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Using the charge exchange of K^- in a hydrogen bubble chamber, we find that $\bar{K}^0$ is 3.7 ± 0.7 Mev heavier than K^-.

The incident K^- ranged in energy from 10 to 150 Mev. We have observed 44 charge-exchange events,

$$K^- + p \rightarrow \bar{K}^0 + n, \qquad (1)$$

in which the $\bar{K}^0$ decays into $\pi^+ + \pi^-$. In five of these events there was a recoil proton consistent with production by the neutron in Eq. (1).

For each event the $\bar{K}^0$ mass was adjusted to give a best fit to both production and decay vertices (taken simultaneously); however, the uncertainties can be best understood in terms of a slightly oversimplified discussion in which the two vertices are fitted separately. The fact that the decay vertex is very exothermic makes the fit insensitive to the assumed $\bar{K}^0$ mass. This means on the one hand that this vertex (taken alone) yields little mass information, but on the other hand it gives a $\bar{K}^0$ momentum p_0 almost independent of uncertainty in its mass.

Cases without associated recoil protons: The production vertex is next fitted by using the calculated p_0 and the momentum p_- of the slow incoming K^- as determined by its measured curvature. This fit of the low-energy, endothermic-production vertex is very sensitive to the $\bar{K}^0$-K^- mass excess; typically a 1-Mev change in mass excess requires about a 5-Mev/c change in p_-. The principal uncertainty is in p_-, caused by multiple Coulomb scattering.

There is in addition a generally smaller error in p_0. The total uncertainty computed from these effects agrees very well with the external consistency of the various events. A least-squares fit is made of p_-(computed) − p_-(measured), with the mass excess taken as the variable; we find

$$M_{\bar{K}^0} - M_{K^-} \text{ (no recoil)} = 4.7 \pm 1.3 \text{ Mev.} \qquad (2)$$

As a check on the reliability of the measured K^- momentum for a particle that is losing momentum rapidly, we have taken a sample of K^- mesons that come to rest in the chamber (as evidenced by the collinear $\Sigma + \pi$ produced from captures at rest) and measured the momentum of the tracks to about 6 cm (150 Mev/c) from the stopping end. The residual range provides a precise measure of the momentum at the point where the curvature measurement is stopped. Comparing the momentum obtained by curvature with that obtained by residual range, we obtained, for this entire sample p(curvature) − p(range) = $+1.5 \pm 4.1$ Mev/c, showing that possible systematic effects in the curvature measurement are small. This 4.1-Mev/c uncertainty has been folded into the mass uncertainty quoted above.

Cases with recoils: We found fives cases with proton recoils associated with the neutrons in Reaction (1). The recoils were found by computing the neutron direction and momentum for each event and searching the appropriate volume of the chamber for a consistent recoil. The mean free path for an n-p collision of sufficiently large angle to make a visible recoil is approximately 100 cm, leading us to expect 4.6 recoils among those events in which the neutron is sufficiently energetic to produce a visible proton recoil. A typical bubble chamber picture contains in addition about eight recoils from background neutrons traversing the chamber. The probability is approximately 10% that in the entire volume searched there should be a recoil which accidentally satisfies coplanarity and conservation of transverse momentum within two standard deviations and lies within a $\bar{K}^0$ mass range of 494 ± 7 Mev.

For an individual event with recoil, determination of the mass difference becomes much more precise, because it does not require a measurement of momentum by curvature in a sensitive way, but only a measurement of proton range and angles. In Table I we have listed the five events in which a recoil was observed, along with the best-fit mass difference calculated for each event. The first event is clearly inconsistent with Eq. (2), therefore we feel justified in identifying this as an accidental recoil.

Table I

Best-fit mass differences for five events in which recoils were observed

Event	$M_{\bar{K}^0} - M_{K^-}$ (Mev)
1	-0.3 ± 1.2
2	$+4.1 \pm 1.3$
3	$+2.5 \pm 1.2$
4	$+9.0 \pm 7.0$
5	-5.0 ± 12.0
Average of 2-5	$+3.3 \pm 0.9$

The combined value including the four recoil events is 3.7 ± 0.7 Mev. If we take the K^- mass to be the same as the K^+, i.e., 494.0 ± 0.2 Mev,[1] the mass of the $\bar{K}^0$ is then 497.7 ± 0.8 Mev.[2] Assuming equality of the K^0 and $\bar{K}^0$ masses, one can combine this measurement with those listed in Footnote 2 to obtain a mass of 497.9 ± 0.6 Mev.

The fact that the $\bar{K}^0$ is heavier than the K^- is rather surprising. If they are members of a charge doublet, as commonly assumed, then one might expect for spinless particles that the charged member should be heavier, although no general proof of this statement is known.[3] On the other hand, if the charged K and neutral K are not members of a doublet--as, for example, in the theory of Pais[4]--then their masses need bear no relation to each other.

We wish to thank Prof. Luis W. Alvarez for his advice and encouragement, and members of the bubble chamber and scanning staff for their assistance.

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Footnotes and references

1. Cohen, Crowe, and DuMond, Nuovo cimento 5, 541 (1957).
2. This may be compared to the following neutral K mass measurements (in Mev):

    491.3 ± 4 (Arnold, Martin, and Wyld, Phys. Rev. 100, 1545 (1955))

    493.3 ± 7.5 (Thompson, Burwell, and Huggett, Nuovo cimento 4, Suppl 3, 286, (1956)).

    501.9 ± 5.3 (Fretter, Friesen, and Lagarrigue, Nuovo cimento 4, Suppl 3, 539 (1956))

    500.8 ± 7.7 (Fowler, Maenchen, Powell, Saphir, and Wright, Phys. Rev. 103, 208 (1956))

    496.3 ± 4 (D'Andlau, Armenteros, Astier, DeStaebler, Gregory, LePrince-Ringuet, Muller, Peyrou, and Tinlot, Nuovo cimento 6, 1135 (1957)).

    499.8 ± 5.1 (Baxter H. Armstrong, UCRL-3470 (1956) (unpublished))

    498.8 ± 1.1 (Crawford, Cresti, Good, Stevenson, and Ticho, UCRL-8593. Following Phys. Rev. Letter).
3. It has been observed by Gasiorowicz and Petermans (Physical Review Letters 1 457 (1958)) that, in perturbation theory, electromagnetic mass corrections for spinless particles should lead to the relation for pions and K mesons

$$\frac{M_{K^+} - M_{K^0}}{M_{\pi^+} - M_{\pi^0}} = \frac{M_\pi}{M_K}$$

contrary to the results presented here.

4. A. Pais, Physical Review 112, 624 (1958).