(3) The effective value of W appropriate to bound nucleons may be much smaller than the values satisfactory for representing the absorption of nucleons crossing the nuclear surface. The probable dominance of surface absorption[24] is well known. However, some estimates[23] including surface absorption imply increases in the effective value of W. On the other hand, some anomalies in slow neutron data were recently explained[25] by moving the absorption beyond the nuclear radius, and if the imaginary potential is concentrated beyond the nuclear surface it will have a smaller effect on bound nucleons.

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*This research was supported in part by the U. S. Office of Naval Research.

†National Science Foundation Senior Post Doctoral Fellow temporarily at Centre D'Études Nucléaires, Saclay, France.

‡Present address: Physics Department, University of Virginia, Charlottesville, Virginia.

[1]J. S. O'Connell, P. A. Tipler, and P. Axel, Phys. Rev. 126, 228 (1962); P. A. Tipler, P. Axel, N. Stein, and D. Sutton, Phys. Rev. 129, 2096 (1963).

[2]K. Reibel and A. K. Mann, Phys. Rev. 118, 701 (1960).

[3]E. G. Fuller and Evans Hayward, Nucl. Phys. 33, 431 (1962).

[4]G. A. Bartholomew, Ann. Rev. Nucl. Sci. 11, 259 (1961), esp. pp. 288 ff.

[5]R. T. Carpenter, Argonne National Laboratory Report ANL 6589 (unpublished).

[6]P. Axel, Phys. Rev. 126, 671 (1962).

[7]Reference 4, p. 274.

[8]E. G. Fuller and Evans Hayward, in Nuclear Reactions, edited by P. M. Endt and P. B. Smith (North-Holland Publishing Company, Amsterdam, 1962), Vol. II, esp. pp. 158-60.

[9]Reference 8, pp. 189-190.

[10]J. R. Huizenga, K. M. Clarke, J. E. Gindler, and R. Vandenbosch, Nucl. Phys. 34, 439 (1962).

[11]E. G. Fuller and Evans Hayward, Phys. Rev. 101, 692 (1956).

[12]T. Tōhei, M. Sugawara, S. Mori, and M. Kimura, J. Phys. Soc. Japan 16, 1657 (1961); a slight energy shift and a reduction of the cross sections by a factor of six has been made in the above results in accordance with M. Sugawara, S. Mori, A. Ono, A. Hotta, and M. Kimura (to be published).

[13]C. S. Young and D. J. Donahue, Bull. Am. Phys. Soc. 8, 61 (1963).

[14]G. Ben-David (Davis) and B. Huebschmann, Phys. Letters 3, 87 (1962).

[15]P. Axel and J. D. Fox, Phys. Rev. 102, 400 (1956).

[16]Reference 8, p. 190.

[17]J. D. Anderson and C. Wong, Phys. Rev. Letters 7, 250 (1961); J. D. Anderson, C. Wong, and J. W. McClure, Phys. Rev. 126, 2170 (1962); J. D. Anderson and C. Wong, Phys. Rev. Letters 8, 442 (1962).

[18]A. M. Lane and J. M. Soper, Phys. Rev. Letters 7, 420 (1961).

[19]A. M. Lane and J. M. Soper, Nucl. Phys. 37, 663 (1962).

[20]B. L. Cohen, R. H. Fulmer, and A. L. McCarthy, Phys. Rev. 126, 698 (1962).

[21]H. Feshbach, Nuclear Spectroscopy, edited by F. Ajzenberg-Selove (Academic Press, Inc., New York, 1960), Part B, see p. 1057.

[22]A. M. Lane, J. E. Lynn, E. Melkonian, and E. R. Rae, Phys. Rev. Letters 2, 424 (1959).

[23]A. M. Lane and J. M. Soper, Nucl. Phys. 37, 506 (1962).

[24]K. Harada and N. Oda, Progr. Theoret. Phys. (Kyoto) 21, 260 (1959); K. Kikuchi, Nucl. Phys. 12, 305 (1959); L. C. Gomes, Phys. Rev. 116, 1226 (1959); G. L. Shaw, Ann. Phys. (N. Y.) 8, 509 (1959).

[25]P. A. Moldauer, Phys. Rev. Letters 9, 17 (1962).

LIFETIME OF HELIUM HYPERFRAGMENTS*

Y. W. Kang,† N. Kwak, J. Schneps, and P. A. Smith
Department of Physics, Tufts University, Medford, Massachusetts
(Received 28 February 1963)

One of the more interesting parameters involved in the decay of hyperfragments is their lifetimes. Because of the possibility of nonmesonic decay, and the suppression of the mesonic decay modes due to the Pauli principle, it is expected that the lifetimes of hyperfragments will be different from that of the free Λ particle. Such considerations have been discussed recently by Dalitz,[1] Dalitz and Liu,[2] and Dalitz and Rajasekharan.[3] Recently data have been presented at the 1962 CERN Conference regarding the lifetimes of ${}_{\Lambda}H^3$ and ${}_{\Lambda}H^4$.[4,5]

We exposed a stack of Ilford K5 nuclear emulsion in the 800-MeV/c K^- meson beam of the Bevatron, in the hope that fast hyperfragments which decay in flight mesonically would be produced in sufficient number to obtain some information on hypernuclear lifetimes. As a result of our findings, we are able to present some data regarding the lifetime of helium hyperfragments.

In scanning this stack, each of the pellicles in

Table I. ${}_\Lambda$He decays at rest.

Decay scheme	Number of events	Total moderation time (10^{-12} sec)
${}_\Lambda He^4 \to \pi^- + p + He^3$	4	18.1
${}_\Lambda He^5 \to \pi^- + p + He^4$	6	55.9
${}_\Lambda He^{4,5} \to \pi^- + p + He^{3,4}$	35	335.2 if all are ${}_\Lambda He^4$ 357.9 if all are ${}_\Lambda He^5$ 352.2 if $\frac{3}{4}$ are ${}_\Lambda He^5$

the beam region was area scanned for K^- stars three times in order to reduce the chance of missing events. All the grey and black prongs from each star and all prongs which gave rise to any type of interaction were investigated as possible hyperfragment decays.

Each hyperfragment decay was analyzed in the usual way. Mesonic decays at rest were identified by momentum balance and comparison of the measured binding energy with known binding energies. Mesonic decays in flight with neutron modes of decay are not included in this analysis. Of the six events which were found that could be interpreted as decays in flight, none involved neutron emission. Also, in order to aid in the identification of the events, profile measurements of track thickness were made on each hyperfragment track. This sufficed to identify almost all the events where there was not a clear distinction between ${}_\Lambda$H and ${}_\Lambda$He from the analysis of the decay alone.

From a scanning of about 25 000 K^- stars, 83 mesonic decays were identified, six in flight and 77 at rest. Of the six in flight, one was ${}_\Lambda H^3$, one was ${}_\Lambda H^4$, two were ${}_\Lambda He^5$, and two were ${}_\Lambda He^{4,5}$. Of the 77 mesonic decays at rest, 26 were ${}_\Lambda$H, 47 were ${}_\Lambda$He, and four were ${}_\Lambda$Li. Of the 26 ${}_\Lambda$H, seven involved neutron emission.

For the ${}_\Lambda$He decays at rest, the numbers decaying according to the various decay schemes (no neutrons) are given in Table I, along with the total moderation time for each class of event. ${}_\Lambda He^{4,5}$ indicates the event may have been ${}_\Lambda He^4$ or ${}_\Lambda He^5$.

The details of the four decays in flight are given in Table II.

In determining a lifetime, we have the problem that many of the events, both in flight and at rest, do not have a unique interpretation, i.e., they could be ${}_\Lambda He^4$ or ${}_\Lambda He^5$. If we wish to use both the in-flight and at-rest events, we cannot use only the uniquely identified events, because it is not clear that the fraction of ${}_\Lambda He^5$ (or ${}_\Lambda He^4$) which can be identified uniquely is the same for at-rest and in-flight decays. With our present low statistics it does not seem worthwhile to try to separate the ${}_\Lambda He^4$ from the ${}_\Lambda He^5$. We find it more useful to combine all our ${}_\Lambda$He events and find a combined lifetime for ${}_\Lambda He^{4,5}$. To do this, we assume 75% of the ${}_\Lambda He^{4,5}$ events are ${}_\Lambda He^5$. Actually, the result is not very sensitive to this choice. Also, we make a correction to take into account the fact

Table II. Decays in flight. R = range of hyperfragment to point of decay in microns; P = momentum at decay point in MeV/c; t = time of flight before decay; T_m = moderation time if hyperfragment would have stopped in pellicle; T = available time if hyperfragment would have left pellicle.

Event	Identification	R	P	t (10^{-12} sec)	T_m (10^{-12} sec)	T (10^{-12} sec)
1	${}_\Lambda He^5 \to \pi^- + p + He^4$	192	454	6.4	15.0	...
2	${}_\Lambda He^5 \to \pi^- + p + He^4$	42	528	1.3	13.4	...
3	${}_\Lambda He^{4,5} \to \pi^- + p + He^{3,4}$	209	555 (${}_\Lambda He^4$) 664 (${}_\Lambda He^5$)	4.8 4.1	...	14.0 14.2
4	${}_\Lambda He^{4,5} \to \pi^- + p + He^{3,4}$	118	374 (${}_\Lambda He^4$) 433 (${}_\Lambda He^5$)	3.9 4.1	11.2 11.9	...

that we cannot distinguish between a decay in flight and a decay at rest for a residual momentum of less than 60 MeV/c, i.e., we do not count the time spent in the last segment of track corresponding to this momentum, about 2.5 microns.

The result we obtained using the Bartlett maximum likehood method[6] is

$$\tau({}_{\Lambda}\mathrm{He}^{4,5}) = 1.4^{+1.8}_{-0.5}\times 10^{-10}\ \text{second.}^{7}$$

It should be pointed out that there may exist in the scanning a bias against finding decays in flight. However, due to the fact that we restricted ourselves to mesonic decays, and that the plates were thrice scanned, we expect such a bias to be small.

The authors are grateful to Dr. E. J. Lofgren, Dr. J. Murray, and the Bevatron staff for making the exposure possible. Thanks are due to A. Bernardi for his assistance in making the measurements, and to Mr. J. Goodridge, Mrs. M. Ciccolo, Mrs. M. Ponton, and Mrs. Y. W. Kang for their careful scanning of the stack.

*Work supported by the U. S. Atomic Energy Commission.

†Present address: Department of Physics, Iowa State University, Ames, Iowa.

[1]R. H. Dalitz, Phys. Rev. 112, 605 (1958); The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois, Report EFINS-62-9 (unpublished).

[2]R. H. Dalitz, and L. Liu, Phys. Rev. 116, 1312 (1959).

[3]R. H. Dalitz and G. Rajasekharan, Phys. Letters 1, 58 (1962).

[4]M. M. Block, C. Meltzer, S. Ratti, L. Grimellini, T. Kikuchi, L. Lerdinara, and L. Monari, Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962).

[5]N. Crayton, D. H. Davis, R. Levi Setti, M. Raymund, D. Skjeggestad, G. Tomasini, R. G. Ammar, L. Choy, W. Dunn, M. Holland, J. H. Roberts, and E. N. Shipley, Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962).

[6]M. S. Bartlett, Phil. Mag. 44, 249 (1953).

[7]R. G. Ammar, W. Dunn, and M. Holland (to be published). These authors have found a similar value for $\tau({}_{\Lambda}\mathrm{He}^{4,5})$ based on a comparable amount of data.

NONSHRINKING DIFFRACTION SCATTERING*

Y. Nambu
Department of Physics and The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
and
M. Sugawara
Department of Physics, Purdue University, Lafayette, Indiana
(Received 10 January 1963)

The purpose of this note is to present arguments which suggest that the forward peak of high-energy elastic scattering does not shrink.

First, we discuss how one should analyze the data to obtain evidence concerning shrinkage. We show that both p - p [1] and π - p [2] scattering are not only consistent with, but rather suggestive of no shrinkage.[3]

Secondly, we present a simple argument which supports no shrinkage in terms of a complex, energy-dependent effective potential. We also construct a more specific model of high-energy elastic scattering and show explicitly how this model predicts no shrinkage and produces a finite (nonzero) total cross section in the limit of infinite energy.

Let $A(s,t)$ be the elastic amplitude as a function of s, the square of the c.m. total energy, and t, the negative of the square of the c.m. momentum transfer. Throughout this note, we assume that $A(s,t)$ behaves, when $s\to\infty$ and t is finite, as

$$A(s,t)\to\beta(t)s^{\alpha(t)}\exp[-\tfrac{1}{2}i\pi\alpha(t)], \tag{1}$$

where $\alpha(t)$ and $\beta(t)$ are real functions of t and $\alpha(0)=1$. According to a recent derivation[4] of (1), this behavior is expected as long as $A(s,t)$ is analytic in the sense of Mandelstam, and the phase $\delta(s,t)$ of $A(s,t)$ satisfies a certain condition.[5] Since this condition is sufficiently weak, we assume (1) and consider in this note how $\alpha(t)$ behaves as a function of t. If $\alpha(t)$ changes with t near $t=0$, the forward peak of high-energy elastic scattering shrinks, while there is no shrinkage if $\alpha(t)$ does not vary.