these experiments in a bubble chamber filled with hydrogen and with deuterium since the interpretation of the data will be surer.

We take great pleasure in thanking J. J. Sakurai for emphasizing the importance of this question and pointing out the discrepancies described here. We are also much indebted to the Cosmotron Group of the Brookhaven National Laboratory, whose help and cooperation made these experiments possible.

* Supported in part by the U. S. Atomic Energy Commission.

[1] D. Feldman, Phys. Rev. **103**, 254 (1956).

[2] Vander Velde, Brown, Glaser, Meyer, Perl, Cronin, and De Benedetti, Bull. Am. Phys. Soc. Ser. II, **2**, 221 (1957).

[3] Brown, Glaser, and Perl, Bull. Am. Phys. Soc. Ser. II, **2**, 19 (1957).

[4] These histograms are slightly different from those recently presented by D. A. Glaser [*Proceedings of the Seventh Annual Rochester Conference on High-Energy Physics, 1957* (Interscience Publishers Inc., New York, 1957)] because some additional events were found when the scanning of the pictures was completed.

[5] Plano, Samios, Schwartz, and Steinberger, Nuovo cimento **5**, 216 (1957).

[6] G. Puppi (private communication). At 870-Mev π^- bombarding energy, below the threshold for producing Σ's, 18 associated Λ^0 events were seen in carbon and 12 in hydrogen in a propane bubble chamber.

[7] R. Adair (private communication). At 950-Mev π^- bombarding energy, just above the threshold for producing Σ's, 20 Λ^0 productions and 17 Σ^0 productions were seen in a hydrogen bubble chamber.

Possible Violation of Charge Independence in Strong Interactions*

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THE striking selection rule governing strange-particle interactions is usually formulated in terms of isotopic-spin invariance. However, apart from the near equality in the binding energies of the hypernuclei, $_\Lambda H^4$ and $_\Lambda He^4$ (which supports the weaker condition of charge symmetry), there has been no direct test for charge independence in strong interactions of strange particles.[1] In this note we discuss the possible violation of such an invariance in view of the recent Michigan experiments.[2]

In the past two years the reactions

$$\pi^-+p\rightarrow\Sigma^-+K^+, \tag{1}$$

$$\pi^-+p\rightarrow\Sigma^0+K^0, \tag{2}$$

as well as

$$\pi^-+p\rightarrow\Lambda^0+K^0, \tag{3}$$

have been extensively studied by several groups.[3] The salient feature of those production processes is that for the Σ^-K^+ production the angular distribution of the *hyperon* is peaked forward in the center-of-mass system, whereas for the Σ^0K^0 production *as well as* for the Λ^0K^0 production the hyperon angular distribution is reported to be backward.

More recently an attempt has been made by the Michigan bubble chamber group to study the reaction[2]

$$\pi^++p\rightarrow\Sigma^++K^+. \tag{4}$$

The matrix elements for the ΣK production are identical in structure to the ones for pion-nucleon scattering as far as their isotopic-spin dependence is concerned.[4] Then the inequality

$$2\left(\frac{d\sigma}{d\Omega}\right)_{\Sigma^0K^0}\leq\left|\left[\left(\frac{d\sigma}{d\Omega}\right)_{\Sigma^-K^+}\right]^{\frac{1}{2}}+\left[\left(\frac{d\sigma}{d\Omega}\right)_{\Sigma^+K^+}\right]^{\frac{1}{2}}\right|^2 \tag{5}$$

must hold at all angles,[5] and the highly anisotropic behavior of the reactions (1) and (2) together with the fact that the total Σ^0K^0 production cross section is at least of the same order of magnitude as the Σ^-K^+ cross section imposes severe restrictions on the angular distribution of the Σ^+K^+ production. In particular, specializing to backward angles, we infer that the Σ^+ production must be frequent in the backward direction unless the Σ^+K^+ cross section (pure $T=\frac{3}{2}$) is much larger than the Σ^-K^+ cross section.[6]

The results of the Michigan group[2] indicate that precisely the opposite is the case. Out of the total of 18 events (which corresponds to the Σ^+K^+ cross section smaller than the Σ^-K^- cross section) no event falls in the region $120°\leq\theta_\Sigma\leq180°$, and the inequality (5) is significantly violated as discussed in reference 2.

The question naturally arises whether the violation of charge independence is characteristic (a) of strange-particle interactions in general, (b) of high-energy interactions in general, or (c) of high-energy strange-particle interactions. One of the crucial experiments along this line is the study of the interaction of slow K^- particles with deuterium or with helium.[7] In K^+-nucleon scattering, where the K^+-p cross section is known to be larger than the K^+-n cross section by a factor of two or more, the inequality

$$\left(\frac{d\sigma}{d\Omega}\right)_{K^+p}\leq\left|\left[\left(\frac{d\sigma}{d\Omega}\right)^{\text{el}}_{K^+n}\right]^{\frac{1}{2}}+\left[\left(\frac{d\sigma}{d\Omega}\right)^{\text{c.e.}}_{K^+n}\right]^{\frac{1}{2}}\right|^2 \tag{6}$$

(where el and c.e. stand for "elastic" and "charge exchange" respectively) ought to be tested. As for high-energy pion interactions, it is worth examining the validity of charge *symmetry* as well as that of charge independence (if the latter is violated) in $\pi^\pm$-d, $\pi^\pm$-He, and $\pi^\pm$-C interactions.[8]

If isotopic spin is not conserved in strange-particle interactions, it is necessary to formulate the "strangeness" rule without recourse to isotopic spin. Purely phenomenologically, we may define $\langle Q\rangle$ which is the average electric charge of mesons or baryons that share approximately the same mass-value.[9] For example, $\langle Q\rangle=\frac{1}{2}$ for $K^{+,0}$, p, n and $\langle Q\rangle=0$ for π, Λ, and Σ. Then, denoting "strangeness" by S and baryon number by B,

$$S=2\langle Q\rangle-B, \tag{7}$$

as expected. The overwhelming success of the "strangeness" selection rule merely points out the existence of a nonspatiotemporal symmetry in nature (which is preserved as long as the C, P, and T invariances separately hold) but by itself neither implies nor justifies the connection between such a symmetry and the rotational symmetry in isotopic-spin space.

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[1] The result of a "world average" prepared at the University of Chicago under V. L. Telegdi gives binding energies of 1.4–1.7 Mev for both $_\Lambda\mathrm{H}^4$ and $_\Lambda\mathrm{He}^4$.

[2] Brown, Glaser, Meyer, Perl, Vander Velde, and Cronin, preceding letter [Phys. Rev. **107**, 906 (1957)].

[3] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **98**, 121 (1955). Budde, Chretien, Leitner, Samios, Schwartz, and Steinberger, Phys. Rev. **103**, 1827 (1956). Summary report by D. A. Glaser based on the works of the Columbia, Brookhaven, Bologna, Pisa, and Michigan groups, *Proceedings of the Seventh Annual Rochester Conference* (to be published).

[4] See, for instance, H. A. Bethe and F. de Hoffmann, *Mesons and Fields* (Row, Peterson and Company, White Plains, 1955), Vol. 2 (Mesons), p. 62.

[5] It is easy to verify that the inequality (5) must hold even if the production matrix is spin-dependent.

[6] This kind of angular distribution is precisely the prediction of the "predissociation" model [D. C. Peaslee, Phys. Rev. **105**, 1034 (1957)]. Field-theoretically this can be accomplished by assuming the predominance of a process involving a direct interaction between the K particle and the pion [S. Barshay, Phys. Rev. **104**, 858 (1956); J. J. Sakurai, Nuovo cimento **5**, 1340 (1957)]. Apart from the failure to explain the Σ^+K^+ production, such a model cannot be taken seriously if strange particles do not exist in parity doublets.

[7] T. D. Lee, Phys. Rev. **99**, 337 (1955).

[8] See Cool, Piccioni, and Clark, Phys. Rev. **103**, 1082 (1956) for the comparison of $\sigma(\pi^+p)$ with $\sigma(\pi^-d)-\sigma(\pi^-p)+4$ mb. For $\pi-$He experiments see J. J. Sakurai, Phys. Rev. (to be published). We have heard from Professor Glaser that a test for charge symmetry in $\pi-$C interactions is now being carried out.

[9] The mass differences among various members of a given charge multiplet may not be purely electromagnetic in origin if isotopic spin is not conserved in strong interactions.

Parity and Electron Polarization: Au^{198}†

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SOON after the experimental verification of parity nonconservation, it became evident that beta decay had to be reinvestigated.[1] Prior to that time, it was generally assumed that the scalar (S) and tensor (T) interactions were dominant and that the coupling constant for vector (V) and axial vector (A) interactions were small or zero.[2] However, Wu, Lee, and Yang pointed out that the results on Co^{58} led to contradictions if one assumed simultaneously (a) validity of the two-component theory, (b) S and T dominant, and (c) invariance under time reversal.[1,3] The evidence from Co^{58} is not sufficient to decide which of these assumptions are incorrect.

Table I. Longitudinal polarization of the electrons from Au^{198}. The beta transition in Au^{198} is first forbidden, $2^-\rightarrow2^+$, and possesses a maximum energy of 0.96 Mev.

Method	Electron energy in Mev	v/c	Polarization
Mott	0.10	0.55	-0.05 ± 0.06
Mott	0.12	0.6	-0.06 ± 0.05
Møller	>0.3	>0.78	$+0.05\pm0.12$
Møller	0.3–0.8	0.78–0.92	$+0.02\pm0.23$

In order to learn more about beta decay, we decided to investigate the longitudinal electron polarization in decays where both Fermi and Gamow-Teller matrix elements are present. The two-component theory predicts a polarization $-(v/c)$ for S, T, and P, and a polarization $+(v/c)$ for V and A.[4,5] For positrons, the signs are interchanged. Electrons in pure Gamow-Teller transitions indeed show a polarization $-(v/c)$,[6–10] as expected from the assumptions (a) to (c) above. Electron decays with pure Fermi transitions are not easily available and we therefore chose mixed transitions, Sc^{46}($4^+\rightarrow4^+$), and Au^{198}($2^-\rightarrow2^+$). The decay energy of Au^{198}, $E_{\max}=0.96$ Mev, is large enough so that one can use both Mott scattering[6] and Møller scattering[10] to determine the polarization. Sc^{46}, with $E_{\max}=0.36$ Mev, can at present only be investigated by the first method and the results are therefore less reliable.

Before presenting the data, we briefly discuss one difficulty encountered when using Mott scattering. Since we reported the first results,[6] we have investigated this method in more detail, using scintillation counters. We have found that the thickness and the position of the scattering foil are extremely important. In particular, the measured left-right ratio depends rather strongly on the angle between the direction of the incoming beam and the analyzer foil. This dependence is most pronounced with the aluminum foil (1 mg/cm^2) which was used as reference scatterer, and is probably connected with energy loss and plural scattering in the relatively thick foil. Thinner aluminum foils do not scatter enough, and we have therefore replaced the aluminum by silver (0.2 mg/cm^2). The polarization can now be calculated by using the theoretical values for Mott scattering in gold and silver.[11] Even with this precaution, the results are less reliable than the ones obtained by using Møller scattering, and more work is required to transform this method into an accurate tool.

Both nuclides, Au^{198} and Sc^{46}, show a polarization which is, in absolute value, considerably below (v/c). Sc^{46}, we find, for $(v/c)=0.6$, a polarization of -0.34 ± 0.10. The results for Au^{198} are given in Table I.