Interaction of a Negative Heavy Meson*

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An interaction caused by a stopping heavy meson has been observed in emulsion. One of the four particles emitted in the interaction is interpreted as a nuclear fragment with a Λ^0 attached. The subsequent mesonic decay of this bound Λ^0 leads to a Q of 34.2±0.9 Mev. The measured mass of the heavy meson is $1010\pm200m_e$. The visible kinetic energy released in the interaction it causes is 50±8 Mev.

I. INTRODUCTION

THIS event was observed in G-5 600μ glass backed emulsion flown at $\lambda=10°$ at an altitude of 15.2 g/cm^2. The emulsions were flown horizontally in stacks of three plates. The event was observed in a routine examination of the 4-in.×10-in. emulsion by low-power hand lens. This "scan-by-eye" is made of all our plates before they are cut into pieces small enough for the microscope stages. Usually only nuclei of high Z, showers of great energy, and high-energy stars are seen in this scan. In this case the star was observed near the track of a carbon nucleus picked up during the "scan-by-eye."

The interaction is observed entirely in one emulsion with the exception of one particle which goes to a facing emulsion. Figures 1 and 2 show a sketch and a photomicrograph of the event. Table I lists the measurements made on the eight particles involved.

Particle a comes from glass and travels 1.635 cm before coming to the end of its range and being captured by an emulsion nucleus. Four particles are emitted in this interaction. Particles c and d have such small ranges that their mass cannot be determined. Their kinetic energies are assigned on the assumption that they are protons. Particle b travels 1 mm in the first emulsion and 1.6 mm in the facing emulsion before leaving the stack. By scattering, gap measurement and δ ray counts, it can be identified as a proton. Its kinetic energy as it leaves the star is 30±7 Mev. The energy was determined from scattering measurements.

TABLE I. Measurements made on the eight particles involved in the event shown in Fig. 1.

Track	Identification	Range in emulsion microns	Kinetic energy Mev	Momentum Mev/c
a	$M=1010\pm200m_e$	16 350		
b	proton	2600	30 ±7	237±27
c	p,d	167 ±3	4.9 ±0.1 if proton	96± 1
d	p,d	16.0±0.5	1.10±0.05 if proton	45± 1
e	$_2He^{4*}$	97 ±1	14.1 ±0.2	324± 3
f	proton	450 ±5	8.9 ±0.2	129± 2
g	π	10 600	24.2 ±0.5	86± 2
h	$_2He^3$	2.9±0.4	1.1 ±0.2	78± 7

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II. MASS MEASUREMENT OF HEAVY MESON

The mass of the heavy meson was measured by three methods; blob density, mean gap length, and multiple scattering. The variation of each of these quantities with range can be used as a measure of the mass provided their variation with range is known for particles of known mass.

The blob density of the heavy meson was measured over the first six millimeters of track. The variation of blob density with range for ending pions was measured over a range of values of blob density which included the values obtained on the heavy meson. The logarithm

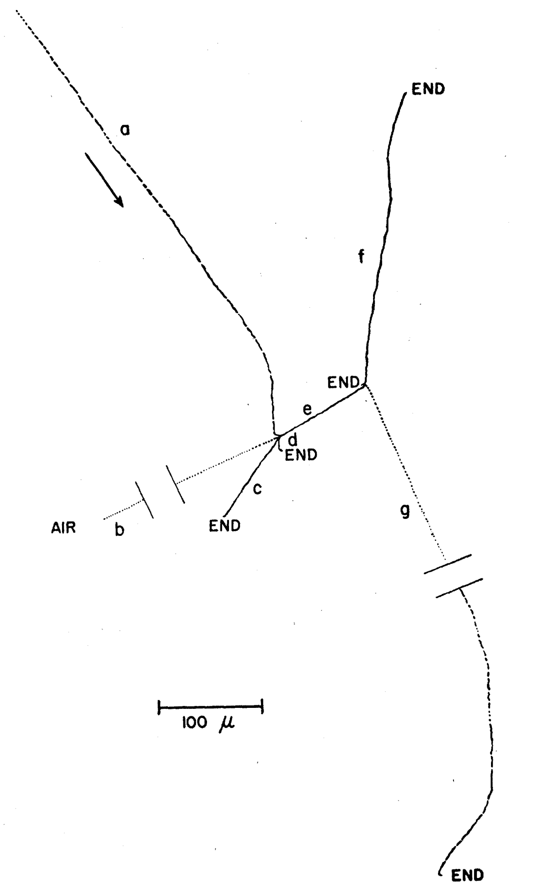


FIG. 1. A projection drawing of a star produced by an incoming heavy meson, a. Fragment e has a Λ^0 attached to it which subsequently suffers mesonic-type decay.

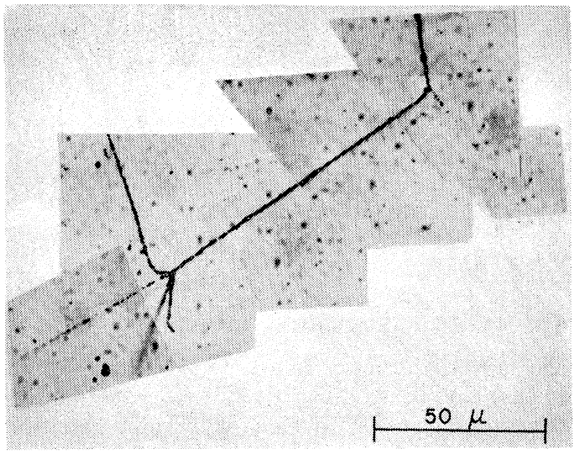


FIG. 2. A photomicrograph of the same event that is sketched in Fig. 1.

of the blob density was plotted as a function of the logarithm of the residual range. A straight line was fitted to the points of the pions by the method of least squares. A straight line with the same slope as the pion curve was passed through the points of the heavy meson to give the heavy meson curve. If R_H and R_π are residual ranges corresponding to the same value of blob density on the heavy-meson and pion curves respectively, then the mass of the heavy meson is given by the relation:

$$M_H = M_\pi (R_H/R_\pi). \quad (1)$$

The mass obtained by this method was $1030 \pm 200 m_e$. A similar treatment for a 2.1 cm proton gave a mass of $1945 \pm 160 m_e$.

The variation with range of the mean gap length for gaps greater than 0.82μ was measured by the method of Menon and O'Ceallaigh.[1] The mass obtained by this method was dependent upon the part of the track used to measure the mean gap length. If only the last centimeter of range was used the mass obtained was $1300 \pm 200 m_e$, whereas if the entire available range was used, the measured mass was $840 \pm 200 m_e$.

Scattering measurements by means of the constant cell method were made on ending pions, protons, deuterons, and the heavy meson. The logarithm of the mean absolute value of the second difference was plotted as a function of the logarithm of the residual range and a straight line fitted to the points by the method of least squares. Within the limits of experimental error it was found that the second difference, $\bar{D}$, varied as $R^{-0.58}$ as predicted by scattering theory and the empirical range-energy relation. Accordingly, lines with this slope were passed through the pions, proton, deuteron and heavy meson points. For the same size cell, the mean absolute value of the second difference is given approximately by:

$$\bar{D}(R) = K/M^{0.42}R^{0.58}, \quad (2)$$

where K is a slowly varying function of the cell length used and the velocity of the particle. Thus if we compare $\bar{D}_H$ of the heavy meson to $\bar{D}_M$ of a known particle at the same range, we have:

$$M_H = M(\bar{D}_M/\bar{D}_H)^{2.38}. \quad (3)$$

This method gave a mass of $970 \pm 200 m_e$ for the heavy meson.

The constant sagitta method of scattering was used to measure the mass. The ranges proposed by Glasser[2] were employed, yielding a mass of $910 \pm 290 m_e$.

The average of these methods is $1010 \pm 200 m_e$, where the error quoted is about twice the standard deviation given by an analysis of the error.

III. THE Λ^0 FRAGMENT

Particle e ends in the emulsion with the emission of three charged particles. It is interpreted as the mesonic decay of a Λ^0 attached to the fragment e. At least 14 cases of the decay of such a fragment have been reported in the last eighteen months,[3] and all can be explained by the assumption that a Λ^0 is bound to the fragment. Its subsequent decay, mesonically or non-mesonically, results in the star at the end of the fragment.

Fragment e seems to be a fragment of charge 2 with a bound Λ^0 which decays mesonically. Preliminary measurements with a densitometer give a charge of 2 or 3 for particle e. The decay scheme which best satisfies all the measurements is:

$${}_2\mathrm{He}^{4*} \to \pi^- + p + {}_2\mathrm{He}^3 + (34.2 \pm 0.9)\ \mathrm{Mev}. \quad (4)$$

The three emitted particles are coplanar to $13° \pm 12°$, where the large error in angle is due to the extremely short range of particle h. Particle f is most probably a proton which stops in the emulsion. Particle g has been identified by gap measurement, blob counting, scattering-range, and scattering-ionization. Its measured mass compared to identified π's is $290 \pm 20 m_e$. We therefore believe it is a π meson although there is neither a decay nor a σ star at the end of its range. However, there is approximately a 30 percent probability that a π^- makes a "zero-pronged" σ star.[4]

The momentum of the three particles emitted from the end of particle e conserve momentum to within 35 ± 25 Mev/c, the error being practically all in the Z direction where the error in measurement is large due to the emulsion shrinkage. The kinetic energy of the three emitted particles is 34.2 ± 0.9 Mev, where the energies are all determined from range measurements and Vigneron's range-energy curve.[5]

[1] M. G. K. Menon and C. O'Ceallaigh, Proc. Roy. Soc. (London) **221**, 292 (1954).

[2] R. G. Glasser (private communication).

[3] Notes of the Padua Meeting, April, 1954 (unpublished).

[4] W. B. Cheston and L. J. Goldfarb, Phys. Rev. **78**, 683 (1950).

[5] L. J. Vigneron, J. phys. et radium **14**, 145 (1953).

The difference between the kinetic energy of 34.2 ± 0.9 Mev and the Q of the decay of the free Λ^0 (37.3 ± 0.5 Mev) is 3.1 ± 1.4 Mev. This represents the binding of the Λ^0 in the ${}_2He^{4*}$ nucleus and is much lower than the 20 Mev with which the last neutron is bound in ${}_2He^4$. The apparent low binding of the Λ^0 seems characteristic of Λ^0 hyperfragments which decay mesonically.[3] This is a somewhat surprising feature of hyperfragments if the Λ^0-nucleon force has the same field theoretic origin as the nucleon-nucleon force. The same choice of the Λ^0-nucleon well parameters as exist in the case of the nucleon-nucleon interaction would result in a greater binding of the Λ^0 because of its greater rest mass. In addition, in a hyperfragment containing two or more neutral particles, the Λ^0 would be bound more strongly than an equivalent neutron because of the nonoperation of the Pauli principle between the Λ^0 and a neutron. Although the role of many-body nuclear forces is not well understood, the apparent low binding of the Λ^0 in nuclear matter may be interpreted in terms of a Λ^0-nucleon interaction that is considerably weaker than the nucleon-nucleon interaction.

IV. THE HEAVY-MESON INTERACTION

The measured mass of the heavy meson initiating the primary event with the conservatively assigned limits of error encompasses the mass of the only certainly established heavy meson, the $\tau (m_\tau \sim 975 m_e)$. If it is assumed that the absorbed meson is a τ meson, the absorption schemes to be considered are:[6]

$$\tau^- + \text{“}p + \text{nucleons”} \rightarrow \text{“}\Lambda^0 + \text{nucleons”} + \gamma \text{ (or } \nu) \quad (1a)$$

$$\rightarrow \text{“}\Lambda^0 + \text{nucleons”} \quad (2a)$$

$$\rightarrow \text{“}\Lambda^0 + \text{nucleons”} + \pi^0 \quad (2b)$$

$$\rightarrow \text{“}\Lambda^0 + \text{nucleons”} + 2\pi^0 \text{ (or } \pi^+ \text{ and } \pi^-). \quad (2c)$$

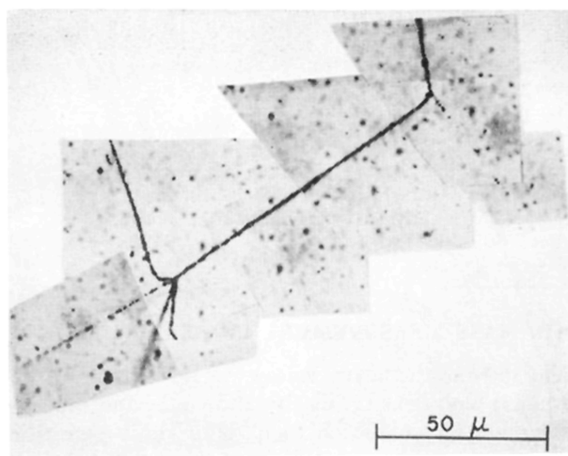
In reaction scheme (1a), the maximum energy available in particles which interact strongly with nuclear matter is ~ 35 Mev. This is well below the measured lower limit on the excitation energy and, therefore, this reaction mechanism must be discarded. Reaction mechanism (2a) releases ~ 320 Mev in a particle which interacts strongly with nuclear matter. Only 50 ± 8 Mev appears as a result of the absorption. Although this is a lower limit in the excitation since momentum is not conserved in the visible particles, the momentum unbalance is only 70 ± 40 Mev/c. It therefore seems rather unlikely that the large fraction of excitation remaining undetected has been taken off by evaporation or recoil neutrons. The available energy in reaction scheme (2b) is 29 Mev, if the assumption is made that the π^0 produced in the absorption process escapes without further interaction with the nucleus in which it was produced. Since such an interaction cannot be ruled out, reaction scheme (2b) is a possible interpretation of the observed event. In a similar fashion, reaction scheme (2c) is also a possible interpretation if one or more of the mesons produced interacts with the nucleus. Indirect corroboration that one of reaction schemes (2)[7] is operative can be obtained by noting that there is some evidence that Λ^0's are produced in pairs with θ^0's in energetic π^- collisions in hydrogen. Copious production of Λ^0's via the above scheme automatically implies that the (τ, nucleon, Λ^0, π) interaction is strong. The apparent absence of τ^- stars in emulsions may be due to the fact that a Λ^0 particle is produced in the absorption act. This removes at least 180 Mev in excitation, and such events may easily go undetected if the Λ^0 is not fortuitously bound to an ejected fragment.

The authors wish to thank the people in the emulsion group who helped with various aspects of this problem; especially Dawn Copeland who found the event and Robert Danielson who exposed the plates.

Note added in proof.—H. DeStaebler [Phys. Rev. **95**, 1110 (1954)] has recently observed a stopping heavy meson in a multiplate cloud chamber. The absorption of the meson produces a Λ° and a L meson (π or μ). This cloud chamber event, therefore, parallels the emulsion event reported above.

[6] Emission of an additional γ ray (or neutrino) does not increase the energy available in interacting particles.

[7] In effect, reaction schemes 2a, 2b, and 2c are all aspects of the same interaction mechanism; in 2b and 2c the role of the pion field is assumed by one or more real mesons whereas in 2a, the pion field enters virtually through the interaction of the Λ^0 with the recoiling nucleons.



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