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ON THE PHASE SHIFT AND ISOTOPIC SPIN ANALYSIS OF THE SCATTERING OF K⁺-MESONS BY NUCLEONS*+

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ABSTRACT: It is suggested that a phenomenological analysis using the impulse approximation of the processes occurring in the scattering of K^+-mesons by deuterons may be used to get the phase-shifts for the $T = 0$ isotopic spin state. Typical curves are given for the elastic, elastic plus inelastic and charge exchange scattering differential cross sections of 100 Mev K^+-mesons by deuterons on the assumption that only S waves contribute and for various ratios of the $T = 1$ and $T = 0$ isotopic spin states phase-shifts.

INTRODUCTION

All ixisting experimental results[1] which give information on K^+

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meson-nucleon scattering are consistent with an isotropic and energy-independent differential cross-section at energies between 40 and 200 Mev. These results come both from pure hydrogen bubble chamber and from nuclear emulsions experiments.

The pure K^+ meson-proton processes, as observed in hydrogen bubble chambers, can only give information on the amplitude for the scattering in the T = 1 isotopic spin state. At the energy of 100 Mev a negative S-wave phase shift $\sin \delta_1 = -0.37$ (with all the other phase shifts equal to zero) fits well the observed repulsive potential at low energies and the isotropy in the scattering, the total cross section being of $4\pi \sin^2 \delta_1/k^2 = 16$ milibarns.

The direct and charge exchange scattering of K^+ mesons by neutrons observed on nuclear emulsion material depend on the amplitude a_o for scattering in the T = 0 state, as well as on the amplitude a_1 for scattering in the T = 1 isotopic spin state. Assuming charge independence, in a material with a number of protons equal to f times the number of neutrons the rate of charge exchange to total (non-coulombian) scattering is $R = (a_1 - a_o)^2/[2(a_1^2 + a_o^2) + 4fa_1^2]$. If there is no interaction in the state T = 0, that is, if $a_o = 0$, we get R = 1/6 for F = 1 and R = 1/7 for f = 5/4. As the experimentally observed ratio is consistent with these values of R, it has been suggested[2] that at low energies only the T = 1 isotopic spin state is responsible for the scattering.

These processes observed in nuclear emulsion give the only available information on K^+ meson-neutron processes and on the contribution of the T = 0 state to the K^+ meson - nucleon interactions. However the complexity of the emulsion material makes the analysis of the experimental results rather difficult. Deuterium bubble chambers and diffusion cloud chambers now in use provide a more convenient sample material containing neutrons.

The impulse approximation[3] has been used with success by Fernbach, Green and Watson[4] and by Rockmore[5] to express the differential cross sections for scattering of pions by deuterons in terms of the amplitudes of elementary processes of pions with protons and neutrons. In Rockmore's formulae the cross-sections for elastic, elastic plus inelastic and charge-exchange scatterings of the π-mesons by deuterons are expressed in terms of the S and P waves phase-shifts for scattering in the charge independent $T = 3/2$ and $T = 1/2$ states of a pion-nucleon system. Comparison of Rockmore results with experiment[6] has shown the reliability of the application of the impulse approximation to this problem.

We now then suggest that a calculation in impulse approximation similar to that of Rockmore, and experiments on the scattering of a K^+ meson beam by the deuterium of either a bubble or a diffusion chamber be used together to get information on the phase shifts for the $T = 0$ isotopic spin state of the K^+ meson-nucleon system.

In this paper we present the formulae, which are analogous to those of Rockmore, giving the differential cross-sections for elastic, elastic plus inelastic and charge exchange scattering of K^+ mesons by deuterons. In particular we present the curves for these differential cross sections for K^+ mesons of 100 Mev energy in the cases of $T = 1$, S wave only contributing to the scattering and of $T = 0$, S wave adding a small contribution to the above (two different signs in this phase-shift are considered).

We have suggested explicitly the work with the positive K-meson for the obvious reason of the greater simplicity (as compared with the negative K-meson) of its interaction with nucleons. The absence of adsorption processes greatly simplifies the phenomenological analysis and in this respect, the K^+ meson interaction is even simpler than that of π-mesons.

The multiple scattering and potential corrections to the impulse approximation calculation have been shown by Rockmore[5] in the pion case to give contributions of opposite signs to the cross sections, so that even if they cannot separately be neglected, their added effect seems not to alter appreciably the values calculated in the pure impulse approximation. Since the estimation of such corrections would necessarily be rather unconvincing, and since we have no reason to believe that the situation is much worse in K-meson case, we have not tried to evaluate them.

FORMULAE AND CURVES

Our notation is the same as that of Fernbach[4] and Rockmore[5]. Phase shifts are indicated in a manner similar to that introduced by Fermi, the first index being either 1 or 0 according to whether the isotopic spin state is T = 1 or T = 0. The second index is omitted for S-waves and for P-waves is either 3 or 1 according to whether the total angular momentum is 3/2 or 1/2.

We define

$$J_o = \int_{E_f} d_3\, q\delta(E_f - E_o)$$

the kinematical factors being those of a collision of a K-meson with a nucleon, and

$$J_o' = \int_{E_f'} d_3\, q\delta(E_f' - E_o)$$

where the kinematics is that of a collision of a K-meson with a deuteron.

The curves are traced for 100 Mev energy K-meson and for the following set of phase-shifts. Curves labelled by A correspond to $\sin\delta_1 = -0.37$, all he other phase-shifts set equal to zero (only T = 1, S-waves contributing to the scattering). They correspond to a ratio R of the charge exchange to the total number of processes equal to 1/6 (for f = 1).

Curves labelled by B correspond to $\sin\delta_1 = -0.37$, $\sin\delta_o = -0.1$ and in this case we have R = 1/5. For the curves C we have $\sin\delta_1 = -0.37$, $\sin\delta_o = +0.1$ and R = 1/9.

The differential cross-section for elastic scattering is

$$\frac{D}{d} = \frac{J_o H^d(\theta)}{4k^2 vwW_N(lab)} \left\{ \left| 3\eta_1 + \eta_o - \frac{\alpha}{v\sin^2\theta_o/2} + (6\eta_{13} + 2\eta_{03} + 3\eta_{11} + \eta_{01})\cos\theta_o \right|^2 + \frac{2}{3}\sin^2\theta_o \left| 3\eta_{13} + \eta_{03} - 3\eta_{11} - \eta_{01} \right|^2 \right\}$$

For elastic plus inelastic scattering we have

$$\frac{d\sigma^{E+I}}{d\Omega} = \frac{1}{k^2}\left\{ \left| \eta_1 + (2\eta_{13} + \eta_{11})\cos\theta_o - \frac{\alpha}{2v\sin^2\theta_o/2} \right|^2 + \sin^2\theta_o \left|\eta_{13} - \eta_{11}\right|^2 + \frac{1}{4}\left|\eta_1 + \eta_o + (2\eta_{13} + 2\eta_{03} + \eta_{11} + \eta_{01})\cos\theta_o\right|^2 - \frac{1}{4}\sin^2\theta_o\left|\eta_{13} + \eta_{03} - \eta_{11} - \eta_{01}\right|^2 \right\} + \frac{H_2 J_o'}{8k^2 vwW_N(lab)} \left\{ \left| 3\eta_1 + \eta_o - \frac{\alpha}{v\sin^2\theta_o/2} + \cos\theta_o(6\eta_{13} + 2\eta_{03} + 3\eta_{11} + \eta_{01}) \right|^2 - \left| \eta_1 - \eta_o - \frac{\alpha}{v\sin^2\theta_o/2} + \cos\theta_o(2\eta_{13} - 2\eta_{03} + \eta_{11} - \eta_{01}) \right|^2 + \frac{1}{3}\sin^2\theta_o\left| 3\eta_{13} + \eta_{03} - 3\eta_{11} - \eta_{01}\right|^2 - \frac{1}{3}\sin^2\theta_o \cdot \left|\eta_{13} - \eta_{03} - \eta_{11} + \eta_{01}\right|^2 \right\}$$

and for the charge-exchange differential cross-section

$$\frac{d\sigma^c}{d\Omega} = \frac{J_o}{4k^2 vwW_N(\mathrm{lab})}\Big\{ (1-H_2) \Big[\big| \eta_1 - \eta_o + (\eta_{11} - \eta_{01} + 2\eta_{13} - 2\eta_{03}) \cos\theta_o \big|^2 + \frac{2}{3}\sin^2\theta_o \big|\eta_{11} - \eta_{01} - \eta_{13} + \eta_{03}\big|^2 \Big] + \frac{1}{3}(1 + H_2)\sin^2\theta_o \big|\eta_{11} - \eta_{01} - \eta_{13} + \eta_{03}\big|^2 \Big\}$$

ACKNOWLEDGMENTS

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1. See for example the reports of Goldhaber et al., in the VI Rochester Conference and in the Padova-Venezia conference, or the more recent reports by Kaplan and Dalitz in the Geneve Conference (July, 1958).
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6. K. C. Rogers and L. M. Lederman, Phys. Rev. 105, 247 (1957).

FIGURE CAPTIONS

Figure 1 : Differential cross section for elastic scattering of 100 Mev K-mesons by deuterons. Only S waves are assumed to contribute. Curve A corresponds to scattering purely in the T = 1 isotopic spin states. Curves B and C include smaller contributions from the T = 0 state.

Figure 2 : Differential cross section for elastic plus inelastic scattering of 100 Mev K^+-mesons by deuterons. Curve A corresponds to scattering of S-waves only in the T = 1 isotopic spin state. Curves B and C admit contributions from the S-waves in the T = 0 state.

Figure 3 : Differential cross section for charge exchange scattering of 100 Mev K^+-mesons by deuterons. Curve A corresponds to scattering only in T = 1 state. Curves B and C are calculated with small contributions from the S-waves of the T = 0 state.

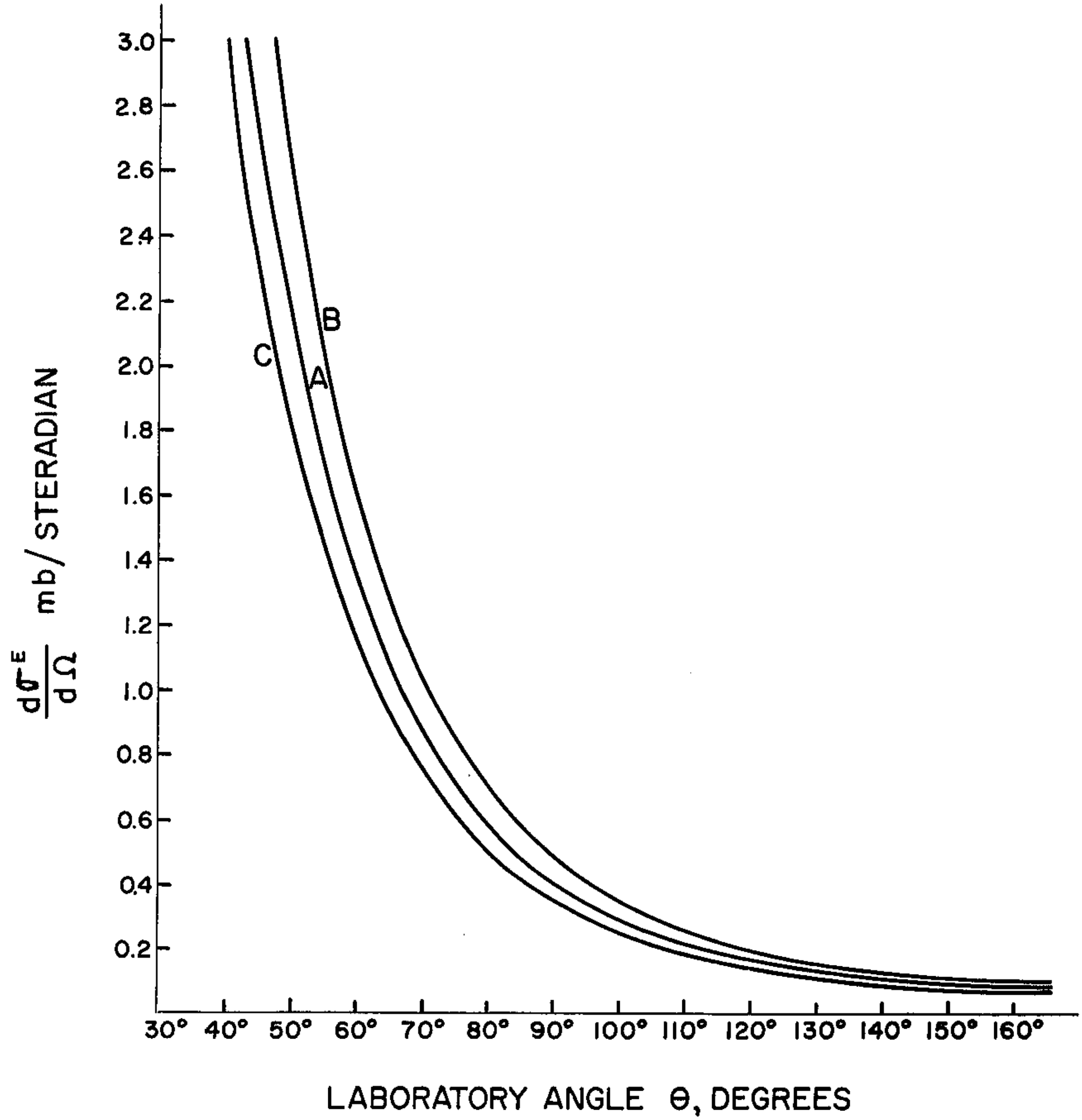

FIG. 1

ELASTIC CROSS SECTION

$K^+ + d \longrightarrow K^+ + d$

100 MEV LAB. ENERGY

CURVE A = T=1, S-WAVE, SIN δ_1 = -0,37

CURVE B = T=1, S-WAVE, SIN δ_1 = -0,37
T=0, S-WAVE, SIN δ_0 = -0,1

CURVE C = T=1, S-WAVE, SIN δ_1 = -0,37
T=0, S-WAVE, SIN δ_0 = +0,1

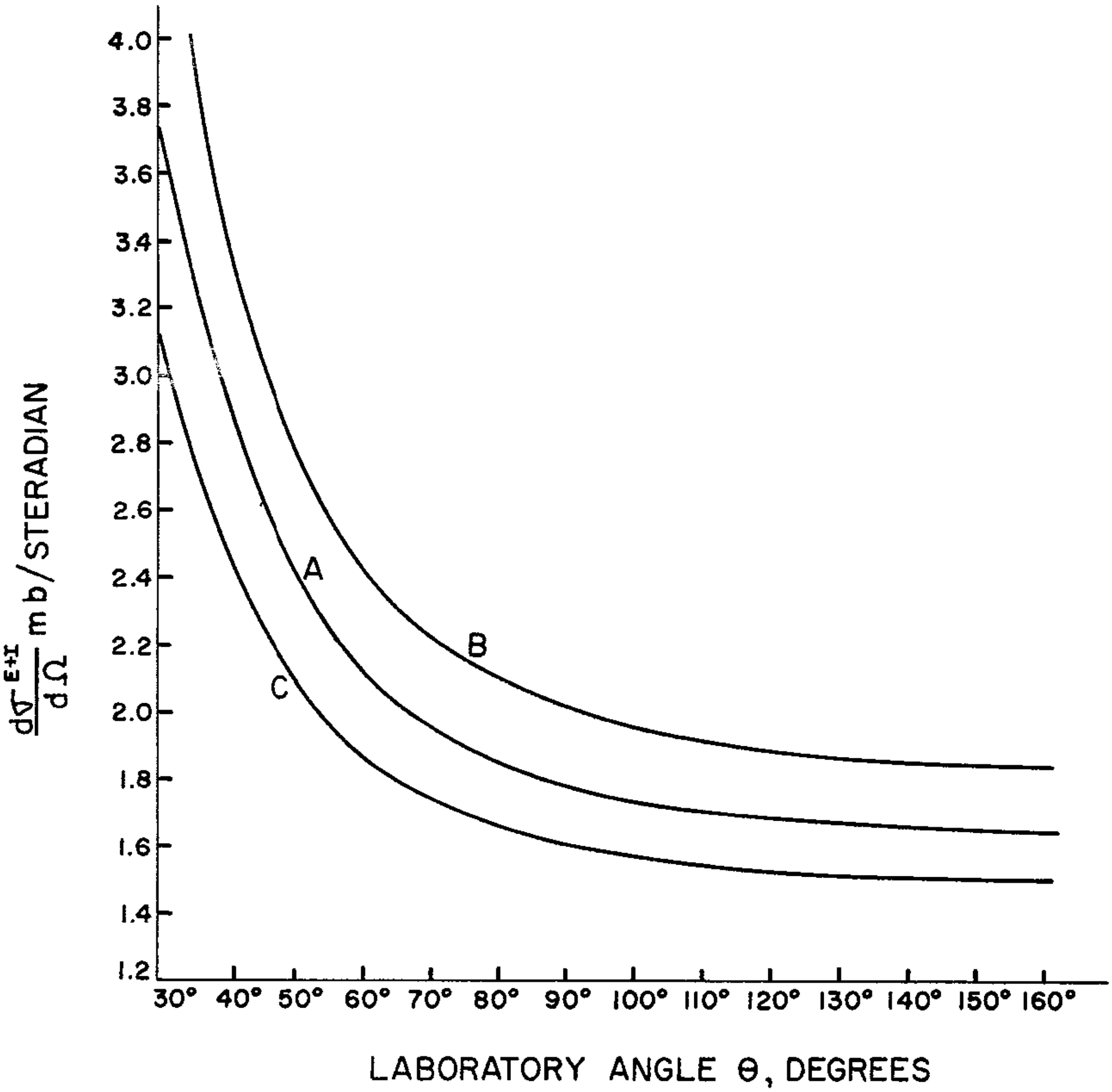

FIG. 2

ELASTIC + INELASTIC CROSS SECTION

$K^+ + d \rightarrow K^+ + d$

AND $K^+ + d \rightarrow K^+ + n + p$

CURVE A = T = 1, S - WAVE, SIN δ_1 = -0,37

CURVE B = T = 1, S - WAVE, SIN δ_1 = -0,37

T = 0, S - WAVE, SIN δ_0 = -0,1

CURVE C = T = 1, S - WAVE, SIN δ_1 = -0,37

T = 0, S - WAVE, SIN δ_0 = + 0,1

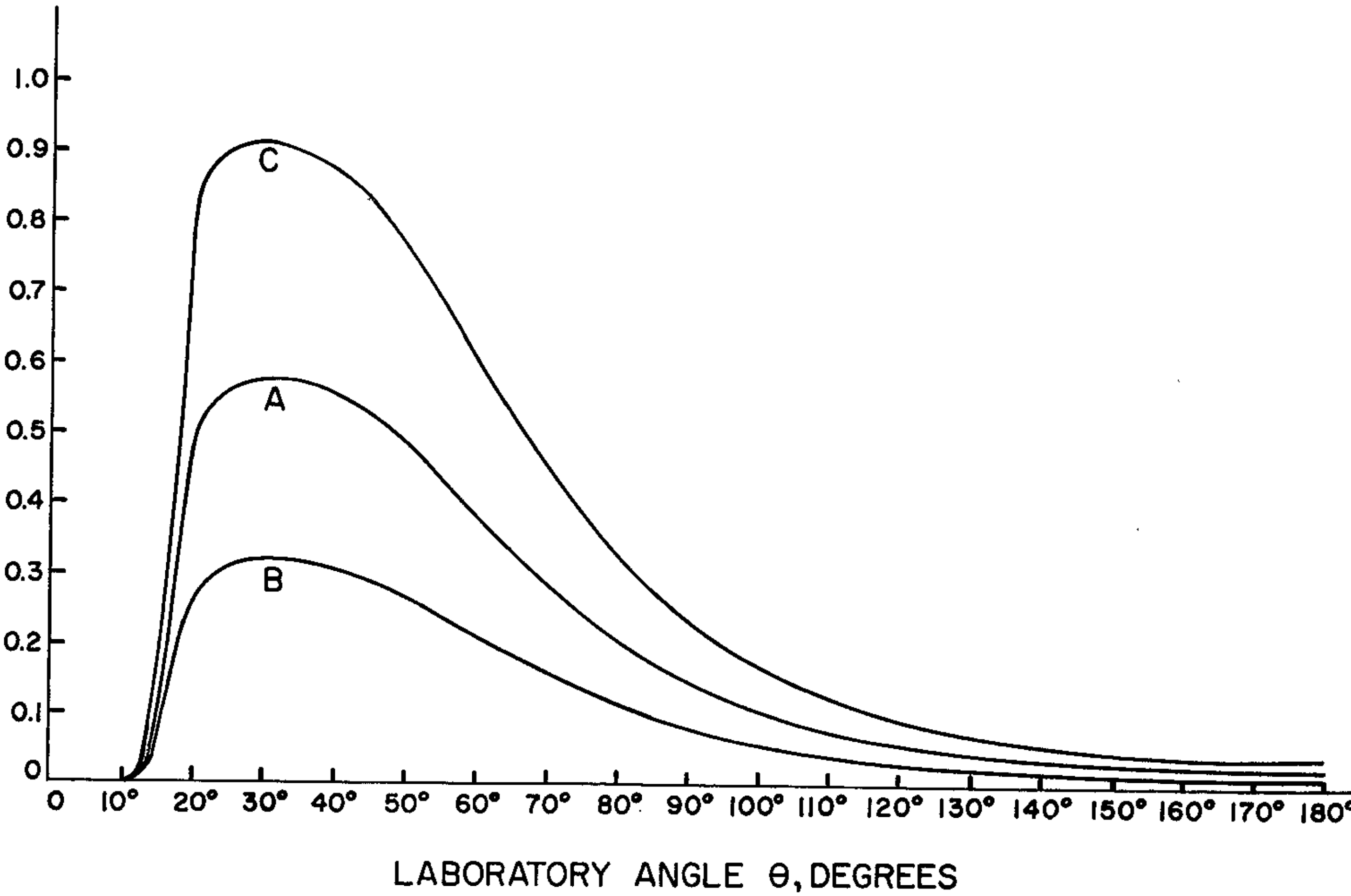

FIG. 3

CHARGE - EXCHANGE CROSS - SECTION

$K^+ + d \longrightarrow K^\circ + p + p$

100 MEV LAB. ENERGY

CURVE A = T = 1, S - WAVE, SIN δ_1 = − 0,37

CURVE B = T = 1, S - WAVE, SIN δ_1 = − 0,37
T = 0, S - WAVE, SIN δ_0 = − 0,1

CURVE C = T = 1, S - WAVE, SIN δ_1 = − 0,37
T = 0, S - WAVE, SIN δ_0 = + 0,1