acta phys. slov. 25 (1975), No. 1

PION ABSORPTION AND $\Sigma - \Lambda$ CONVERSION FOLLOWING K⁻ CAPTURE

SATYA PRAKASH GOEL*, YOG PRAKASH**, Hamburg

The capture interactions of K^- mesons with single and two nucleons in emulsion nuclei are studied by computer simulation. The K^- meson is assumed to be captured in (*i*) the (0—10) % density region of nuclear matter (*ii*) the (0—25) % density region of nuclear matter and (*iii*) uniformly throughout the nuclear volume. The absorption probability of pions and the rate of the $\Sigma - \Lambda$ conversion following the K^- capture are estimated. The results obtained from surface absopriton of K^- mesons are in fair egreement with the corresponding experimental results. This agreement is used to infer that the K^- mesons are absorbed on the nuclear periphery, most probably in the (0—25) % density region of the nuclear matter.

The rates of absorption of charged as well as neutral pions are found to be broadly similar. Similarly, the rates of the $\Sigma - \Lambda$ conversion are broadly similar for the charged as well as the neutral Σ hyperons.

I. INTRODUCTION

The nuclear captuꞁe of K^- mesons has been rather extensively studied-[1—5], theoretically, in nuclear emulsion and lately in bubble chambers also. A K^- meson may undergo nuclear capture interacting with a single nucleon (N) via the mesonic mode with the production of a pion (π) and a hyperon (Y) in the final state, i.e. $K^- + N \rightarrow \pi + Y$. It may also interact with a cluster of nucleons via the non-mesonic mode in which a hyperon and a nucleon are produced in the final state, i.e., $K^- + NN \rightarrow Y + N$. Subsequently, the final state particles undergo secondary interactions in the parent nucleus. These secondary interactions complicate the experimental study of the K^- captures in complex nuclei. It is often difficult to estimate directly the process from which an emitted particle is produced. Further, the interaction of a K^- meson can occur on any nucleus of the two groups (light and heavy) of the constituent nuclei of nuclear emulsion and heavy liquid bubble chambers. The light and the heavy nuclei of these media differ considerably in mass, charge and size. The secondary interactions of the final state particles are, therefore, likely to yield different results depending on whether the K^- capture interaction occurred on a light or a heavy nucleus.

The criteria generally used in experimental work to distinguish K^- captures on the light and the heavy nuclei are the emission of the Auger electrons or of low energy α particles and protons (having a range of track < 30 um), the presence of recoil and the kinematic analysis of the capture star [3]. However, the results of studies of K^- captures in a diamond loaded emulsion indicate that the use of track lengths and the presence of the Auger electrons are not adequate to separate K^- captures on the light and the heavy nuclei [6]. It is, perhaps, because of the use of not precise criteria that different estimates [7—9] of the fraction of K^- captures occurring on the heavy emulsion nuclei, varying from 50 to 75 %, have been reported. Similarly, estimates [10—13] of the non-mesonic K^- captures occurring on the light nuclei vary from 22 to 60 %.

We study K^- captures through computer simulation, using the Monte Carlo (*MC*) method. Mesonic as well as non-mesonic absorption interactions of K^- mesons are simulated separately in the light and the heavy emulsion nuclei. It may be mentioned that the results of computer simulation studies are dependent on the nature of the chosen model of interaction and the accuracy of the input parameters. However, such studies provide useful information which might serve as a guide line for future experimental work and in the light of which the validity of experimental results can be examined.

In this paper we present results of the pion absorption and the $\Sigma - \Lambda$ conversion and compare them with the corresponding experimental results. We also examine the validity of the peripheral absorption hypothesis of K^- mesons. The calculations of Jones provided the first indication that the K^- mesons might be absorbed on the nuclear periphery [14]. This received support from Wilkinson who also suggested that K^- meson interactions are a powerful tool to study the texture of nuclear surface [15—19]. It is indeed mainly for this reason that the study of kaonic atoms has recently received a great deal of attention [20—28]. However, several groups of workers

* Physics Department, Kurukshetra University, KURUKSHETRA (Haryana), India. Now at Deutches Elektronen-Synchrotron DESY, HAMBURG, West Germany.

** Physics Department, University of Jammu, JAMMU (Jammu and Kashmir), India.

¹ The bibliography is too large to be given here in full.

Reference for earlier work may be made to: (*a*) Butler C. C., Cosmic Ray Phys. *1* (1952), 68; (*b*) Wilson J. G., Prog. Cosmic Ray Phys. *2* (1954), 57; (*c*) Bridge M. S., Prog. Cosmic Ray *3* (1956), 145; (*d*) Walker W. D., Prog. Elementary Particle and Cosmic Ray Phys. *4* (1968), 73; and (*e*) Franzinetti C. and Morpurgo G., Nuovo Cimento Suppl. *6* (1957), 469.

For later work, other references, particularly [2] to [5] of this work may be seen.

have argued against the peripheral absorption hypothesis of K^- mesons [29–34]. Further information bearing on this question is, therefore, called for and is presented in this paper.

II. MC COMPUTER SIMULATION

II. 1. The procedure of simulation

The mesonic K^- capture interactions with single nucleons simulated in this work are presented in Table 1. The processes $K^- + p \to \Lambda^\circ + \Pi^+ + \Pi^-$, $K^- + p \to \Lambda^\circ + \Pi^\circ + \Pi^\circ$ and $K^- + n \to \Lambda^\circ + \Pi^\circ + \Pi^-$ are energetically possible but very infrequent [5] and have, therefore, not been simulated.

For the non-mesonic interactions it is assumed that the K^- meson interacts only with two correlated nucleons; the probability of occurrence of a larger number of correlated nucleons is considered to be very small and hence the interaction of K^- mesons with clusters of more than two nucleons is ignored. In the correlated pair of nucleons, the nucleons are assumed to be randomly oriented with respect to each other but it is also assumed that the pair appears as a single entity to the K^- meson and absorbs the latter as one unit, sharing the rest mass energy of the meson equally between the two nucleons. The various interactions of K^- mesons with two nucleons considered in this work are presented in Table 2.

The reactions and their branching ratios presented in Table 1 and 2 are taken from Ref. [3]. It may be mentioned that the branching ratios given in this reference are valid for conjugate nuclei having an equal number of protons and neutrons. This raises no problem for the light emulsion nuclei (*CNO*) as all of them are conjugate but the heavy emulsion nuclei (AgBr) are not conjugate. Therefore, simulation is done for the K^- captures in carbon (as a representative of the light nuclei) and in two fictitious conjugate heavy nuclei having a mass equal to that of bromine and silver, respectively. Simulation is done for the K^- capture in the real heavy emulsion nuclei also. It is worth pointing out that the branching ratios used for the real nuclei (Ag and Br) were identically the same as given for the conjugate nuclei. This amounts to changing, to some extent, the branching ratios of the various single and two nucleon interactions of K^- mesons. By comparing the results for the fictitious and the real heavy nuclei, a check is made on the sensitivity of the results with respect to the change in the values of the branching ratios.

For the purpose of simulation, the K^- capture interactions are divided into three parts: (*i*) interactions with single nucleons as given in Table 1; (*ii*) interactions with two nucleons (other than two neutrons) as given in

Table 1
Rates % of K^- interactions with single nucleons (conjugate nuclei)

Interaction	Rate (%)	Q-value (MeV)	Remarks
(*a*) $K^- + p \to \Pi^+ + \Sigma^-$ (*b*) $K^- + p \to \Pi^- + \Sigma^+$	14.1 19.8	95.0 102.9	Emission together of charged Σ and Π($\Sigma^-\Pi^+$ or $\Sigma^+\Pi^-$) is taken as a sign of primary $K^- - p$ interactions
(*c*) $K^- + p \to \Pi^0 + \Sigma^0$ (*d*) $K^- + p \to \Pi^0 + \Lambda^0$	10.9 10.3	104.4 181.4	Only neutral particles are produced in the final state of reactions (*c*) and (*d*) and, therefore, it is difficult to study them experimentally.
(*e*) $K^- + n \to \Pi^0 + \Sigma^-$	12.1	100.9	Emission of Σ^- alone is taken as a sign of $K^- - n$ interaction though there may be misidentification if Π^+ is absorbed and Σ^- alone is emitted from reaction (*a*).
(*f*) $K^- + n \to \Pi^- + \Sigma^0$ (*g*) $K^- + n \to \Pi^- + \Lambda^0$	12.1 20.7	101.1 178.1	Emission of Π^- alone may be confused with the emission of Π^- from reaction (*b*) if Σ^+ is absorbed.

Table 2
Rates (%) of K^- interactions with two nucleons (conjugate nuclei)

Interaction	Rate (%)	Q-value (MeV)	Remarks
(*a*) $K^- + nn \to \Sigma^- + n$	0.0	235.9	This reaction is assumed to have zero rate because fast Σ^- are accompanied with fast protons which are attributed to reaction (*b*)
(*b*) $K^- + np \to \Sigma^- + p$	19.0	235.9	Emission of fast Σ^- accompained with fast protons is usually taken as a sign of this reaction.
(*c*) $K^- + np \to \Sigma^0 + n$ (*d*) $K^- + np \to \Lambda^0 + n$	9.5 35.0	239.4 316.4	Only neutral particles are produced in reactions (*c*) and (*d*) in the final state
(*e*) $K^- + pp \to \Sigma^+ + n$	11.0	241.2	This is the only reaction producing Σ^+
(*f*) $K^- + pp \to \Sigma^0 + p$ (*g*) $K^- + pp \to \Lambda^0 + p$	5.5 20.5	239.4 316.4	From reactions (*f*) and (*g*) protonsare produced with neutral hyperons while from reaction (*b*) protons are produced with Σ^- hyperons

Table 2; and (*iii*) interaction with two neutrons (the results of this part are to be communicated separately).

Each part is simulated separately. For each nucleus, three separate locations of the initial K^- meson capture interaction, belonging to one of the three parts mentioned above, are chosen, i.e., (*a*) on the nuclear periphery within the (0–10) % density region of the nuclear matter (*RI*); (*b*) on the nuclear periphery within the (0–25) % density region of the nuclear matter (*RII*); and (*c*) uniformly throughout the nuclear volume (*RIII*). For each nucleus 1800 events are simulated.

For the sake of computational convenience, the procedure of simulation is divided into the following three parts:

II.1.1. The initial interaction

The K^- meson is assumed to be absorbed first on a single nucleon, then on two nucleons (excluding two neutrons) and lastly on two neutrons. Further, it is also assumed that the probability of occurrence of the initial K^- absorption is the same everywhere first in *R*I, then in *R*II and finally in *R*III for each nucleus. The initial interaction with two neutrons is always the same, i.e., $K^- + nn \to \Sigma^- + n$; only the location of its occurrence changes. The choice of a particular interaction with single nucleons and two correlated nucleons other than two neutrons is made randomly; the probability of occurrence of a reaction is determined by its branching ratio as given in Tables 1 and 2, respectively, for single and two nucleon interactions of K^- mesons.

The Fermi momentum of the nucleon (*s*) with which the K^- meson interacts is derived from the Fourier transform of its wave function [35]. The energy release (*Q*-value) of a particular reaction minus the average binding energy of the nucleon (*s*) on which the K^- meson is absorbed is shared by the final state particles. The K^- meson is assumed to be absorbed from the *s* state [2] and the energy and momentum of the final state particles are calculated by assuming that they are distributed isotropically in the centre-of-mass system. At the end of the initial interaction stage, the nature, momentum and location of the final state particles are known.

II.1.2. The nuclear cascade

The final state particles produced from the initial interaction are now followed, one at a time, as they interact with nucleons and scatter inside the nucleus. A nuclear cascade is set up and all particles involved in it are followed until they are emitted from, or absorbed in, the parent nucleus.

The momentum of the target nucleon with which the incident particle interacts is calculated in a manner identical to that of the nucleon (*s*) with which the K^- meson interacts initially. In conjugate nuclei, the probability of the target nucleon being a proton or a neutron is considered to be the same; in non-conjugate nuclei, the ratio of the number of protons or neutrons to that of the total number of nucleons is used to determine whether the target nucleon is a proton or a neutron; e.g., bromine has 35 protons and 45 neutrons and so the probability of the target nucleon being a proton is 35/80 and that of a neutron is 45/80. The interaction mean free path is found from the relevant cross-sections (i.e., cross-sections for pion-nucleon, hyperon-nucleon or nucleon-nucleon interactions) supplied as input parameters.

An interaction is forbidden if after the interaction the energy of a nucleon is found to be less than its Fermi energy. If the interaction is allowed, the energy of both the particles (which they have after the interaction) is compared with their respective potential-well depths. A particle is assumed to be absorbed if its energy is less than its potential well depth. If a nucleon is absorbed, the difference between its energy and its Fermi level is imparted to the nucleus as excitation energy. In the case of absorption of pions or hyperons, their entire kinetic energy is transferred to the nucleus as excitation energy. If the energy of a particle is greater than its potential well depth, it is further followed until it is absorbed or emitted. A particle is assumed to be emitted if it has an energy greater than its potential well depth and the next point of its interaction falls outside the nucleus.

The nature, energy and momentum of every outgoing particle are recorded. Each emitted particle is assumed to impart a momentum (equal and opposite to its own) to the residual nucleus. The nuclear mass and charge are adjusted after the emission of each particle.

Absorbed Σ hyperons are assumed to get converted into Λ° hyperons by interacting with single nucleons; the reactions assumed to occur are:

$$\Sigma^- + p \to \Lambda^\circ + n; \quad \Sigma^+ + n \to \Lambda^\circ + p; \quad \Sigma^\circ + p \to \Lambda^\circ + p;$$

and

$$\Sigma^\circ + n \to \Lambda^\circ + n.$$

The charge exchange reactions of the Σ hyperons are not considered in the present work.

An absorbed pion is assumed to interact with a pair of nucleons, *pp*, *pn* or *nn*. The pion absorption is treated in the manner of Bertini [36], i.e., for the absorption of a Π^+, the nucleon pair should have at least one neutron; for Π^-, at least one proton; while Π° could be absorbed equally well on *pp*, *pn* or *nn* pair. The number of nucleon pairs of a particular type in a nucleus is estimated from the number of protons and neutrons, e.g., a carbon nucleus can have $3pp$, $3nn$ or $6np$ pairs. Now Π^+ can be absorbed on an nn or an np pair; the probability of absorption on a particular type of pair is determined by the relative numbers of pairs on which the absorption is likely to occur. Thus, the probability of Π^+ being absorbed on an np pair is considered to be 66.7 % as against 33.3 % on an nn pair in a carbon nucleus.

The particles produced from the absorption interactions of the Σ hyperons or pions are also followed until they are emitted or absorbed.

The absorption of a Λ° hyperon is assumed to lead to the production of a hyperfragment. It is further assumed that once a Λ° hyperon is trapped, it remains so even during the ensuing evaporation of the excited nucleus.

After the completion of the nuclear cascade, the nucleus acquires a momentum which is the vector sum of the random momentum impulses received from the outgoing particles. The nucleus is also excited and the magnitude of the excitation energy is estimated. Some of these results are to be communicated separately.

II.1.3. The nuclear evaporation

The excited nucleus is assumed to de-excite itself via evaporation. The simulation of the process of nuclear evaporation follows the work of Le Couteur [37] as discussed by Powell et al. [1] and the procedure is identical to that of Singh et al. [38].

II.2. Input parameters

II.2.1. The nuclear parameters

The various nuclear parameters like the Fermi level, the potential well depths of protons and neutrons, the Coulomb barrier for protons and the density of nuclear matter used in the present work are the same as used by the authors for the simulation of the nuclear capture of the Σ^- hyperons [35]. The basis of calculation of these parameters is given in Table 3 of reference [35].

The nuclear potential well depth for pions is assumed to be 40 MeV and that for the Σ hyperons to be 32 MeV (same as for the Λ° hyperons). The Σ^+ hyperon and the Π^+ meson are assumed to experience the same Coulomb barrier as the protons. While the Coulomb potential is added to the nuclear potential in the case of positively charged particles, it is subtracted from the nuclear potential in the case of negatively charged particles (i.e. the Σ^- hyperon and the Π^- meson) while considering the total potential seen by the charged

Table 3
Calculated absorption probability (%) of pions

Nucleus	Pion	Absorption probability (%) for the location of K^- absorption interaction in		
		(0–10) % density region	(0–25 %) density region	nuclear volume
Carbon	Π^+	12	17	60
	Π^-	14	22	60
	Π^0	23	25	61
Bromine	Π^+	13	16	75
	Π^-	11	15	60
	Π^0	24	26	76
Silver	Π^+	16	20	70
	Π^-	20	24	70
	Π^0	28	42	74

particles. The neutral particles, the Σ° and the Λ° hyperons and the Π° meson are assumed to experience, like the neutron, only their respective nuclear potentials.

II.2.2. The scattering cross-sections

The scattering cross-sections used in the work are also the same as mentioned in reference [35]. Thus, for pion-nucleon scattering interactions, the total elastic scattering cross-sections are taken from Anderson et al. [39]. Assuming charge independence [40], the Π^+p and Π^-p interactions are assumed to be identical to Π^-n and Π^+n, respectively; the $\Pi^\circ p$ and $\Pi^\circ n$ interactions are considered to be the same and the $\Pi^\circ p$ scattering cross-sections are taken to be equal to the mean of Π^+p and Π^-p scattering cross-sections.

The differential cross-section for the pion-nucleon scattering is given [40] by

$$\frac{d\sigma}{d\Omega} = \frac{1}{k^2}(A + B\cos\Theta + C\cos^2\Theta),$$

where A, B and C are coefficients whose values depend on the relevant phase shifts. The value of the variable k is obtained from the integration of the above expression.

For the pion-nucleon scattering of up to $\sim$ 200 MeV only s and p partial waves with $l = 0$ and $l = 1$, respectively, are considered [42]. It may be pointed out that in the present work pions are produced only from the single-nucleon interactions of the K^- mesons. The maximum Q-value from such interaction is ~ 181 MeV (see Table 1). Therefore, we consider the phase shifts for the s and the p waves only and derive them according to the procedure suggested by Orear [42]. Resonance production is not considered in this work.

The low energy hyperon-nucleon scattering is assumed to be predominantly an s wave interaction and, therefore, it is assumed to be isotropic in the cm system. The total scattering cross-section for the $\Lambda^0 p$ interaction are taken from Sechi-Zorn et al. [43] and those of the $\Sigma^+ p$ and $\Sigma^- p$ interactions from Fast et al. [44]. Hyperon-neutron interaction cross-sections are assumed to be the same as the hyperon-proton ones. The $\Sigma^0 p$ scattering cross-section is taken to be equal to the mean of the $\Sigma^+ p$ and the $\Sigma^- p$ scattering cross sections.

The nucleon-nucleon scattering is treated in a manner identical to that of Metropolis et al. [45] and the total as well as differential scattering cross-sections for pp, pn and nn scattering interactions are taken from these authors.

II.2.3. The frequencies of emission and the momenta of evaporated particles

The particles likely to be emitted during nuclear evaporation are n, p, ^2H, ^3H, ^3He, ^4He and ^8Li (which is considered to represent, as an average, the emission of all fragments heavier than ^4He). The frequencies of emission of these particles are calculated for different nuclear temperatures from the evaporation theory for three mass regions of the nuclear mass. The momenta of ^2H, ^3H, ^3He and ^8Li are treated to be constant and taken from Key et al. [46]. The momenta of n, p and ^4He, the particles commonly emitted during nuclear evaporation, are treated as variable and taken from Dostrovsky et al. [47]. The details are given by Singh et al. [38].

III. RESULTS AND DISCUSSION

The results for the heavy fictitious and real nuclei are broadly similar. This indicates that the calculated results are not much influenced by a small change in the values of the branching ratios of the various K^- capture reactions. We therefore present results only for the real heavy emulsion nuclei.

III.1. Absorption of pions

We first mention the experimental results with which the results of the work are compared. In a nuclear emulsion, the rates of the emission of pions from the parent nucleus are inferred from the distribution of the stable prongs and the energy spectra of the emitted charged particles. This procedure leads

to an anomalously [48] high absorption rate (~ 80 %) of the Π^0 mesons while the rate of absorption of the charged pions is estimated to be only ~ 10 %. From bubble chamber studies, Davis et al. [49] estimate that the absorption probability of all poins is the same, ~ 10 % while according to Schorochoff [50] the rate of absorption of the Π^0 mesons in a freon bubble chamber is somewhat higher, between 30 % and 50 %.

The rates of absorption of pions estimated in this work are presented in Table 3. The rate of absorption of the Π^0 meson is somewhat higher than those for the Π^+ and Π^- but the difference is not as large as in the experimental results of Schorochoff [50]. Our results certainly do not support the nuclear emulsion [48] result of a very high absorption rate of the Π^0 meson and seem to be, in this respect, in fair agreement with the bubble chamber results of Davis et al. [49].

The results of the present work indicate a higher rate of absorption of charged pions than the experimentally estimated rate (~ 10 %) even when the K^- meson is assumed to be absorbed in RI. It could be due to the potential (40 MeV) chosen in this work. The potential also might vary with changes in the density of nuclear matter which a pion is likely to experience as it moves inside the nucleus after its creation from the K^- absorption. Such a change in the pion potential has not been considered in the present work. Whether a pion is near the nuclear surface or deep inside the nuclear volume it is assumed to see the same potential. This tends to enhance the calculated rate of pion absorption.

It may be mentioned that the calculated rates of pion absorption are similar for the light as well as the heavy nuclei. The results for the four heavy nuclei are also similar indicating that a small change in the branching ratios of the initial K^- meson absorption interactions does not affect the rates of pion absorption in any appreciable manner.

The results of this work are significant in another respect. The rates of pion absorption are broadly similar for the K^- absorption in RI and RII (the rates are actually, in general, slightly larger for RII) but these increase sharply for RIII. This supports, as discussed in sec. III.3, the hypothesis of the peripheral absorption of the K^- mesons (at least so far as the single nucleon interactions of the K^- mesons are concerned).

III.2. THE RATE OF THE $\Sigma - \Lambda$ CONVERSION

The rates of the $\Sigma - \Lambda$ conversion or of the Σ hyperon absorption are presented in Table 4 separately for the Σ hyperons produced from single and two nucleon interactions of the K^- mesons. Several features of these results are worth mentioning.

Table 4

Calculated rates (%) of $\Sigma - \Lambda$ conversion — separately from single and two nucleon capture interactions of K^- mesons

Nucleus	Σ Hyperon	$\Sigma - \Lambda$ conversion rate (%) of Σ hyperons produced from K^--single nucleon interactions in			$\Sigma - \Lambda$ conversion (%) of Σ hyperons produced from K^- -two nucleon interactions in		
		(0–10) % density region	(0–25) % density region	nuclear volume	(0–10) % density region	(0–25) % density region	nuclear volume
Carbon	Σ^+	47	50	79	30	47	71
	Σ^-	58	70	78	41	46	69
	Σ^0	56	61	80	31	48	63
Bromine	Σ^+	43	58	90	35	60	82
	Σ^-	63	70	98	31	47	76
	Σ^0	56	60	92	46	52	92
Silver	Σ^+	53	58	92	50	60	70
	Σ^-	64	74	91	41	62	72
	Σ^0	52	63	92	51	61	71

III.2.1. Σ hyperons produced from single nucleon interactions

The absorption rates of the Σ hyperons are the lowest for the K^- absorption in RI. However, the difference between these and the corresponding rates for RII is not large while the rates for RIII are much higher than those for RI and RII. This also has a bearing on the peripheral hypothesis of the K^- absorption and will be further discussed in sec. III.3.

It is worth noting that though there is a broad similarity in the values of the rates of absorption of the Σ^+, Σ^- and Σ° hyperons, the rate of absorption of the Σ^0 hyperon is, in general, somewhat higher than those of the Σ^+ and Σ° absorptions for RI and RII. This seems to be a direct consequence of the Σ^0-nucleon interaction cross-section having a larger value than the Σ^+- and Σ^0-nucleon interaction cross-sections. For RIII, the Σ hyperons are produced deeper inside the nucleus and consequently interact more with nucleons (as they traverse the nuclear matter) than is the case for RI and RII. The result is that the difference in the values of the interaction cross-sections of the various Σ hyperons with nucleons is smeared out and the rates of absorption of all Σ hyperons for RIII are expected to be the same as is, indeed, the case (see Table 4).

The results are also similar for all nuclei for RI and RII but smaller by (5–10) % for the light nuclei when RIII is considered.

III.2.2. Σ hyperons produced from two nucleon interactions

The Σ hyperons produced from two nucleon interactions of the K^- mesons are more energetic than those produced from their interactions with single nucleons. The latter have less energy firstly because of the low Q-value of the K^- meson single nucleon interactions and secondly because these are produced along with pions which, being much lighter, take away a major share of the energy release. The Σ hyperons produced from two nucleon interactions share not only a larger energy but share it with nucleons and are, consequently, left with more kinetic energy. These are, therefore, less likely to be absorbed. This is reflected in the lower rates of absorption of these hyperons as can be seen from Table 4. The difference is more pronounced for RI and RII than for RIII as in the latter case, the Σ hyperons interact more with nucleons (as already mentioned in sec. III.2.1) and are, therefore, likely to be absorbed very frequently (see the last column of Table 4).

The absorption probability of all the Σ hyperons (Σ^+, Σ^- as well as Σ^0) are nearly the same in this case. The difference in the values of the interaction cross-sections of the Σ hyperons with the nucleons do not seem to be effective in producing different rates of absorption of the Σ hyperons when these are produced with a relatively larger energy.

The rates of absorption of the Σ hyperons produced from two nucleon K^- capture interactions are also similar for the light as well as the heavy nuclei.

III.2.3. Combined results

The experimental estimates of the rate of multinucleon interactions of the K^- mesons in complex nuclei vary [2] from 10 % to 50 % (though there seems to be some agreement [51] that the rate might actually be ~ 20 %). For the purpose of comparison with experimental results, we combine the single and two nucleon interaction results of the rates of the $\Sigma - \Lambda$ conversion in three ratios, i.e., 90 : 10, 70 : 30 and 50 : 50. The combined results are presented in Table 5. The corresponding experimentally estimated rates are presented in Table 6.

The calculated $\Sigma - \Lambda$ conversion rates do not appear to change much with the ratio in which the results of the single and two nucleon interactions are mixed (as seen from Table 5). A comparison with experimental results shows that the calculated $\Sigma - \Lambda$ conversion rates for RI and RII are in fair agreement with the experimentally estimated rates. The calculated rates for RIII are much larger.

The calculated $\Sigma - \Lambda$ conversion rates are similar for the light as well as the heavy nuclei. This does not support the estimate of Condo and Hill [35]

Table 5
Calculated rates (%) of $\Sigma - \Lambda$ conversion — combined results from single and two nucleon interactions of K^- mesons

Nucleus	Localition of K^- interaction	$\Sigma - \Lambda$ conversion rate (%) — results from single and two nucleon interactions of K^- mesons combined in the ration: 90 : 10 Σ^+	90 : 10 Σ^-	90 : 10 Σ^0	70 : 30 Σ^+	70 : 30 Σ^-	70 : 30 Σ^0	50 : 50 Σ^+	50 : 50 Σ^-	50 : 50 Σ^0
Carbon	(0–10) % density region	45	56	53	42	53	49	39	50	44
Carbon	(0–25) % density region	50	68	60	49	63	57	49	58	55
	nuclear volume	78	77	78	77	75	75	75	74	72
Bromine	(0–10) % density region	43	60	55	41	53	53	39	47	51
	(0–25) % density region	58	68	59	59	63	58	59	59	56
	nuclear volume	89	96	92	88	91	92	86	87	92
Silver	(0–10) % density region	53	62	52	52	57	52	52	54	52
	(0–25) % density region	58	72	63	59	60	62	59	68	62
	nuclear volume	89	89	89	85	86	86	81	82	82

Table 6
Experimental $\Sigma - \Lambda$ conversion rates (%)

Conversion rate (%) ($C(\Sigma)$)	Medium	Reference
~ 50	Helium	Block et al [52]
$41 \leq C(\Sigma) \leq 65$	Emulsion	K^--collaboration [53]
~ 50	Emulsion	Patrick [54]
~ 52 ±10	Freon (CF_3Br)+ Propane (C_3H_8)	Davis et al. [49]
~ 50 ±10	Freon	Barth [55]
~ 50 ±5	Freon	Schorochoff [50]

that the rate of the charged Σ conversion in heavy nuclei is much larger than that in the light nuclei (70 % against 20 %). Our results are more akin to the results from the diamond load emulsion [56] which also do not support the suggestion [33] that the Σ hyperons are more frequently emitted from the light emulsion nuclei and that the $\Sigma - \Lambda$ conversion is more probable in the heavy nuclei.

It should be pointed out that the potential seen by the Σ hyperons in nuclear matter may actually be different from the one chosen in the present work (32 MeV). Further, these hyperons are assumed, as in the case of pions, to see the same potential whether they are near the nuclear periphery or deep inside the nuclear volume. This is likely to result in larger values of the calculated rates of the $\Sigma - \Lambda$ conversion.

III.3. PERIPHERAL ABSORPTION HYPOTHESIS

An examination of the peripheral absorption hypothesis of the K^- meson is one of the major objective of this work. The procedure we have adopted (i.e. to study the results of occurrence of the initial absorption interaction of the K^- mesons in three regions of nuclear matter, RI, RII, RIII, and then compare them with the corresponding experimental results) is chosen for achieving this objective.

The calculated rates of the pion absorption for RIII are much larger than the corresponding experimentally estimated rates ((60–75) % vs 10 %). This rules out the possibility that the single nucleon capture interactions of the K^- mesons might occur uniformly throughout the nuclear volume. In view of the broad similarity of the rates of pion absorption for RI and RII and their fair agreement with the experimental results, we can infer that the single nucleon interactions of the K^- mesons are likely to occur on the nuclear periphery in all complex nuclei, perhaps, whith in the (0—25) % density region of nuclear matter. Though the pion absorption rates for RI, are in general, somewhat smaller than those for RII and one might be tempted to infer further that the K^- mesons might undergo interactions with single nucleons within the (0—10) % density region, we think caution is required at this stage as the results for RI and RII are not much different from one another.

The calculated rates of the $\Sigma - \Lambda$ conversion for RI and RII are, as already mentioned in sections III.2.2 and III.2.3, in fair agreement with the corresponding experimental estimates while those for RIII vary, as seen from Tables 4 and 5, from $\sim$ 80 % to $\sim$ 90 %; the experimental estimate is only $\sim$ 50 %. The last column of Table 4 shows that the rate of the $\Sigma - \Lambda$ conversion even of the Σ hyperons produced from two nucleon interactions of the K^- mesons in RIII is much larger than the experimental estimate of this value. The results are equally applicable to the light as well as the heavy nuclei. This indicates that the K^- mesons are likely to undergo absorption interactions with single as well as two nucleons on the nuclear periphery, perhaps, within the (0—25) % density region of nuclear matter in all complex nuclei. So far as the question of narrowing down the region of initial interactions (i.e. the choice between RI and RII) further is concerned, we feel our results are not precise enough to make the choice unambiguously.

III. CONCLUSION

We draw the following conclusions from this work: (*i*) The rates of absorption of charged as well as neutral pions following the nuclear capture of the K^- mesons are broadly similar. (*ii*) The rates of the $\Sigma - \Lambda$ conversion following the K^- capture are also broadly similar for charged as well as neutral Σ hyperons. (*iii*) The K^- mesons undergo absorption interactions with single as well as multi-nucleons most probably on the surface of all complex nuclei, perhaps, within the (0—25) % density region of the nuclear matter.

REFERENCES

[1] Powell C. F., Fowler P. H., Perkins D. H., *The Study Elementary Particles by the Photographic Method.* Pergamon Press, London 1959.
[2] Burhop E. H. S., Davis D. H., Zakrzewski J., Prog. Nucl. Phys., *9* (1963), 155.
[3] Nikolic M. M., Prog. Elem. Partic'e and Cosmic Ray Phys., *8* (1964), 201; Eisenberg Y., Koch W., Nikolic M., Schneeberger M., Winzeler H., Nuovo Cimento, *11* (1959), 351; and ref. [11].

[4] Davis D. H., Sacton J., *High Energy Phis. Vol. 2.* Ed. Burhop E., H. S. Academic Press, London 1967.
[5] Burhop E. H. S., *High Energy Phys. Vol. 3.* Ed. Burhop E.H.S., Academic Press, London 1969.
[6] Chinn L., Lord J. J., Piserchio R. J., Davis D. F., Nouvo Cimento, *62 A* (1969), 10.
[7] Grote C., Hauser I., Kundt U., Krecker U., Lanius K., Lewin K., Meier H. W., Nouvo Cimento, *14* (1959), 532.
[8] Csjethey-Barth M., Scaton J., Bulletin Inst. Phys. Brussels, *4* (1962).
[9] Hill R. D., Suppl. Nuovo Cimento, *19* (1961), 83.
[10] Evans D., Jones D. B., Sanjeevaiah B., Zakrzewski J., Beniston M. J., Bull V. A., Davis D. H., Proc. Roy. Soc., A *262* (1961), 73.
[11] Nikolic M., Eisenberg Y., Koch W., Schneeberger M., Winzeler H., Helv. Phys. Acta, *33* (1960), 221.
[12] Eisenberg Y., Friedman M., Alexander G., Kessler D., Nuovo Cimento, *22* (1961), 1.
[13] Condo G., Hill R. D., Phys. Rev., *129* (1963), 388.
[14] Jones P. B., Phyl. Mag., *3* (1958), 33.
[15] Wilkinson D. H., Phil. Mag., *4* (1959), 215.
[16] Wilkinson D. H., *Proc. Kingston Conf. Nucl. Structure.* University of Toronto Press, 1960.
[17] Wilkinson D. H., *Proc. Rutherford Jubilee Inter. Conf.* Manchester 1961.
[18] Wilkinson D. H., *Proc. Intern. Conf. High Energy Phys. and Nuclear Structure.* CERN, Geneva 1963.
[19] Wilkinson D. H., Comments on Nucl. and Particle Phys., *1* (1967), 36, 80.
[20] Wilkinson D. H., *Proc. Intern. Conf. Nucl. Structure.* Tokyo, 1967; Proc. Intern School of Phys., *39* (1967), 132; J. Phys. Soc. Japan, Suppl., *24* (1968), 469.
[21] Rook J. R., Nucl. Phys., B *20* (1970), 14.
[22] Wycech S., Nucl. Phys., B *28* (1971), 541.
[23] Alberg M., Henley E. M., Wilets L., Cpmments on Nucl. and Particle Phys., *5* (1972), 1.
[24] Koch M., Backenstos G., Bamberger A., Bergstrom I., Bounin P., Bunaciu T., Egger J., Hultherg S., Lynen U., Pitter H., Schwitter A., J. Phys., *33* (1972), 160.
[25] Koch J. H., Sternheim M. M., Phys. Rev. Lett. *28* (1972), 1061.
[26] Zafiratoc C. D., Sci. American, *227* (1972), 100.
[27] Bardeen W. A., Torigoe E. W., Phys. Lett., B *38* (1972), 135.
[28] Backenstos G., Bamberger A., Bergstrom I., Bounin P., Bunaciu T., Egger J., Hultberg S., Koch K., Krell M., Lynen U., Ritter H. G., Schwitter A., Stearns R., Phys. Lett., B *38* (1972), 181.
[29] Gilbert F. C., Violet C. E., White R. S., Phys. Rev., *107* (1957), 228.
[30] Gilbert F. C., White R. S., Phys. Rev., *109* (1958), 1770.
[31] McCarthy I. E., Prowse D. J., Nucl. Phys., *17* (1960), 96.
[32] Condo G. T., Hill R. D., Martin A. D., Phys. Rev., *133* (1964), A 1280.
[33] Condo G. T., Hill R. D., Phys. Lett., *13* (1964), 271.
[34] Bugg W. M., Condo G. T., Cohn H. O., Hill R. D., Nucl. Phys., A *124* (1969) 212.
[35] Goel S. P., Prakash Y., Nucl. Phys., B *56* (1973), 617.
[36] Bertini H. H., Phys. Rev., *131* (1963), 1801.

[37] Le Couteur, Proc. Phys. Soc., A *63* (1950), 259, 498.
[38] Singh T., Prakash Y., Bhalla K. B., Lokanathan S., Nuovo Cimento, *68 A* (1970), 591.
[39] Anderson H. L., Davidon W. C., Kruse U. E., Phys. Rev., *100* (1950), 339.
[40] Goldman I. I., Krichenkov V. D., Kogan V. I., Galitski V. M., *Problems in Quantum Mechanics*. Translated, edited and arranged by D. ter Haar. Infosearch Ltd., London 1964.
[41] Lock W. O., Measday D. F., *Intermediate Energy Nucl. Phys.* Methuen and Co., Ltd., London 1970.
[42] Orear J., Phys. Rev., *100* (1955), 288.
[43] Sechi-Zorn B., Kehoe B., Twitty J., Burnstein R. A., Phys. Rev., *175* (1968), 1735.
[44] Fast G., Helder J. C., deSwart J. J., Phys. Rev. Lett., *22* (1969), 1453.
[45] Metropolis N., Bivins R., Storm M., Turkevich A., Miller J. M., Friedlander G., Phys. Rev., *110* (1958), 185.
[46] Key A. W., Lokanathan S., Prakash Y., Nuovo Cimento, *36* (1965), 50.
[47] Dostrovsky I., Rabinovitz R., Bivins R., Phys. Rev., *111* (1958), 1959.
[48] *European* K^-*-Collaboration*, Nuovo Cimento, *13* (1959), 690.
[49] Davis H., Oppenheimer F., Knight W. L., Stannard F. R., Treutler O., Nuovo Cimento, *53 A* (1968), 313.
[50] Schorochoff G., Bulletin Inst. Phys. Brusselles, No. *40* (1969).
[51] *Helium Bubble Chamber Collaboration Group*, Proc. Inter. Conf. High Energy Phys. Rochester 1960.
[52] Block M. M., Nuovo Cimento, *20* (1961), 715;
Block M. M., Bruecker E. B., Gessaroli R., Kikuchi T., Kovacs A., Meltzee C. M., Kraemer R., Nussbaum M., Pevsner A., Schlein P., Strand R., Cohn H. O., Harth E. M., Leitner J., Lendinara L., Monari L., Puppi G., Nuovo Cimento, *20* (1961), 715, 724.
[53] *European* K^- *Collaboration*, Nuovo Cimento, *14* (1959), 315.
[54] Patrick J. W., Ph. D. Thesis. Lawrence Radiation Lab., Barkeley, 1966.
[55] Csethey-Barth M., Schoorochoff G., vanBist P., Nucl. Phys., *B 14* (1969), 316.
Davis D. F., Chinn L., Lord J. J., Piserchio R. J., Nuovo Cimento, *47* (1967),
[56] 573.

Received November 23th, 1974