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Unstable ${}_1H^4$ Fragment from the Capture of a Σ^- Hyperon*

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A 10×15×5 cm stack of Ilford G-5 emulsion was exposed to the 3.0-Bev π^--meson beam of the Berkeley Bevatron. A number of events involving K-mesons, hyperons, and hyperfragments have been observed. One interesting case is discussed here. A nine prong star is produced by a π^- meson, from which a Σ^- hyperon emerges. This in turn produces a star with three visible prongs, one of which is a ${}_1H^4$-hyperfragment decaying into two visible colinear tracks, one of which has been identified as a π^- meson. This π^- meson was followed to the end of its range, and its energy was determined to be 51±1 Mev, making it possible to calculate a reliable value for the binding energy of the Λ^0 in the fragment. The result yielded 3.3±1 Mev. Analysis of the particles emerging from the Σ^- star showed that momentum balance could be achieved by assuming emission of a high-energy neutron, whose calculated energy of 41 Mev agrees well with the energy of 42 Mev for a neutron produced in the postulated elementary interaction $\Sigma^-+p\rightarrow\Lambda^0+n+Q$.

A STACK (10×15×5 cm) of Ilford G-5 emulsion exposed to the 3.0 Bev π^--meson beam of the Berkeley Bevatron yielded a number of events involving K-mesons, hyperons, and hyperfragments. The analysis of these observations will be reported later.

An interesting event, shown in Fig. 1, has been located. A nine-prong star initiated by a 3.0-Bev π^- contains a track 12 620μ long (Σ^-) which ends in a three-prong capture star (1, 2, and 3). One prong (3) of the secondary star is a singly charged track 255μ long which comes to rest in the emulsion, decaying into a colinear saturated track 8μ long (a) and a π^- meson (b) which forms a ρ ending after passing through 21 pellicles, with a range of 36 170μ. Table I lists the experimental data for the individual tracks of the event. In order to identify track Σ^-, an integral gap *vs* range measurement was carried out, and compared with that of identified protons (P), deuterons (D), and π mesons (π). This is shown in Fig. 2. A K^--meson found in the same stack is plotted also for comparison. It is clearly seen that the mass of particle Σ^- must lie between that of the proton and that of the deuteron. In addition, a grain density *vs* range measurement on track Σ^- at 12 000μ residual range and on a π-meson track for comparison, gives for the former a mass of 2270±150 electron masses. This identifies the particle as a Σ^- hyperon.

TABLE I. Identity, range, energy, and momentum of individual tracks in Σ^- star and hyperfragment decay.

Track	Identity	Range (microns)	Energy (Mev)	Momentum (Mev/c)
	Σ^-	12 620	63	
1	α	80	12.3	
2	p	7	.6	
3	${}_1H^4$	255	11.0	
a	${}_2He^4$	8	2.4	134
b	π^-	36 170	51±1	130

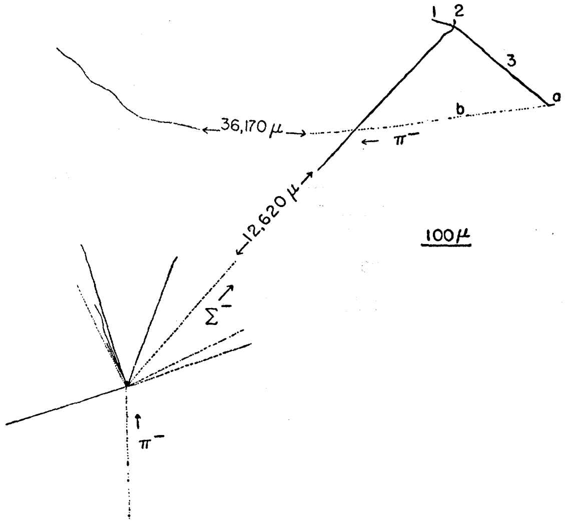

FIG. 1. Projection drawing of Σ^- hyperon produced by 3-Bev π^-. Tracing shows the capture of Σ^- and subsequent emission of $H_1{}^4$ hyperfragment undergoing mesonic decay.

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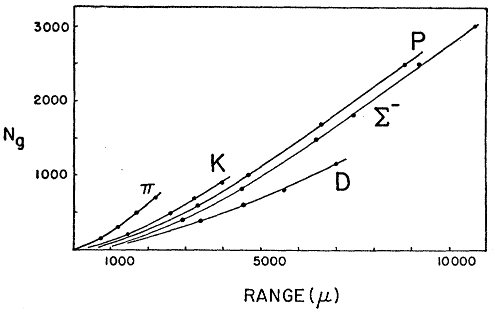

FIG. 2. Plot of gap frequency *vs* residual range for π, κ^-, P, Σ^-, and D.

Since fragment 3 undergoes mesonic decay, it must be a hyperfragment containing a Λ^0 hyperon. It is then assumed that the capture of the Σ^- takes place in a heavy nucleus, according to the process

$$\Sigma^- + p \rightarrow n + \Lambda^0 + Q, \tag{1}$$

which is in accordance with the scheme of Gell-Mann and Pais.[1] Q is the mass excess of the Σ^- over the Λ^0, equal to 78 Mev. Considering this process first as an elementary interaction between particles at rest, we calculate that the neutron in this reaction is emitted with an energy of 42 Mev. In the star under consideration, the Λ^0 definitely appears bound to a fragment, which will be shown to be ${}_1H^4$; in addition, there are two other visible tracks, which are most probably an alpha particle and a proton. (See Table I.) To balance the residual momentum of the visible prongs, 280 Mev/c, the emission of a neutron must be postulated. A π^0 meson could not be assumed because it would have to have an excessively high energy. A neutron of this momentum corresponds to an energy of 41 Mev. This checks surprisingly well with the energy of the neutron as calculated above for the elementary interaction, implying that the emitted neutron did not appreciably penetrate the nucleus. The process also implies that the Λ^0 strongly interacts with nuclear matter, since its energy is changed from about 40 to 10 Mev in the fragment.

It is of interest to compare the total kinetic energy output of the Σ^- star with the Q value of reaction (1). The energy of the visible tracks plus the neutron totals 65 Mev, which is consistent with the Q-value of 78 Mev, taking the difference to represent binding energy.

Fragment (3), emerging from the Σ^- star, is a singly charged track coming to rest in the emulsion. Since it decays colinearly into a π^- and a visible recoil nucleus, an accurate measurement of the energy release was possible. As seen in Table I, this energy release is 53.4 Mev, which is considerably in excess of the Q-value for the decay of a free Λ^0. This rules out the possibility that the recoil nucleus is ${}_2He^3$. The large energy difference must arise from the large binding energy of the last proton in ${}_2He^4$. The process accordingly should be represented as

$${}_1H^{4*} \rightarrow {}_2He^4 + \pi^- + Q \; (Q = 53.4 \text{ Mev}),$$

or

$$\Lambda^0(\text{bound}) \rightarrow p + \pi^- + 36.9 \text{ Mev}, \tag{2}$$
$$p + {}_1H^3 \rightarrow {}_2He^4 + 19.8 \text{ Mev}.$$

Since the fragment decays into visible tracks only, the energy release may be readily calculated, from which a good value can be obtained for the binding energy of the Λ^0. Taking the value for momentum of the π^-, 130 Mev/c, to be more reliable, the energy of the ${}_2He^4$, corresponding to this momentum, is found to be 2.3 Mev. This may be compared with the direct value of energy obtained from a range of 8μ, namely 2.4 Mev. For the binding energy of the Λ^0 in the fragment we obtain

$$\begin{aligned} \text{B.E.}(\Lambda^0) &= 36.9 + 19.8 - 53.4 \\ &= 3.3 \pm 1. \end{aligned}$$

The meaning of the numbers appearing here is made clear by reference to the reactions in (2). This value may be compared with the binding energy of the second neutron in ${}_1H^3$ which is 6.3 Mev.

The event we have described is of interest for the following reasons:

(1) It is a case of Σ^- capture in which the emergence of a Λ^0 can be detected because it is bound in an unstable fragment.

(2) The fragment decays into two colinear tracks, furnishing a reliable value for the binding energy of the Λ^0 in the fragment.

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[1] M. Gell-Mann and A. Pais, *Proceedings of the International Physics Conference, Glasgow* (Pergamon Press, London, 1955).