flow be irrotational throughout the nucleus, a wide range of values of B becomes possible, some of which are larger than $(3/8\pi)AMR^2$. It is of interest that values of B which make $(\Delta R/R)_{\Delta E}$ nearly equal to $(\Delta R_c/R_c)_{\text{ex}}$ are obtained by assuming an extreme model with a spherical proton core of the size estimated above surrounded by a fluid neutron shell. In any event, it appears that the irrotational character of the flow must be abandoned in the B-M theory.

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* On leave from the Massachusetts Institute of Technology, Cambridge, Massachusetts.

[1] McClelland, Mark, and Goodman, Phys. Rev. **97**, 1191 (1955).
[2] Mark, McClelland, and Goodman, Phys. Rev. **98**, 1245 (1955).
[3] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab Selskab. Mat.-fys. Medd. **27**, No. 16 (1953).
[4] L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953); L. I. Schiff, Phys. Rev. **92**, 988 (1953).

K-Meson Mass from a K-Hydrogen Scattering Event*

WARREN W. CHUPP, GERSON GOLDHABER, SULAMITH GOLDHABER, WILLIAM R. JOHNSON AND JOSEPH E. LANNUTTI
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
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ONE of the basic problems in the classification and understanding of K-mesons is the relation between the various modes of decay ($K_{\pi 2}\equiv\theta^+$, $K_{\mu 2}$, $K_{\mu 3}$, K_{e3}, and τ). There has been much discussion recently[1] on the K-meson mass and to what extent the masses of the various K-mesons (or perhaps just different decay modes) differ from that of the τ meson (965.3 m_e).

In this connection, we want to report here on a K_L^+-particle which underwent a scattering from hydrogen in a nuclear emulsion stack and thus enabled us to obtain a rather good mass measurement. The mass value obtained as the weighted mean of two independent methods is 973 ± 12 m_e.

The emulsion stack (Ilford G.5, 600μ pellicles) was exposed to the focused K^+, beam[2] of the Bevatron in a momentum channel of 411 ± 12 Mev/c (proper time of flight of $\sim10^{-8}$ sec). The incoming track was picked 4 cm after entering the stack on the basis of the expected grain density for K-particles of the appropriate momentum. On following the track, the scattering event (Fig. 1) was found after 5.16 cm of travel in the emulsions.[3] Both of the two outgoing tracks end in the emulsion. One is a proton of 2.427 ± 0.034 mm range (variable-cell-length scattering measurements give a mass of 0.96 ± 0.3 M_p). The other is a K-particle of 32.21 ± 0.54 mm range which emits a secondary on coming to rest. The secondary particle is emitted at a dip angle of 36° and leaves the stack after traversing seven pellicles with a path length of 7.1 mm in the stack. Grain density and blob density measurements have been made on the track of the secondary relative to 280 ± 20 Mev π mesons. (See Table I.) The average values obtained are $g/g_0=1.25\pm0.03$ and $b/b_0=1.17\pm0.03$. These measurements permit us to exclude a τ' meson ($\tau'\rightarrow\pi^++2\pi^0$) almost with certainty as the τ' can give a π^+ meson of energy up to $E_{\max}=53.0$ Mev corresponding to a $g/g_0=1.63$ and a $b/b_0=1.37$.[4,5] Our measured values are 13 and 7 times their respective standard deviations from the latter values. The measurements on the scattering event (see Fig. 1) are summarized in Table II. The errors for the angular measurements include observational errors and the effect of multiple scattering. Since all dip angles in the scattering event are smaller than 5°, errors in the dip angle measurements and distortion effects hardly influence the space angle. The maximum deviation of one prong from the plane of the other two is 0.45° which is of the same order as the deviation evaluated from the errors in the

TABLE I. Measurements on the secondary of the scattered K-particle.[a]

Emulsion number	Relative grain density[b] g/g_0	Relative blob density[b] b/b_0
31–12	1.16 ± 0.08	1.03 ± 0.08
31–13	1.19 ± 0.09	1.15 ± 0.09
31–14	1.31 ± 0.09	1.19 ± 0.09
31–15	1.43 ± 0.09	1.33 ± 0.09
31–16	1.38 ± 0.09	1.23 ± 0.09
31–17	1.15 ± 0.07	1.18 ± 0.09
31–18	1.14 ± 0.08	1.16 ± 0.09
Average	1.25 ± 0.03	1.17 ± 0.03

[a] The grain density and blob density measurements were normalized to minimum ionization by comparison with 280 ± 20 Mev π mesons of 1.007 ± 0.005 minimum in each emulsion.
[b] These values include a dip correction by the cosine of the dip angle.

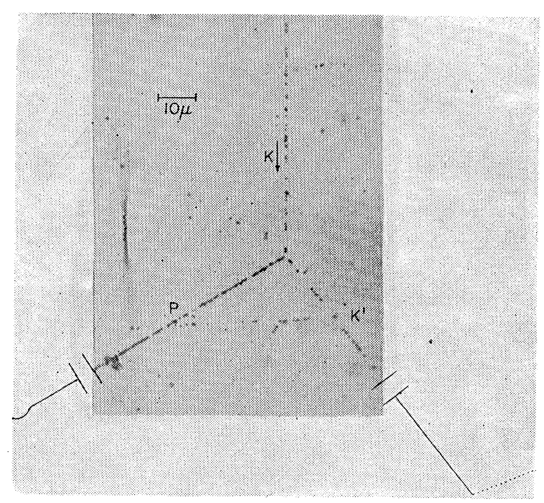

FIG. 1. A photomicrograph of a K-hydrogen scattering event $E_K=102$ Mev. Both outcoming particles come to rest (endings are sketched in) in the emulsion. $R_{K'}=32.21$ mm, $R_p=2.427$ mm (Observer: S. Livingston, Photomicrograph: R. P. Michaelis).

TABLE II. Measurements on the scattering event.

Measurement \ Particle	Incident K-particle	Scattered K-particle (K')	Recoil proton (p)
Dip angle	$+4.78°\pm0.33°$	$-3.85°\pm0.27°$	$-1.04°\pm0.07°$
Projected angle	0°	38.9° ±0.18°	59.1° ±0.34°
Range	⋯	32.07 ±0.54 mm	2.427±0.034 mm
Range (corrected for dip)	⋯	32.21 ±0.54 mm	2.427±0.034 mm
Space angles (computed)	0°	38.80°±0.2°	59.12°±0.35°

measurements. The actual mass determination was carried out by two independent methods.

a. *From the scattered K-particle range and conservation of transverse momentum.*—In this method two sets of the quantity $\beta_{K'}\gamma_{K'}$ are obtained for assumed K-particle mass values. (1) The quantity $R_{K'}/M_K$ is a function of the velocity of the K-particle only. Thus from the measured value of $R_{K'}$ we have obtained a set of values of $\beta_{K'}\gamma_{K'}$ as a function of the mass of the K-particle. (Curve A, Fig. 2.) (2) The momentum of the scattered K-particle ($P_{K'}=289.15\pm1.85$ Mev/c) is determined by transverse momentum balance from the proton momentum ($P_p=211.08\pm0.91$ Mev/c) which has been obtained from the proton range. Using this momentum for the K-particle, another set of values of $\beta_{K'}\gamma_{K'}(=P_{K'}/M_Kc)$ as a function of K-particle mass is calculated. (Curve B, Fig. 2.) The intersection of the bands formed by curves A and B, together with their resoective errors, gives the K-particle mass as $972\pm12\ m_e$.

In passing from ranges to momenta we have used the tables of Barkas and Young[6] which are based on Vigneron's calculations.[7] This method utilizes the range and space angles of both outcoming particles and is principally sensitive to the errors in the range measurements. As two range measurements are used, uncertainties in the range-energy relation and emulsion composition tend to cancel out.

b. *From the conservation of energy and momentum in the scattering event.*—In this method the K-particle mass was expressed analytically in terms of the recoil proton energy (from proton range) and the two space angles only. The resulting mass is $984\pm79\ m_e$. The much larger error inherent in this method is mainly due to the very strong dependence on the error in the angular measurement. The agreement between the two mass determinations together with the coplanarity check and the absence of a recoil or electron at the scattering center (Fig. 1) leads us to believe that our interpretation of the event as a K-hydrogen scattering is correct.

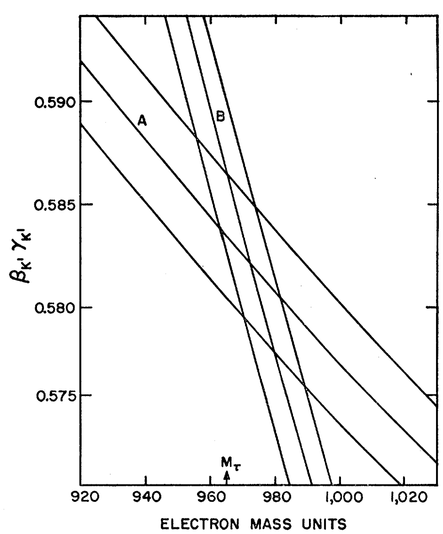

FIG. 2. A plot of $\beta_{K'}\gamma_{K'}$ as a function of K-particle mass. Curve A is based on the scattered K-particle range $R_{K'}=32.21$ mm. Curve B is based on the scattered K-particle momentum $P_{K'}=289.15$ Mev/c which is obtained from the recoil proton range. The intersection of curves A and B together with their error limits defines the K-particle mass as $972\pm12\ m_e$. The mass of the τ meson M_τ is shown for comparison.

We wish to thank Professor E. Segrè for many helpful discussions.

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[1] See for instance the summary by B. Rossi of the papers presented on this topic in the Proceedings of the Fifth Annual Rochester Conference on High-Energy Physics (University of Rochester Press, Rochester, to be published).

[2] Kerth, Stork, Birge, Haddock, and Whitehead, Bull. Am. Phys. Soc. **30**, No. 3, 41 (1955).

[3] A comparison between the momentum of the incoming particle as obtained from the magnetic momentum selection and from the kinematics of the scattering event affords an additional check on its identity as a K-particle. The incoming particle has a momentum of 411 ± 12 Mev/c as defined by its $H\rho$. After 5.16 cm of travel in the emulsion this momentum is reduced to 316 ± 24 Mev/c in agreement with $P_K=333.71\pm2.1$ Mev/c as obtained from the kinematics of the collision.

[4] R. M. Sternheimer, Phys. Rev. **91**, 256 (1953).

[5] J. R. Fleming and J. J. Lord, Phys. Rev. **92**, 511 (1953). Also J. R. Fleming, M.S. thesis, University of Washington, 1954 (unpublished).

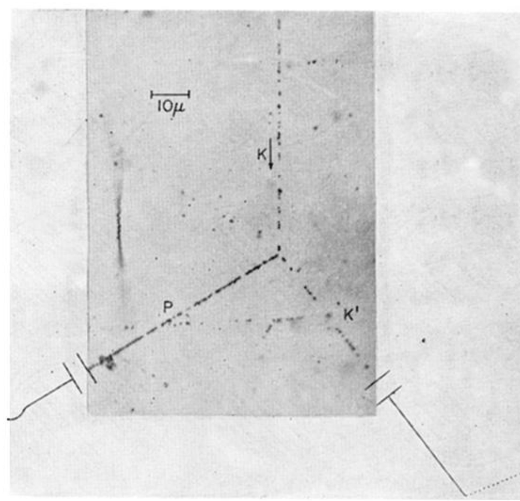
[6] W. H. Barkas and B. M. Young, University of California Radiation Laboratory Report UCRL-2579 (revised) (unpublished).

[7] L. Vigneron, J. physiol. (Paris) **14**, 145 (1952).

Mass Measurement and Excited States of F^{21}†

NELSON JARMIE
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
(Received May 31, 1955)

NEW masses of the isotopes of light nuclei have been of interest particularly to those working with systematic studies. We wish to report that we have experimentally determined that F^{21} is heavy-particle-stable and has a mass defect of 6.125 ± 0.030 Mev or an atomic mass of 21.005703 ± 0.000025 amu. Alpha particles from the reaction $O^{16}(t,\alpha)N^{15}$ were used for the energy calibration. Excited states of F^{21} are indicated at 0.33, 1.11, 1.84, and 2.16 Mev. Masses used in the calculations were taken from the review article of Ajzenberg and Lauritsen.[1]



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