of zero-mass kaons on neutrons:

$$1-\frac{1}{z^2}=\frac{4(M_n+M_\Sigma)^2}{2g_{K\Sigma N}{}^2F_{K\Sigma N}{}^2(0)}\frac{1}{2\pi}\int_{(M_\Lambda+m_\pi)^2}^{\infty}\frac{ds}{s-M_n{}^2}$$

$$\times[\sigma_{K^+n}{}^0(0)-\sigma_{K^-n}{}^0(0)]. \tag{6}$$

$\sigma_{K^\pm n}{}^0(s)$ is the total cross section for the scattering of zero-mass kaons on neutrons at total c.m. energy $\sqrt{s}$, $g_{K\Sigma n}$ is the strong $K\Sigma N$ coupling constant, $F_{K\Sigma N}{}^2(0)$ is an invariant form factor normalized so that $F_{K\Sigma N}(M_K{}^2)=1$, and we denote by z the renormalized coupling constant $G_A{}^{\Sigma N}/G_A{}^0$.

We assume now that the off-mass-shell corrections are small,[1,2] and that we can use the method of Ferrari and Selleri[6] to cancel the factor $F_{K\Sigma N}{}^2(0)$. Since the cross sections of kaons on neutrons are not as well known as those for kaons and pions on protons, we follow the method proposed in Ref. 2. We approximate the integral in (6) by only taking into account the contribution of the known resonances,[7] for which we use the zero-width limit approximation.[8]

Our numerical results are not unique, as there are some ambiguities concerning the value of $g_{K\Sigma N}$. If, as in Ref. 3, we use values of $g_{K\Sigma N}$ calculated from various D/F ratios, we obtain, for $D/F\sim 3$,[9] the result $z=0.97$; for $D/F\sim 1.7$,[10] the result is $z=0.96$. If we take the values listed by Dashen et al.,[11] we get for exact SU(3) the result $z=0.92$, and for broken SU(3), $z=0.797$. The results are quite close, and, as was noted in Ref. 3, the renormalization is in the opposite direction to that in Refs. 1 and 2.

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PHOTOPRODUCTION CROSS SECTIONS FOR π^+ AND K^+ MESONS AT 3.4 TO 4.0 GeV AND THEIR COMPARISON WITH SU(3)*†

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We report here measurements of the differential cross sections for the reactions

$$\gamma+p\rightarrow\pi^++n, \tag{1}$$

$$\gamma+p\rightarrow K^++\Lambda^0, \tag{2}$$

$$\gamma+p\rightarrow K^++\Sigma^0, \tag{3}$$

for incident laboratory photon energies between 3.4 and 4.0 GeV and for meson center-of-mass angles from about 25° to 45°. Our results agree with the cross-section inequalities predicted from unbroken SU(3). The measured behavior of $d\sigma/dt$ as a function of t shows similarities to that observed in studies of meson-nucleon scattering.

The experiment used the bremsstrahlung beam from the Cambridge Electron Accelerator. The mesons produced in the above reactions were detected by a magnetic spectrometer which has been described elsewhere.[1] For each event, the particle's trajectory through the spectrometer was determined by arrays of scintillation counters. From this trajectory information, the meson's production angle and momentum

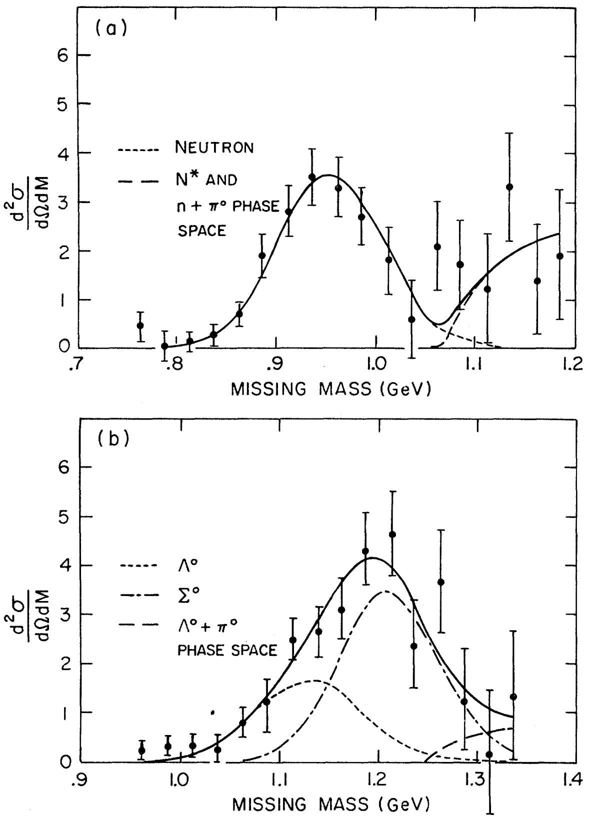

FIG. 1. Missing-mass spectra for (a) π^+ mesons, (b) K^+ mesons. In each case the solid line is a three-parameter, least-squares fit to the data using curves, calculated from our resolution, representing the missing masses which can be produced. The units on $d^2\sigma/d\Omega dM$ are arbitrary.

were calculated. The π^+ and K^+ mesons were identified by a differential Cherenkov counter similar to but larger in size than the one described by Hill et al.[2] The Cherenkov light is focused onto light pipes that form two concentric apertures. When the counter is tuned for K's, their light falls entirely in the center aperture, whereas the light from π's, μ's, and positrons falls almost entirely in the outer aperture. The light-pulse amplitudes were measured and recorded for each event. A three-dimensional plot of the number of events versus the pulse heights in the two apertures gives a clear separation of K^+'s from other particles. By another method, the contamination of μ's and positrons in the π^+ data was found to be negligible.

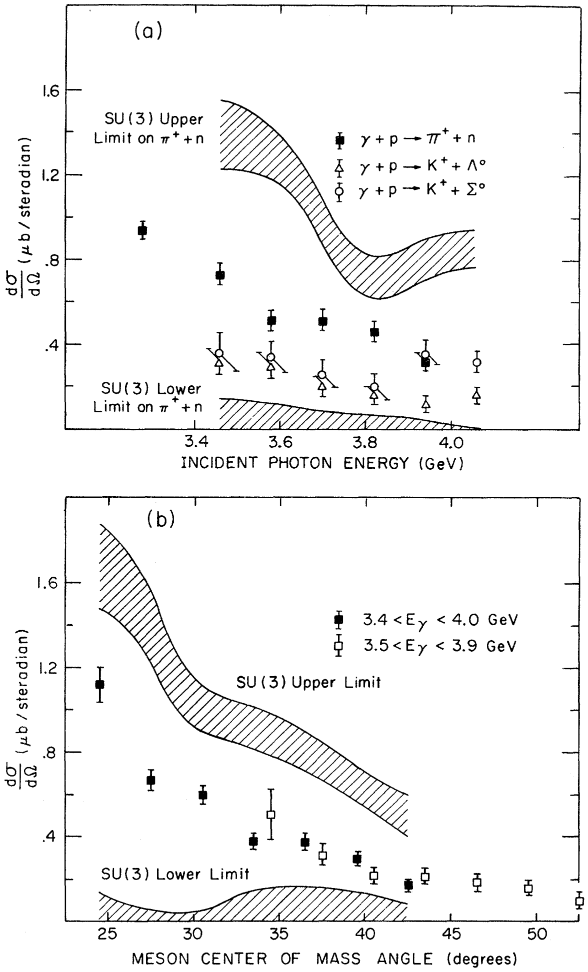

FIG. 2. (a) The differential cross sections for $\gamma + p \to \pi^+ + n$, $K^+ + \Lambda^0$, and $K^+ + \Sigma^0$ as a function of the incident photon energy. The cross sections are averaged over meson center-of-mass angles from 25° to 45°. (b) The differential cross section for $\gamma + p \to \pi^+ + n$ as a function of the pion on the $\pi^+ n$ cross section are shown. The uncertainty in the limits, which are obtained from the measured $K^+\Lambda^0$ and $K^+\Sigma^0$ cross sections, is represented by their width and contains the correlated error[3] in the $K^+\Lambda^0$ and $K^+\Sigma^0$ cross sections. The systematic uncertainty in the cross sections (absolute scale) is estimated to be ±12%.

Because a bremsstrahlung beam contains a continuous spectrum of photon energies, we subtracted the meson yields measured at two accelerator electron energies usually 3% apart. The difference gives, in effect, the yield from relatively monochromatic ($\Delta E/E = \pm 1.5\%$) photons. Knowing the effective photon energy and the meson momentum, angle, and mass, we can plot the subtracted yield as a function of the effective mass, M, of the other particle produced with the meson. Such a missing-mass spectrum for π^+ mesons is shown in Fig. 1(a).

This spectrum shows a peak corresponding to the neutron and the integral under the peak gives the differential cross section for π^+n production. The position of the neutron peak serves as an absolute energy calibration of the apparatus and the width of the peak serves as a check on the calculated resolution of the apparatus. The integral under the neutron peak is obtained by making a three-parameter fit (n, N_{1238}^*, and $n\pi^0$ phase space) to the missing-mass spectrum utilizing our theoretical (and experimentally verified) resolution function and energy calibration. Such a fit is shown in Fig. 1(a). The differential cross section obtained from many such subtractions is shown in Fig. 2.

When measuring K^+ cross sections, a spectrometer with excellent resolution would give a missing-mass spectrum with separate peaks located at the Λ^0 and Σ^0 masses. Our resolution was not sufficient to separate these two; indeed, we obtained a single peak whose width, however, is wider than our known resolution and whose centroid falls between the Λ^0 and Σ^0 masses. As with the π's, we obtained the individual $K^+\Lambda^0$ and $K^+\Sigma^0$ cross sections by making a three-parameter fit (Λ^0, Σ^0, and $\Lambda^0\pi^0$ phase space) to the missing-mass spectra. A typical missing-mass spectrum is shown in Fig. 1(b). The $K^+\Lambda^0$ and $K^+\Sigma^0$ differential cross sections are shown in Figs. 2(a), 3(b), and 3(c). The $K^+\Lambda^0$ and $K^+\Sigma^0$ cross sections obtained in this manner are correlated.[3]

Unbroken SU(3) symmetry predicts the following relationship between the amplitudes for Reactions (1), (2), and (3)[4]:

$$\sqrt{2}(\gamma p\,|\pi^+n) = -\sqrt{3}(\gamma p\,|K^+\Lambda^0) - (\gamma p\,|K^+\Sigma^0). \tag{4}$$

Relation (4) together with our measured $K^+\Lambda^0$ and $K^+\Sigma^0$ cross sections (corrected for phase space) can be used to predict upper and lower limits on the π^+n cross section. These limits are shown in Fig. 2 where relation (4) is used for amplitudes measured at the same center-of-mass total energy and production angle.[5] The measured π^+n cross section agrees very well with these limits.

Other tests of SU(3) cross-section relations have been made[6] at the same Q as well as[7] at the same s but at energies lower than the ones in this experiment. These comparisons show some agreement and some disagreement with

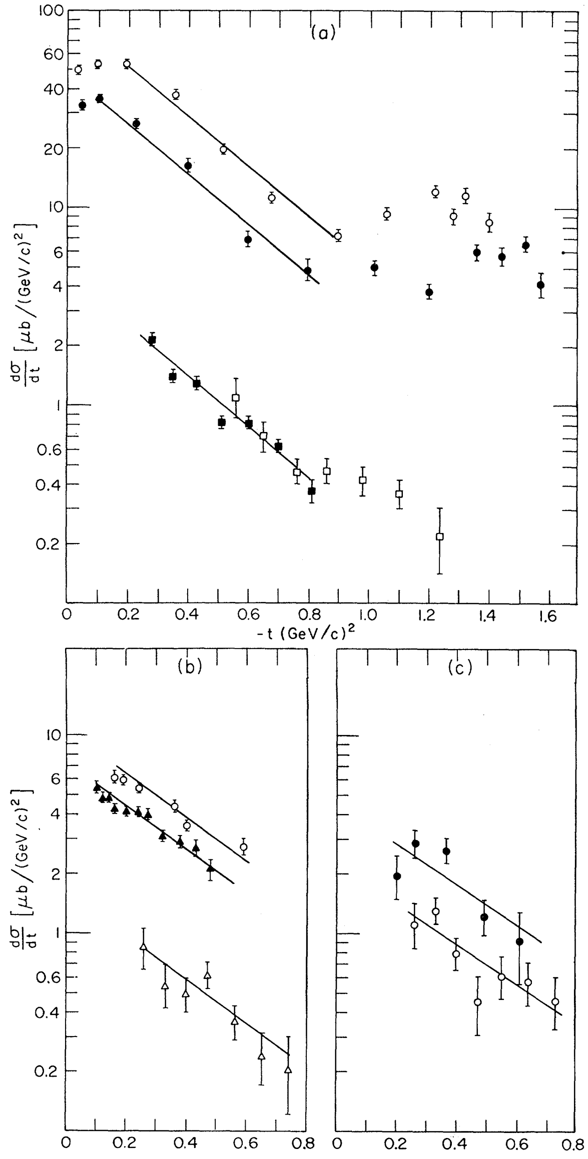

FIG. 3. $d\sigma/dt$ as a function of $-t$. (a) $\gamma+p\rightarrow\pi^++n$. □, $3.4<E_\gamma<4.0$ GeV, and ■, $3.52<E_\gamma<3.88$ GeV, this experiment; 0, $E_\gamma=1.10$ GeV, and ●, $E_\gamma=1.20$ GeV, J. R. Kilner, thesis, California Institute of Technology, 1965 (unpublished). From a previous experiment,[1] another point is located at $d\sigma/dt=(4.0\pm0.6)\times10^{-3}$ μb/(GeV/c)^2 and $-t=3.1$ (GeV/c)^2 for $E_\gamma=3.75$. (b) $\gamma+p\rightarrow K^++\Lambda^0$. △, $3.4<E_\gamma<4.1$ GeV, this experiment; ▲, $E_\gamma=1.2$ GeV, C. W. Peck, Phys. Rev. 135, B830 (1965); ○, $E_\gamma=1.05$ GeV, B. D. Anderson et al., Phys. Rev. Letters 9, 131 (1962). (c) $\gamma+p\rightarrow K^++\Sigma^0$. ○, $3.4<E_\gamma<4.1$ GeV, this experiment; ●, $E_\gamma=1.16$ GeV, Anderson et al., loc. cit. The slopes of the lines drawn through the data points are determined from our data and are given in the text. The systematic uncertainty in the cross sections measured in this experiment (absolute scale) is estimated to be ±12%.

SU(3) predictions. Comparison of the data at the same s instead of Q (or at the same Q instead of s) does not completely resolve the disagreement.

In Fig. 3 we have plotted our results for $d\sigma/dt$ along with the results of other experiments performed at lower energies. In the region of momentum transfers $-t$ from 0.2 to 0.8 (GeV/c)^2, the photoproduction differential cross sections can be expressed in the form $d\sigma/dt = Ae^{Bt}$, with B nearly independent of incident photon energy. For the π^+n, $K^+\Lambda^0$, and $K^+\Sigma^0$ cross sections measured in this experiment, B was found to be 3.0 ± 0.3, 2.7 ± 0.7, and 2.5 ± 0.6 (GeV/c)$^{-2}$, respectively. A similar behavior, but with larger values of B, is found in several meson-nucleon reactions.[8-13] For momentum transfers greater than $-t = 0.8$ (GeV/c)^2, the photo-π^+ cross sections show a secondary "peak" or break in slope which becomes less pronounced with increasing photon energy. This behavior is similar to that observed in meson-nucleon scattering with the break again at $-t \simeq 0.8$ (GeV/c)^2.

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$$\sqrt{2}\,(\gamma p|\pi^+ n)|_{\text{res}} = -(\gamma p|K^+\Sigma^0)|_{\text{res}}.$$

Our data, showing only small resonant effects, if any, is consistent in amplitude and phase with this relation.

[5] Using t as a parameter rather than $\cos\theta_{\text{c.m.}}$ changes the comparison insignificantly; for our data $\cos\theta_{\text{c.m.}}$ for π^+ and K^+ differs by less than 2° at the same t. Using some of our preliminary results on π^+ photoproduction at $E_\gamma = 2.65$ GeV, we can compare the cross sections at the same Q value and center-of-mass angle; our results are still consistent with Eq. (4).

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