a pion charge exchange; hence they are less probable.

There was no evidence of a fork from the Λ^0 decay in the region of the angles of emission of the Λ^0 hyperon, which correspond to $B_c = 0\text{–}10$ MeV. However, the probability of the $\Lambda^0 \to p\pi^-$ decay in the examined region does not exceed $\sim 18\%$. Moreover, the angles of emission of Λ^0 may be different if at least one neutron is emitted during the decay. The lack of evidence for the existence of Λ^0, therefore, is consistent with our interpretation.

Thus, there are serious reasons to regard this event as the formation of a bound state of a charmed Λ_c^+ baryon with nucleons–a supernucleus ${}_c\mathrm{Be}({}_c\mathrm{He}, {}_cC)$:

$$p + \mathrm{Ag, Br} \to {}_c\mathrm{Be}({}_c\mathrm{He}, {}_c\mathrm{C}) + \overline{D^0} + X \quad \overline{D^0} \to k^+\pi^-(\pi^0)$$
$$\hookrightarrow \Lambda^0 \pi^+\pi^\pm\pi^\pm ppp + kn(k \geqslant 0),$$

which decays in the time $\sim(2\text{–}5)\times 10^{-14}$ sec.

We hope that the observed event will stimulate further search to resolve finally the problem of the existence of supernuclei.

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[2)]*The weighted mean for 23 measurements is given. The error was determined with allowance for the* correlations of the individual measurements.

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