It is possible that this is to be explained by the absence of special screening in the former case.

The average value of a computed from the data of Table II and from the results of this work is

$$a = -(0.108 \pm 0.0094).$$

The angular distributions of $\mu \rightarrow e$-decay electrons are given in Refs. 9 and 12. Combining those with our data, yields the angular distribution shown in Fig. 2, which represents 13,770 cases of $\mu \rightarrow e$ decays. It can be seen from Fig. 2 that, within the experimental accuracy, the electron angular distribution is described by $1 + a \cos \theta$ with $a = -(0.111 \pm 0.015)$.

In conclusion, the authors express their gratitude to V. P. Dzhelepov, B. S. Neganov, and V. N. Mekhedov for help in emulsion irradiation, and to N. M. Polievktov-Nikoladze for assistance in the statistical analysis of the results.

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HYPERFRAGMENTS IN NUCLEAR EMULSIONS

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The properties and relative frequency of appearance of hyperfragments were investigated. Some effects produced by other types of unstable heavy particles are also mentioned.

THIS investigation was performed with two emulsion stacks which were exposed to cosmic rays in the atmosphere. One stack consisted of $600\,\mu$ Ilford G5 emulsions which were exposed at the time of the international expedition in the valley of the Po River, The second stack consisted of NIKFI R-type emulsions $400\,\mu$ thick, which were exposed in the Soviet Union. The scanning located all stars with prong numbers $N_h \geq 8-10$ or $n_s \geq 2-3$ as well as σ stars and all double stars regardless of the number of prongs.

The main procedure was area scanning with $10 \times 10 \times 1.5$ magnification. In a small number of instances all black prongs were continued until they emerged from the emulsion, and sometimes even up to their termination in other emulsions. But, as a rule, only those double stars were fixed, which were entirely in the field of view of the objective. Altogether there were found six τ mesons, one τ' meson, one Λ^0 particle, four K^- mesons, one Σ^- hyperon and ten hyperfragments, of which five decayed with emission of a π meson.

Not a single case of Σ^+ or of K^+ decay was found, since the method used excluded the possibility of observing such particles. For all primary stars associated with unstable heavy particles, all black and gray tracks were followed until they stopped or emerged from our portion of the pellicle stacks.* Not a single instance of pair production was found in 14 primary stars.

Of the six τ^+ mesons, five were found by area scanning and one by continuing backward the tracks of stopped π mesons. In all cases the tracks of secondary π mesons were observed to be coplanar within $2-3°$. The parent disintegrations were registered in only two cases (10 + 0n and 11 + 3n). The τ' meson[1] was produced in a 3 + 0n star with very small visible energy release. The two black tracks of the parent star (besides the τ' meson) belong to stable particles. After traversing 17 mm the τ' meson stopped inside of the emulsion and decayed. A photomicrograph of this event is shown in Fig. 1.†

The mass of particle 1 was determined to be $(860 + 50)\, m_e$ from gap length density and the residual range. At the stopping point B the track of a secondary π^+ meson begins, which afterwards undergoes $\pi \to \mu \to e$ decay.‡ The length of the π^+ track is $1930\,\mu$. The photomicrograph reveals the tracks of two relativistic particles 5 and 6 leaving the stopping point of the τ' meson and forming an angle of 1° to 2°. Measurement of multiple scattering gives for track 6

$$p\beta c = (66 \pm 10) \text{ Mev},$$

whence it follows that this particle is an electron. Track 5 disappears within the emulsion after a range of $\sim 250\,\mu$, which can reasonably be interpreted as the annihilation of a positron in flight. The present event thus evidently represents the decay

$$\tau' \to \pi^+ + \pi^0 + \pi^0$$

followed by

$$\pi^0 \to \gamma + e^+ + e^-.$$

*In some instances the tracks of the particles of interest were traced in other portions of the pellicle stack which were in laboratories at Budapest, Erevan and Leningrad. The authors wish to thank the staffs of those laboratories for their assistance.

†This event was discovered by L. U. Bannik.

‡The π^+ meson stops and decays at the point C. The apparent reduced ionization at E is associated with the passage of the track from one emulsion to another.

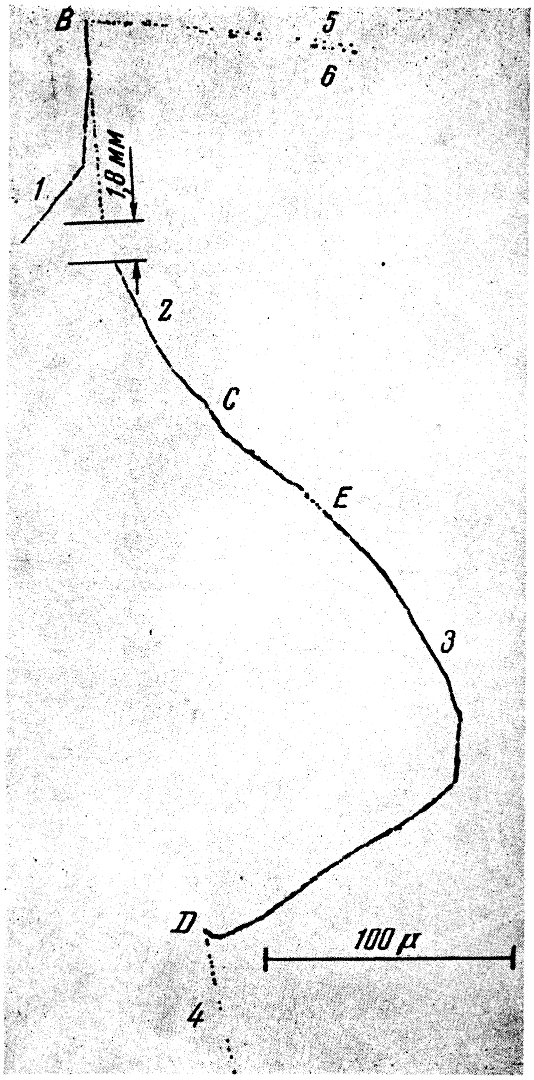

FIG. 1

If this interpretation is correct, then at the present time among K^+ decays leading to π^0 mesons e^+e^- pairs have been observed not only in decays of the type K_{e3}.

Of the four K^- mesons which we found three were detected through systematic scanning and subsequent analysis of the σ stars that possessed a large number of prongs or other unusual characteristics. The parent disintegration was recorded in only one instance (11 + 4n or 11 + 3p).

The K^- meson of the photomicrograph in Fig. 2* had a mass of $(1100 + 250)\, m_e$ as measured from multiple scattering and the residual range.† One

*Discovered by M. I. Tret'iakova.

†Here and hereinafter, except for particle 3 of event No. 2, we used the constant-sagitta method in determining masses from multiple scattering and range.

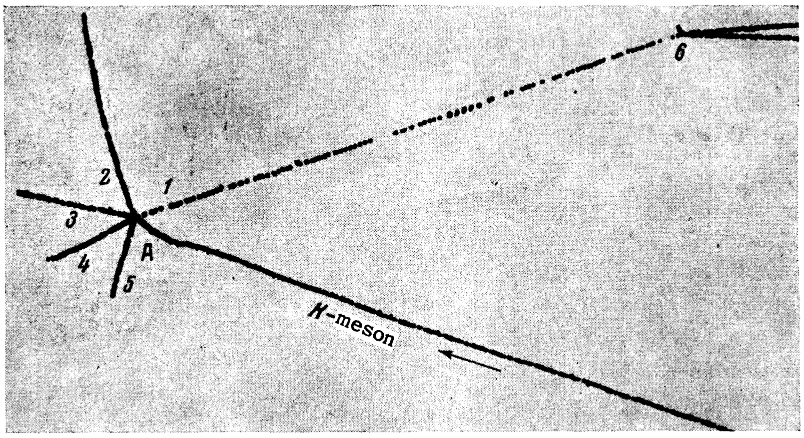

FIG. 2

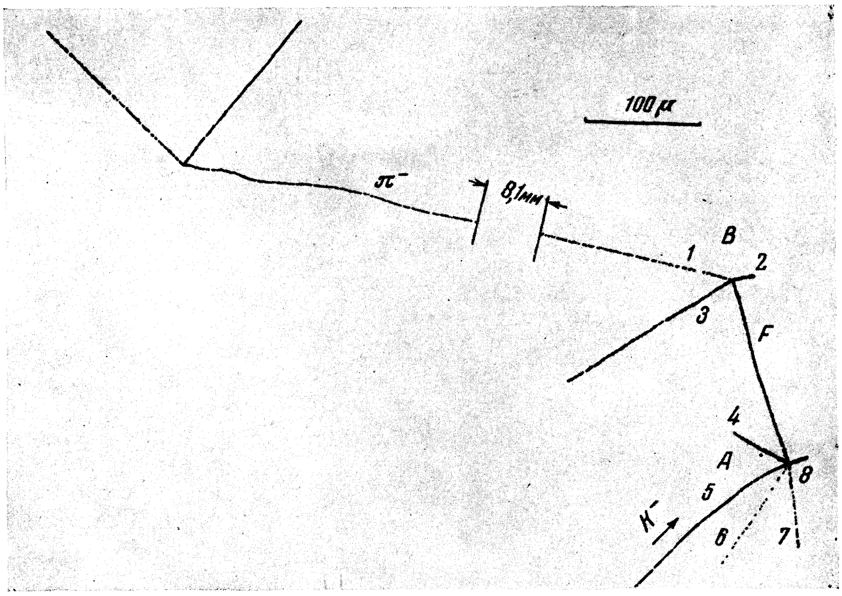

FIG. 3

of the particles (track 1) produced in the five-prong σ star gave rise to a small secondary disintegration at a distance of $\sim 5560\,\mu$ from the σ star. Multiple scattering and ionization measurements of the connecting track show it to be due to a proton with $E = (103 \pm 13)$ Mev. In a σ star produced by another of the K^- mesons which we observed, a proton possessing the relatively large energy $E \sim 75 - 80$ Mev was also found. It has been noted in the literature that the appearance of high-energy protons can be regarded as an indirect argument for the capture of a stopping K^-, according to the scheme

$$K^- + 2N \rightarrow N + \Sigma$$

(see Ref. 2, for example).

A kinematical analysis of the σ star in Fig. 2 showed that for all possible hypothetical forms of nuclear capture the total energy release considerably exceeds $m_\pi c^2$. The same can be said concerning two of the three other σ_K stars, with four and five secondary prongs, respectively. The third σ_K star also has 5 prongs. It appears that all of the σ_K stars which we discovered were produced through K^- capture in light nuclei of the emulsion. This is completely understandable from our scanning method, whereby preferential selection was made of σ stars that possessed a large number of prongs, large visible energy release or other noteworthy properties. It thus follows that the true number of K^- mesons is a few times greater than the number of those actually found, i.e., it is about the same as the number of τ mesons or even somewhat greater. This result fully agrees with experimental findings regarding the ratio of K^+ and K^- mesons generated in cosmic-ray collisions (see Ref. 3, for example).

TABLE I

Track	4	5	6	7	8	F
Range (μ)*	54.7	>27300	>27500 non-stopping	4880	18	161
Error in range (%)	1.7	—	—	0.1	5.1	0.4
Spread of ranges (%)	1.8	—	—	1.4	2	1.2
Angle β with horizontal plane†	+16.0	—	+7.9	−19.8	+15.8	0
Error in angle β (degrees)	2	—	0.3	1	7	—
Azimuthal angle φ (degrees)‡	44.5	—	126.6	167.8	269.8	0
Error in φ (degrees)	0.7	—	0.7	0.7	1.7	0.7
Number of δ electrons with range $\geq$ four grains**	0	—	—	—	0	0
Charge Z	$\leqslant 2$	−1	± 1	+1	$\leqslant 2$	$\leqslant 2$
Method of measuring mass and its magnitude (m_e)	—	$\langle\alpha\rangle - R$: 914 ± 170 $I - R$: 658 ± 55	$I - \langle\alpha\rangle$: 343^{+94}_{-62}	$\langle\alpha\rangle - R$: 1250 ± 340 $I - R$: $2700 \pm$ ± 300	—	—
Identification of particle	p	K^-	π^-	p	He^4_2	${}_\Lambda He^5_2$
Energy of particle (Mev)	2.47 ± 0.04	—	66.3 ± 6.5	35.3 ± 0.3	4.6 ± 0.2	21.3 ± 0.3

*All data refer to an unprocessed emulsion.

†All tracks in the direction of the surface bear the plus sign; tracks in the direction of the glass are given with the minus sign.

‡Taken counterclockwise with respect to an arbitrary direction which is the same for all tracks of the star and the track of the hypernucleus.

**1 grain on the track; 3 grains outside of the track.

One of the remaining K^- mesons deserves special mention. The pertinent data are given in Table I and the photomicrograph of this event is shown in Fig. 3.* Particle 5 is a stopping K^- meson, 7 is a proton and 6 is a π meson. There is no sign of thin-down at the ends of tracks 4, 8 and F so that each of these particles must have a charge ≤ 2. From an analysis of the event at B it follows that particle F is the hyperfragment ${}_\Lambda He^5_2$ (see below, event No. 1).

If 8 were a proton or α particle its energy would be 1.2 or 4.6 Mev, respectively, which is considerably below the height of the Coulomb potential barrier in heavy nuclei of the emulsion. It can therefore be assumed that the K meson was captured in a nucleus of C^{12}, N^{14} or O^{16}. We therefore considered all of the conceivable reactions in C^{12}, N^{14} or O^{16} for all possible masses and charges of particles 4, 6, 7, and 8. It was found that energy and momentum conservation are fulfilled only by

$$K^- + C^{12}_6 \rightarrow {}_\Lambda He^5_2 + He^4_2 + 2p + \pi^- + n.$$

*Discovered by N. V. Kirsanova. A detailed analysis is given in Ref. 4.

The K^- mass is then

$$m_{K^-} = (494.3 \pm 6.8) \text{ Mev},$$

which is in good agreement with data given in other papers.*

It must be pointed out that conservation of energy and momentum are not fulfilled if F is assumed to be a hyperfragment other than ${}_\Lambda He^5_2$. We have thus encountered one of the rare cases in which double identification of a hyperfragment is possible, through the phenomena at its decay and from a consideration of the generation process.† The decisive circumstance is the fact that the hyperfragment was produced in a σ_K- star. We can expect that hyperfragments due to K^- capture can generally be identified much more easily and completely than in the usual instances. This may be especially important in studying hyperfragments that undergo nonmesonic decay. Even more favorable conditions are realized in the nuclear capture

*For example, Ref. 5 gives $m_{K^+} = (493.66 \pm 0.36)$ Mev. The K^- mass is less accurately known, but we can reasonably assume that $m_{K^-} = m_{K^+}$.

†Ref. 6 describes a similar instance of double identification of a hyperfragment resulting from K^- capture.

of Σ^- hyperons, but, unfortunately, this event is observed much less frequently.

We found only one Σ^- hyperon, produced in a $9 + 2n$ or $9 + 1p$ star. One of the gray prongs of the parent star produces in flight a secondary disintegration with small Q (4 black prongs ending in the same emulsion). The length of the Σ^- track is $715\,\mu$.

The mass was determined from multiple scattering and residual range, which gave $M = (1.0 \pm 0.4)\,m_p$ for a gap scheme corresponding to a proton. For gap schemes corresponding to a τ meson and a π meson the mass was $(1.3 \pm 0.3)\,m_p$ and $(1.4 \pm 0.3)\,m_p$, respectively. The Σ^- was stopped in producing a three-prong σ star with one gray track (range $> 3800\,\mu$) and one black track (range $385\,\mu$). The third track is very short, being only $\sim 1.5\,\mu$. Comparison of the ionization and multiple scattering shows that the gray track is probably that of a proton with about 90 Mev.

Although many interesting papers have already been published concerning investigations of hyperfragments there is still no reliable and sufficiently complete information regarding the frequency of their generation and the dependence of this frequency on the character and energy of the generating particles. This results from the difficulty of identifying hyperfragments reliably, especially in the case of nonmesonic decays. Therefore, different investigators use entirely different criteria which are very difficult to correlate; it is thus extremely difficult to compare different data on the frequency of hyperfragment generation. For combining data, it would be important to agree on uniform criteria; for this purpose we believe that the rules suggested in the review article, Ref. 7, are quite suitable. These rules require reliable proof that the event in question is not a σ star and that the kinetic energy of the proposed hyperfragment is small enough to exclude clearly the possibility of the disintegration of some nucleus by collision. Data concerning hyperfragments that undergo mesonic decay are especially reliable and should, we believe, provide the basis for various quantitative comparisons.

In the present work we found ten hyperfragments which satisfy the criteria of Ref. 7. Five of these underwent nonmesonic decay, while the others underwent mesonic decay.* The parent disintegrations were of the types $19 + 3n$ (or $19 + 2p$), $17 + 4n$ (or $17 + 3p$), $41 + 7n$ (or $41 + 6p$), $15 + 2n$, $13 + 4n$, $17 + 4p$, $5 + 0n$, $27 + 13n$ and $14 + 5p$. It is noted that as a rule the very large number N_h of gray and black prongs in the parent disintegrations is considerably larger than in stars containing τ mesons. For the mean number of gray and black prongs we have

$$\overline{N}_h = 18.7 \pm 3.7,$$

which is in good agreement with the data in other papers (see Ref. 8, for example). It would be very interesting to obtain corresponding data for different types of "strange" particles when the nature and energy of the generating particles are known.

In addition to the hyperfragments which have been mentioned $\sim$ 37,000 stars were found with either $N_h \geq 8-10$ or $n_s \geq 2-3$, which corresponds to about 10^5 cosmic-ray stars of all types. Thus from cosmic rays we obtain one mesonic decay of a hyperfragment in about 2.5×10^4 nuclear disintegrations of all kinds. This agrees in general with the results obtained by other investigators. The data are given in Table II.

TABLE II

Primary particles	Reference	Number of Disintegrations	Number of Mesonic Decays
Cosmic rays	[9]	24 000	2
Cosmic rays	[10]	27 000	2
Cosmic rays	[11–12]	119 000	5
Protons with E_p = 6 Bev	[11]	10 000	0
π^- mesons with E_{π^-} = 3 Bev	[11–12]	80 000	3
π^- mesons with E_{π^-} = 4.7 Bev	[13]	150 000	30
Cosmic rays	Present work	100 000	4

The table shows that for 270,000 cosmic-ray stars there are 13 mesonic decays, i.e., about one decay for 20,000 stars. Also, bombardment with 4.7-Bev π^- mesons yields one mesonic decay for only 5000 disintegrations.* It would not be legitimate to make a direct comparison of these results, because in cosmic rays a large percentage of the disintegrations are produced by particles of relatively low energies. Further work is needed with accelerators that produce particles of various kinds with energies of a few billion electron volts.

In Ref. 7 and elsewhere it is stated that a large

*One of the hyperfragments which underwent mesonic decay was produced in a σ_K star and is therefore excluded from subsequent compilations giving the frequency of generation and the nature of the parent disintegrations.

*A rapid increase of the frequency of hyperfragment generation is noted with increasing π^- energy.

percentage of hyperfragments is found among double-centered stars with very short connecting tracks. In the present work, we observed seven double-centered stars in which the connecting track did not exceed $10\,\mu$. In only one of these instances was it possible to prove by means of a detailed kinematical analysis that the secondary disintegration could not have resulted from a stopped π^- meson. In this case the secondary star had five prongs of which one was a proton with the range $11{,}300\,\mu$ ($E_p \approx 56$ Mev.). In one of the other six cases the secondary star also contains a proton of the relatively high energy ~ 50 Mev, and in a third case the secondary disintegration also has five prongs but the total Q is small. In all of the events that were found, the primary stars have very many black and gray prongs;* the average of these is $\overline{N}_h = 14 \pm 2.7$. However, it must be remembered that this increase of $\overline{N}_h$ above the normal level would have had to occur on the basis of the usual mechanisms for the appearance of the double-centered stars under consideration.

The individual characteristics of the hyperfragments are summarized in Table III. (In calculating the angles the hyperfragment track was assumed to emerge from the center of the secondary star.)

Event No. 1. Fig. 3 is the photomicrograph of this event. Particle 1 is a π^- meson which produces a σ star in stopping. The measured widths of tracks 2, 3, and F showed $Z \leq 2$ for each of these particles. The tracks of 1, 2 and 3 are coplanar to within 3°. This points to the formation of star B by the decay of a stopped hyperfragment to three charged particles. A kinematical analysis of B was carried through for all possible masses of 2 and 3, assuming their charge to be 1 or 2. It appeared that for all of the proposed decay schemes, with one exception, the combined momentum is clearly different from zero. The combined momentum is zero only in the scheme

$$_{\Lambda}He_2^5 \rightarrow He_2^4 + p + \pi^-.$$

Then the combined kinetic energy of all the particles is

$$Q = (34.2 \pm 0.4)\ \text{Mev},$$

and the binding energy of the Λ^0 particle is $B_\Lambda = (2.7 \pm 0.4)$ Mev, which is in good agreement with published data (Ref. 7, for example). The normal to the decay plane and the direction of motion of the hyperfragment form an angle of 82°.

Event No. 2. The mass of the particle F* was determined from multiple scattering and range using the cell schemes for H_1^4, He_2^5 and Li_3^6; the result was $M_F = (6 \pm 2)\,m_p$. Twelve δ electrons were discovered along the F track. Since ~ 5.5 δ electrons are expected along a proton track of this range, the charge of F evidently exceeds unity. On the other hand, the F track shows no sign of thin-down upon stopping as is always observed in Li tracks. Combining these results, we can assume that the charge of F is two. This is also supported by a comparison of the track widths for protons, α particles, and F.

The track of 3 has the character of a light meson. Its mass, from multiple scattering and range, is $(230 \pm 90)\,m_e$. On this basis 3 was identified as a π^- meson which upon stopping produced a nuclear disintegration accompanied by the emission of only neutral particles. Tracks 1, 2, and 3 lie in the same plane within the limits of error. The errors are quite large since track 1 is only $1.6\,\mu$ long. The combined momentum of 1, 2 and 3 is close to zero only if 2 is a proton. The charge of 1 must then be two. If it is assumed that this event represents the scheme

$$_{\Lambda}He_2^4 \rightarrow He_2^3 + p + \pi^-,$$

the binding energy of Λ^0 is

$$B_\Lambda = (3.1 \pm 0.4)\ \text{Mev},$$

which differs extremely from the results of other investigations. The most probable interpretation apparently is given by

$$_{\Lambda}He_2^5 \rightarrow He_2^4 + p + \pi^-.$$

The decay energy appears to be $B_\Lambda = (3.0 \pm 0.4)$ Mev. The normal to the decay plane and the direction of the hyperfragment track is 56°.

Event No. 3. From measurements of the thickness of the track of F it follows that its charge cannot be more than two. The tracks of 1 and 2 are collinear within the limits of error, from which it follows that 1 decayed after stopping. The mass of 1 from multiple scattering and ionization is $(235 \pm 90)\,m_e$ so that 1 can be regarded as a π meson. In addition, $p\beta c = (89.5 \pm 8)$ Mev, which completely agrees with

$$_{\Lambda}H_1^4 \rightarrow He_2^4 + \pi^-.$$

*The parent stars are of the types 12 + 1n (or 12 + 0p), 9 + 1n (or 9 + 0p), 17 + 2n (or 17 + 1p), 30 + 7n (or 30 + 6p), 14 + 2p, 9 + 2n (or 9 + 1p) and 7 + 1n (or 7 + 0p).

*The letter F everywhere designates a hyperfragment.

TABLE III

No. of the hyperfragment	Track	Range (μ)	Error in range (%)	Range spread (%)	Angle β with horizontal plane (degrees)	Error in β (degrees)	Azimuthal angle φ (degrees)	Error in φ (degrees)	Number of δ electrons with range $\geq$ four grains	Charge Z	Method of measuring mass and its magnitude (m_e)	Identification of particle	Energy of particle (Mev)	Parent star
1	F	161	0.4	1,2	0		0	0,7	0	$\leqslant 2$		$_{\Lambda}He_2^5$	21,3±0,3	
	1	8481	0,1	3,0	− 9,0	4	232,3	0.7		−1		π^-	21,0±0,4	
	2	19,3	4,2	2.0	+12,4	7	79,5	1,7	0	$\leqslant 2$		He_2^4	4,8±0,2	
	3	401	0,5	1,6	−18,5	2	278,2	0,7	0	$\leqslant 2$		p	8,4±0,1	
2	F	883			−3	0,5	0		12	2	$\langle\alpha\rangle-R$: 11000±3700	$_{\Lambda}He_2^5$		13+4 n
	1	1,6			−3	2	100	7				He_2^4	0,2±0,1	
	2	244	1,5	1,6	+8	0,5	233					p	6,2±0,2	
	3	13535	0.3	1.2	+9	0,5	37			−1	$\langle\alpha\rangle-R$: 230±90	π^-	27.4±0,3	
3	F	88			−1		0	1		$\leqslant 2$		$_{\Lambda}H_1^4$		5+0 n
	1	>12350			−34	1	219	1			$\langle\alpha\rangle-I$: 235±30	π^-	51,7±5,5	
	2	8,8	~15		+30	7	45	3				He_2^4	2,5±0,4	
4	F	450			+2					2<Z<5	$\langle\alpha\rangle-R$: 14700±3700	$_{\Lambda}Li_3$ or $_{\Lambda}Be_4$		
	1	3,2			−40		226					Recoil nucleus		17+4 p
	2	13400			−68		71					π^-	27,2	
	3	280			+70		0					p, d or t	7,4	
5	F	82			+48,5		0			3 or 4		$_{\Lambda}Li_3^7$		27+13 n
	1	10			+13,3		127					He_2^4		
	2	38			−17,6		24					p		
	3	178			− 3,6		311					p		
	4	7476			+ 6,6		214					π^-		
6	F	33								$\geqslant 4$		$_{\Lambda}B_5$		17+4 n or 17+3 p
	1	260												
	2	1315												
	3	14,6												
	4	413												
	5	19												
7	F	61			−28,7		0			~3		$_{\Lambda}Li_3$		41+7 n or 41+6 p
	1	50			+39,6		299							
	2	612			−72,3		353							
	3	>19000			+33,5		167					p		
8	F	55			−31		0			$\geqslant 2$		$_{\Lambda}He_2$ or $_{\Lambda}Li_3$		15+2 n
	1	1590			−40,7		310							
	2	3816			+6,6		256				$\langle\alpha\rangle-R$: 1970±330	p		
	3	1												
9	F	124			+33					$\geqslant 4$		$_{\Lambda}Be_4$		19+3 n or 19+2 p
	1	2660			+22		225				$\langle\alpha\rangle-R$: 2020±550	p		
	2	1004			+5,6		143				$\langle\alpha\rangle-R$: 3490±740	d		
											$I-R$: 4040±370			
	3	11750			−28,2		4				$\langle\alpha\rangle-R$: 2020±423	p		
	4	202			−18,2		0			1		p, d, t		
10	F	92			−8,7					3<Z<6 ±1	$I-\langle\alpha\rangle$: 725^{+170}_{-140}	$_{\Lambda}Be_4$		14+5 p
	1	>10700			−29	4	0	0,7			700±85; 1380±150	p or K	$\langle\alpha\rangle$: 57±5 if p	
	2	8	10	2	+34,8	7	87,6	4		3 or 5		Li_3^8 or B_5^8	4,1 (Li) 10,7 (B)	

The range of 2 is 8.8μ, which also agrees with this decay scheme (see Ref. 14, for example). The directions of emission of the hyperfragment and the secondary π meson form an angle of 64°.

Event No. 4. The charge of F was measured from the count of δ electrons and track thin-down near stopping. The first method gave Z > 2, while the second method gave Z = 3 to 4 (thinned length

$10-20\mu$). The mass of F as measured from multiple scattering and range is $(8 \pm 2)\,m_p$. Track 2 stops in a σ star and therefore belongs to π^- meson. The hypothesis of F decay to three charged particles leads to considerable difference from zero for the combined momentum no matter what assumptions are made regarding the nature of 1 and 3. It can thus be concluded that we are dealing with the decay of one of the isotopes of $_\Lambda$Li or $_\Lambda$Be accompanied by the emission of one or more neutral particles. A more detailed analysis was not made because of the great inaccuracy in determining the momentum of 1 and the resulting inaccuracy in determining the neutron momenta.

Event No. 5. The track of F shows thin-down beginning at $10-15\mu$ from the track end. This is evidence that the decay of the hyperfragment occurred after stopping and that it is triply charged. This last conclusion agrees with the measurement of the F track thickness before the thin-down begins. Track 4 belongs to a π^- meson which gives a σ star after stopping. For any assumptions regarding the nature of 1, 2, and 3 that are compatible with charge conservation, the combined momentum of all the charged secondary particles differs from zero. This result is not changed even if it is assumed that the hyperfragment has charge four. The emission of neutral particles must therefore also be assumed. It appears that for all possible decay schemes with one exception the binding energy B_Λ assumes large negative values. The exception is the decay scheme

$$_\Lambda\mathrm{Li}_3^7 \to \mathrm{He}_2^4 + 2p + n + \pi^-,$$

for which $B_\Lambda = (1.9 \pm 1.2)$ Mev. This must be regarded as the most likely interpretation.

Event No. 6. The F track shows thin-down for $20-25\mu$, which is evidence of stopping of the hyperfragment and corresponds to Z = 4 to 5. Five charged particles resulted from the decay without including a single π meson. F is apparently a $_\Lambda B_5$ hyperfragment which underwent nonmesonic decay accompanied by neutron emission.

Event No. 7. The F track shows thin-down for $10-15\mu$, which corresponds to $Z \sim 3$. Measurements of the track density at large distances from the stopping point lead to the same value. Track 3 leaves our part of the emulsion stack after traversing $\sim 19{,}000\,\mu$. If this track belonged to a π meson its ionization could exceed the minimum by a factor of less than 1.6; in actuality the ionization in track 3 is close to triple the minimum amount,

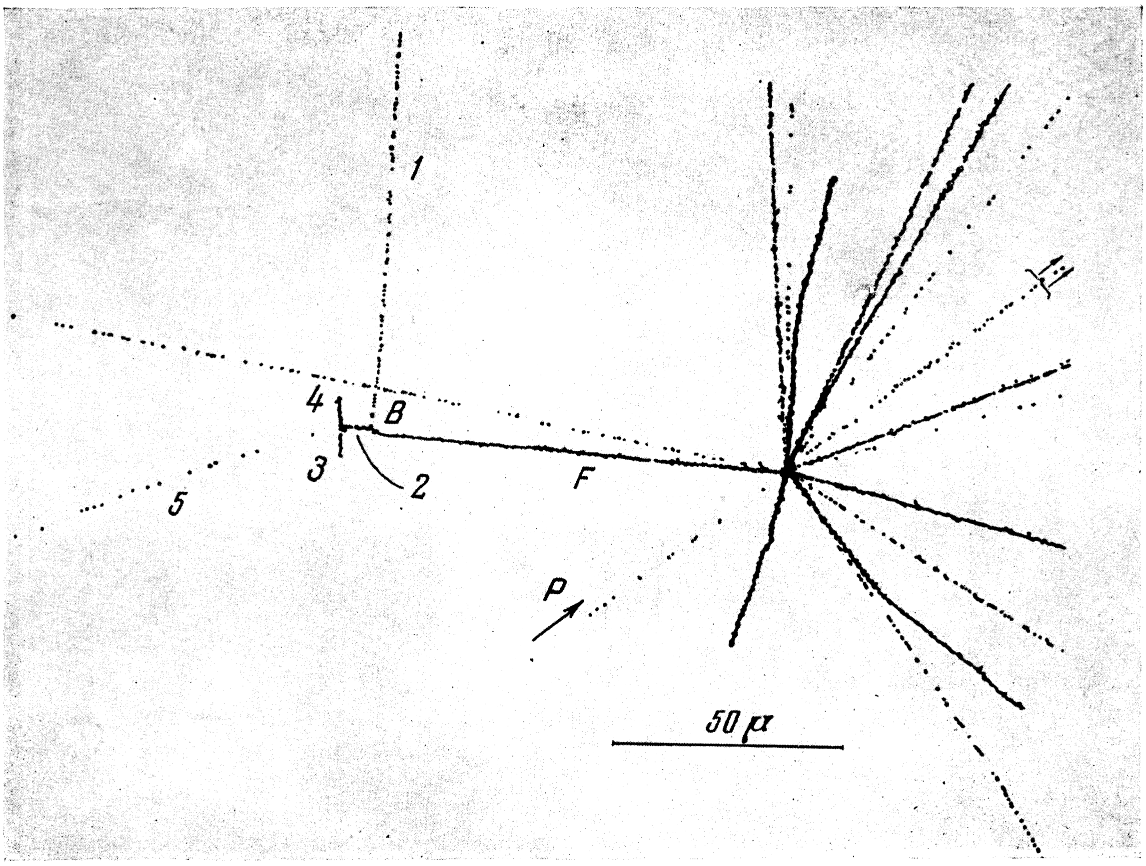

FIG. 4

thus representing a proton with close to 63 ± 14 Mev. The event as a whole is apparently the nonmesonic decay of ${}_\Lambda Li_3$ in which neutral particles are also emitted.

Event No. 8. From measurements of track thickness it follows that F has charge $Z \geq 2$. At the very end of the track thinning for a distance of $\sim 5\,\mu$ is observed, which is less than the usual thinned-down distance for lithium ($\sim 12\,\mu$). The tracks of α particles as a rule show no thin-down; on this basis, too, it can be concluded that $Z \geq 2$. If the hyperfragment is a lithium isotope there remains the possibility of decay in flight shortly before complete stopping, by which the short thinned length would be accounted for. Of course, this is not a necessary interpretation. 2 must be a proton since its mass, from multiple scattering and residual range, is $(1.1 \pm 0.2)\,m_p$. The nature of 3 is doubtful. We cannot exclude the possibility of a mere chance clustering of grains. The event as a whole must apparently be considered to be the decay of one of the isotopes of ${}_\Lambda Li_3$ or ${}_\Lambda He_2$.

Event No. 9. The track of F is considerably thinned in its last $20\,\mu$, which is evidence of stopping and gives $Z \sim 4$. The mass of 1 was measured from multiple scattering and residual range. Classification of gaps according to the schemes for p and d gives $(1.1 \pm 0.3)\,m_p$ and $(0.9 \pm 0.4)\,m_p$, respectively. 1 is thus a proton. The mass of 3 is $(1.1 \pm 0.2)\,m_p$ and $(1.2 \pm 0.2)\,m_p$ from the proton and τ meson gap schemes, respectively. Thus 3 is also a proton. The mass of 2 is $(1.2 \pm 0.4)\,m_p$, $(1.9 \pm 0.4)\,m_p$ and $(1.7 \pm 0.45)\,m_p$ for the p, d and τ gap schemes, respectively. Therefore we can reasonably assume that 2 is a deuteron. Gap length measurements on the track of 2 are in good agreement with this identification, leading to $(1.1 \pm 0.06)\,m_d$. The thickness of track 4 shows that this particle is singly charged. The combined momentum of 1, 2, 3 and 4 is not zero for the different possible hypotheses concerning the nature of 4. This event can therefore be regarded as nonmesonic decay of an isotope of ${}_\Lambda Be_4$ accompanied by the emission of neutral particles.

Event No. 10. Fig. 4 is a photomicrograph of this event.* The parent star is of the type 14 + 5p or 14 + 3p, since the two particles indicated by arrows possibly comprise a (e^+e^-) pair from the decay $\pi^0 \rightarrow e^+ + e^- + \gamma$. Track F has thin-down for $\sim 20\,\mu$ at its end, so that

$$3 < Z_F < 6.$$

On the other hand, it follows from an analysis of 1 and 2 that $Z_F = 2.4$ or 6. Comparison of the data leads to $Z_F = 4$. Track 2 ends in the characteristic "hammer" whose formation is preceeded by β decay. Therefore 2 is most likely Li_3^8 (or, with smaller probability, B_5^8).

Particle 1 leaves the emulsion stack. Its mass was determined from multiple scattering and ionization, with special attention paid to the reliability of the measurements. Multiple scattering was measured on the portions of the track which were more than 3.5 mm distance from the edge of the emulsion, with a cell length of $112\,\mu$. The measurements include a negligible noise effect as is confirmed by measurements with doubly large intervals. Special measurements showed little distortion, which was also excluded by the method of third differences and various other methods. The results obtained with and without elimination of the distortion are in very good agreement. The width of the distribution curve of absolute second differences also agrees with the prediction of multiple scattering theory. The result is $p\beta c = (88 \pm 7)$ Mev.

Ionization was measured by grain counts, by blob counts and from mean gap length. In the first case the number g of grains per unit track length was compared with the grain number g_0 in the tracks of relativistic particles. Measurements were performed by two observers, whose results practically coincided, giving

$$m' = \left(725 \ \pm {}^{170}_{140}\right) m_e.$$

In the second and third cases results were compared for 1 and the tracks of control π mesons with about the same velocity and dip angle. Prior to that, it was shown especially that in the central portions of the plate and in portions close to the event under consideration (i.e., close to the edge) the ionization characteristics of the particles agree when they have equal velocity. Measurements by the second method yielded

$$m'' = (700 \pm 85)\, m_e,$$

and by the third method,

$$m''' = (1380 \pm 150)\, m_e.$$

It follows that 1 could be regarded as a K meson. Then the event as a whole would be similar to events described in Refs. 15 to 17. However, it must be noted that of the three methods mentioned for measuring ionization the most reliable from a methodological point of view is the last, which gives the largest value for the mass. Therefore 1

*This event was found by U. G. Guliamov.

could possibly be a proton, so that we would have nonmesonic decay of $_{\Lambda}Be_4$ accompanied by neutron emission.

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STUDY OF HIGH-ENERGY NUCLEAR-ACTIVE PARTICLES WITH IONIZATION CHAMBERS

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Nuclear-active particles with energy $> 10^{11}$ ev were studied at an altitude of 3860 m above sea level by means of ionization chambers placed under absorbers of various thickness and of a counter hodoscope. Integral spectra of ionization bursts in the chambers are presented, and conclusions are drawn regarding the absorption mean free path in air and in lead of nuclear-active particles with energy $> 10^{11}$ ev.

HIGH-ENERGY nuclear-active particles ($E > 10^{11}$ ev) were studied in Autumn 1955 at 3860 m elevation by means of an array consisting of six pulse ionization chambers placed under lead absorbers of varying thickness (20, 50, and 80 cm, Fig. 1). The ionization chambers were constructed of brass cylinders with walls 3.8 g/cm^2 thick and an internal diameter of 22.5 cm. The effective area of each chamber was 0.22 m^2. The chambers were filled with argon at 4 atmos.

The electronic system made it possible to record the ionization pulse heights in each of the six chambers. The interval of recorded pulses ranged from that due to the passage of a single relativistic particle to that due to 1.5×10^4 particles, assuming the trajectories to lie on the mean chord of the chamber. A hodoscope consisting of 972 counters with total area of ~ 10 m^2 was used in conjunction with the ionization chambers. Alternate triggering was provided: the array was operated whenever