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HIGH-ENERGY PHYSICS WITH HYDROGEN BUBBLE CHAMBERS[1]

Prepared by

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Abstract

This paper discusses recent experience with liquid hydrogen bubble chambers in high-energy physics experiments.

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HIGH-ENERGY PHYSICS WITH HYDROGEN BUBBLE CHAMBERS

Luis W. Alvarez[*]

1. INTRODUCTION

Five years ago, our laboratory undertook to adapt the bubble chamber, newly invented by Glaser, to operation with liquid hydrogen, and in large sizes. It was hoped that this development would yield important new experimental data when the Bevatron was completed. Accompanying papers by other members of the hydrogen bubble chamber group describe the various chambers built in the five-year period, and the associated data-reduction apparatus that is needed for efficient utilization of the chambers. Experiments with the 10-cm chamber have yielded interesting data on the interaction of 300-Mev bremsstrahlung radiation with protons, and have shown that a hydrogen bubble chamber is a convenient neutron spectrometer in the 10- to 25-Mev range; the full width (at half maximum) of the 14-Mev neutron line from T + D is 1 Mev. This paper, however, describes only those experiments performed at the Bevatron with chambers of 25 cm and 40 cm diameter.

2. INTERACTION OF K^- MESONS WITH PROTONS

The first serious experiment done at the Bevatron with the 25-cm chamber was on the interaction of K^- mesons with protons, both at rest and in flight. A special target and beam station were installed in one of the curved sections of the Bevatron magnet. In this manner, it was possible to leave the bubble chamber set up in one place for months at a time, since it did not interfere with other beams from the Bevatron. The Bevatron crew, under the direction of Dr. Edward J. Lofgren and Mr. Harry H. Heard, developed a technique that allowed the bubble chamber to have a small fraction of the circulating beam, before or after the major portion of the beam was deposited on another target. This technique of beam sharing on multiple targets is most important in bubble chamber operation, since a bubble chamber can seldom use the full beam from the Bevatron or similar machine. By this means a bubble chamber can receive a large fraction of all the beam pulses during a year, without seriously curtailing the activities of other users of the accelerator.

The beam of negative particles in the "K^- beam" consists originally of about 10^3 negative pions to 1 negative K meson to 10^{-3} antiproton. After momentum degradation in the absorber, the numbers are about 5×10^3 negative muons to 10^3 negative electrons to 1 negative K meson. From these numbers, one might conclude that he had not been very successful in "cleaning up the beam." But the elimination of negative pions, and their substitution by muons and electrons, is a great help in the scanning of films; the large background of strongly interacting particles has been replaced by a background of tracks that travel through the chamber without confusing interactions.

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The results of the 1956 experiment on K^- mesons have been published.[1] About 250 K^- mesons were observed to stop in the chamber, and the relative rates of formation of the various hyperons were measured. In addition, the lifetimes of the Σ^-, Σ^+, and Λ hyperons were measured accurately, and the branching ratio of the two modes of decay of the Σ^+ hyperon was determined. The existence of two neutral particles (Σ^0 and $\bar{\theta}^0$) postulated in the Gell-Mann[2] and Nishijima[3] schemes was demonstrated. Limits on the mass of the Σ^0 were set.

The experiments mentioned in the preceding paragraph have recently been extended, using an improved K^- beam and the 40-cm chamber. The electromagnetic separator of Murray and Horwitz[4] has increased the ratio of stopping K^- mesons to tracks that cross the chamber. Whereas formerly one observed one stopping K^- meson for every 150 pictures under good operating conditions, the corresponding number is now one in three pictures. Several pictures with three and four stopping K^- mesons have been seen on the most recent run, which was interrupted in April 1958 by a generator failure at the Bevatron. More than 1000 new K^- stoppings have been observed in hydrogen, and we hope to have in the near future a similar number stopping in liquid deuterium. The K^- beam will then be altered to allow a more detailed study of the interactions in flight of K^- mesons with protons and deuterons.

3. INTERACTIONS OF ANTIPROTONS WITH PROTONS

The electromagnetic separator mentioned above was set to pass antiprotons, rather than K^- mesons, and we observed one antiproton stopping in the 40 cm chamber for every 150 pictures. Before the generator breakdown, about 100 antiprotons had been observed to stop in hydrogen. A similar experiment, using deuterium, will be performed in the next few months. The average multiplicity of the charged prongs is 3.2. One case has been found in which a pair of neutral K mesons ($K^0 + \bar{K}^0$) is observed as annihilation products.

4. CATALYSIS OF NUCLEAR FUSION REACTIONS BY MUONS

As mentioned earlier, the main contamination in the original K^- beam was a flux of negative muons. While scanning for K^- interactions, we observed an unusual type of event,[5] which looked much like the decay of a negative pion at rest, followed by the decay of a negative muon at rest into an electron. Such a reaction is, of course, impossible in hydrogen, since the well-known Panofsky reactions destroy the pions before they can decay at rest. Further studies showed that the primary particle that decayed was the negative muon, as shown by its terminal curvature. The secondary particle, which had a range of 1.6 cm rather than the 1.0 cm characteristic of the muon from a π decay, was a muon, as shown by its decay electron spectrum. It was then shown that the reaction was one that had been proposed a number of years ago by Frank,[6] and more recently by Zeldovich.[7] The reaction is one in which the negative muon catalyzes the fusion of a proton and deuteron to form He_3. The energy liberated in the reaction is given to the muon, so that it appears in the chamber as an "internally converted muon." A number of checks were made to show that this was indeed the reaction being seen. The deuterium concentration was increased, and the fraction of stopped muons that acted as catalysts increased as expected. As a final confirmation, three cases were observed in which one muon catalyzed two separate fusion reactions before undergoing its natural decay.

5. PRODUCTION AND DECAY OF HYPERONS FROM NEGATIVE PIONS

The most recent experiment performed with the 25-cm chamber involved the associated production of hyperons and K mesons by negative pions of approximately 1 Bev kinetic energy.[8] Reactions studied were

$$\begin{aligned} \pi^- + P &\rightarrow \Lambda + K^0 \\ &\rightarrow \Sigma^- + K^+ \\ &\rightarrow \Sigma^0 + K^0 \\ &\qquad \searrow \Lambda + \gamma . \end{aligned}$$

The angular distributions, differential cross sections in the center-of-mass system, and total cross sections for all three reactions were determined at several incident-pion energies. Particular attention was paid to the question, "Is there an up-down asymmetry in the decay of the hyperons, relative to the production plane?." In order for such an asymmetry to be seen, the hyperons must first of all be produced in a polarized condition relative to the production plane, and second, parity must not be conserved in the decay process. In the case of the directly produced Λ hyperons, a large up-down asymmetry was observed, and the maximum value of the product of the polarization and the asymmetry coefficient was 0.77 ± .16. No significant asymmetry was observed in the decay of Σ hyperons of either charge; our failure to observe an asymmetry could be due either to an absence of polarization, or to a very small value of the parity-nonconserving term in the decay. A study of the decay of Σ hyperons produced by the interaction of K mesons and protons is now under way, using data obtained from the most recent run in the 40-cm chamber.

6. INTERACTION OF HIGH-ENERGY K⁻ MESONS WITH PROTONS

In the beam used in the experiments described in Section 5, there was a contamination of K⁻ mesons of about one in 150. We have observed a number of elastic and inelastic interaction of K⁻ mesons with hydrogen. In some cases the K mesons are scattered elastically, and in other cases hyperons are produced. Two reactions that we had hoped would manifest themselves did not show up. These are

$$\begin{array}{ccccccc} & K^- & + & P \rightarrow & \Xi^{\overset{-}{0}} & + & K^{\overset{+}{0}} , \\ S = & -1 & & 0 & -2 & & +1 . \end{array}$$

These reactions are allowed by the strangeness rules, and if observed would have yielded confirmation of the strangeness assignment of the Ξ hyperon, and the first evidence for the existence of the Ξ^0 hyperon. No significant information can be gleaned from the fact that the reaction was not observed, because with "reasonable cross sections" of a few tenths of a millibarn we expected to see no more than approximately one event of each type.

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