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## ABSTRACT

A beam of 480 Mev/c $K^+$ mesons incident on targets of tungsten and copper inside a triggered, multiplate cloud chamber was used to look for the reaction $K^+ + n \rightarrow K^o + p$. No events were found that could be interpreted as either the decay or interaction of neutral K mesons. The nature of the experiment and possible explanations of this unexpected result are presented in this paper.

# I. $K^+$ CHARGE EXCHANGE*
# SEARCH FOR $K^+$ CHARGE EXCHANGE

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## I. Introduction

If strangeness is conserved in strong interactions, then $K^+$-neutron collisions[1] may have only two final states -- $K^+$-neutron and $K^o$-proton. Consequently, if the $K^+$ meson is assigned a strangeness of +1, the $K^o$ meson produced in the charge-exchange reaction should also have a strangeness +1. An experiment was designed utilizing this charge-exchange reaction to study the decay and interactions of the neutral K mesons so produced. The experiment produced no events that could be interpreted as either the decay or interaction of neutral K mesons. The nature of the experiment and the possible explanations of this unexpected result are presented in this paper.

## II. Experimental Procedure

The experiment was performed using 480 Mev/c $K^+$ mesons which were selected by momentum analysis with magnets and velocity analysis with Cerenkov counters (Fig. 1). The beam was focused into a multiplate cloud chamber containing a 1/2-in.-thick target, 1/4-in.-thick scintillation counter, and seventeen 1/4-in.-thick lead plates. Fig. 2 shows their relative placement in the chamber. A charge-exchange event must have made a count in a defining counter, $D_1$, a count in $C_1$

* Work done under the auspices of the U.S. Atomic Energy Commission.
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(a velocity interval Cerenkov counter counting only K mesons), no count in $C_2$ (a threshold Cerenkov counter counting only $\pi$ mesons), a count in defining counter $D_2$, and no count in $A_1$, (an anticoincidence scintillator immediately behind the charge-exchange target). A signal generated by this coicidence is used to expand the chamber and photograph the event. After counter $C_2$ an 8.43-cm beryllium absorber removes protons from the beam and also degrades the K momentum to the final value of 480 Mev/c. The chamber had a volume of 16 by 20 by 8 in. and was photographed stereoscopically with two cameras. The multiplate chamber was operated in a manner such that it was triggered only on specifically selected events,[2] with beam-associated background reduced to $\sim 1\%$ of total in a Bevatron pulse. This reduction was accomplished by using the fact that the number of $K^+$ mesons was $\sim 2\%$ of the beam tracks. The beam spill was made long compared to an artificially shortened sensitive time of the cloud chamber. This sensitive time was limited by a high-voltage clearing field before the triggering event and afterward by shutting off the Bevatron beam. The time sequence of these operations is shown in Fig. 3. When no "charge-exchange" event occurs during an acceleration cycle, the beam spill extends over a period of 200 msec and the high-voltage clearing field remains on, thus clearing all tracks out of the chamber. When a "charge-exchange" event does occur, the high voltage is turned off in a short time ($\sim 0.1$ μsec) and the rf accelerating voltage is simultaneously turned off, causing the proton beam in the Bevatron tank to spiral away from the target and thus stopping the flux of particles entering the chamber.

This technique is very effective, and is discussed in more detail elsewhere.[2,3]

In order to keep a continuing check that the counters were indeed selecting $K^+$ mesons and that the cloud-chamber sensitivity was proper, counter $A_1$ was periodically removed from anticoincidence $(D_1 + C_1 - C_2 + D_2)$, and the charged $K^+$ mesons then traversed the chamber and came to rest in the lead plates. This type of trigger will be referred to as a "through K" trigger.

Table I shows the relative counting rates of the various components of the beam:

Table I

Relative counting rates

| Beam Component | Relative Number |
|---|---|
| $\pi^+ + K^+ = D_1 + D_2$ | 2000 |
| $K^+ = D_1 + D_2 + C_1 - C_2$ | 14 |
| $K^+$ charge exchange $D_1 + D_2 + C_1 - C_2 - A$ | 1 |

Two types of targets were used in the chamber during the experiment; one was a 1/2-by-4-by-4-in. piece of tungsten, and the other was copper of the same dimensions. For purposes of analysis, the results from both targets are combined.

## III. Scanning and Analysis

The pictures were scanned twice by two different experimenters in stereoscopic reprojection (in addition to the rush scanning during the run). The same criteria and technique were used by both scannors, and the results were the same for both. The technique and criteria are as follows:

The picture is reprojected and its register number noted. Then, without reference to the picture logbook, the scanner judges from the evidence in the picture whether or not he believes the electronic trigger for this picture was for a "charge exchange" (i.e., no charged particle passes through the anticounter) or for a through K. Having put the picture into one of these two categories, he then applies further criteria for event selection. If the event has been classified as a charge-exchange, he judges the quality of the incoming track or tracks to decide whether there is one that satisfies conditions on ionization density, position, and timing consistent with being a K particle. The presence or absence of background is also noted.

If the event has been classified as a through K, the same things are noted as above. In addition, the range of the $K^+$ and whether or not it has a secondary decay product is determined and, if so, the range of the secondary is also measured.

Every charge-exchange trigger is, of course, not necessarily a true charge exchange. Some of the types of events that simulate a charge-exchange electronic trigger ($D_1 + C_1 - C_2 + D_2 - A_1$) are $K^+$ back-scatter in the target, $K^+$ decay in flight with the secondary missing the scintillator $A_1$, interaction of the $K^+$ in the gas of the chamber or in the clearing-field electrode, or slow protons arising from $\pi^+$ interactions ($\pi^+ + n \rightarrow \pi^o + p$) in the material ahead of the chamber which simulate an acceptable time of flight. Most of these false events can be excluded by inspection.

A calculation of the pure charge-exchange rate to be expected, based upon $K^+$ interactions in emulsion[4] and taking $\sigma_{ex} = 1.6 \times 10^{-27}$ $cm^2$/neutron, indicates that 1.4% of the $K^+$ mesons might be expected to charge exchange in a 1/2-in. tungsten target. The higher observed trigger rate (1/14 - 7%) is indicative of the additional processes mentioned above.

## IV. Experimental Results

Of the nearly 1000 pictures triggered by either charge-exchange or through K electronic signal, approximately 700 were selected as suitable for analysis on picture quality alone. The results shown in Table II apply only to these 700 analysed pictures.

Table II

Classification of events

| | | |
|---|---|---|
| I. | Charge-exchange trigger | |
| | A. Single, proper incoming track | 22.9% |
| | B. Backscatters | 3.7% |
| | C. Decays and interactions before target | 10.4% |
| | D. Multiple (more than one) proper incoming tracks | 34.6% |
| | E. No acceptable incoming track | 28.4% |
| II. | Through trigger | |
| | A. Single, proper incoming track with secondary | 46.1% |
| | B. Single, proper incoming track without secondary | 25.9% |
| | C. Decays and interactions before target | 8.5% |
| | D. Pictures with no clearly recognizable $K^+$ | 19.5% |

Reference to Table II indicates that in the category of charge-exchange triggers the data divides itself into three roughly equal parts and a fourth smaller one. Category A consists of those pictures in which one, and only one, track enters the target and disappears, and the track quality meets all criteria for identification as a $K^+$. Category D consists of those pictures that had more than one track entering the target, one or more of which satisfied the track quality criteria. Category E consists of those that had no track satisfying the $K^+$ track criteria and presumably consisted of some slow protons and poorly-timed pions. Categories B and C constitute the smaller fourth group.

The expected rate of real charge-exchange events, $N_T$, leading to a visible $K^o$ decay can be related to the observed inelastic-scattering rate, $N_O$, by using the following simplification of conclusions from emulsion data:[3]

(a) $K^+$ angular distribution in inelastic scatters is isotropic in the laboratory system.

(b) The $K^o$ resulting from charge exchange probably goes forward.

(c) Nearly all prongs in inelastic events have ranges less than that for 10-Mev protons.

(d) 20% of inelastic scatters are charge-exchange.

The observed inelastic-scattering rate, $N_O$, includes only the inelastic scatters when the scattered $K^+$ goes in the backward hemisphere and no star prongs enter the antiscintillator; it also includes charge-exchange events where the $K^o$ does not decay before or in the anticounter.

If we put the true rate of inelastic scatters in the target equal to N, we can calculate the observed rate, $N_O$, as a function of N:

We obtain $N_T$ as a function of $N_O$ by the use of the known relation between $N_T$ and N. The number of $K_1^o$ that decay in the chamber should be

(1) $\frac{0.8\ N}{2}$ = number of inelastic scatters with $K^+$ going backward concluded from (a) and (d) above.

(2) 0.2 N = number of true charge exchanges.

(3) $\frac{0.48 \times 0.2}{2}$ N = number of $K_1^o$ that decay in scintillator.

(The factor 2 assumes that half of all $K^o$ are short-lived, and 0.48 is calculated for the known geometry by using $1 \times 10^{-10}$ sec for the $K_1^o$ half life). Combining factors (1), (2), and (3), we have

(4) $N_O = (1) + (2) - (3) = 0.55\ N.$

(5) $N_T = \frac{0.2}{2}\ N\ (1-0.48),$

or

(6) $N_T = 0.052\ N.$

Substituting $N = N_o/0.55$, we have the desired relation

(7) $N_T = 0.094\ N_o.$

The factor 1/2 in (5) accounts for the $K_2^o$ mode, which is assumed to have such a long half life that it would not decay in the chamber with appreciable probability, and the correction for those that decay in the anticounter and do not trigger the chamber is (1-0.48).

There are two choices for $N_O$ in order to predict $N_T$. The first consists of using categories A and B of Table II and is overconservative. The second includes category D also. Table III gives the predicted decays and the probability that none should occur. None were observed.

Table III

Predicted $K^0$-meson decays and probabilities that no decays occur

| $N_O$ | Number Predicted $K_1^0$ | Number Predicted $K_2^0$ | Probability of no decay $K_1^0$ |
|---|---|---|---|
| A + B | 10 | 0 | $4\times10^{-5}$ |
| A + B + D | 23 | <2 | $8\times10^{-11}$ |

## V. Discussion

As a check on the reliability of $K^+$ identification, the "through K" pictures were also analysed. The pictures were divided into two principal categories; those with secondary and those without secondaries. An integral range-plot is made for each category and the observed ranges yield an incoming $K^+$ momentum of $461 \pm 30$ Mev/c. In Fig. 4 is a differential range-plot of those $K^+$'s with secondaries and those without. The plot indicates that 21% of the K's without secondaries stop in the target and simulate charge exchange events, or 6% of all $K^+$ triggers. This rate is indeed the same as the "electronic charge exchange" rate.

Since the K mesons which are photographed during "through K" triggers traverse a large amount of material (W, Cu, and Pb plates) it might be expected that some of them would charge exchange and have a $K_1^o$ associated; no such event was seen. The $K^+$ track length was 4.75 charge-exchange mean free paths in lead, 0.93 in tungsten, and 0.75 in copper.

In summary, we conclude that we see fewer neutral K mesons than expected. The reasons that may be concluded from this experiment are several: (a) the cross section for charge exchange in tungsten and copper as calculated from emulsion data may be lower than expected, (b) all neutral modes produced in this reaction are long-lived (i.e., $K^o \neq \frac{K_1^o + K_2^o}{2}$ and thus escape the chamber, (c) all neutral K mesons are made with so low an energy that they decay in the target or scintillator $A_1$ and are thus never detected, or, lastly, (d) there is some systematic error in electronic identification of the $K^+$ which triggers the chamber on unwanted events -- the evidence for this latter possibility is not strong, as indicated above.

In order to explore these questions more fully, a counter experiment has been performed to measure the charge-exchange cross section in tungsten, carbon, and copper, as well as emulsion. The evidence from this experiment is that our assumed charge-exchange cross section in tungsten was correct. However, calculations of the double scattering of the $K^+$ and $K^o$ in the nucleus show that it is large, ~ 30%. Any second scattering will lower the energy of the produced $K^o$ to the point where they will most probably decay before the antiscintillator.

Therefore, a crude estimate shows the ratio of the observed short-lived $K_1^o$ decay to the total $K^+$ disappearance rate will be decreased from the expected 1/2 to ~ 0.25 or less. In two following papers we report on this experiment and one other in which charge exchange reactions resulting in neutral K decays have been seen and the cross section for the reaction has been measured.

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## FIGURE LEGENDS

Fig. 1. Plan view of 480 Mev/c $K^+$ beam. Not to scale.

Fig. 2. Detail of lead plates 1 to 17, charge-exchange target, and anticoincidence counter inside the cloud chamber. Plate 1 has a hole for beam entry.

Fig. 3. Timing sequence for clearing field and beam spill. Dotted portion illustrates maximum length of spill which is about 200 msec in this experiment.

Fig. 4. Differential range plot for "through K's". Solid histogram is for $K^+$ with no secondaries, dashed histogram is for $K^+$ with secondaries. The abscissa is in units of the average range for a 461 Mev/c $K^+$. The target is located at T.

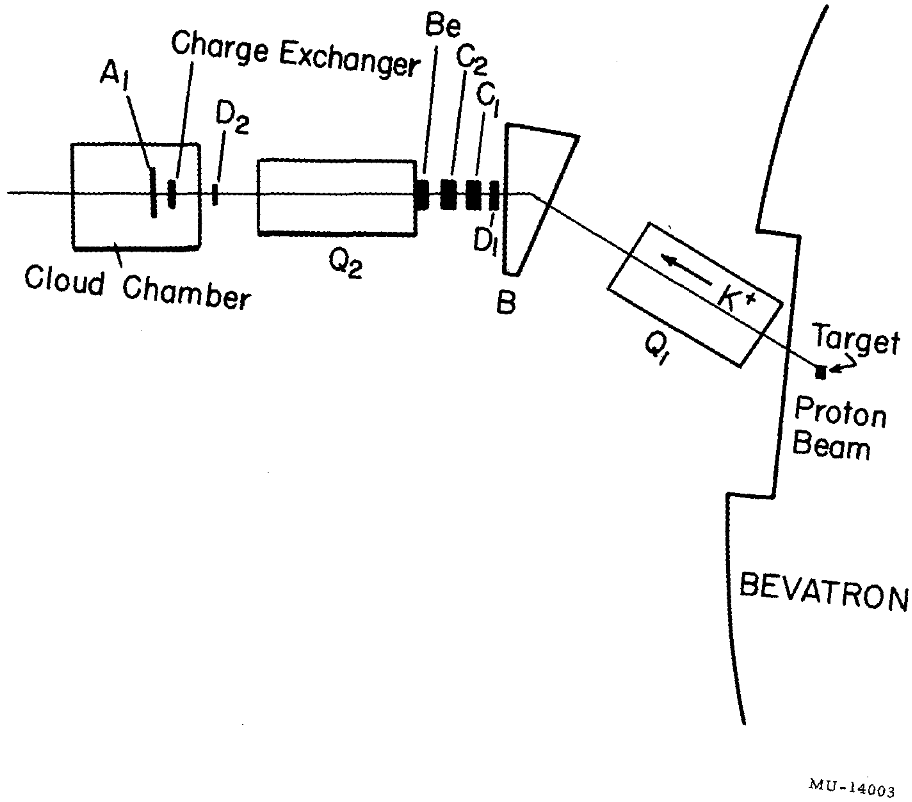

Be
Charge Exchanger
$C_2$
$A_1$
$C_1$
$D_2$
$D_1$
Cloud Chamber
$Q_2$
B
$K^+$
$Q_1$
Target
Proton
Beam
BEVATRON
MU-14003

Fig. 1

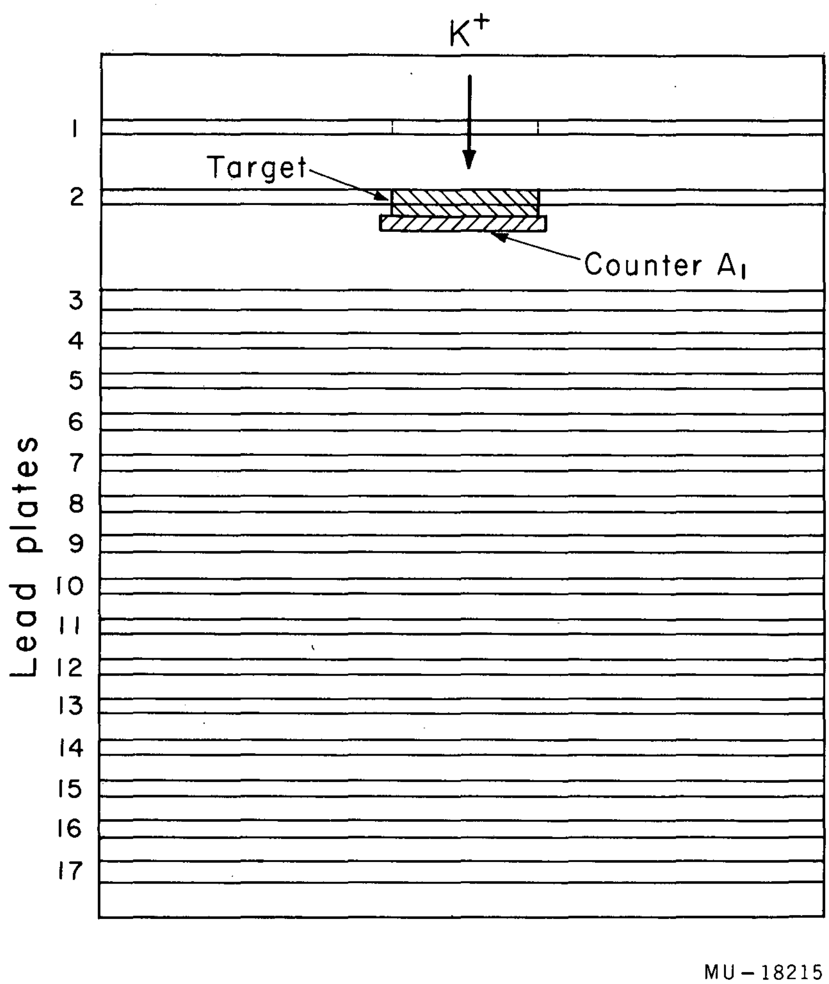
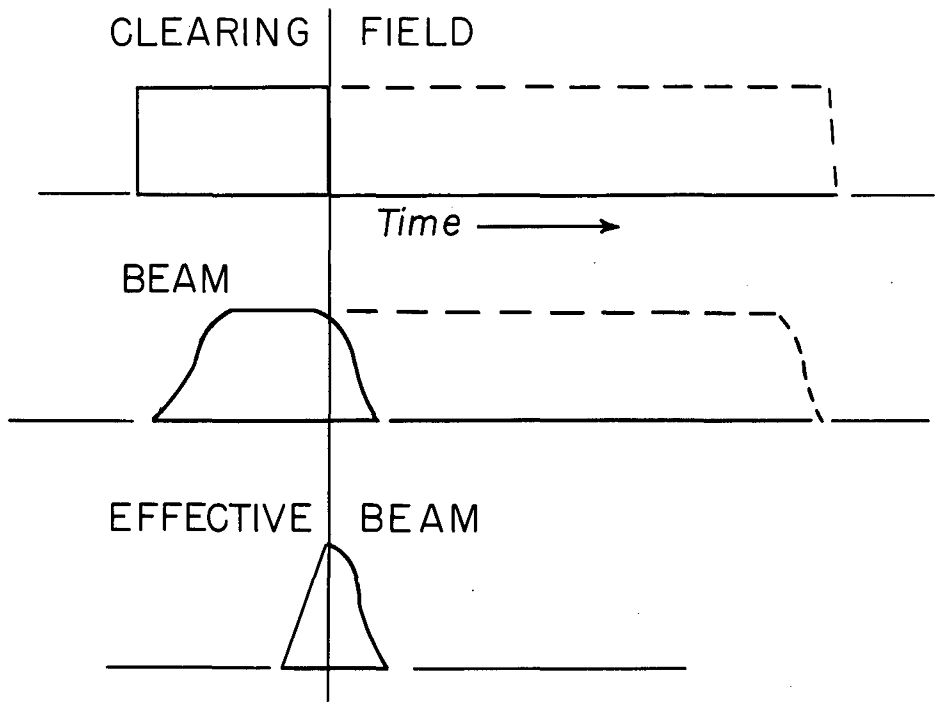

K+
1
Target
2
Counter A1
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Lead plates
MU-18215

Fig. 2




MU-14004

Fig. 3

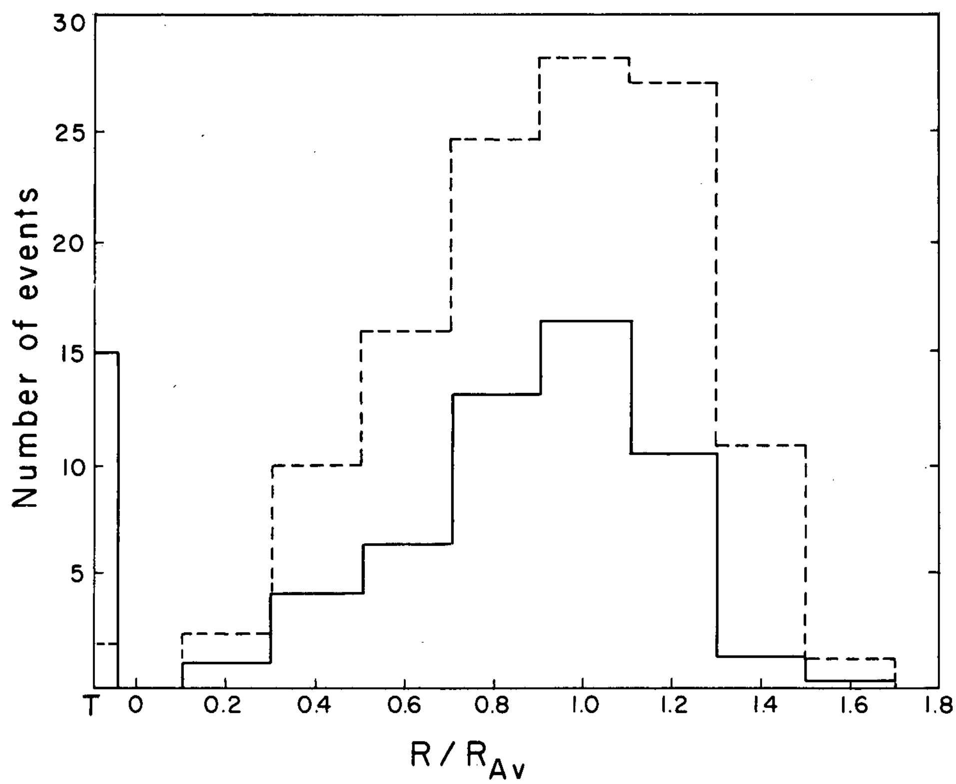

30
25
20
15
10
5
Number of events
T
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
R / R_Av
MU-18214

Fig. 4

## REFERENCES

1. M. Gell-Mann and A. Pais, Phys. Rev. 97, 1387 (1955).
2. Birge, Courant, Lanou, and Whitehead, Proc. International Conference on Mesons and Recently Discovered Particles, Padua-Venezia, Sept. 1957. (To be published in Nuovo cimento Supplement).
3. Courant, Birge, Lanou, and Whitehead, to be published in Nuclear In str. and Methods.
4. Lanutti, Goldhaber, Goldhaber, Chupp, Giambuzzi, March, Quareni, and Wateghin, Phys. Rev. 109, 2121 (1958).