FIZIKA 5 (1973) 187-194

# DOUBLE STRANGE EXCHANGE OF K$^-$ MESONS OF A MOMENTUM OF 1.5 BeV/c IN NUCLEAR EMULSION

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Recived 18 August 1973

*Abstract*: In this work an analysis has been made of processes of double strange exchange of K$^-$ mesons leading to the production of hyperfragments together with strange particles. The process of double strange exchange of K$^-$ mesons on nuclei (with the formation of two hyperons of strangeness $S =$ $= -1$ in the final state) is brought about through a secondary interaction of $\Xi$ hyperons or $\pi$ mesons with nucleons in the nucleus in which they are produced. The contribution of individual channels in the production of events with a hyperfragment and strange particles is discussed.

## 1. Introduction

The processes of interaction of K$^-$ mesons with nuclei leading to the production of two hyperons and a K$^+$ or K$^0$ meson

$$K^- A \to YYK^{+0}(A-2)$$

are brought about by involving two nucleons from the nucleus. In the course of the processes two nucleons from the nucleus are transformed into two hyperons of strangeness $S = -1$.

Events in which two hyperons of strangeness $S = -1$ are emitted have been found earlier in a nuclear emulsion exposed to K$^-$ mesons of a momentum higher than 1 BeV/c[1-4]. The first results with a larger statistics on the production of two $\Lambda$ hyperons in the final state of the interaction of K$^-$ mesons with nuclei were obtained with K$^-$ mesons of a momentum of 1.47 BeV/c in bubble chambers[5].

This work is a continuation of an earlier work[6] in which the production of two hyperons in the final state of the interaction of 1.5 BeV/c $K^-$ mesons with emulsion nuclei was analyzed in events with a hyperfragment.

## 2. *Experimental method and results*

Details concerning the emulsion stack, scanning and the criterion for selection of hyperfragments have been given earlier[7]. We analyzed 500 events with a hyperfragment, which were found by scanning 14450 events of the interaction of $K^-$ mesons in nuclear emulsion. $(94 \pm 3)\%$ of the events with a hyperfragment are due to the interaction of $K^-$ mesons with heavy nuclei (Ag, Br) in nuclear emulsion. The probability of production of hyperfragments ($P_{hf}$) on heavy nuclei in nuclear emulsion is $(4.2 \pm 0.1)\%$, while that on light ones (C, N, O) is $(0.94 \pm \pm 0.05)\%$.

All tracks of events with a hyperfragment were followed in our part of the stack, measured and analyzed. Data on the methods used for indentification of tracks have been given earlier[6, 7].

Out of all the analyzed events with a hyperfragment we found 27 in which besides a hyperfragment strange particles were emitted. About 96% of events with a hyperfragment and strange particles are due to the interaction of $K^-$ mesons with heavy nuclei in nuclear emulsion. In addition to a hyperfragment in 4 events only a K meson was emitted, in 17 only a $\Sigma$ hyperon, while in 6 events a K and a $\Sigma$ hyperon were emitted. The ratio of indentified $\Sigma^-/\Sigma^+$ is about 5.3. On the basis of the interaction or decay of K mesons and according to the characteristics of the primary events in which these K mesons were emitted it was established that out of 10 identified K mesons 9 were $K^+$ and 1 was $K^-$.

All the identified $\Sigma$ hyperons and K mesons had energies lower than 350 MeV (the majority within the energy range (40 — 120)MeV) and were emitted dominatly in the forward direction with respect to the incidence direction of the primary $K^-$ meson. The forward /backward ratio for $\Sigma$ hyperons and K mesons is $18/5 = = 3.6$ and $8/2 = 4$ respectively.

Out of 27 events with a hyperfragment and strange particles only for 12 event the hyperfragment was quite certainly established. The basic characteristics of emitted hyperfragments and strange particles for events in which the hyperfragment was certain are given in Table 1. For events 2, 4, 7, the decay mode of the hyperfragment was not determined, but on the basis of the decay itself and the characteristics of the hyperfragment track we may state that these are certain hyperfragments. Consequently the lower limit of the production frequency of strange particles in events with a hyperfragment is 2.4%.

Table 1

| No. | Hyperfragment: Range ($\mu$m) | Decay | $B_\Lambda \pm \Delta B_\Lambda$ (MeV) | Identified strange particles | End of the strange particle track |
|---|---|---|---|---|---|
| 1 | 5025 | ${}^3_\Lambda H \to \pi + {}^1H + {}^2H$ | 0.35 ± 0.55 | K | $K\varrho$ in flight |
| 2 | 425 | Mesonic<br>$Z \leq 3$ | | K<br>$\Sigma$ | Leaving the stack<br>$\Sigma\varrho$ at rest |
| 3 | 317 | ${}^4_\Lambda He \to \pi + {}^1H + {}^3He$ | 2.22 ± 0.61 | $\Sigma$ | $\Sigma^\pm \to \pi^\pm + n$ |
| 4 | 307 | $Z = 2$ | | K | Leaving the stack |
| 5 | 223 | ${}^5_\Lambda He \to n + {}^1H + {}^3H$ | 3.21 ± 1.84 | $\Sigma$ | $\Sigma\varrho$ at rest |
| 6 | 44 | ${}^9_\Lambda Be \to n + {}^2H + {}^6Li$ | 8.89 ± 3.09 | K<br>$\Sigma$ | Leaving the stack<br>$\Sigma\sigma$ at rest |
| 7 | 6.4 | | | K | $K^+ \to \pi^+ + \pi^+ + \pi^-$ |
| 8 | 6.3 | ${}^{14}_\Lambda N \to n + 2{}^1H + {}^4He + {}^7Li$<br>${}^{13}_\Lambda C \to n + {}^1H + 2{}^2H + {}^7Li$ | 15.10±3.56<br>10.63±3.60 | K<br>$\Sigma$ | $K\sigma$ in flight<br>$\Sigma\sigma$ in flight |
| 9 | 5.8 | ${}^9_\Lambda Be \to n \times 2{}^2H + {}^4He$ | 11.15±7.35 | $\Sigma$ | $\Sigma\varrho$ at rest |
| 10 | 5.6 | ${}^{14}_\Lambda N \to n + 2{}^1H + {}^4He + {}^7Li$ | 10.98±5.02 | K<br>$\Sigma$ | $K\varrho$ in flight<br>$\Sigma\sigma$ in flight |
| 11 | 3.5 | ${}^6_\Lambda He \to n + {}^2H + {}^3H$ | 4.41±1.64 | K<br>$\Sigma$ | $K\varrho$ in flight<br>$\Sigma\sigma$ at rest |
| 12 | 2.8 | ${}^5_\Lambda He \to n + {}^1H + {}^3H$ | 3.97±1.60 | $\Sigma$ | $\Sigma\varrho$ at rest |

Among events in which the hyperfragment was not certain we found two events in which a $\pi$ meson was emitted and one event in which a $K^-$ meson was emitted. In events in which a $\pi$ meson was emitted the secondary star did not arise from the decay of the hyperfragment, since the probability of producing many strange particles and $\pi$ mesons in the final state of the interaction of 1.5 BeV/c $K^-$ mesons with complex nuclei can be neglected. Also in the event in which a $K^-$ meson was emitted the secondary star did not arise from the decay of the hyperfragment, but from the interaction or decay of particles produced in the process of $K^-$ reemission. For the remaining 12 events in which the formation of a hyperfragment was not certain we are unable to state whether the secondary star arose from the decay the hyperfragment or from the interaction or decay of particles produced in the process of interaction of the $K^-$ meson.

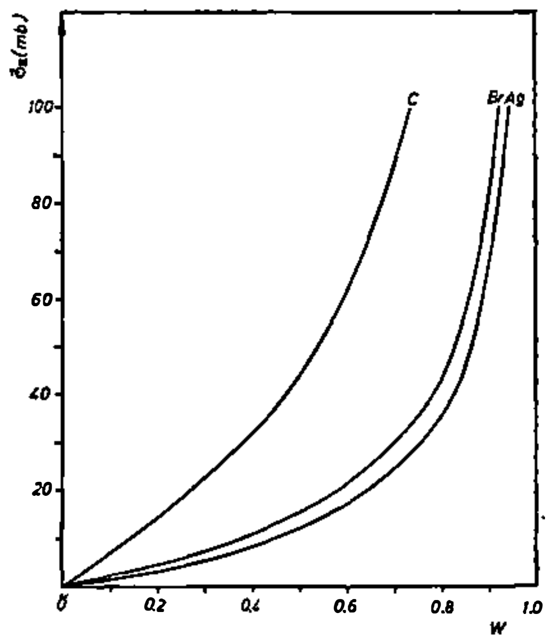


Fig. 1 The probability of occurrence of two successive interactions in the nucleus as a function of the cross-section for the interaction of the secondary particle.

## *3. Discussion*

Events in which a hyperfragment and strange particles are emitted are due to the processes of interaction of $K^-$ mesons with complex nuclei in nuclear emulsion followed by the secondary interaction of the $\pi$ meson

$$K^- + N \rightarrow Y + \pi$$

$$\pi + N \rightarrow K + Y,$$

and of the $\Xi$ hyperon

$$K^- + N \rightarrow \Xi + K$$

$$\Xi + N \rightarrow Y + Y.$$

The probability $W$ that two successive interactions will occur in the nucleus is given in Fig. 1 as a function of the cross-section $b$ for the interaction of secondary particles with nucleons in the nucleus for a $K^-$ momentum of 1.5 BeV/c. The value of $W$ is calculated under the assumption that $\pi$ mesons and $\Xi$ hyperons from the $K^-N$ interaction have the same direction as the $K^-$ meson. This assumption is justified by previous results [6,8], according to which $\pi$ mesons of an energy higher than the threshold energy for strange particle production and the $\Xi$ hyperons from the $K^-N$ interaction are emitted at small angles with respect to the direction of $K^-$ mesons.

The number of events in which a hyperfragment and strange particles are formed by the secondary interaction of the $\pi$ meson per one event of interaction of the $K^-$ meson can be calculated from the relation

$$N_{\pi s} = W\left(\frac{\sigma_{\pi s}}{\sigma_{\pi z}}\right) P_{hf} \cdot \eta \cdot \varepsilon,$$

where $\sigma_{\pi s}$ is the cross-section for the production of charged strange particles by the $\pi N$ interaction, $\sigma_{\pi z}$ is the cross-section for the interaction of the $\pi$ mesons with nucleons, $\eta$ is the number of produced $\pi$ mesons per one event with a hyperfragment, and $\varepsilon$ is the fraction of these $\pi$ mesons having an energy above the threshold energy for the production of charged strange particles.

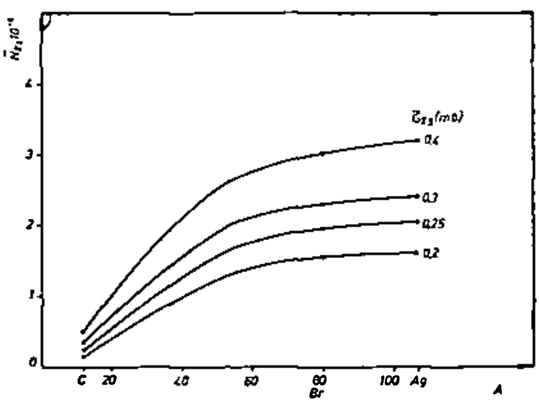


Fig. 2. The number of events per one interaction of $K^-$ mesons as a function of the atomic number of the target nucleus.

The value of $\eta$ was estimated on the basis of the results of identification of tracks to be 1.46. In the same way it was established that in about 54% of events with a hyperfragment the $\Lambda$ hyperon was produced with a $\pi$ meson. It can be assumed that in events in which the $\Lambda$ hyperon is produced by the $K^-N \rightarrow \Lambda\pi$ interaction the $\pi$ mesons have an energy higher than the threshold energy for strange particle production, since the probability of capture of a $\Lambda$ hyperon in the nucleus in which it is produced rapidly decreases with increasing energy of the $\Lambda$ hyperon[6]. Since the final state of the $K^-N$ interaction, $\Lambda\pi\pi$, proceeds predominantly through the formation of the resonance $Y^*(1385)$[10], from a kinematic analysis it can be concluded that $\pi$ mesons in this case cannot have an energy higher than the threshold energy for the strange particle production. Consequently the fraction of $\pi$ mesons having an energy above the threshold energy for the strange particle production is 0.37.

In Fig. 2 calculated values of $N_{\pi s}$ are given as a function of the atomic number of the target nucleus for values of $\sigma_{\pi s}$ lying in the interval (0.2 — 0.4)mb. It is seen that the quantity $N_{\pi s}$ strongly depends on the atomic number of the target nucleus and on the cross-section $\sigma_{\pi s}$. From a kinematic analysis of the $K^-N \rightarrow \Lambda\,\pi$ interaction and on the basis of the dependence of the probability of capture of the $\Lambda$ hyperon on energy we can conclude that the mean value of the energy of the $\pi$ mesons produced in events with a hyperfragment by the quoted interactions of $K^-$ mesons is about 1 BeV. The mean value of the cross-section $\sigma_{\pi s}$, calculated for heavy nuclei in nuclear emulsion, is 0.25 mb for $\pi$ mesons of an energy of about 1 BeV[11]. Consequently the number of events per one interaction of $K^-$ mesons with heavy nuclei followed by the secondary interaction of the $\pi$ meson is $2.10^{-4}$.

Starting from the number of the analyzed interactions of $K^-$ mesons on heavy nuclei (11200) and on the basis of the above quoted data we can state that (7 — 15)% of events in which a hyperfragment and strange particles were detected are due to the process of interaction of $K^-$ mesons followed by the secondary interaction of the $\pi$ meson.

The process of interaction of $K^-$ mesons involving the $\Xi$ hyperon cannot be considered in the same way as that involving the $\pi$ meson, because the corresponding values of the cross-section for the $\Xi$ N interaction are unknown. Starting from the fact that out of 27 events with a hyperfragment and strange particles at least 10 are due to the process of interaction of $K^-$ mesons involving the $\Xi$ hyperon, we can determine the lower limit of the value of the cross-section for the inelastic $\Xi$N interaction. To determine this value it is necessary to know the number of produced $\Xi$ hyperons per one interaction of $K^-$ mesons and the probability of hyperfragment production per number of events in which the $\Lambda$ hyperon arose from the $\Xi$ N interaction.

The mean number $N_{\Xi}$ of produced $\Xi$ hyperons per one interaction of $K^-$ mesons with heavy nuclei can be defined as follows

$$N_{\Xi} = \left(\frac{\sigma}{\sigma_g}\right)\left(\frac{\sigma_{\Xi}}{\sigma_{KN}}\right),$$

where $\sigma_{in}$ is the cross-section for the interaction of $K^-$ mesons with heavy nuclei, $\sigma_g$ is the geometric cross-section, $\sigma_{\Xi}$ is the cross-section for the $\Xi$ hyperon production by the $K^-N$ interaction, and $\sigma_{KN}$ is the cross-section for the interaction of $K^-$ mesons with a nucleon. Since we take events in which the interaction of $K^-$ meson has already occurred, then the ratio $(\sigma_{in}/\sigma_g)$ is equal to one. Using the known values of $\sigma_{\Xi}$ and $\sigma_{KN}$ for a $K^-$ momentum of 1.5 BeV/c[12] we found that for heavy nuclei $N_{\Xi}$ is $1.11 \cdot 10^{-2}$.

The probability of hyperfragment production with respect to the number of events in which the $\Lambda$ hyperon was produced in the interaction of $K^-$ mesons with heavy nuclei, which was determined on the basis of the results obtained in this experiment and the coorresponding values of the cross-section for the $K^-N$ interactions, is 12%. Since possible values of the energy of $\Lambda$ hyperons produced in the $\Xi$ N and $K^-N$ interactions do not considerably differ from each other, it can be assumed that the probability of hyperfragment production with respect to the number of events in which the $\Lambda$ hyperon is produced both in the first and second case of interaction is the same.

On the basis of the above quoted data it can be concluded that 10 events with a hyperfragment and strange particles will arise from the process of interaction of $K^-$ mesons involving the $\Xi$ hyperon, if the probability of the process is 0.66. In that case it can be seen from Fig. 1 that the cross-section for the $\Xi N$ interaction must be 23 mb. This is the lower limit of the value of the cross-section for the inelastic $\Xi N$ interaction. This value is in good agreement with that estimated in the work of Jauneau et al.[3] for $\Xi$ hyperons produced in the interaction of 1.47 BeV/c $K^-$ mesons. Hence it follows that the process of interaction of $K^-$ mesons followed by the secondary interaction of the $\Xi$ hyperon is dominant in the production of events with a hyperfragment and strange particles.

Since at the surface of heavy nuclei there is a possibility of formation of $He^4$--clusters[14], events with a hyperfragment and strange particles may also arise from the interaction

$$K^- + He^4 \rightarrow Y + Y + N + N\, K^{+0}.$$

However, the probability of producing events with a hyperfragment and strange particles by these interactions is lower than $10^{-5}$ for a $K^-$ momentum of 1.5 BeV/c.

## 4. *Conclusion*

The lower limit of the valuc of the strange particle production frequency in events with a hyperfragment is 2.4%.

Events with a hyperfragment and strange particles mainly arise from the process of double strange exchange of $K^-$ mesons on heavy nuclei in nuclear emulsion involving a secondary interaction of the $\Xi$ hyperon. Only (7—15)% of the events arise from a secondary interaction of the $\pi$ meson.

### Acknowledgement

The authors would like to thank Miss R. Žižić and Mrs. N. Antanasijević for careful measurements.

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# DVOSTRUKA PROMENA STRANOSTI $K^-$ MEZONA IMPULSA 1.5 BeV/c U NUKLEARNOJ EMULZIJI

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## Sadržaj

U ovom radu su analizirani procesi dvostruke promene stranosti $K^-$ mezona koji dovode do produkcije hiperfragmenta zajedno sa stranim česticama. Proces dvostruke promene stranosti $K^-$ mezona na jezgrima (sa obrazovanjem dva hiperona sa stranošću $S = -1$ u finalnom stanju) se ostvaruje preko sekundarne interakcije $\Xi$ hiperona ili $\pi$ mezona sa nukleonima u jezgru u kome su i stvoreni. Doprinos pojedinih kanala u produkciji događaja sa hiperfragmentom i stranim česticama je diskutovan.

Donja granica vrednosti frekvencije produkcije stranih čestica u događajima sa hiperfragmentom iznosi 2.4%. Događaji sa hiperfragmentom i stranim česticama nastaju uglavnom iz procesa dvostruke promene stranosti $K^-$ mezona na teškim jezgrima, u nuklearnoj emulziji koji ide preko sekundarne interakcije $\Xi$ hiperona. Samo (7—15)% događaja nastaje preko sekundarne interakcije $\pi$ mezona.