Fermi energy $E_0^H \simeq 2.5\times10^{-14}$ erg ($E_0^H/k \simeq 180°K$); effective mass in the plane perpendicular to the trigonal axis $m_1^H = m_2^H = 0.05\,m_0$ (m_0 is the free electron mass) and in the direction of the trigonal axis $m_3^H = 0.7\,m_0$.

The magnitude of the anisotropy of the hole surface and the value of the effective masses are in good agreement with recently published work on cyclotron resonance[3] in Bi ($m_1^H = m_2^H = 0.068\,m_0$ and $m_3^H = 0.92\,m_0$) and on the anomalous skin effect[4] ($m_3^H/m_1^H = 12.8$). In these works, and also in Reneker's, this group of holes has been described by the anomalously small value of bounding energy ($E_0^H = 0.18\times10^{-14}$ erg, $E_0^H/k = 13°K$) which was suggested by Heine[6] and by Strelkov and Kalinkina[7] to explain the appreciable electronic specific heat of Bi.

We should point out that n^H in one ellipsoid of revolution is 0.34×10^{18} cm^{-3}, and is practically equal to the concentration of electrons in Shoenberg's three-ellipsoid model, $n^e = 0.39\times10^{-18}$ cm^{-3}. These two groups of 'light' electrons and holes must evidently be responsible for the galvanomagnetic properties of Bi. The difference between the mean effective masses of the electrons in Shoenberg's three-ellipsoid model,

$$\overline{m}^e = [m_1(m_2m_3 - m_4^2)]^{1/3} = 0.053m_0$$

and of the holes in the one-ellipsoid model,

$$\overline{m}^H = (m_1^2m_3)^{1/3} = 0.13m_0$$

agrees well with the difference of mean mobilities $\overline{\tau}/\overline{m}$ of the electrons and holes ($\overline{\tau}^e/\overline{m}^e \simeq 2\overline{\tau}^H/\overline{m}^H$) assuming approximately the same relaxation times.

Since the heat capacity of the 'light' holes is negligibly small compared with the observed[7] linear term in the heat capacity of Bi, we must assume that there exist at least three groups of carriers.[8,1]

[1] Brandt, Dubrovskaya, and Kytin, JETP **37**, 572 (1959), Soviet Phys. JETP **10**, 670 (1960).

[2] N. B. Brandt, Приборы и техника эксперимента (Instrum. and Meas. Engg.) No. **2** (1960).

[3] Galt, Yager, Merritt, and Cetlin, Phys. Rev. **114**, 1496 (1959).

[4] G. E. Smith, Phys. Rev. **115**, 1561 (1959).

[5] D. H. Reneker, Phys. Rev. **115**, 303 (1959).

[6] V. Heine, Proc. Phys. Soc. **A69**, 513 (1956).

[7] I. N. Kalinkina and P. G. Strelkov, JETP **34**, 616 (1958); Soviet Phys. JETP **7**, 426 (1958).

[8] N. B. Brandt and V. A. Venttsel, JETP **35**, 1083 (1958), Soviet Phys. JETP **8**, 757 (1959).

Translated by R. Berman
264

PRODUCTION OF A Σ HYPERON BY 8.3 Bev/c NEGATIVE π MESONS

WANG KANG-CHANG, WANG CHU-CHIEN, V. I. VEKSLER, N. M. VIRYASOV, I. VRANA, TING TA-CHAO, KIM HU IN, E. N. KLADNITSKAYA, A. A. KUZNETSOV, A. MIKHUL, NGUYEN DIN TU, A. V. NIKITIN, and M. I. SOLOV'EV

Joint Institute for Nuclear Research

Submitted to JETP editor March 24, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **38**, 1356-1359 (April, 1960)

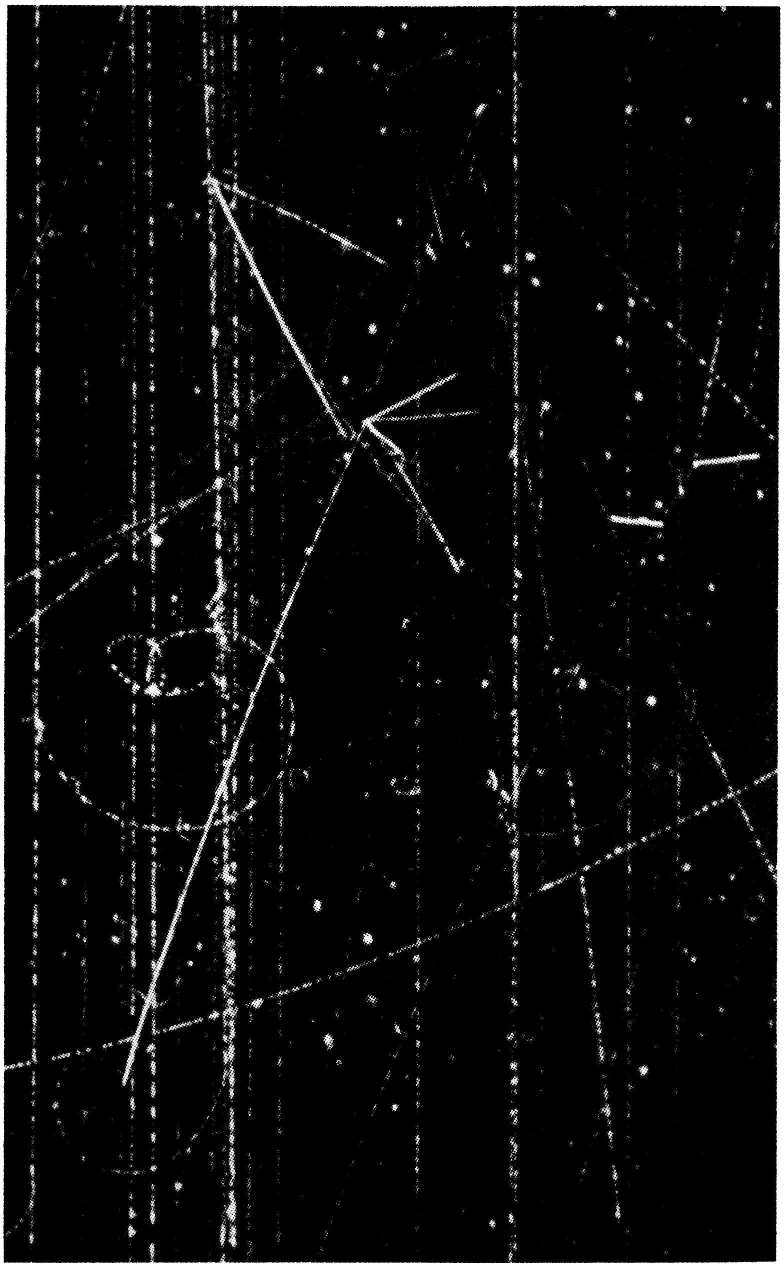
ONE event of production and decay of a $\overline{\Sigma}^-$ hyperon was found out of 40,000 pictures obtained by a beam of negative 8.3 ± 0.6 Bev/c pions in a propane bubble chamber[1] with a constant magnetic field of 13,700 oe. A photograph and diagram of this event are shown. A π^- meson (track 1) gives a star at point O, from which emerge four charged particles of high energy (tracks 2, 6, 7, 16), two K^0 mesons (tracks 4, 5, 14, 15), and one particle of low energy (short track 17). The track of the positively charged particle 2 is deflected at point A. At a distance of 7.7 mm from the point of deflection is a six-prong star. The center of the star lies in the plane of tracks 2 and 3 within the limits of the error of measurement (47′). The decay of particle 2 at point A into particle 3 and a neutral particle N in the direction AB is in very good agreement with the kinematics of a Σ decay (see Table I). Track 3 is that of a π^+ meson.

The momentum of particle N was determined by equating the perpendicular components of the momenta of particles 3 and N at point A.

Assuming a decay according to the scheme $\Sigma^+ \to \pi^+ + n$, we obtain $M_2 = 1182 \pm 14$ Mev.

The energy and momentum balance at point B is given in Table II. Star B has five positive particles (tracks 8, 9, 11, 12, 13) and one negative (track 10). The negative particle is a π meson. Tracks 9, 11, 12, 13 stop in the chamber and we take them to be protons. Particle 8 has a high momentum and escapes from the chamber. From the measurements of ionization* and momentum it follows that track 8 belongs to a π^+ meson. The measurement of the energy balance at point B shows that the energy of the charged particles of the star is already much larger than the kinetic energy of a neutron with a momentum of 1628 ± 100 Mev/c. Consequently, star B can be caused only by the annihilation of an antineutron on a carbon nucleus. The most probable reaction is

$$\overline{n} + C \to He_2^4 + 4p + 3n + \pi^+ + \pi^- + n\pi^0.$$



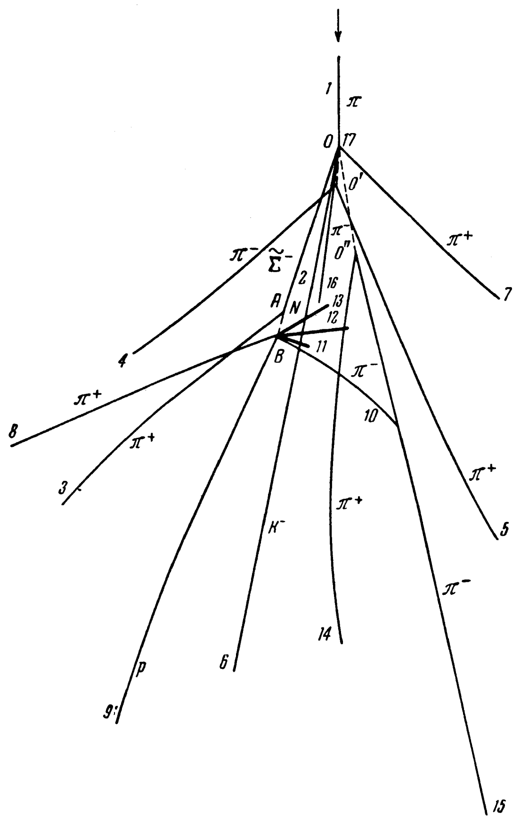


TABLE I. Kinematics at Point A

Track	Sign of charge	P_{meas}, (Mev/c)	P_{cal}, (Mev/c)	Particle	Angle
2	+	1104±600	1798±100	$\bar{\Sigma}^-$	
3	+	244±10		π^+	$\varphi(3,2)=39°38'\pm20'$
AB	0		1628±100	$\bar{n}$	$\varphi(AB,2)=5°29'\pm20'$

The energy carried away by neutrons should be added to the energy of the charged particles. Assuming that on the average they carry away the same energy as the protons, $E_n = 144 \pm 5$ Mev; also, the binding energy of the nucleons in the nucleus is $E_b = 64$ Mev. Assuming that, apart from charged π mesons, there are still neutral π mesons which carry away, on the average, half the energy of the charged π mesons, $E_{\pi^0} \approx \frac{1}{2}E_{\pi^\pm} = 645$ Mev, then the total energy in the star is $E_{tot} = 2336$ Mev.

The energy obtained in this way is close to the

TABLE II. Kinematics at Point B

Track	Sign of charge	P_{meas}, (Mev/c)	P_{cal}, (Mev/c)	Particle	E_{kin}, (Mev/c)	E_{mass}, (Mev)	Total E (Mev)
AB	0		1628±100	$\bar{n}$	940±100	2·939	2818±100
8	+	1044±55		π^+	920±56	140	
9	+	445±9		p	101±3		
10	—	183±25		π^-	90±20	140	
11	+	228±4		p	27±2		
12	+	270±5		p	38±2		
13	+	257±5		p	27±2		
ΔP			703	$\sum E = 1203 \pm 60 + 280$		$= 1483 \pm 60$	
				$E_n = 3(48 \pm 3)$		$= 144 \pm 5$	
				$E_b = 8 \cdot 8$		$= 64$	
						1691±61	
				E_{π^0}		645	
				Total energy at point B		2336	

TABLE III. Kinematics at Point O

Track	Sign of charge	P_{meas}, (Mev/c)	P_{cal}, (Mev/c)	Particle	Visible E_{kin}, (Mev)	E_{mass}, (Mev)	Total E (Mev)
1	—	—	8300±600	π^-	8200±600	140 =	8340±600
2	+	1104±600	1798±100	$\bar{\Sigma}^-$	964±80	1196	
V_1^0	0		654±29	K^0 or $\bar{K}^0$	323±27	494	
6	—	1456±70		K^-	1043±60	494	
7	+	790±45		π^+	663±45	140	
V_2^0	0		1475±71	$\bar{K}^0$ or K^0	1060±60	494	
16	—	300±50		π^-	190±50	140	
	0			N		939	
					(4243±138)+3897=8140±138		

TABLE IV. Kinematics at Points O′ and O″

Track	Sign of charge	P_{meas}, (Mev/c)	P_{cal}, (Mev/c)	Particle	Angle	Angle of noncoplanarity
V_1^0	0		654±29	K^0 or $\bar{K}^0$		$\eta = 33'$
4	—	324±25		π^-	$\varphi(V_1^0, 4) = 41°18' \pm 15'$	
5	+	453±22		π^+	$\varphi(V_1^0, 5) = 24°43' \pm 15'$	
V_2^0	0		1475±71	$\bar{K}^0$ or K^0		$\eta = 8'$
14	+	207±8		π^+	$\varphi(V_2^0, 14) = 26°50' \pm 15'$	
15	—	1299±70		π^-	$\varphi(V_2^0, 15) = 5°3' \pm 15'$	

total annihilation energy of the antineutron. Consequently, at point A there occurred the decay $\bar{\Sigma}^- \to \pi^+ + \bar{n}$.

The probability of a chance coincidence in one picture of various events which may have imitated the phenomenon under consideration is, according to our estimate, $\sim 10^{-9}$.

We consider the most probable reaction in the primary star to be

$$\pi^- + C \to \bar{\Sigma}^- + K^0 + \bar{K}^0 + K^- + p + \pi^+ + \pi^- + \text{recoil nucleus}$$

For the lifetime of the $\bar{\Sigma}^-$ we obtained the value $(1.18 \pm 0.07) \times 10^{-10}$ sec.

Hence, the data presented is evidence of the fact that we have observed a new type of particle, the charged antihyperon $\bar{\Sigma}^-$.

*S. Otwinowski and I. Vrana studied the possibility of measuring the ionization in our chamber. Out of 60 different pictures 40 m of track, the momentum and nature of which were known, were measured. It was found that for a track length 20 cm one may reliably (96%) separate π mesons and protons up to a momentum of 1200 Mev/c. The measured value of the ionization of track 8 (of length 20 cm) was 1.02 ± 0.19, and should be, by the β^{-2} law (Blinov et al.[3]), 1.86 for a proton and 1.04 for a π meson.

[1] Wang Kang-Chang, Solov'ev, and Shkobin, Приборы и техника эксперимента (Instrum. and Meas. Engg.) No. 1, 41 (1959).

[2] S. Otwinowski, Report, High-Energy Laboratory, Joint Institute for Nuclear Research, 1960.

[3] Blinov, Krestnikov, and Lomanov, JETP **31**, 762 (1956), Soviet Phys. **4**, 661 (1957).

[4] Willis, Fowler, and Rahm, Phys. Rev. **108**, 1046 (1957).

Translated by E. Marquit
265