The spectrometer response for the muonic L and K x rays is determined experimentally by study of the 2.75-MeV line from Na^{24} and the 6.14-MeV line following the β decay of N^{16}.

We have comparable experimental data for Ta^{181}, U^{235}, and Pu^{239}, but are still working on the theory for odd-A nuclei. It is worth noting that the observed spectra from the last two of these targets are very similar in appearance to those presented here.

---

*Work supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

†National Science Foundation Predoctoral Fellow.

‡Now at Brooklyn College, Brooklyn, New York.

[1] J. A. Wheeler, Phys. Rev. 92, 812 (1953).

[2] B. A. Jacobsohn, Phys. Rev. 96, 1637 (1954).

[3] L. Wilets, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 27, No. 16 (1953).

[4] W. Frati and J. Rainwater, Phys. Rev. 128, 2360 (1962).

[5] G. Culligan, H. Hinterberger, H. Øverås, V. L. Telegdi, and R. Winston, to be published; G. Culligan, R. Lundy, V. L. Telegdi, R. Winston, and D. D. Yovanovitch, to be published.

[6] C. C. Trail and S. Raboy, Rev. Sci. Instr. 30, 425 (1959).

[7] G. Backenstoss, D. Quittman, H. L. Acker, and H. Marshall, to be published.

[8] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 29, No. 3 (1954).

[9] J. A. Bjorkland, S. Raboy, C. C. Trail, R. D. Ehrlich, and R. J. Powers, Phys. Rev. 136, B341 (1964).

[10] A. Edmonds, Angular Momentum in Quantum Mechanics (Princeton University Press, Princeton, New Jersey, 1957).

POSSIBLE EXISTENCE OF A p-He^3 RESONANCE WITH $Q = 11$ MeV PRODUCED IN $_\Lambda He^4$ DECAY*

M. J. Beniston, B. Krishnamurthy, R. Levi Setti,† and M. Raymund
The Enrico Fermi Institute for Nuclear Studies and Department of Physics,
The University of Chicago, Chicago, Illinois

(Received 13 August 1964)

We are currently surveying the nuclear emulsion data on π^--mesic decays of hyperfragments in order to obtain statistically improved observations of the final-state interactions present in these events.[1,2] Previously other workers have looked for states of Li^4, primarily in reactions such as p-He^3 scattering[3-7] or $He^3(d,n)$.[8] A careful analysis of p-He^3 scattering data by Tombrello[9] shows only the possibility of some very broad states of Li^4, for proton energies of ≤ 11.5 MeV. The hyperfragment data for the decay mode (decay at rest)

$$_\Lambda He^4 \to \pi^- + p + He^3 \tag{1}$$

indicate the possible existence of a very sharply defined state of Li^4 corresponding to a "two-body configuration" in ~20% of the events, namely:

$$_\Lambda He^4 \to \pi^- + Li^{4*} \to p + He^3 + (10.62 \pm 0.20)\ \text{MeV} \tag{2}$$

[using $Q_\Lambda = (37.58 \pm 0.15)$ MeV and $B_\Lambda(_\Lambda He^4) = 2.33 \pm 0.10)$ MeV[10]].

This phenomenon was first noticed in Fig. 1, where a scattergram of proton energy versus pion energy is given for all identified cases of Reaction (1). The solid curve in Fig. 1 is the boundary of the allowed region calculated using a binding energy $B_\Lambda(_\Lambda He^4)$ of 2.33 MeV.[10] The extraordinary feature is the spike in the pion energy which has its center at (23.68 ± 0.08) MeV

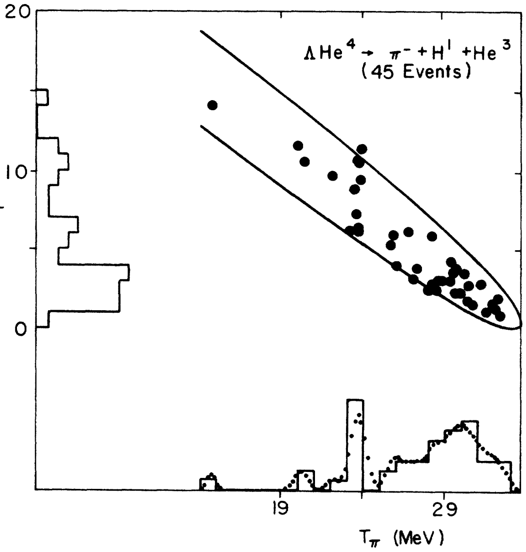

FIG. 1. A scattergram of proton energy versus pion energy for the decay $_\Lambda He^4 \to \pi^- + H^1 + He^3$. Solid circles: A Gaussian ideogram which provides an indication of the significance of the pion energy peak between 23 and 24 MeV. Solid line: The kinetic boundary based on $B_\Lambda(_\Lambda He^4) = 2.33 \pm 0.10$ MeV.

Table I. $_\Lambda He^4$ events which appear to decay via Reaction (2) showing hyperfragment range (R_{HF}), recoil range (R_{He^3}), pion energy (T_π), binding energy (B_Λ), and momentum unbalance (Δ_p).

Event[a]	R_{HF} (μm)	R_{He^3} (μm)	T_π (MeV)	B_Λ (MeV)	Δ_p (MeV/c)	Cosθ
Parma 4	95	37.0	23.68 ± 0.45	1.48	8	−0.931 ± 0.035
Be 256	•••	14.0	23.65 ± 0.45	1.02	14	0.179 ± 0.053
345	124	34.3	23.72 ± 0.45	2.29	14	−0.881 ± 0.028
398	207	20.4	23.66 ± 0.45	2.04	2	−0.381 ± 0.045
1-47-9	56	30.2	23.20 ± 0.41	2.33	9	−0.885 ± 0.071
1-50-13	88	5.2	23.92 ± 0.42	2.86	19	0.599 ± 0.040
2-62-4	18	5.0	23.54 ± 0.41	3.49	10	0.621 ± 0.051
2-63-2	519	3.5	23.80 ± 0.41	2.18	7	0.837 ± 0.042
3-42-5	87	3.2	23.97 ± 0.41	1.48	36	0.814 ± 0.041

[a] References for all of these events may be found in reference 10.

with a statistical spread

$$\sigma = (0.23 \pm 0.20)\ \text{MeV}. \qquad (3)$$

From π^- range straggling alone one expects 0.40 MeV for (3), which suggests the upper limit should be taken. The Gaussian ideogram of pion energies (dotted curve in Fig. 1), based on the known B_Λ resolution, indicates that the effect is significant.

The events in the 23.68-MeV spike were examined for possible contamination by other species (notably $_\Lambda He^5$). Table I presents the data relevant to this question for the $_\Lambda He^4 \to \pi^- + p + He^3$ events with pion kinetic energy $23 \leq T_\pi \leq 24$ MeV. The last four events in Table I have short ranges for the He^3 recoil, and from a critical examination carried out in a previous work[10] one expects this subsample of events to contain at most a contamination of one or two $_\Lambda He^5$ hyperfragments. Essentially this is due to the confusion of He^3 with He^4 recoils at very low momenta. However, the first five events in the Table have very long He^3 recoils, and thus are reliably identified. Other features to note are (1) the generally low momentum unbalance found which also suggests good identifications, (2) the fairly long hyperfragment ranges which stand as evidence against a contamination by rare decay modes of heavy ($A > 5$) hyperfragments, and (3) the fact that the binding energies measured show no significant deviation from the known population for $_\Lambda He^4$ events. Thus, a total background of not more than two events is reasonable for the 23.68-MeV spike.

Conceivably, contamination could be ruled out in a π^- spectrum from $_\Lambda He^4$ decays as observed in the helium bubble chamber,[11] where heavier hyperfragments are absent. Unfortunately, the errors on the present helium bubble chamber measurements of pion momenta are too large to permit a detailed interpretation of the spectrum.[12] One may conclude, however, that these data are not inconsistent with the nuclear emulsion results.

Figure 2 shows a scattergram of pion energy versus cosθ where θ is the angle of the He^3 recoil relative to the pion direction, calculated in

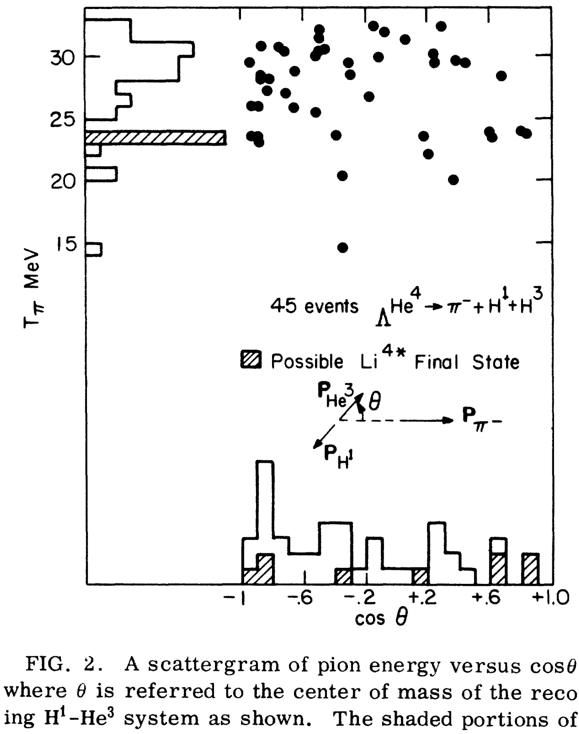

FIG. 2. A scattergram of pion energy versus cosθ where θ is referred to the center of mass of the recoiling H^1-He^3 system as shown. The shaded portions of the histograms indicate events probably involving Li^{4*}. The shaded portion of the cosθ histogram is not inconsistent with a cos$^2\theta$ distribution.

the center of mass of the proton-He^3 system. The preponderance of negative values of $\cos\theta$ for all events plotted is a well-known effect[1] due to the identification bias favoring long He^3 recoils, as discussed above. Figure 2 summarizes the scanty experimental information on the spin of this Li^4 state and is consistent with a $\cos^2\theta$ distribution. $_{\Lambda}\mathrm{He}^4$ has $J=0$ and the decay $\Lambda \to p+\pi^-$ goes dominantly to an s-wave final state. Simple arguments then show that the quantum numbers $J^P=1^-$ are the only ones consistent with a $\cos^2\theta$ distribution.

In conclusion, an effect in the π^--energy histogram from $_{\Lambda}\mathrm{He}^4$ decays in nuclear emulsions has been observed, and is best interpreted as evidence for an excited state of Li^4, (10.62 ± 0.20) MeV above decay to proton and He^3. The width observed is (0.23 ± 0.20) MeV, which agrees with the pion energy resolution (~0.40 MeV) in nuclear emulsions only if the upper limit (0.43 MeV) is taken. The narrow resonance width at this excitation energy could be understood in terms of an $I=2$ state of Li^4, whose p-He^3 decay would be forbidden by isospin conservation. However, a number of difficulties are encountered if we adopt this isospin assignment: (1) There are 3 MeV available for the allowed $3p+n$ decay mode which is not seen; (2) application of the $\Delta I=\frac{1}{2}$ rule suggests that the decay $_{\Lambda}\mathrm{He}^4 \to \pi^+ + \mathrm{H}^{4*}$ should occur with frequency equal to $_{\Lambda}\mathrm{He}^4 \to \pi^- + \mathrm{Li}^{4*}$, which is inconsistent with present hyperfragment observations; and (3) arguments given earlier suggest a spin of 1^-, but with isospin assignment $I=2$, a 1^- state is rather unlikely.[13]

These results should be checked by conventional experiments such as proton-He^3 scattering in the previously unexplored energy region around[7] $E_p=11.5$ to $E_p=19$ MeV.[14]

We wish to thank Dr. F. Von Hippel and Dr. F. Abraham for helpful discussion, and Mr. B. Beeken for his faithful computer work.

---

*Research supported by the U. S. Air Force Office of Scientific Research.

†Present address: CERN, Geneva, Switzerland.

[1] R. Ammar, R. Levi Setti, W. E. Slater, S. Limentani, P. E. Schlein, and P. H. Steinberg, Nuovo Cimento 13, 1156 (1959).

[2] D. H. Davis, R. Levi Setti, and M. Raymund, Nucl. Phys. 41, 13 (1963).

[3] K. P. Artemov, S. P. Kalinin, and L. N. Samilov, Zh. Eksperim. i Teor. Fiz. 37, 663 (1959) [translation: Soviet Phys.–JETP 10, 474 (1960)].

[4] S. Bashkin, R. W. Kavanagh, and P. D. Parker, Phys. Rev. Letters 3, 518 (1959).

[5] H. A. Brench, W. L. Imhof, and F. J. Vaughn, Bull. Am. Phys. Soc. 7, 268 (1962).

[6] T. A. Tombrello, C. Miller Jones, G. C. Phillips, and J. L. Weil, Nucl. Phys. 39, 541 (1962).

[7] T. B. Clegg, A. C. L. Barnard, J. B. Swint, and J. L. Weil, Nucl. Phys. 50, 621 (1964).

[8] N. A. Blasov, G. F. Bogdanov, S. P. Kalinin, B. V. Rybakov, and V. A. Sidorov, Proceedings of the International Conference on Neutron Interactions with Nuclei, Columbia University, 1957 [Atomic Energy Commission Report TID-7547 (unpublished)], p. 236.

[9] T. A. Tombrello, Bull. Am. Phys. Soc. 9, 164 (1964); and private communication.

[10] M. Raymund, Nuovo Cimento 32, 555 (1964).

[11] M. M. Block, R. Gessaroli, S. Ratti, L. Grimellini, T. Kikuchi, L. Lendinara, L. Monari, and E. Harth, Nuovo Cimento 28, 299 (1963).

[12] The authors are indebted to the helium bubble chamber group for the opportunity of examining their data on the π^- spectrum from $_{\Lambda}\mathrm{He}^4 \to \pi^- + p + \mathrm{He}^3$ decay.

[13] R. H. Dalitz, private communication.

[14] A. A. Vanetsian and E. D. Fedchenko, At. Energ. (USSR) 2, 123 (1957).

EVIDENCE FOR AN N^* RESONANCE AT 1425 MeV*

Stuart Lee Adelman
Cavendish Laboratory, Cambridge, England

(Received 9 September 1964)

Strong evidence has been found for the existence of a resonance in the pion-nucleon system at an effective mass of approximately 1425 MeV.

A sample of 30 000 photographs was obtained from the CERN 32-cm hydrogen bubble chamber of a separated K^- meson beam of momentum $P_K = 1.455 \pm 0.025$ GeV/c.[1,2] All events of two-prong topology were studied. We base our conclusions on those which were kinematically fitted in the inelastic modes:

$$\text{(a) } K^- + p \to \pi^+ + K^- + n \quad \text{(732 events)},$$

$$\text{(b) } K^- + p \to p + K^- + \pi^0 \quad \text{(381 events)},$$

$$\text{(c) } K^- + p \to p + \pi^- + K^0 \quad \text{(553 events)}.$$

The mode identifications were checked by measuring the bubble density along each track and comparing it with the expected ionization due to