for $U=0$ and 1. This gives the relation

$$(Y_1^{*0}\bar{Y}_1^{*0})=\tfrac{1}{2}(\Xi^{*0}\bar{\Xi}^{*0})+\tfrac{1}{2}(N^{*0}\bar{N}^{*0}) \qquad (10)$$

together with the associated triangle inequalities on the cross sections. Y_1^{*0} is once again a difficult particle to observe, since it will normally decay by π^0 emission, so that the inequalities implied by (10) will be difficult to check experimentally. It would again be possible to use isotopic spin invariance to replace $(Y_1^{*0}\bar{Y}_1^{*0})$ by the amplitudes for charged Y_1^* pair production in (10), but only at the cost of weakening the inequalities.

To sum up, the most meaningful and at the same time experimentally accessible predictions of the unitary symmetry theory for Reaction (1) would seem to be the three inequalities (7).

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Absorption of Σ^- Hyperons in Photographic Emulsion Nuclei

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396 Σ^- capture stars in nuclear emulsion have been analyzed. The new data have been combined with 231 similar events previously reported. The rate of hyperfragment emission from Σ^- stars is $(2.7^{+0.5}{}_{-0.4})\%$. Both this rate and an estimate of the frequency of cryptogragment formation are compared with the analogous quantities pertinent to K^- absorptions at rest. Evidence is presented that hyperfragments predominantly originate from Σ^- absorptions in the light elements of the emulsion, while cryptogragments are formed following Σ^- absorption in heavy nuclei.

INTRODUCTION

BECAUSE of the strong Pauli suppression in complex nuclei of the charge-exchange reaction, the absorption at rest of a Σ^- hyperon in an emulsion nucleus is always-expected to create a Λ^0 hyperon with a resultant energy release of about 80 MeV. Sacton *et al.*[1] in a previous work studied the trapping probabilities of these Λ^0 hyperons and found them to be appreciably smaller in both the heavy (silver and bromine) and the light (carbon, nitrogen, and oxygen) emulsion nuclei than those of Λ^0 hyperons produced by K^--meson interactions at rest. The main purpose of this work has been to investigate further the above result by adopting the same procedures as used by Sacton *et al.*[1] but with a much larger sample of events. In addition, however, the chance that a Σ^- capture in silver or bromine gives rise to cryptofragment formation has been estimated not only from the frequency of emission of a fast proton from the capture star but also from a comparison of the visible energy releases in Σ^- captures and the nonmesonic decays of heavy hypernuclei.[2]

EXPERIMENTAL PROCEDURE

Two stacks of 1200 μ-Ilford K5 emulsions, each exposed to stopping K^- mesons at the Berkeley Bevatron and previously used for hyperfragment studies,[3,4] were used in this experiment. The Σ^- capture events were found by following out the grey and black tracks from about 50 000 K^- capture stars, in one stack to their end points in the emulsion, in the other only within the pellicle containing the parent star. Σ^- hyperons of ranges less than 200 μ were rejected from the sample in order to reduce to negligible proportions the background of nonmesonically decaying hyperfragments and also to enable a satisfactory distinction to be made between the tracks of Σ^- hyperons and slow π^- mesons.

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[1] J. Sacton, M. J. Beniston, D. H. Davis, B. D. Jones, B. Sanjeevaiah, and J. Zakrzewski, Nuovo Cimento 23, 702 (1962).

[2] D. H. Davis, R. Levi Setti, M. Raymund, O. Skjeggestad, G. Tomasini, J. Lemonne, P. Renard, and J. Sacton, Phys. Rev. Letters 9, 464 (1962).

[3] R. G. Ammar, R. Levi Setti, W. E. Slater, S. Limentani, P. E. Schlein, and P. H. Steinberg, Part I, Nuovo Cimento 15, 181 (1960). Part II, Nuovo Cimento 19, 20 (1961).

[4] See for example, R. G. Ammar, L. Choy, W. Dunn, M. Holland, J. H. Roberts, E. N. Shipley, N. Crayton, D. H. Davis, R. Levi Setti, M. Raymund, G. Tomasini, and O. Skjeggestad, Nuovo Cimento 27, 1078 (1963).

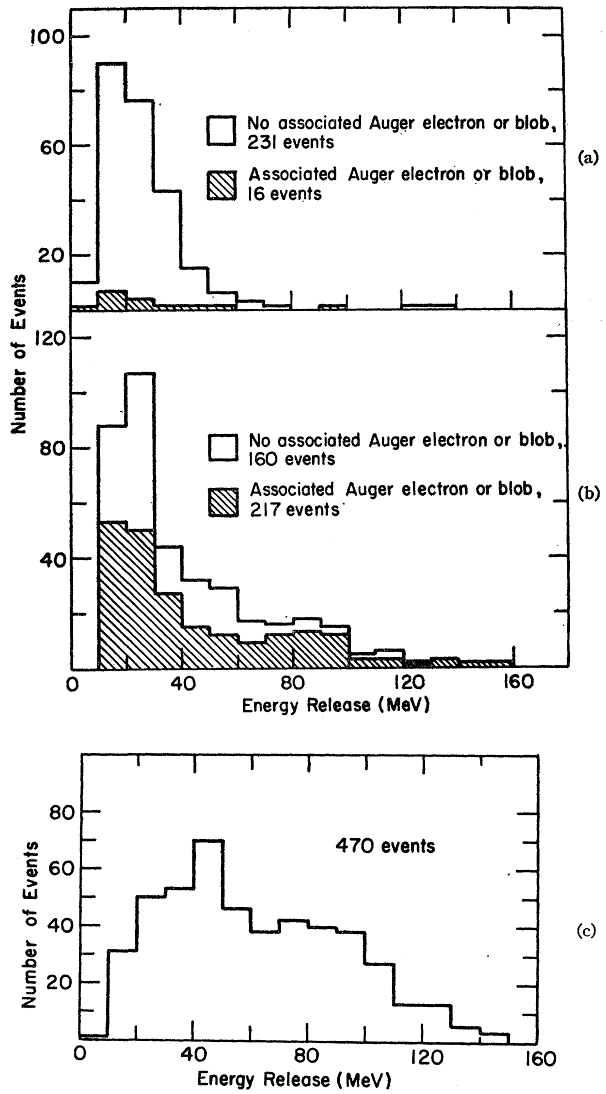

FIG. 1. Energy release of (a) Σ^- stars containing at least one prong of length between 3 μ and 32 μ; (b) Σ^- stars containing no prong of length between 3 μ and 32 μ; (c) of heavy "spallation" hyperfragment decays.

A Σ^- star has been defined as previously[5,1] as having one prong longer than 200 μ or at least two prongs longer than 5 μ. The number of Σ^- captures so found has been multiplied by the correction factor $3.61^{+0.48}_{-0.38}$ in order to compensate for cases which do not satisfy the above criteria and to obtain the actual number of interacting Σ^- hyperons. This correction factor has been determined from a study of the capture-star characteristics in emulsion of 278 Σ^- hyperons resulting from K^- absorptions in hydrogen.[6] As before,[1] the ranges of all secondary particles from each Σ^- capture star were measured and a careful search was made for short hyperfragment, recoil and slow electron tracks.

[5] K^- European Collaboration Part II. Nuovo Cimento **14**, 315 (1959).

[6] D. H. Davis, and O. Skjeggestad. EFINS report 63-7 (unpublished).

RESULTS AND DISCUSSION

In this work 396 Σ^- capture stars which satisfy the above criteria have been found. In the analysis to be presented below, a further 173 events from the work of Sacton *et al.*[1] and 58 events contained in the compilation by Davis and Skjeggestad[6] have also been included. These 627 events correspond to a corrected number of 2260^{+300}_{-240} Σ^- absorptions.

The Σ^- capture stars have been classified according to whether or not they possess at least one prong of length between 3 μ and 32 μ. The presence of such a short prong is taken as an indication of a capture by a light emulsion nucleus since the emission of positively charged particles of low energies from heavy nuclei is inhibited by the Coulomb barrier effect. That this separation is a good one is borne out by the frequency of observation in the two samples of Auger electrons or blobs,[7] a sign of heavy nucleus capture. This frequency is 6% for those stars containing a short prong and 58% for the remainder, a sample including captures on both light and heavy nuclei.

Fifty-seven resolvable hyperfragments and 3 double-centered events were found and, thus, the frequency of emission of hyperfragments following Σ^- absorption at rest in emulsion nuclei is from this work $(2.7^{+0.5}_{-0.4})\%$. For the resolvable events only in two cases was there no short-range particle emitted in the primary disintegration, and in two others an associated Auger electron was observed. The suggestion put forward by Sacton *et al.*,[1] that most, if not all, of the observed hyperfragments result from captures on light nuclei has therefore been substantiated. This is similar to the findings of Abeledo *et al.*[8] and others that the emission of observed hyperfragments following K^- absorptions at rest in emulsion is also predominantly from the light nuclei.

The visible energy-release distributions for Σ^- captures involving or not the emission of short-range particles are given in Figs. 1(a) and 1(b), respectively, while Fig. 1(c) shows the corresponding distribution found for the nonmesonic disintegrations of short-range hyperfragments, presumably of mass between A=60 and A=100, produced by the interactions in emulsions of K^- mesons of momenta 800 MeV/*c*.[9] The visible energy release has been computed by assuming all charged particles of range 5 μ or greater are protons and that each has a binding energy of 8 MeV. The observation of energy releases beyond 80 MeV implies the formation and decay of unobserved hyperfragments,

[7] For a definition of a 'blob' see D. Evans, B. D. Jones, B. Sanjeevaiah, J. Zakrzewski, M. J. Beniston, V. A. Bull, and D. H. Davis, Proc, Roy. Soc. (London) **A262**, 73 (1961).

[8] D. Abeledo, L. Choy, R. G. Ammar, N. Crayton, R. Levi Setti, M. Raymund, and O. Skjeggestad, Nuovo Cimento **22**, 1171 (1961).

[9] Unpublished results of Ref. **2**.

so-called cryptofragments.[1,10] Fifty-seven events show energy releases greater than 80 MeV and, thus, a lower limit for cryptofragment formation may be set at 2.5±0.4%. However, if it is assumed that the Σ^- captures leading to cryptofragment formation present the same visible energy release spectrum as that of the decays of heavy hyperfragments, one can estimate that 136 cryptofragment decays will have yielded energy releases below 80 MeV. Thus, the over-all estimate of the rate of cryptofragment formation for Σ^- captures in emulsion nuclei becomes 8.6%. This, and the following estimates could be increased by as much as 30% if a large number of heavy hyperfragments remain unobserved by not emitting any charged particles when they decay.[11]

It is possible to estimate by the same procedure the rate of cryptofragment formation amongst the sample of Σ^- capture events at which an associated Auger electron or blob is seen, that is a sample which contains predominantly captures in the heavy emulsion nuclei. For these 233 events, the correction factor $[\Sigma^-_{\text{total}}/\Sigma^-\sigma]_{\text{Auger or blob}}=4.16^{(6)}$ and 40 show energy releases in excess of 80 MeV, leading to an estimate of the cryptofragment formation rate in silver and bromine of 13.8%.

An alternative method of estimating the cryptofragment rate is, as was previously used by Sacton *et al.*[1] from the comparison of the emission frequencies of fast protons from Σ^- captures and the nonmesonic decays of heavy hyperfragments. Figure 2 gives the range distributions of secondary particles separately for Σ^- absorptions with and without short-range particle emission and nonmesonic heavy spallation hyperfragment decays, again from Davis *et al.*[2] If the emission of a proton of range exceeding 10 000 μ[12] (i.e., of kinetic energy greater than 52 MeV) is taken as a sure indication of Λ^0 hyperon trapping and subsequent stimulated decay and one presumes that such an emission is as likely from a cryptofragment as from a hyperfragment decay, one obtains an over-all cryptofragment formation rate of 10.2% and for the sample with associated Auger electrons and blobs, 15.6%. These numbers are in quite good agreement with those derived from the visible energy-release distributions although it should be remembered that many events appear in both samples. The infrequent observation of short prongs amongst those events exhibiting high-energy releases confirms the suggestion of Sacton *et al.*[1] that the crypotofragments are formed preferentially in the heavy nuclei of the emulsion.

[10] D. H. Davis, M. Csejthey-Barth, J. Sacton, B. D. Jones, B. Sanjeevaiah, and J. Zakrzewski, Nuovo Cimento 22, 275 (1961).

[11] Monte Carlo calculations of the nonmesonic disintegrations of heavy hypernuclei indicate that a sizable fraction of them only involve the emission of neutrons. [Private communications from M. J. Beniston and J. P. Lagnaux (1963)].

[12] Changes in this acceptance criterion do not sensitively affect the estimate of cryptofragment formation provided the range of the proton is made to exceed 6 mm.

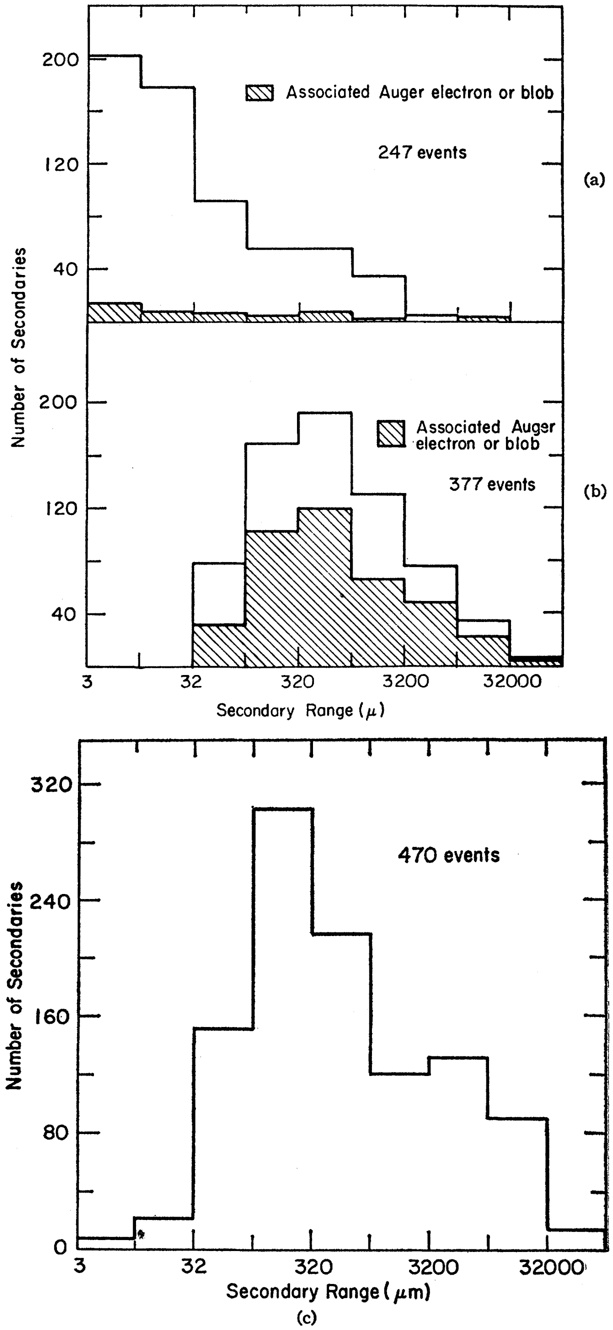

FIG. 2. Range distribution of secondaries from (a) Σ^- stars containing at least one prong of length between 3 μ and 32 μ; (b) Σ^- stars containing no prong of length between 3 μ and 32 μ; (c) heavy spallation hyperfragment decays.

It is interesting to compare the hyperfragment emission and cryptofragment formation rates following the captures of Σ^- hyperons and K^- mesons in emulsion nuclei. For K^- captures in emulsion these rates are, respectively, 5±1%[13] and 30±7%.[10] However, whereas

[13] K^- European Collaboration Part I. Nuovo Cimento 13, 690 (1959).

Σ^- captures always lead to the creation of a Λ^0 hyperon within the capturing nucleus, this is not so for K^- captures where in 27% of the cases a Σ hyperon is emitted.[5] By considering only that sample of K^--meson captures which subsequently lead to the creation of a Λ^0 hyperon one finds that the rate for hyperfragment emission is $7\pm1\%$ and cryptofragment formation is $41\pm7\%$. These values are considerably higher than those found for Σ^- absorptions, namely $2.7^{+0.5}_{-0.4}\%$ and between 8.6 and 10.2%, respectively. Moreover, recently Knight *et al.*[14] estimated from a study of the frequency of emission of Λ^0 hyperons from K^- captures at rest in a propane-freon mixture that the rate of cryptofragment formation in bromine was $51\pm14\%$, much higher than 13.8 to 15.6% found for Σ^- captures in such nuclei.

The similarity of the energy spectra of Λ^0 hyperons created by the absorptions of K^- mesons and Σ^- hyperons strongly suggest that any differences in the subsequent trapping probabilities of Λ^0 hyperons must be ascribed to differences in the creation mechanisms. Martin[15] has pointed out that Σ^- hyperons would be expected to be captured at greater distances from the center of the nucleus and therefore the trapping probability of the Λ^0 hyperons should be smaller than for the case of K^- absorption. Using a Λ^0 hyperon-nucleon cross section of 22.3 mb[16] and a Λ^0 hyperon-nucleus potential well depth of 25 MeV,[17,2] he estimates that the cryptofragment rate in silver following Σ^- absorption should be about 10%, essentially in agreement with our findings. However, his estimate of about 18% for the case of K^- absorption in silver is in contradiction with the experimental evidence and would suggest that in this case many of the Λ^0 hyperons are created well within the capturing nucleus, perhaps from Σ conversion.

[14] W. Knight, F. R. Stannard, F. Oppenheimer, B. Rickey, and R. Wilson, Report to the International Conference on Hyperfragments, St. Cergue, 1963 (unpublished).

[15] A. D. Martin. Nuovo Cimento **27**, 1359 (1963).

[16] G. Alexander, J. A. Anderson, F. S. Crawford, W. Laskar, and L. J. Lloyd, Phys. Rev. Letters **7**, 348 (1961).

[17] R. H. Dalitz, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961* (Academic Press Inc., New York, 1961).

CONCLUSIONS

(1) The frequency of emission of hyperfragments from Σ^- absorptions in emulsion is found to be $2.7^{+0.5}_{-0.4}\%$.

(2) The frequency of formation of cryptofragments is estimated to be between 8.6 and 10.2% for all Σ^- captures. This estimate increases to between 13.8 and 15.6% for a sample of captures for which there is seen in association an Auger electron or blob, i.e., a sample rich in captures in heavy nuclei.

(3) From a study of short prongs and Auger electrons the previous suggestions of Sacton *et al.*,[1] that hyperfragments are emitted predominantly from light emulsion nuclei while cryptofragments are formed preferentially in the heavy nuclei have been substantiated.

(4) The trapping probabilities for Λ^0 hyperons following Σ^- capture are much smaller in both heavy and light emulsion nuclei than is the case following K^- capture. The cryptofragment rate following Σ^- capture in a heavy nucleus agrees well with that calculated by Martin[15] using $\sigma_{\Lambda N}=22.3$ mb and $D_\Lambda=25$ MeV. However, his estimate of this rate for K^- absorption is well below the experimental values. It is suggested that in the case of K^- absorption a substantial number of the Λ^0 hyperons must be created well within the nucleus, not on the periphery as was assumed by Martin.

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