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SEARCH FOR AN 80-msec ACTIVITY IN LIGHT NUCLEI*

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(Received January 12, 1959)

In view of the report[1] of an 80-msec half-life activity produced by the capture of π^- mesons in carbon we have considered various possible products including He^7 and low-lying isomeric states, particularly[2] in Be^{11}. Such activities, if they exist, should also be formed by (n,p) reactions with fast neutrons.

Samples of 0.5-1.5 g of Li, Be, B, B^{10}, and C were exposed to 15.5-Mev neutrons resulting from a 20-μa beam of 600-kev deuterons incident on a thick Zr-tritium target. In the first set of experiments a pivoted arm moved the sample in 0.1 sec a distance of 2 feet from the neutron source to a position in front of a paraffin-shielded Pilot-*B* scintillator, 2 inches thick by 3 inches in diameter, and at the same time the beam was removed from the target. Backgrounds here were relatively high, so for the second series of tests we moved the detector to the shielded control room and the samples were transferred pneumatically in $\frac{1}{3}$ sec in thin-walled aluminum "rabbits." Beta rays of >4 Mev were accepted and their decay was displayed on a 100-channel analyzer adapted to serve as a time-channel analyzer. 21-msec B^{12} produced in the crystal was detected in the first series of experiments. Other activities observed include 0.17-sec Li^9 from the Be sample, and 0.8-sec Li^8 plus 13.6-sec Be^{11} from the B sample.

No other activities between ~0.05 and 10 sec were found. On the basis of the known 30-mb cross section for producing Li^8 by the $B^{11}(n,\alpha)Li^8$ reaction at $E_n = 15.5$ Mev, we find that the upper limits for cross sections of (n,p) reactions in the various nuclei, leading to the formation of a high-energy beta-ray emitter of 80-msec half-life, are (in millibarns) as follows: Li-1.2; Be-4; B^{11}-50; B^{10}-0.8; and C-2. Cross-section limits for producing nuclides of up to 10-sec half-life, other than those already known, are within an order of magnitude of these figures. The $Be^9(n,p)Li^9$ reaction, which has not been reported previously, has a cross section of ~0.6 mb at $E_n = 15.5$ Mev according to our rough preliminary measurements.

Meanwhile we have learned that the 80-msec activity reported by the CERN group is not confirmed by Love et al.[3] in a similar experiment.

We are indebted to M. Goldhaber for suggesting this problem.

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*Work done under the auspices of the U. S. Atomic Energy Commission.

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[1]Burgman, Fischer, Leontic, Lundby, Meunier, and Stroot, Phys. Rev. Lett. 1, 469 (1958).

[2]A 13.6-sec half-life has been assigned to the ground state of Be^{11} by M. J. Nurmia and R. W. Fink, Phys. Rev. Lett. 1, 23 (1958), and by D. E. Alburger and D. H. Wilkinson, Phil. Mag. 3, 1332 (1958); D. H. Wilkinson and D. E. Alburger, Phys. Rev. (to be published).

[3]R. T. Siegel (private communication); see Love, Marder, Nadelhaft, Siegel, and Taylor, preceding Letter [Phys. Rev. Lett. 2, 107 (1959)].

$\bar{K}^0$-K^- MASS EXCESS*

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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,

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

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 ± 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 five 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), and therefore we feel justified in identifying this as an accidental recoil.

The combined value of the no-recoil result and 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 reference 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 Professor Luis W. Alvarez

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±1.3
3	+2.5±1.2
4	+9.0±7.0
5	-5.0±12.0
Average of 2-5	+3.3±0.9

for his advice and encouragement, and members of the bubble chamber and scanning staff for their assistance.

*This work was done under the auspices of the U. S. Atomic Energy Commission.

[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, Suppl. Nuovo cimento 4, 286, (1956)]; 501.9±5.3 [Fretter, Friesen, and Lagarrigue, Suppl. Nuovo cimento 4, 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, University of California Radiation Laboratory Report UCRL-3470 (1956) (unpublished)]; 498.8±1.1 [Crawford, Cresti, Good, Stevenson, and Ticho, following Letter, Phys. Rev. Lett. 2, 112 (1959)].

[3]It has been observed by S. Gasiorowicz and A. Petermann [Phys. Rev. Lett. 1, 457 (1958)] that, in perturbation theory, electromagnetic mass corrections for spinless particles should lead to the following relation for pions and K mesons: $(M_{K^+}-M_{K^0})/(M_{\pi^+}-M_{\pi^0}) = M_\pi/M_K$, contrary to the results presented here.

[4]A. Pais, Phys. Rev. 112, 624 (1958).

K^0-K^+ MASS EXCESS

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In a study of associated production by 1.12-Bev/c negative pions incident on a liquid hydrogen bubble chamber, we find a discrepancy between the K^0 and K^+ production and decay dynamics, if we use currently accepted values for the masses involved. The discrepancy is most easily resolved if the mass of the K^0 exceeds that of the K^+ by about 5 Mev.

The experiment is sensitive to the mass values, in spite of the high energies involved, because one is working close to associated production threshold. The method follows.

The average beam momentum $\bar{P}_{\rm inc}$ and its rms half-width $\delta\bar{P}_{\rm inc}$ are determined from 16 selected events of the type

$$\pi^- + p \rightarrow \Sigma^- + K^+, \qquad (1)$$

in which the K^+ stops in the chamber, and thus has its momentum accurately determined by range. Using currently accepted mass values (Table I), we obtain the result

$$\bar{P}_{\rm inc} = 1123.5 \pm 2.4 \text{ Mev}/c,$$
$$\delta\bar{P}_{\rm inc} = 8.2 \pm 2 \text{ Mev}/c, \qquad (2)$$

where the error in beam momentum includes propagation of the (relatively small) contributions from the uncertainties in the π^-, Σ^-, and K^+ masses, as given in Table I.

For each event of the type

$$\pi^- + p \rightarrow \Lambda + K^0, \qquad (3)$$

with one or both of the Λ and K^0 decaying in the chamber, the momentum of the incident pion is calculated from the production and decay dynamics. This is done as a routine part of the data analysis. When 494 Mev is used as the K^0 mass, the beam momenta thus obtained are systematically about 1% too low, as compared with the Σ^-K^+ result in Eq. (2). This is the discrepancy referred to at the beginning.

The data were accordingly rerun through an improved IBM program which includes the added feature that it propagates errors in the beam momentum. In this program a K^0 mass of 498.0 Mev was used; this was close to the value suggested by the discrepancy. The discrepancy was thereby of course very much reduced.

From the events in which both the Λ and K^0 decay in the chamber we then select those with small errors, $\delta\bar{P}_{\rm inc} < 20$ Mev/c, on the incident pion momentum. It is a simple matter to transform the residual discrepancy between the resulting $\bar{P}_{\rm inc}$ and the value obtained from Eq. (2) into a deviation of M_{K^0} from 498, and propagate the errors thereon.

There were 34 ΛK^0 events that passed the selection criterion. From these events, and using the value $M_{K^0} = 498$ in the IBM program, we obtain $\bar{P}_{\rm inc} = 1121.1 \pm 2.3$. In order to agree with the Σ^-K^+ result (2), the K^0 mass must be increased by an additional 0.8 Mev. We finally obtain the result

$$M_{K^0} - M_{K^+} = 4.8 \pm 1.1 \text{ Mev}, \qquad (4)$$