Very strong and narrow resonance signals have been obtained by observing the variation of the transmitted z beam. By feeding the rf field from the (amplified) photocurrent generated by the modulated x beam an atomic oscillator can be constructed. Further experiments along the above lines are under way in collaboration with Dr. A. Bloom and Dr. E. Bell and with Mr. E. S. Ensberg.

[1] H. G. Dehmelt, Phys. Rev. **103**, 1125 (1956).
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Isotope Shift in the Spectrum of Indium I

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DETERMINATIONS of the isotope shifts in five lines of the arc spectrum of indium[1] were derived from measurements of the differences in wavelength of the lines emitted by natural indium and by indium enriched in In^{113}; they depended on the accuracy of the mass spectrograph analysis of the enriched isotope, since the measured displacement had to be multiplied by a conversion factor derived from the isotope abundance ratio. This was stated by the Atomic Energy Research Establishment, Harwell, England to be $(49.7\pm0.1)\%$ In^{113}, from which follows the conversion factor 2.20.

It has since been possible by observing the absorption of an atomic beam of indium enriched in In^{113} to resolve the lines of In^{113} from those of In^{115} in the strong hfs components (0 and 662 millikaysers) of the line 4101 A, and thus to measure the isotope shifts directly. These were, respectively, 7.8 and 9.9 mK, with a probable error of ±0.5 mK. The conversion factors required to obtain these shifts from the displacements (4.77 and 5.41 mK) measured in the earlier work are, respectively, 1.64 and 1.83; the mean, 1.74 ± 0.1, corresponds to an abundance of $(61.5\pm3)\%$ of In^{113}.

The indium enriched in In^{113} actually used in the earlier work had been kept; it was sent for reanalysis to the Commissariat à l'Ènergie Atomique, Saclay, France. Three analyses gave values of 60.0, 61.4, and 64.6% In^{113}; a new analysis made at Harwell gave the value 61.5% In^{113}. These results confirm the requirements of the purely spectroscopic measurements, and it appears that the analysis of 49.7% must have been in error; and that the conversion factor to be used should be 1.74 ± 0.1, which is independent of isotope analyses, though in good agreement with the new analyses. The isotope shifts calculated with this conversion factor are

Wavelength (A)	4511	4101	3256	3039	2710
Displacement (mK)	5.0	5.1	4.3	4.3	4.0
Isotope shift (mK)	8.7	8.9	7.5	7.5	7.0.

In all cases the lines of In^{113} are shifted to the red. The value for 4101 A is the average of the individual shifts of the four hfs components, which were

Component (mK)	0	281	381	662
Displacement (mK)	4.8	4.9	5.3	5.4
Isotope shift (mK)	8.3	8.5	9.2	9.4.

The probable error of the isotope shifts is 0.5 mK for the visible lines and 1 mK for the ultraviolet lines.

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Report on Long-Lived K^0 Mesons*

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THE experiment previously reported[1] which established the existence of a long-lived neutral V particle is being continued. In this report, we give evidence that (1) strengthens the previous surmise[1] that these are indeed K-mass particles with decay modes primarily into $\pi e\nu$ and $\pi\mu\nu$, (2) establishes rather convincingly the existence of the $\pi^+\pi^-\pi^0$ mode[2], (3) provides additional evidence for the particle mixture theory.[3]

We have now examined 5000 photographs taken in the neutral V beam at the Cosmotron. The experimental arrangement differed from that previously employed[1] in that a $\frac{1}{16}$ in. Lucite "thin window" was placed on the entrance side of the cloud chamber and the collimation and shielding arrangements were im-

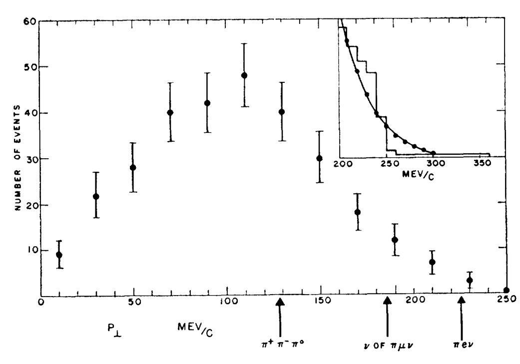

Fig. 1. Transverse momenta of the positive, negative, and neutral secondaries of 100 events. The arrows indicate the cutoffs for various decay modes. The inset magnifies the end point and compares with a resolution folded linear cutoff at 230 Mev/c.

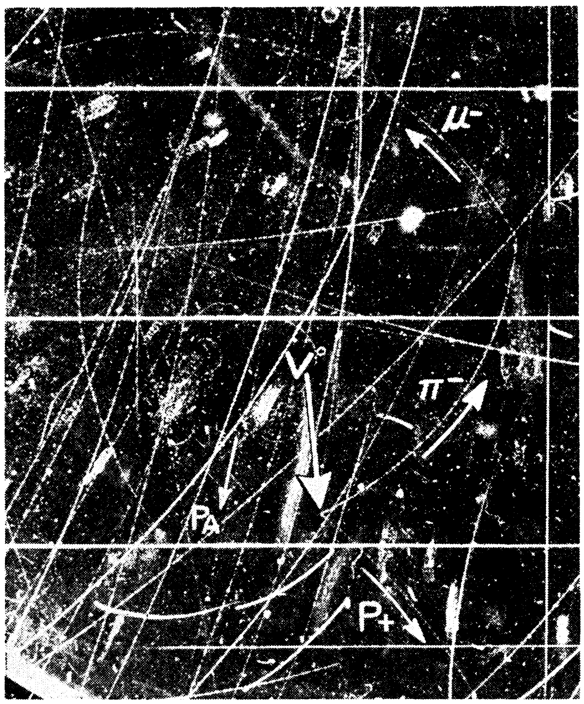

FIG. 2. Example of $K^0 \rightarrow \pi^+ + \pi^- +$neutral particle. P_+ is shown to be a pion by ionization measurements. P_A is a proton track used in the ionization calibration.

proved. These changes permitted us to increase the external proton beam flux by about a factor of four (to $\sim 4 \times 10^8$ protons per pulse). The thin window reduced the solid angle, the net effect being to increase the V^0 yield to 1 found per 35 pictures as compared to 1 per 60 pictures in the original arrangement.

We have now analyzed one hundred V^0 events. Assuming these to represent disintegrations of neutral particles into a positive, negative, and single neutral secondary, we have plotted in Fig. 1 the distribution of transverse momenta for all 300 secondary tracks. The neutral transverse momenta are deduced from the measured curvatures and angles made by the charged secondaries with the precisely known incoming beam direction. The graph is independent of any secondary mass assignments. The observed cutoff in transverse momentum is very close to 230 Mev/c, as determined by folding resolution into a linear shape of spectrum at the upper end point. See inset to Fig. 1. This coincides with the reaction $K^0 \rightarrow \pi^\pm + e^\mp + \nu$. These facts provide considerable support to the original supposition that we are observing neutral K mesons which decay principally into three-body final states like $\pi e \nu$ and $\pi \mu \nu$.[4] For simplicity, we now assume these to be neutral counterparts of the K^+ meson. To make an independent determination of secondary masses, ionizations of charged secondaries are being determined by photometric analysis using a system similar to one described by Caldwell and Pal.[5] This system is promising because of the large flux of protons of various energies which serve to calibrate the measurements in each picture. We have so far identified four cases of $\pi^+ e^-$, two cases of $e^+ \pi^-$, one case of $\mu^+ \pi^-$, and one case of $\pi^+ \pi^-$ (see below). A level of confidence estimated at 80% is required for an identification.

We have also analyzed the events kinematically[6] assuming an incoming K^0 and, admitting only the neutral counterparts of K^+ decay, have found 5 cases which fit only $\pi^+ e^- \nu$, 2 cases of $\pi^- e^+ \nu$, and 11 cases of $\pi^\pm e^\mp \nu$. This analysis selects those events which have secondaries with transverse momenta which are above the cutoff for all but one decay mode.

There are 19 events that are kinematically consistent with $\pi^+ \pi^- \pi^0$ decay mode. These events are also consistent with $\pi e \nu$ and $\pi \mu \nu$ modes. One of these, shown in Fig. 2, is of particular interest. The negative prong undergoes $\pi - \mu$ decay. ($P_\mu^* = 31.4 \pm 2.0$ Mev/c; five $\pi - \mu$ decays and one sigma star have been observed among the K^0 secondaries.) The positive track has a momentum of 88.3 ± 1.5 Mev/c, low enough to be identifiable by ionization measurements. The calibration of the picture, Fig. 3, was made by measuring the ionizations of several protons and a "minimum" track, all of which were within 5 cm of the vertex in height, all in the general region of the event, and all dipping by less than 18°. In addition, the known π^- and μ^- were used. The measured ionization of the positive track is then $(2.4 \pm 0.2) \times$minimum, in good agreement with a π. We estimate that we can exclude the μ assignment with a 90% confidence level. A microscope blob count relative to proton track P_A again gave good agreement with a π assignment. $Q_{\pi\pi}'$ is 11.3 Mev/c and would permit $\pi^+ \pi^- \gamma$ as well as $\pi^+ \pi^- \pi^0$. We refer to Dalitz[7] for support of the conclusion that the former is quite unlikely for spin-zero K mesons. The $Q_{\pi\pi}'$ for the 19 possible τ's fit the phase space distribution which is known to be valid for τ^+. A strong "contamination" of other modes would give many high $Q_{\pi\pi}'$ values. We note here that if, as now seems very likely, τ and θ are

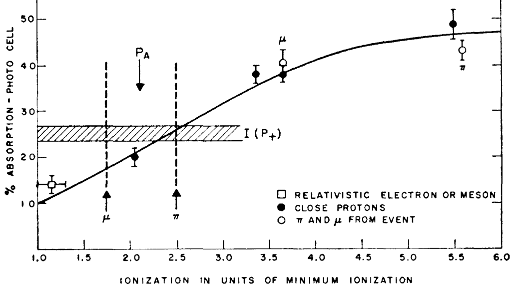

FIG. 3. The ionization calibration for the event in Fig. 2. The vertical dashed lines represent the ionization of the positive secondary if it is a π or a μ. The "minimum" track is either a fast meson ($I = 1.0$) or a fast electron ($I = 1.3$).

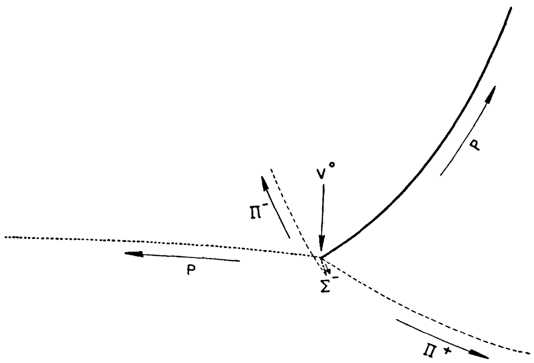

FIG. 4. Tracing of V^0 interaction in helium. See text.

the same particle, one would expect of the order of, or less than, one-third of the θ_2^0's to show 3π decay, a prediction quite consistent with our results.

The particle mixture theory[3] predicts that the long-lived θ_2^0's should interact with equal probability in a manner characteristic of strangeness +1 and −1. We have observed, in our K^0 beam, the interaction depicted in Fig. 4. The event is interpreted as the absorption of a θ_2^0 in a helium nucleus to give a Σ^- of 82 Mev, a π^+ of 81 Mev, and protons of 144 Mev and 9 Mev. A neutron of 30 Mev is required for energy-momentum conservation. This requires an incident θ_2^0 of 250-Mev kinetic energy, which is quite reasonable at our production angle. Since the V^- primary is unmeasurable, an alternative interpretation that the unstable particle is a K^- is possible, but this would require an incident θ_2^0 energy of ~1 Bev. In either case, negative strangeness is observed in a beam which originates with an overwhelming proportion of positive strangeness K's. The event is $\gtrsim$ ten θ_1^0 mean lives from any wall. Neutron production is excluded by the arguments in reference 1.

These results, together with the observation that only one-half the Λ^0's produced in the Columbia bubble chamber[8] are accompanied by $\theta_1^0 \to 2\pi$ events, now constitute an experimental picture completely consistent with the particle mixture theory of the neutral K mesons. The relevance of the failure of charge conjugation invariance to the K^0 problem has recently been discussed by Lee, Oehme, and Yang.[9] The interference effects discussed there are being sought, but the problem is made difficult by the effect of scanning bias.

We wish to note here the contributions of Professor E. T. Booth to the planning and execution of the early phases of this experiment and to thank Dr. Morton Fuchs for his assistance in the analysis of data. Mr. G. Impeduglia continues his invaluable scanning efforts. The cooperation of the Cosmotron staff is gratefully acknowledged.

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Angular Distributions of Positrons from $\pi^+ - \mu^+ - e^+$ Decays Observed in a Liquid Hydrogen Bubble Chamber*

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LEE and Yang[1] have shown that the nonconservation of parity in weak reactions, predicted by them and confirmed by Wu, Ambler, Hayward, Hoppes, and Hudson,[2] is likely to lead to the polarization of the μ mesons from $\pi - \mu$ decay and to a fore-aft asymmetry of the electrons from the following $\mu - e$ decay. After this anisotropy was observed for the high-energy part of the electron spectrum by Garwin, Lederman, and Weinrich[3] for μ^+ mesons stopped in carbon, it seemed desirable to investigate the $\pi^+ - \mu^+ - e^+$ angular distribution integrated over the whole momentum spectrum for μ^+ mesons stopped in liquid hydrogen. It is likely that the most effective depolarizing effect on the stopping μ^+ mesons results from the capture and loss of electrons in the last fraction of its range. It is then plausible that the depolarization of the slowing μ^+ mesons might be least in substances with high ionization potentials and there may be less depolarization in hydrogen than in carbon.

One-hundred-Mev π^+ mesons, produced by bombarding a copper target with one-Bev protons in the Cosmotron, were selected by magnetic analysis and directed into a liquid hydrogen bubble chamber, 6 in. long, 2 in. deep, and 3 in. high. Appropriate absorber was placed in the beam so that the π mesons stopped in the chamber. According to Lee and Yang,[1] the μ mesons are polarized with their spin along the direction of emission from the stopped π mesons. Since the π mesons decay isotropically, the μ mesons are polarized at random with respect to any magnetic field in the

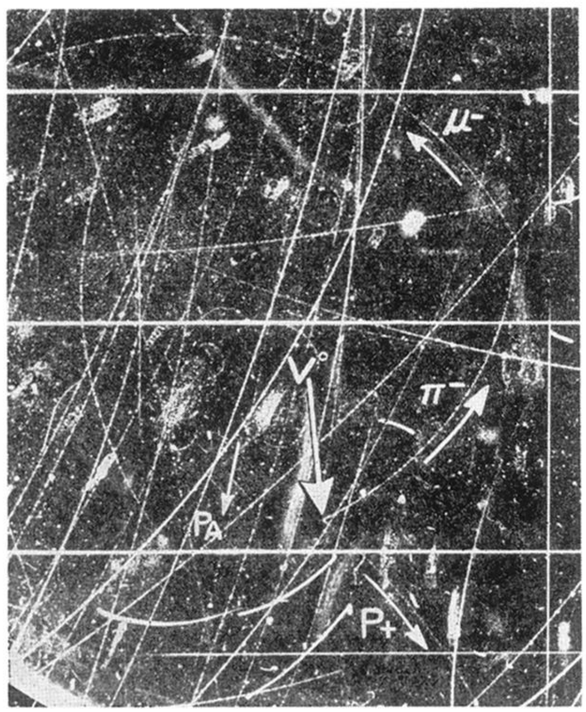

FIG. 2. Example of $K^0 \rightarrow \pi^+ + \pi^- +$neutral particle. P_+ is shown to be a pion by ionization measurements. P_A is a proton track used in the ionization calibration.