defined by

$$\varphi_f = \arg[iA(K_L{}^0p \to K_S{}^0p)_{t=0}] = \varphi + \tfrac{1}{2}\pi.$$

Thus, we find for an average value

$$\varphi_f = -43° \pm 8°,$$

which may be compared with the experimental result of Ref. 2 for hydrogen (−42° ± 17°), and also with the results for copper[12] (−45.2° ± 7.3°) and for carbon[13] (−37° ± 10°). Within the errors, the regeneration phase for hydrogen is the same as for heavy nuclei in agreement with recent optical model calculations.[14]

In summary, we find the main features of the reaction $K_L{}^0p \to K_S{}^0p$ in the momentum range 1.3 to 8.0 GeV/c to be the following: (1) The cross section σ falls as $(p_{\mathrm{lab}})^{-n}$, with $n = 2.1 \pm 0.2$. (2) The forward differential cross section $(d\sigma/dt)_{t=0}$ falls as $(p_{\mathrm{lab}})^{-m}$, with $m = 1.3 \pm 0.3$. (3) The ratio of the real to imaginary part of the forward amplitude is consistent with unity over the entire energy region, with an average value of 0.82 ± 0.20. (4) The average values of φ, the phase of the forward amplitude, and φ_f, the regeneration phase, are −133° ± 8° and −43° ± 8°, respectively. (5) If the reaction is assumed to be dominated in the forward direction by Reggeized ω exchange, then the average value of the trajectory intercept $\alpha_\omega(0)$ is 0.47 ± 0.09.

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Interpretation of the Reaction $K_L{}^0p \to K_S{}^0p$†

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Recent data on $K_L{}^0p \to K_S{}^0p$ are interpreted in terms of two distinctly different Regge models, both of which provide good descriptions of the data. The forward differential cross sections for $K_L{}^0p \to K_S{}^0p$ and $\pi^-p \to \pi^-p \to \pi^0n$ are used to determine an f/d ratio for the nonflip coupling of vector mesons to baryons.

The recent data[1-3] on the reaction

$$K_L{}^0p \to K_S{}^0p \tag{1}$$

add interesting information to the class of pseudoscalar-meson-baryon inelastic scattering reactions. The behavior of Reaction (1) is in several ways similar to pion charge exchange,

$$\pi^-p \to \pi^0n. \tag{2}$$

Both reactions have forward peaks in the differential cross section, show structure in the region $0.3 \leq -t \leq 0.8$ GeV^2, and fall rapidly for $-t \gtrsim 1.0$ GeV^2. Meson exchanges in the t channel are highly restricted for both reactions. Reaction (1) is expected to be dominated by ω exchange,[4] whereas Reaction (2) has been well described in terms of ρ exchange.[5]

In this Letter we analyze Reaction (1) in terms of two distinctly different Regge models. The first is the model of Ahmadzadeh and Kaufmann[6] (hereafter called AKM) and the second is the strong-cut Regge-absorption model (SCRAM).[7] Both models have been successful in describing Reaction (2), and we present their extension to Reaction (1) below. By comparison of the forward cross sections of (1) and (2) we also extract information on the f/d ratio for the nonflip coupling of vector mesons to baryons.

The amplitudes in AKM are written as t-channel helicity amplitudes using a form suggested by the Veneziano model. The reactions are assumed to proceed by the exchange of vector-meson trajectories (ω, ρ) and lower-lying trajectories (ω', ρ') with the same quantum numbers as the vector mesons. For Reaction (1), the ω and ρ amplitudes (or ω' and ρ' amplitudes) are identical except for their residues, and in our fit we consider composite $\omega+\rho$ and $\omega'+\rho'$ exchanges, denoted by V and V', respectively. The nonflip amplitude A' and the flip amplitude B are written as $A'(K_L{}^0p \to K_S{}^0p) = -(A_V{}' + A_{V'}{}')$ and $B(K_L{}^0p \to K_S{}^0p) = -(B_V + B_{V'})$. Both $A_V{}'$ and B_V vanish for t values where $\alpha_V(t) = 0, -2, \cdots$. The trajectories are assumed to be linear with a common slope, and for our fit we have used $\alpha_V(t) = \alpha_V(0) + t$ and $\alpha_{V'}(t) = t$. The variables of the fit are the nonflip residues $\beta_V{}^n$ and $\beta_{V'}{}^n$, the flip residues $\beta_V{}^f$ and $\beta_{V'}{}^f$, and the trajectory intercept $\alpha_V(0)$.

The SCRAM amplitudes are expressed in the s-channel helicity formalism as a sum of a Regge exchange term and an absorptive-cut correction term. The nonflip (++) and flip (+−) amplitudes are of the form $M_{+\pm} = M_{+\pm}{}^V + \lambda_{+\pm} M_{+\pm}{}^{\text{cut}}$, where V again refers to a composite $\omega+\rho$ exchange for Reaction (1). The $\lambda_{+\pm}$ are parameters which account for additional cut strength arising from absorption via inelastic scattering. The expected range is $1.0 \lesssim \lambda \lesssim 2.0$. The nonflip and flip amplitudes are expected to have zeros in $-t$ at ~0.2 and ~0.6 GeV^2, respectively, caused by cancelations of the pole and cut terms and not by the usual Regge nonsense-zero mechanisms[8] as in the AKM amplitudes. For our fit, the cut strengths $\lambda_{+\pm}$, the Regge residues $\gamma_{+\pm}$, and the trajectory intercept $\alpha_V(0)$ were varied.

The fitted parameters for both models, shown in Table I, were determined by a maximum-likelihood method using all $K_L{}^0p \to K_S{}^0p$ events from Ref. 1 in the intervals $0.05 < -t < 1.2$ GeV^2 and $2.0 < p_{\text{lab}} < 7.0$ GeV/c. The results are compared to the data in Figs. 1 and 2. The differential cross sections shown in Fig. 1 are well described by both models. Even below 2 GeV/c, where s-channel resonances are expected to be important, good agreement is observed for $-t \lesssim 1.0$ GeV^2.

The forward differential cross sections are compared with the models in Fig. 2(a). The data below 10 GeV/c are well reproduced both in magnitude and in energy dependence. For comparison to the preliminary high-energy measurements from Serpukhov[3] the models have been extrapolated to 50 GeV/c and are seen to be consistent with the data. The phase of the forward amplitude as a function of laboratory momentum is shown in Fig. 2(b). Good agreement is again observed below 10 GeV/c. However, the extrapolations of the models to high energy are clearly

Table I. Fitted parameters for AKM and SCRAM for $K_L{}^0p \to K_S{}^0p$ and $\pi^-p \to \pi^0n$.

	AKM			SCRAM		
					$\pi^-p \to \pi^0n$ [a]	
Parameter	$K_L{}^0p \to K_S{}^0p$	$\pi^-p \to \pi^0n$ [a]	Parameter	$K_L{}^0p \to K_S{}^0p$	Sol. I	Sol. II
$\alpha_V(t)$	$0.51+t$	$0.5+0.9t$	$\alpha_V(t)$	$0.36+t$	$0.47+0.9t$	$0.42+t$
$\alpha_{V'}(t)$	t	$-0.02+0.9t$	γ_{++}	−44.5	−22.6	−34.9
$\beta_V{}^n$ (GeV^{-1})	13.2	9.81	γ_{+-}	67.2[b]	85.7	129.3
$\beta_V{}^f$ (GeV^{-2})	166.0[b]	119.0	λ_{++}	2.08	1.29	1.31
$\beta_{V'}{}^n$ (GeV^{-3})	11.2	−36.0	λ_{+-}	1.85	1.51	1.55
$\beta_{V'}{}^f$ (GeV^{-2})	−230.0[b]	38.0	E_0 (GeV)	0.17[c]	0.17	0.27

[a] For AKM see Ref. 6. For SCRAM see Ref. 7, where two solutions are given.
[b] The relative sign of the nonflip and flip amplitudes is not determined by our fits.
[c] Parameter held fixed in the fit.

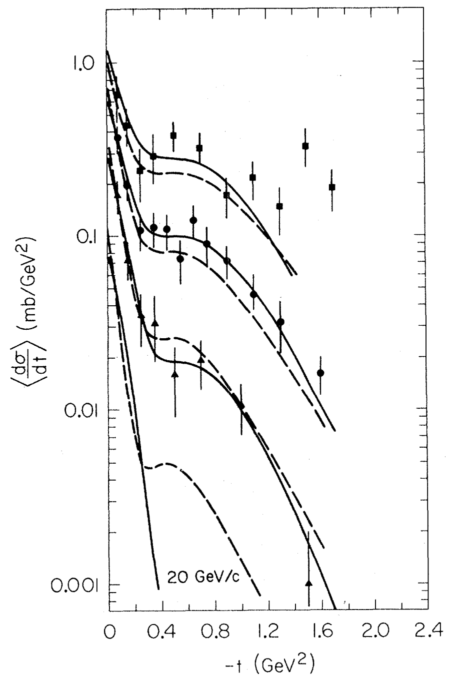

FIG. 1. Differential cross sections for $K_L{}^0p \to K_S{}^0p$. The data are from Ref. 1 and have been averaged over three momentum intervals: $1.3 \leq p_{lab} \leq 2.0$ GeV/c (squares), $2.0 \leq p_{lab} \leq 4.0$ GeV/c (circles), and $4.0 \leq p_{lab} \leq 8.0$ GeV/c (triangles). The solid (dashed) curves here and in Fig. 2 are the result of a fit with AKM (SCRAM).

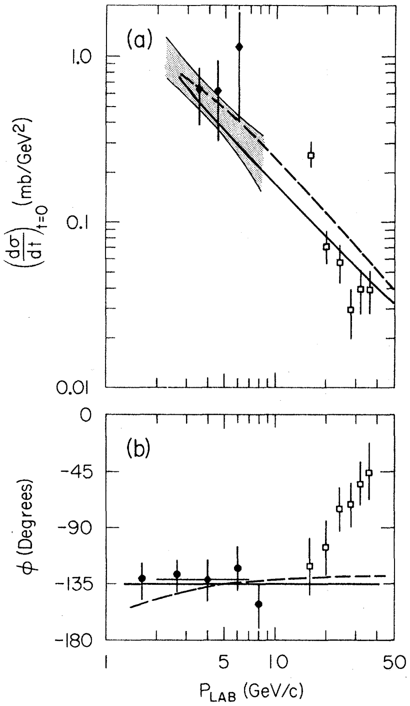

FIG. 2. (a) Forward differential cross section for $K_L{}^0p \to K_S{}^0p$. The results of the Regge-model fits for $2 \leq p_{lab} \leq 7$ GeV/c are extrapolated to 50 GeV/c. The data are from Ref. 1 (shaded region), Ref. 2 (diamonds), and Ref. 3 (open squares). (b) Phase of the forward amplitude. The data from Ref. 1 are shown by circles.

incompatible with the measured phases. If these preliminary measurements are confirmed, the validity of most Regge models, including AKM and SCRAM, will be in serious doubt.[9]

Since both models give equally good descriptions of $K_L{}^0p \to K_S{}^0p$ below 10 GeV/c, we cannot favor one over the other. However, the predicted differential cross sections at 20 GeV/c, shown in Fig. 1, are significantly different for $-t \gtrsim 0.4$ GeV^2. Measurements in this momentum region would certainly be helpful in evaluating the models.

Further observations may be made on the results of the fits:

(1) *Trajectory intercept.*—The value of the ω-trajectory intercept is somewhat model dependent. The effective intercept $\alpha(0) = 0.47 \pm 0.09$ reported in Ref. 1 was found by assuming that the phase of the forward amplitude is given solely by the Regge signature factor. Consequently, the effective intercept is in better agreement with the AKM value (0.51) than the SCRAM value (0.36) since the latter is affected by the cut contribution in the forward direction.

(2) *Strength of flip and nonflip amplitudes in AKM.*—It has been speculated[10] that the t-channel helicity amplitudes are dominated by nonflip for Reaction (1) and flip for Reaction (2). However, the absolute value of the ratio of nonflip to flip couplings, $|\beta_V{}^n/\beta_V{}^f|$, is found to be the same for both reactions in the AKM fits.

(3) *Strength of flip and nonflip amplitudes in SCRAM.*—The absolute value of the ratio for s-channel helicity couplings, $|\gamma_{++}/\gamma_{+-}|$, is nearly twice as large for Reaction (1) as for Reaction (2) in the SCRAM fits.

(4) *Secondary amplitudes in AKM.*—The behavior of the secondary amplitudes in Reactions (1) and (2) is quite different; in particular the secondary flip amplitude is much more important for $K_L{}^0p \to K_S{}^0p$.

(5) *Cut strengths in SCRAM.*—The λ parameters indicate that the inelastic contributions to the cuts are considerably stronger for KN than for πN. It would be interesting to see whether this feature is maintained, say, for KN charge exchange.

We turn now to the question of determining an f/d ratio for the vector-meson–baryon SU(3) coupling by comparison of the forward differen-

Table II. Comparison of $(d\sigma/dt)_0$ for $K_L{}^0p \to K_S{}^0p$ and $\pi^-p \to \pi^0 n$.

p_{lab} (GeV/c)	$(d\sigma/dt)_0$ (mb/GeV^2) $K_L{}^0p \to K_S{}^0p$	$\pi^-p \to \pi^0 n$	$R(K_S{}^0p/\pi^0n)$
2–3	0.88 ± 0.20[a]	0.82 ± 0.10[c,d]	1.07 ± 0.28
3–4	0.62 ± 0.14[a]	0.80 ± 0.10[d,e]	0.78 ± 0.20
4.8	0.44 ± 0.11[a]	0.53 ± 0.02[e]	0.83 ± 0.22
5.9	0.35 ± 0.10[a]	0.37 ± 0.02[f]	0.95 ± 0.28
16–20	0.16 ± 0.05[b]	0.14 ± 0.01[f]	1.13 ± 0.35
	Weighted average		0.91 ± 0.12

[a]Ref. 1. [b]Ref. 3. [c]Ref. 12. [d]Ref. 13. [e]Ref. 14. [f]Ref. 15.

tial cross sections for Reactions (1) and (2). The data[1, 3, 12-15] are summarized in Table II, where R is the ratio $[d\sigma(K_S{}^0p)/dt][d\sigma(\pi^0n)/dt]^{-1}$ evaluated at $t=0$. R is observed to be independent of energy with an average value of 0.91 ± 0.12. At $t=0$, the nonflip amplitudes may be written[16] as

$$A(K_L{}^0p \to K_S{}^0p) = -\gamma[(3f-d)Z_{\omega K\bar{K}}(s)-(f+d)Z_{\rho K\bar{K}}(s)],$$

$$A(\pi^-p\to\pi^0n) = -2\sqrt{2}\gamma(f+d)Z_{\rho\pi\pi}(s),$$

where the Z functions describe the dynamics of the indicated processes exclusive of the coupling constants. In the Regge picture, the phase of each Z function is given by the signature factor for the exchanged trajectory. Consequently, to a good approximation the phases for all three Z functions are equal since $\alpha_\rho(0)$ and $\alpha_\omega(0)$ are nearly equal.[1] Furthermore, we expect that $|Z_{\rho K\bar{K}}(s)/Z_{\rho\pi\pi}(s)|\approx 1$ and $|Z_{\rho K\bar{K}}(s)/Z_{\omega K\bar{K}}(s)|\approx 1$, which lead to

$$\frac{f}{d}=\frac{1+(2R)^{1/2}}{1-(2R)^{1/2}}=-6.8^{+1.3}_{-2.0}. \qquad (3)$$

Equation (3) is related, via isospin invariance and the optical theorem, to the expression of Barger and Rubin[17]:

$$\frac{f}{d}=\frac{\sigma_T(\pi^-p)-\sigma_T(\pi^+p)+\sigma_T(K^-n)-\sigma_T(K^+n)}{\sigma_T(\pi^-p)-\sigma_T(\pi^+p)-\sigma_T(K^-n)+\sigma_T(K^+n)}. \qquad (4)$$

This expression yields an estimate of $-3 \lesssim f/d \lesssim -5$. However, note that (3) depends only on the ratio of two experimental cross sections whereas (4) depends on the ratio of sums and differences of four different cross sections and is therefore much more susceptible to possible systematic effects in the data.

The results of the AKM and SCRAM fits also give f/d ratios:

$$\left[\frac{f}{d}\right]_{\text{AKM}}=\frac{1+\beta_V{}^n(1)/\beta_V{}^n(2)}{1-\beta_V{}^n(1)/\beta_V{}^n(2)}=-6.7,$$

$$\left[\frac{f}{d}\right]_{\text{SCRAM}}=\frac{1+\sqrt{2}[\gamma_{++}(1)/\gamma_{++}(2)]}{1-\sqrt{2}[\gamma_{++}(1)/\gamma_{++}(2)]} = \begin{cases}-2.1, & \text{solution I}\\ -3.5, & \text{solution II.}\end{cases}$$

It is unfortunate, but not unexpected, that the f/d ratio is model dependent. For comparison, Barger and Olsson[18] have found a value of -2.0 in a Regge analysis of πN, KN, and NN total cross sections, whereas Salin[19] has found a value of -11 in a Regge analysis of $\pi N\to YK$ and $KN \to Y\pi$ reactions. Our results suggest that the f/d ratio lies between -3 and -7.

In conclusion, we find that (1) the recent $K_L{}^0p \to K_S{}^0p$ cross-section data may be understood in terms of either AKM or SCRAM, both of which have been successful in describing π^-p charge exchange; (2) the predictions of both models on the phase of the forward amplitude disagree with the preliminary data above 20 GeV/c; (3) the complexity of the differential cross section requires significant secondary contributions which could be due to either lower-lying trajectories (as in AKM) or cuts (as in SCRAM); (4) the ω-trajectory parameters are consistent with a linear trajectory of unit slope passing through the physical ω mass; and (5) the f/d ratio for $V\bar{B}B$ nonflip coupling lies in the range -3 to -7, although the exact value is model dependent.

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C-Invariance Violation and the Isotensor Current*

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We suggest a model in which the isotensor electromagnetic current, whose existence is strongly suggested by recent work, has a component which violates charge-conjugation invariance, which, on the other hand, is satisfied by the conventional isovector and scalar components. This is found to provide a simple explanation of recent results, and is consistent with all present experimental knowledge.

Recently,[1] the authors discussed the question of whether there was an effect due to an isotensor electromagnetic current in the photoproduction of pions from nucleons in the region of the first resonance, and we concluded, using data on the process $\gamma n \rightarrow \pi^- p$ obtained from deuterium measurements, that there was indeed evidence for such a term. The deuterium measurements were taken seriously since two independent measurements[2] were consistent with each other, and also they were consistent with those deduced from the π^-/π^+ ratio wherever the latter data exist.[3] To make the conclusion definite, however, experimental study of $\pi^- p \rightarrow \gamma n$ was suggested. Very recently, the first results of this process in the resonance region have been made at 360 MeV.[4] Although the model-independent test of Ref. (1) cannot be carried out without measurement over a range of energy, these results again indicate an isotensor term of about the same sign and magnitude as was suggested on the basis of the deuterium data. However, the actual differential cross section for the process, at least at angles greater than about 80°, does not agree at all well with its inverse reaction. Provided the data on $\gamma n \rightarrow \pi^- p$ are correctly deduced from the deuterium measurements, this is an evidence for C-invariance violation of approximately 2 standard deviations.

There are other evidences for C-invariance violation: the charge asymmetry in $\eta \rightarrow \pi^+\pi^-\pi^0$ (3 standard deviations),[5] and the asymmetry in $e^- p \rightarrow e^- \Gamma$,[6] where Γ denotes unobserved final states. In this Letter, we point out that the present experimental knowledge does not rule out a possibility that the isotensor component of the electromagnetic current violates C invariance, and such a theory, therefore, helps to unite the seemingly independent evidences for C-invariance violation mentioned above, in contrast to the case with isoscalar and isovector C-invariance violation.

Let J_i and K_i denote the negative- and positive-C components of the electromagnetic current, respectively, where i denotes their isospin properties. We will discuss the implications of various experiments and their self-consistency.

(a) $\eta \rightarrow \pi^0 e^+ e^-$.—$K_1$ is responsible for the decay $\eta \rightarrow \pi^0 e^+ e^-$.[7] Since the upper bound for the branching ratio 0.01%,[8] to this accuracy, the effect of K_1 is negligible.

(b) $\eta \rightarrow \pi^+\pi^-\pi^0$.—The charge asymmetry in η