K^+ Meson Photoproduction from Complex Nuclei*

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K^+ meson yields have been measured from various elements using a bremsstrahlung beam of maximum energy of 1150 MeV. The K^+ mesons were detected using a magnetic spectrometer set at a momentum of 415 MeV/c and laboratory angle of 35°. These kinematical conditions correspond to an angle of 90° in the center of mass and a photon energy of 1054 MeV for the reaction $\gamma+p\rightarrow K^++\Lambda$. The targets used were Be, C, Al, Cu, Ag, W, and Pb. The results show a slight decrease in the yield per proton as a function of atomic number. A crude estimate yields a mean free path in nuclear matter of the order of 10 F for the geometry of this experiment.

MEASUREMENTS of the photoproduction of K^+ mesons from various complex nuclei have been made to obtain qualitative information concerning the Z dependence of the cross section.

The K^+ mesons were detected and identified by the magnetic spectrometer described by Anderson *et al.*[1] The spectrometer was set at a laboratory angle of 35° and a momentum of 415 MeV/c. These kinematical conditions correspond to a center-of-mass angle of 90° and a photon energy of 1054 MeV for the reaction $\gamma+p\rightarrow K^++\Lambda$. The angular aperture was limited to $\pm 2°$ and the momentum resolution was $\pm 5\%$. Selection of the K^+ mesons by momentum, specific ionization, decay requirement, and time of flight reduced the contamination from pions and protons to less than 1%. Production from the air was measured to be less than 1%. Targets were chosen as thick as possible consistent with a reasonable attentuation and degradation of the photon beam and energy loss of the emerging K^+ mesons. The targets varied in thickness between 2 and 6 g/cm², with a maximum correction due to gamma-ray absorption of 10%. These corrections are included in the data presented below. We believe that the relative nonstatistical errors of measurement are limited to about 3%.

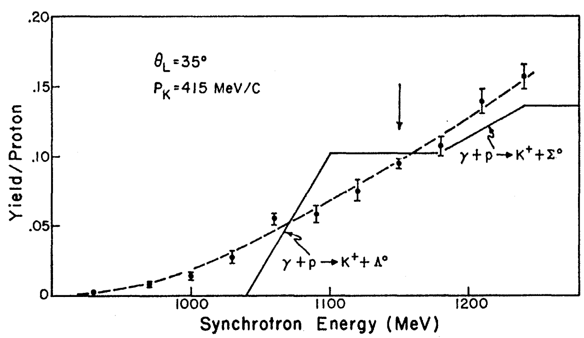

FIG. 1. K^+ meson yield per equivalent quanta from carbon as a function of the peak energy of the synchrotron. Statistical errors of data points are indicated. The solid curve shows the yield expected for K^+ meson photoproduction from hydrogen. The arrow indicates the synchrotron operating energy for the comparison of the various yields.

Using carbon as a target, the yield was measured as a function of the synchrotron energy. The results are shown in Fig. 1. The solid curve shows the yield expected for hydrogen. The shape of the latter curve is calculated using the known characteristics of the magnet and bremsstrahlung spectrum, while the scale of the ordinate is arbitrarily normalized to make a suitable comparison to the yield from carbon. The first rise in the curve for hydrogen is due to the contribution from $K^+\Lambda$ production, while the second is due to $K^+\Sigma^0$ production. It is seen from the experimental data for carbon that due to the Fermi motion in the nucleus the production extends to an energy about 120 MeV below the kinematic threshold for free protons. Because of this motion, photons with an energy of 1150 MeV will produce K^+ mesons from the reactions $\gamma+p\rightarrow K^++\Sigma^0$ and $\gamma+n\rightarrow K^++\Sigma^-$ in addition to those from the reaction $\gamma+p\rightarrow K^++\Lambda$. Previous measurements[1,2] have shown that the $K^+\Sigma^0$ yield is about 30% of that for $K^+\Lambda$ and that the ratio of yields for $K^+\Sigma^-$ and $K^+\Sigma^0$ is of the order of unity. The production from neutrons introduces a Z dependence on the yield per proton due to the change of Z/A with atomic number. Using the above values of relative yield, we estimate this effect to be less than 5% for the range of elements used in this experiment. No attempt was made to correct the data for this effect.

The measured yields per proton per monitor unit of internsity are given in Table I. At 1150 MeV, this monitor unit is equal to 4.7×10^{10} equivalent quanta. The

TABLE I. K^+ meson yield per proton per monitor unit for the various elements used. One monitor unit is 4.7×10^{10} equivalent quanta at 1150 MeV.

Element	(Yield/proton)/monitor unit
Be	$(10.7\ \pm0.54)\times10^{-2}$
C	$(9.03\pm0.33)\times10^{-2}$
Al	$(8.19\pm0.35)\times10^{-2}$
Cu	$(8.53\pm0.38)\times10^{-2}$
Ag	$(6.34\pm0.33)\times10^{-2}$
W	$(6.86\pm0.55)\times10^{-2}$
Pb	$(7.14\pm0.37)\times10^{-2}$

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[1] R. L. Anderson, E. Gabathuler, D. Jones, B. D. McDaniel, and A. J. Sadoff, Phys. Rev. Letters 9, 131 (1962).

[2] R. L. Anderson, F. Turkot, and W. M. Woodward, Phys. Rev. 123, 1003 (1961).

cross section for a hydrogen target at this kinematical point is 1.57×10^{-31} cm^2/sr.[1] Under the conditions of this experiment, this cross section would provide a yield for hydrogen of 0.126 K^+ mesons per monitor unit.

A rough estimate of the mean free path in nuclear matter can be made by assuming that the production of K^+ mesons depends only on the number of protons in the nucleus, and that the absorption depends on the distance traveled in leaving the nucleus. Accordingly, a plot of the logarithm of the yield per proton versus $A^{1/3}$, where A is the atomic weight, would yield a straight line whose slope is inversely proportional to the mean free path. Figure 2 shows such a plot of the experimental data points with their statistical errors. The line which is drawn is a least-squares fit for the function $\exp[-(r/\lambda)A^{1/3}]$. The resulting slope is 0.095. This yields a value for the mean free path λ equal to about 10 F, assuming a value of 1 F for the nuclear radius r. However, this is only an order of magnitude estimate since a complete analysis would require consideration of effects of nuclear motion, Coulomb scattering, and geometrical factors. The fact that some of the points

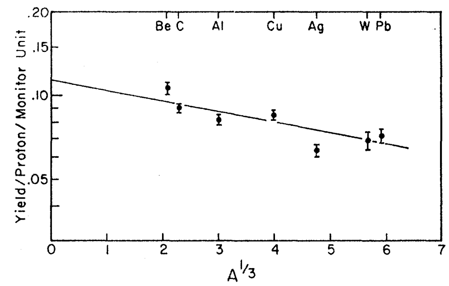

FIG. 2. K^+ meson yield per proton per monitor unit plotted on a logarithmic scale as a function of $A^{1/3}$, where A is the atomic weight. Statistical errors are indicated. The straight line is a least-squares fit for the function $\exp[-(r/\lambda)A^{1/3}]$.

deviate fron the straight line by an amount for outside the statistical error indicates that such systematic effects are present.

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Three-Pion Decays of Unstable Particles*

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The properties of particles of arbitrary spin and parity that decay into three pseudoscalar mesons are surveyed, with primary attention to 3π decays, in order to find efficient means of detecting such particles. Among the topics considered are the general forms of amplitudes subject to invariance and symmetry requirements, the regions of vanishing density in the Dalitz plot, branching ratios, angular correlations among vectors normal to and lying in the production and decay planes, and special decay modes through two-particle resonances. The angular correlations are discussed in detail for processes independent of the intrinsic spin of the production particles, as is appropriate in coherent nuclear processes, and a framework of analysis is provided for more complex problems. A complete characterization of $K\rightarrow 3\pi$ decays is given in terms of ΔI rules and final-state isospin. The suggestion is made that a second pion, with the same quantum numbers as the ordinary pion, should be found at an energy less than 2 BeV. This prediction is based on the possibility that the pion is primarily a nucleon-antinucleon bound S state and that the force of binding is therefore so strong that it should produce more than one bound S state.

I. INTRODUCTION

THE multiplicity of recently discovered baryon resonances raises the possibility, perhaps even the confident expectation, of a similar richness and regularity in the family of meson resonances. Some of these mesons will decay into two particles; others will prefer a three-particle mode of decay, thus complicating the experimental analysis.

A number of interesting unstable mesons are likely to decay into three pions. We undertake here a phenomenological description of such processes in order to find efficient methods for identifying the quantum numbers of the particles from experimental data. The 3π states have, of course, the symmetry imposed by Bose statistics. This symmetry, properly exploited, supplies information in addition to that deduced from conservation laws and, according to one's viewpoint, makes the phenomenological procedure more simple or more complex than it is for other three-particle decays. Much of the discussion is, however, directly applicable to general

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