[18]Philippe H. Eberhard and Werner O. Koellner, Lawrence Radiation Laboratory Reports No. UCRL-20159, 1970 and No. UCRL-20160, 1971 (unpublished). The accuracy of the coding of the amplitudes and the relevant kinematics into the fitting program was checked in a variety of ways. The isobar-model amplitudes were calculated for a set of standard events and compared with the amplitudes calculated by other programs independently coded at Lawrence Berkeley Laboratory, Berkeley; SLAC, Stanford; and CEN, Saclay. In addition, Monte Carlo events were used to generate a variety of mass and angular distributions for each wave of Table III, and these were checked to be physically consistent with the quantum numbers. The polarization calculations were checked explicitly by hand for several events.

[19]Particle Data Group, Rev. Mod. Phys. 43, S1 (1971).

[20]The following masses were used to calculate the mixing angle: $m_N = 1515 \pm 15$, $m_\Sigma = 1670 \pm 10$, $m_\Lambda = 1690 \pm 10$, $m_\Xi = 1832 \pm 37$, and $m_\Lambda = 1518 \pm 2$ MeV.

[21]R. Barloutaud (private communication).

[22]The analysis of Ref. 5 uses an expression for this ratio which yields 3.3. We believe that the expression incorrectly normalizes the Breit-Wigner weight used to calculate an average Σ(1385) momentum over the Dalitz plot. The normalization of this weight should be independent of the incident momentum. If this change is made, their expression yields a result consistent with ours.

[23]See, for example, R. H. Dalitz, in *Symmetries and Quark Models*, edited by R. Chand (Gordon and Breach, New York, 1970).

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K^+p and K^+d Total Cross Sections in the Momentum Range 0.57–1.16 GeV/c*

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K^+p and K^+d total cross sections were measured in the momentum range 0.57–1.16 GeV/c using a secondary, separated kaon beam of the Lawrence Berkeley Laboratory Bevatron and conventional transmission-counter techniques. No evidence was found for structure in the cross section of either reaction as previously indicated near 0.7 GeV/c.

Previous experimental results[1,2] have shown structure in both K^+p and K^+d total cross sections near 0.7-GeV/c incident momentum. Since this structure was observed near the upper limit of the momentum range which could be covered in our previous experiment,[1] it could not be investigated in great detail. The present experiment was designed to cover the momentum interval from 0.57 to 1.16 GeV/c so as to permit a systematic study of the region near 0.7 GeV/c as well as to provide for further detailed evidence on any other structure in this region.

The experiment was performed using a standard transmission-counter technique employing much of the apparatus of the previous experiment.[1] Although the beam was, as in the previous experiment, a separated kaon beam derived from a target in an external proton beam of the LBL Bevatron, the present beam transport system was designed to provide kaons of higher maximum momentum. Accordingly, principal differences from the previous experiment involve changes in the beam transport system and in the configuration of beam-defining counters appropriate for the higher momenta employed.

The beam could be tuned to momenta up to 1.5 GeV/c and consisted typically of 10^3 K's/pulse, along with 10^4 protons, 10^4 pions and muons, and 10^3 positrons. Figure 1 shows the bending and focusing magnets which comprise the beam transport system together with the beam-defining counters. Selection of kaons was accomplished with the use of three Čerenkov counters: one made of quartz, C_0, one of Plexiglas, C_1, and one threshold counter, C_2, employing Freon gas at variable pressure. Additional selection was based on time-of-flight criteria using the two pairs of beam counters, S_1S_3 and S_2S_4. This system gave a rejection ratio $>2\times10^4$ for particles other than kaons.

The target assembly consisted of three identical

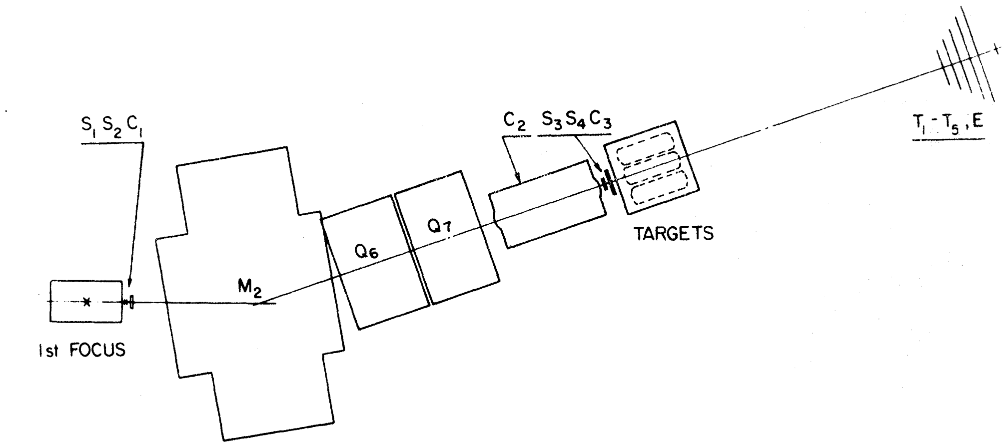

FIG. 1. Experimental configuration of counters and magnets using a secondary kaon beam from the Lawrence Berkeley Laboratory Bevatron. $S_1 \cdots S_4$ and $C_1 \cdots C_3$ are beam-defining scintillation and Čerenkov counters, respectively; $T_1 \cdots T_5$ are transmission counters, and E is an efficiency, scintillation counter. Bending magnet M_2 and quadrupole magnets Q_6 and Q_7 are the final elements of the beam transport system.

flasks, each 18 in. in length; one with liquid hydrogen, one with liquid deuterium, and one empty, any one of which could be remotely positioned in the kaon beam as needed. Provision was made for continuous monitoring of the vapor pressure of the hydrogen and deuterium during the experiment, and the deuterium purity was measured at each refilling.

The transmission-counter assembly containing counters $T_1 \cdots T_5$ shown in Fig. 1 was moved during the experiment so that the minimum-detectable scattering angle corresponded to a fixed, minimum-

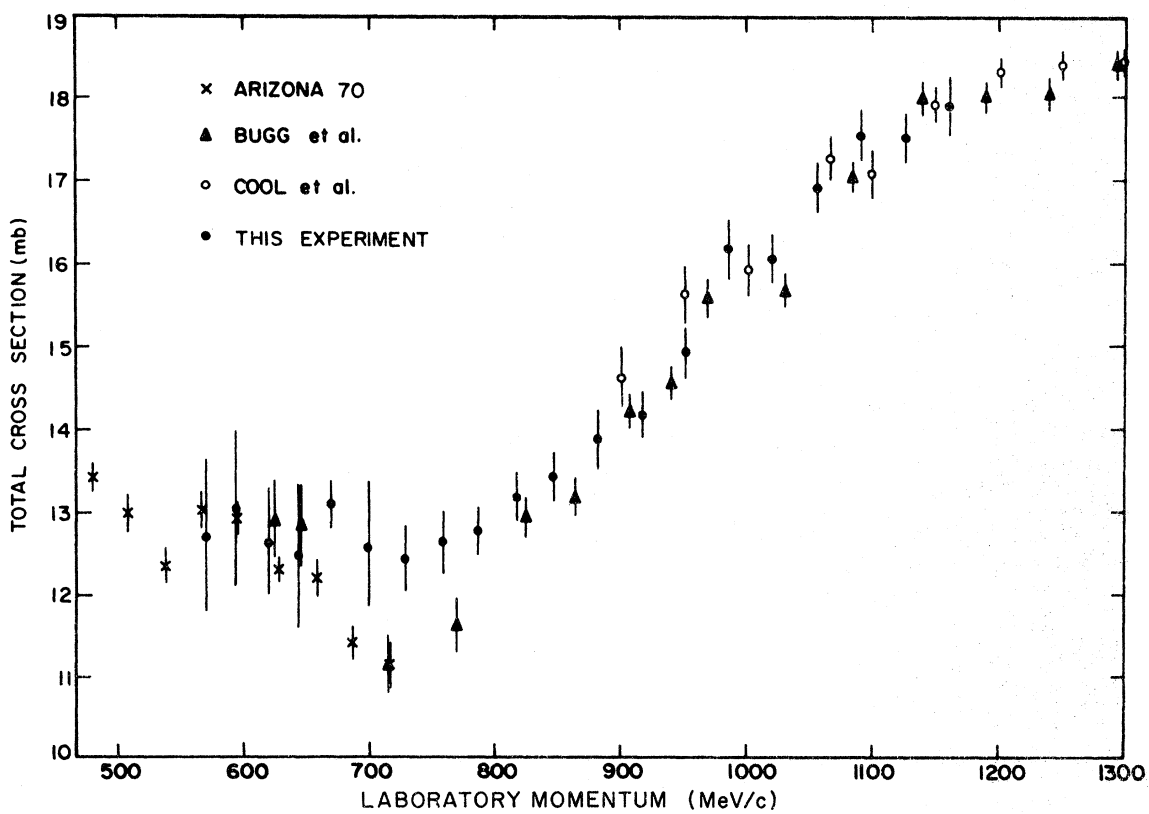

FIG. 2. K^+p total cross sections together with the results of other experiments. The symbols correspond to the following references: ▲, Ref. 2; ○, Ref. 3; ×, Ref. 1; ●, present work.

TABLE I. $K^{+}p$ and $K^{+}d$ total cross sections.

Momentum (MeV/c)	$\sigma(K^{+}p)$ (mb)	Error (mb)	$\sigma(K^{+}d)$ (mb)	Error (mb)
569	12.70	0.90	25.4	0.90
593	13.05	0.95	26.3	0.90
618	12.65	0.65	26.3	0.50
643	12.50	0.85	26.4	0.70
668	13.10	0.30	26.5	0.40
698	12.60	0.75	27.3	0.60
727	12.45	0.40	27.9	0.60
757	12.65	0.40	28.1	0.35
786	12.80	0.30	28.3	0.45
817	13.20	0.30	28.9	0.35
846	13.45	0.30	29.3	0.50
881	13.90	0.35	30.3	0.30
916	14.20	0.30	30.75	0.40
951	14.95	0.30	32.1	0.30
985	16.20	0.35	32.9	0.40
1020	16.10	0.30	34.5	0.40
1055	16.95	0.30	34.95	0.40
1090	17.60	0.30	36.35	0.40
1125	17.55	0.30	36.8	0.40
1160	17.95	0.35	37.7	0.40

detectable four-momentum transfer, $\sqrt{-t}$, such that $t = -2.95\times10^{-3}$ (GeV/c)^2. In order to eliminate systematic errors depending upon the order in which the transmission counters of increasing size were arranged along the beam, each datum point was studied both with the counters $T_1 \cdots T_5$ arranged as shown in Fig. 1, and with the order reversed.

Uncorrected total cross sections were obtained by linear extrapolation to zero scattering angle of the cross sections obtained from individual transmission counters at each momentum point. In the subsequent analysis, corrections and uncertainties due to several factors were included (see Ref. 3) in order to arrive at the values for $K^{+}p$ and $K^{+}d$ total cross sections and the corresponding estimates of the errors shown in Table I, Fig. 2, and Fig. 3.

In addition to statistical errors, the following corrections and uncertainties contributed significantly to the computation of the cross sections and errors listed:

(a) correction for direct Coulomb and Coulomb-nuclear interference effects, typically uncertain by less than ±0.1 mb, giving an uncertainty in the

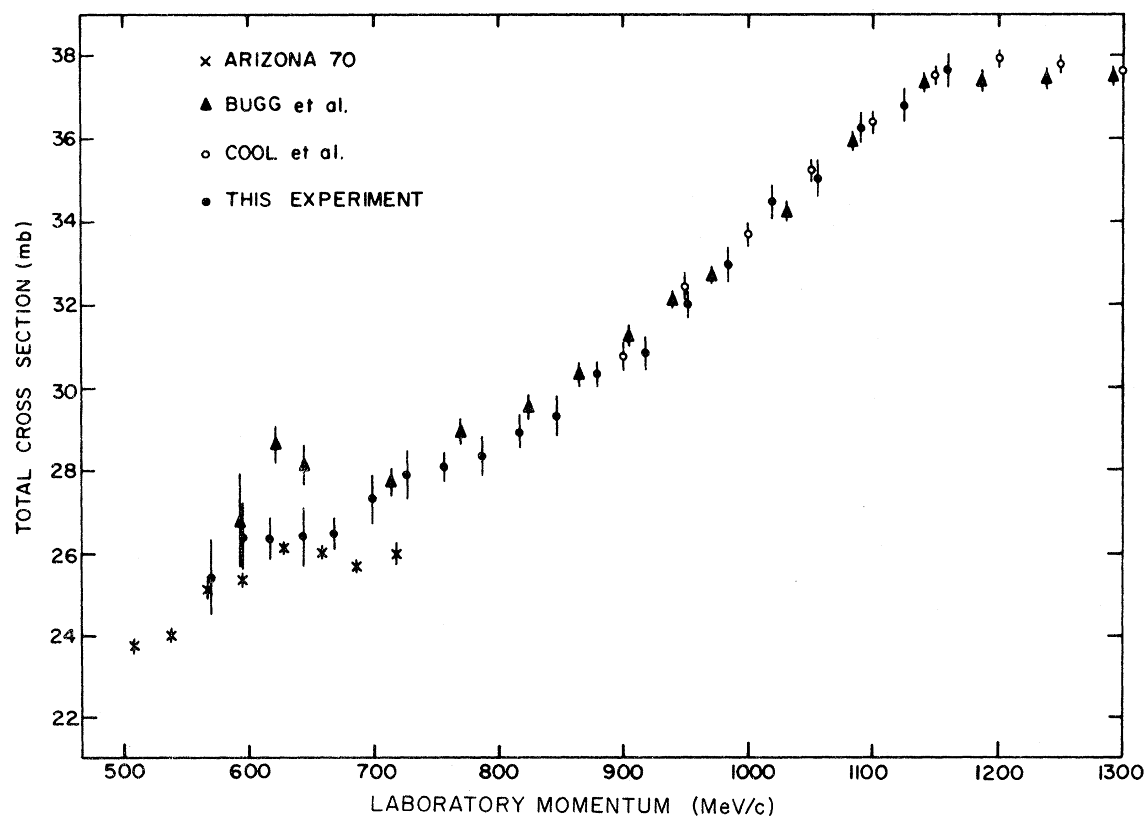

FIG. 3. $K^{+}d$ total cross sections together with the results of the other experiments. The symbols correspond to the following references: ▲, Ref. 2; ○, Ref. 3; ×, Ref. 1; ●, present work.

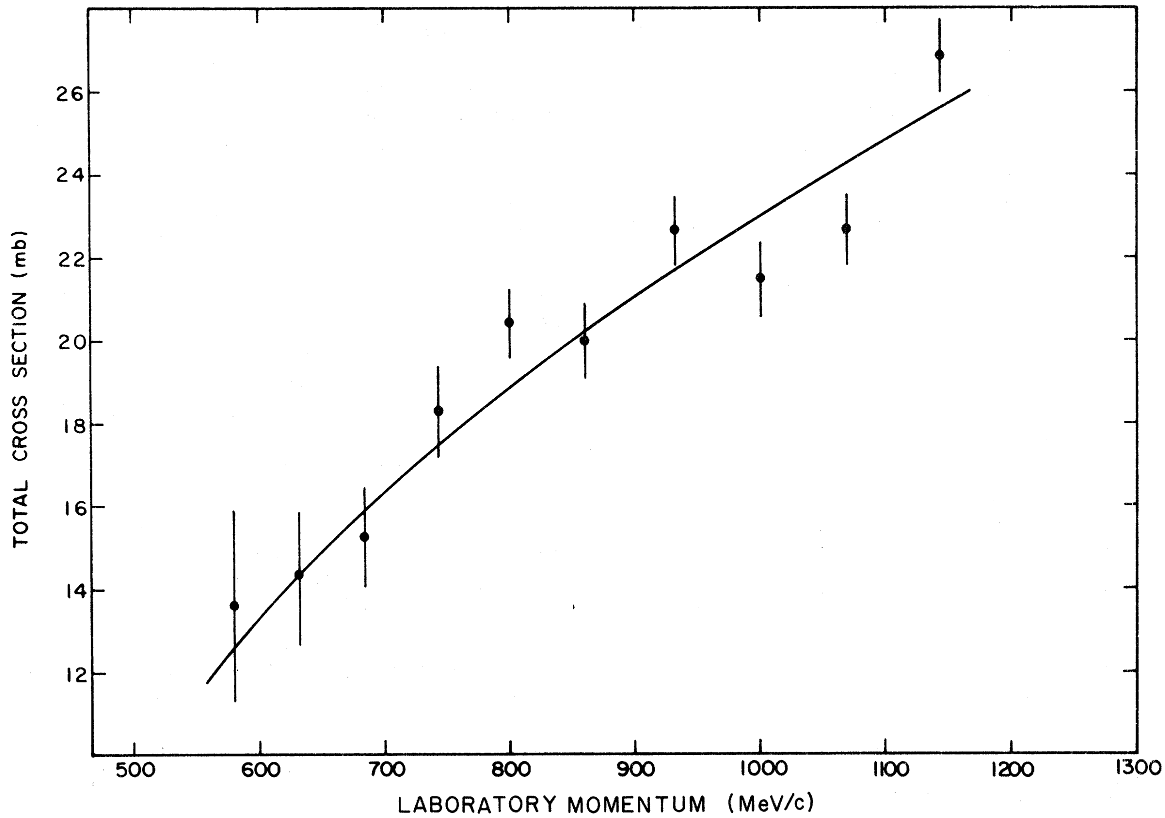

FIG. 4. K^+-nucleon, $I = 0$ (σ_0) total cross sections.

total cross section of less than ±0.7%,

(b) correction for loss of kaons by decay processes, with a corresponding uncertainty of less than ±0.1 mb in the cross section,

(c) uncertainty in target density and effective target length, typically leading to uncertainties of less than ±0.3% in the cross section,

(d) variations from one Bevatron pulse to the next in guiding the external proton beam onto the production target for the secondary kaon beam giving an uncertainty in total cross section less than 1.5%.

Further analysis of the data was performed in order to derive the cross sections for the individual isotopic spin state $I = 0$. Preliminary to this, the K^+d data were subjected to an unfolding analysis wherein the effects of the Fermi momentum distribution of the nucleons in deuterium, determined from the Moravcsik deuteron wave function, were removed.[4] The $I = 0$ isospin state was extracted from the unfolded K^+d cross sections by the use of the usual formulas including the use of the Glauber screening corrections as modified by Wilkin.[5] The values for the $I = 0$ total cross sections are shown in Fig. 4 where the data from adjacent momentum intervals have been averaged. The most notable feature of the $I = 0$ K^+N cross section is the lack of significant structure. We see no evidence of the previously reported $Z_0^*(1780)$.[4,6,7]

The results shown in Figs. 2 and 3 indicate that the values for the total cross section of the previous experiment for the three highest momenta were in error. In order to reach these points, in the previous experiment,[1] the kaon production target was moved in the magnetic field of the bending magnet in which it was located, thus altering slightly the optical properties of the beam. It is felt that this effect could account for the observed discrepancy with the previous work.

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Study of Electromagnetic Processes at 1 GeV/c in a Hydrogen Bubble Chamber and Production-Rate Limits for New Low-Mass Particles

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The Bethe-Heitler theory of pair production by photons and of bremsstrahlung by electrons is compared with observations of these processes in a liquid-hydrogen bubble chamber. Agreement between theory and experiment is found within the statistical limits of the experiment which are typically $\sim\frac{1}{2}\%$ of the total cross sections studied. The form of the experiment also allows limits to be set on the production of new particles of mass less than 100 MeV in high-energy hadronic collisions.

I. INTRODUCTION

The first relativistic calculations of the cross sections for the bremsstrahlung (BS) of electrons and the electron-positron pair production (PP) by photons in the field of an atomic nucleus were performed[1] by Bethe and Heitler (BH) in 1934. The effects of screening by the atomic electrons are accounted for in terms of the form factor for the electronic charge distribution. The BH theory assumes the Born approximation and is limited to coherent processes where the atom remains in its ground state. It was extended in 1939 by Wheeler and Lamb[2] (WL) to the complementary incoherent processes where the atom is excited or ionized. This work was also in the Born approximation and allowed for only the lowest-order quantum electrodynamic (QED) processes. The results of BH and WL are summarized in the Appendix.

Since 1939 much theoretical work has been carried out, both as regards improvements in the Born approximation and in allowing for the effects of radiative and other corrections from higher-order QED diagrams. For recent reviews of this work see Motz *et al.*[3] and other references contained therein.

Good agreement between theory and experiment has been obtained; a recent review of the experimental situation has been given by Roy and Reed.[4] Generally the formulas in the Appendix are satisfied to about 1% except where the three-momentum transfer (q) to the target atom is large, i.e., $q \geq \frac{1}{2}$ MeV/c. For these high-q processes the corrections from higher-order QED diagrams become important, and most of the recent experimental investigations of BS and PP have been directed to this region.

This paper describes a bubble chamber study of BS and PP in liquid hydrogen in the low-q region, this field having been somewhat neglected experimentally, especially for the case of hydrogen where incoherent processes are as important as coherent ones. The statistical accuracy of the data obtained allows comparison with the BH and WL formulas to an accuracy of a few percent, representing a significant improvement on any previous published study in hydrogen.

The experimental arrangement is described in Sec. II, and Secs. III and IV describe the analysis and results of the BS and PP studies. Finally,