The radial density distribution of electrons at $t=4$, 5.6, and 7.1 c.u. was measured between $r=10\mu$ (3.5×10^{-4} c.u.) and the value R quoted in Table I. For each value of t the density distribution can be fitted by a power law:

$$\Pi(r)\propto r^{-\gamma}, \qquad (1)$$

where γ is slowly increasing with r. The average exponent γ in the indicated interval is given in Table I. The measured values of γ are in agreement with the distribution functions close to the shower axis as calculated by Nishimura and Kamata,[4]

$$\Pi(E_0, r, t)\propto r^{s-2}, \qquad (2)$$

with s defined by

$$\lambda_1'(s)t+\ln(E_0 r/K)=0, \qquad (3)$$

in the notation of Rossi and Greisen. Our measurements do not show any significant deviations from electromagnetic cascade theory at a primary energy of 2.5×10^{13} ev. Pomeranchuk[6] and Migdal[7] also obtained Eq. (2) from their theory. Their value of s is defined by

$$\lambda_1'(s)t+\ln(E_0/E)=0. \qquad (4)$$

Our observations, however, are not in agreement with these results.[8]

One of the three innermost tracks in the forward cone undergoes a secondary interaction of type $4+29_p$ after 7.5 cm. Its energy can be estimated[9] from the angular distribution of the 29 shower particles to be 5×10^{11} ev using

$$\ln\gamma_C=-\frac{1}{n}\sum_{i=1}^{n}\ln\tan\theta_i+\ln C, \qquad (5)$$

with $C=0.7$ as determined experimentally and discussed elsewhere.[10] Within a cone of half opening angle 1.7×10^{-3} rad from the axis, we found four high-energy electron pairs originating at distances less than 1 c.u. from the primary event. They are attributed to two π^0 mesons. Their energies can be estimated both from Pinkau's[5] method and from the angular separation of the pairs. One obtains for the π^0 mesons energies between 100 and 500 Bev. The energy of these π^0's and the secondary interaction are smaller by a factor of 50 to 100 compared with the π^0 starting the main cascade.

Assuming a primary energy of 5×10^{14} ev ($\gamma_C=500$), we would obtain for the high-energy π^0 meson in the center-of-mass system an energy of at least 25 Bev which is unusually high. Lowering the primary energy would even increase this value. An alternative explanation of the event would be a reaction of the kind.

$$p+\mathfrak{N}\to K+\Sigma^0+\mathfrak{N}+\pi+\pi+\ldots,$$

$$\Sigma^0\to\gamma+\Lambda^0,$$

where the primary proton emerges after the collision as a Σ^0 of very high energy. A lower limit for the primary energy under this assumption is 2×10^{14} ev. This explanation would avoid the very high energy of the π^0 meson in the center-of-mass system. Due to the very short lifetime of the Σ^0, it also offers a somewhat better explanation for the short distance between the primary event and the origin of the cascade.

This event seems to be the highest energy proton collision in nuclear emulsion which has been described so far, since all the other events known to us with energies greater than 10^{14} ev per nucleon were produced by α-particles.[11-13] It shows that the primary proton spectrum certainly extends to these very high energies.

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REMARK ON STRONG INTERACTIONS

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In a recent note of Pais,[1] the question has been raised as to the conservation of parity, P, in certain of the strong interactions. The framework for the discussion was the doublet approximation, (DA),[2] a rather high group of symmetries invoked for two classes of Yukawa-type meson-baryon interactions, the pion (nonstrange meson)-baryon interactions and the K meson (strange meson)-baryon interactions. These symmetries provide selection rules inhibiting, among other things, the following reactions:

$$K^- + p \to \Sigma^+ + \pi^-,$$
$$\pi^+ + p \to \Sigma^+ + \pi^+,$$
$$K^+ + n \to K^0 + p. \qquad (1)$$

Now these processes are observed to occur and we shall comment further on this in a moment. In order to overcome the selection rules, Pais[3,4] has first discussed at length the possibility of a perturbation to the DA, called the DP, which conserves P but violates charge independence and charge symmetry, as well as the invariances leading to the selection rules mentioned above. Pais has given reasonable arguments that the specific interaction introduced for the DP (which involves the assumption that the charged and neutral K mesons have opposite intrinsic parity) may exhibit itself in K-meson physics as a development in powers of $f^2(m_K/m_\pi)^2$, and in π-meson physics as a development in powers of f^2, where f^2 is of the order of the fine structure constant, and (m_K/m_π) is the ratio of the K-meson mass to the pion mass. One might then expect deviations from charge independence in, for example, the absorption of K^- on deuterium.[3] In the most recent note,[1] however, an alternative viewpoint is discussed, to the effect that the DP conserves isotopic spin but not parity. Strong four-fermion interactions are mentioned in this connection, although, if the charged and neutral K mesons are indeed a doublet, one may have to worry about the possible existence of the old, charge-independent $KK\pi$ interaction suggested some time ago by Goldhaber,[5] the present author,[6] and Schwinger[7] (this interaction implies parity-doublets only if the strong interactions are rigorously invariant under DP). The point that Pais[1] makes is that the effects of parity-nonconservation in the DP would be more markedly evident in the "inhibited" processes, (1), than in the following "allowed" processes which proceed through the DA (as well as the DP):

$$\pi^- + p \to \Sigma^- + K^+ \text{ or } \Lambda^0 + K^0,$$
$$K^- + p \to \Sigma^- + \pi^+ \text{ or } \Sigma^0 + \pi^0. \qquad (2)$$

In this note we would like to raise and discuss the following question: Is it really a reasonable approximation to discuss possible parity-nonconserving effects in connection with reactions (1), induced by the DP, when experiment tells us that these "inhibited" reactions occur with as great, if not greater, cross sections[8] than the "allowed" reactions (2), induced by the combined DA and DP? Indeed, it may quite reasonably be asked whether it is a reasonable approximation to talk about a perturbation to a system of very high symmetries when the so-called perturbation so completely erases the simplest experimental manifestations of the hypothesized symmetries. The analogy usually made here with the distortion of charge independence in the pion-nucleon system by electromagnetism would seem to be open to the remark that, contrary to this situation, the rudiments of charge independence are amply evident in the experiments.[9]

Suppose we consider a somewhat different division of the eight Yukawa-type interactions from that usually considered,[10] that is, the division into pion and K-meson interactions, respectively, with all suitable combinations of strange and nonstrange baryons. Consider a division into the interactions of the nonstrange baryons with both pions and K mesons, and the interactions of the strange baryons among themselves, with both pions and K mesons. Symbolically, we have for the two groups of interactions, designated hereafter by (I) and (II), the following[11]:

$$(\mathrm{I}) \begin{cases} \bar{N}\gamma_5 N\pi \\ \bar{N}\Gamma_1\Sigma K \\ \bar{N}\Gamma_2\Lambda K \end{cases} \qquad (\mathrm{II}) \begin{cases} \bar{\Xi}\gamma_5\Xi\pi; \;\; \bar{\Sigma}\gamma_5\Sigma\pi \\ \bar{\Sigma}\Gamma_3\Lambda\pi; \;\; \bar{\Xi}\Gamma_4\Sigma\bar{K} \\ \bar{\Xi}\Gamma_5\Lambda\bar{K}. \end{cases} \qquad (3)$$

We assume the conventional isotopic spin multiplet assignments and the conservation of isotopic spin. The Γ_i, with $i=1...5$, are either the unit matrix or γ_5, depending upon the intrinsic parities of the strange particles involved in the coupling.

It would appear that at present our most direct experimental contact is with the couplings in (I). Analyses of pion-nucleon and K-meson–nucleon elastic scattering experiments with the tool of the forward-angle dispersion relations come fairly directly to the three renormalized coupling strengths and the two (unknown) relative parities involved in (I),[12] although the determination of all of these quantities by this method may not be unambiguous and recourse to specific experiments may be necessary. Similarly, photoproduction of pions and of Λ and Σ particles with K mesons may be analyzed to yield information concerning the primary Yukawa-type processes in (I).[13] The renormalized coupling strengths associated with the interactions in (II) are presently somewhat more difficult to relate to experimental results.[14] We do not know whether they are all necessarily primary (since several are either induced by others together with the interactions in (I) or are induced by the latter interactions alone) or whether they are very strong or even moderately strong, as the interactions in (I) appear to be. Some of these interactions may indeed be weaker.[15] Models in which the primary pion-hyperon couplings are taken to be quite strong have been widely discussed, especially with reference to calculations of the forces giving rise to hyperfragments.[16,17] It is difficult to see how any firm conclusions can be reached from these calculations as to the primary nature or strength of the pion-hyperon interactions, since an infinitely repulsive core is usually placed at about the range of the force mediated by the exchange of a single K meson and since, in the case of Λ binding, the exchange of at least two pions is involved (this process is not only related to primary and effective pion-hyperon couplings, but also to pion-nucleon scattering through the K-meson cloud of the hyperon). The experimental data on the associated production of Λ and Σ particles in pion-nucleon collisions and on K^- absorption by protons,[18] as well as that on K-meson–nucleon scattering, is not inconsistent with the possibility that these processes are induced largely by the interactions in (I) in two possible situations: (1) The relative Σ-Λ parity is even, but the coupling strengths of Λ and Σ particles to K mesons and nucleons differ (in order to avoid the selection rules of the DA). (2) The relative Σ-Λ parity is odd (in this case the above coupling strengths are also likely to differ).[19,20] The presently indicated degree of parity conservation in associated production and K^- absorption[21,22] would seem to preclude the existence of comparably strong interactions in (II) which, taken together with the interactions in (I), did not conserve parity. However, terms in (II) with coupling constants an order of magnitude or more smaller than the pion-nucleon coupling are not necessarily precluded. For example, in the case of even relative Σ-Λ parity, a scalar coupling of Λ to Σ and π would give rise to parity-nonconserving effects in interference with the interactions in (I). Since in certain processes such relatively weak couplings might interfere more effectively with the effects induced by the interactions in (I), it would seem useful to consider experimentally a variety of further processes involving strange particles in discussing the possibility of parity-nonconserving effects. Such processes as the following might further probe the interactions in (II):

$$\Sigma^- + p \to \Lambda + n, \qquad \Xi^- + p \to \Lambda + \Lambda,$$
$$\Sigma^- + p \to \Sigma^- + p, \qquad K^- + p \to \Xi^- + K^+,$$
$$\Xi^- + p \to \Xi^- + p. \tag{4}$$

The elastic and inelastic hyperon-nucleon interactions with small momentum transfer may be particularly sensitive to the single pion exchange and thus to the nature of the pion-hyperon couplings.[14] Without the introduction of quadrilinear interactions of various sorts, whose purpose is to distort the hypothesized very high symmetry of the Yukawa-type meson-baryon interactions (for which there is, at present, no experimental support), there is yet much room within the limits of our very scant knowledge of the Yukawa-type interactions, in group (II) in particular, for possible small effects of parity nonconservation. If the conservation of parity in the strong interactions is indeed a rigorous invariance, it may not be necessary to "explain" it in terms of other specially constructed symmetries of the Hamiltonian, unless experiments give indication of the presence of these latter symmetries in at least as convincing a manner as they indicate the charge independence of the pion-nucleon system in the absence of electromagnetic effects.

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STRONG-COUPLING THEORY OF THE $S=-1$ HYPERONS: THE Λ^0 AS A BOUND STATE*

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It has always appeared to be an attractive idea to eliminate some of the hyperons by considering them to be bound states.[1] We have tried a variant of this idea: suppose that the strangeness-producing interaction (perhaps that of the K mesons with nucleons) were to produce different core particles and that the pion interactions produced whatever additional multiplicity were present within the different strangeness subspaces.

Thus, restricting ourselves to linear charge-independent pion interactions, for the $S=-1$ case, we consider the interaction of pseudoscalar pions with an isotopic spin-one baryon core in the static approximation (a $T=0$ core would require a quadratic interaction with pions); we shall treat this system in the strong-coupling approximation which has been recently extended to treat cases of this type.[2] Further, we assume that the parameters to be used are the same as those used in the nucleon case: this may be viewed as an extension of global symmetry.

The interaction Hamiltonian is taken to be

$$H_1 = \frac{2g}{\kappa}(2\pi)^{\frac{1}{2}} \int d^3x\; T_\alpha \phi_\alpha\; \vec{\sigma}\cdot\vec{\nabla} U,$$

where κ is the π mass, T_α the 3×3 spin-one matrices (the factor of two is necessary to achieve correspondence with the nucleon case since τ_α is used rather than $\tau_\alpha/2$, the nucleon isotopic spin). We then find a band structure as in the nucleon case: for the $y=\frac{1}{2}$ band with $\vec{Y}=\vec{T}+\vec{J}$ (the vector sum of the isotopic spin and total angular momentum), the levels above the ground state are given by

$$E_{jt} = \frac{27}{64}\left(\frac{j(j+1)+t(t+1)-\frac{3}{4}}{g^2/\kappa a}\right)\kappa,$$

and $|(j-t)| \leq \frac{1}{2} \leq j+t$, j is half-odd integral, t is integral. Thus the ground state is $j=\frac{1}{2}$, $t=0$, the next state $t=1$, $j=\frac{1}{2}$, and the next above that $t=1$,