In the opposite case low-intensity rarefaction shock waves are possible if

$$\left(\frac{E_{\parallel}}{E_{\perp}}\right)^2 > \frac{V^2}{|P_2 - P_1|}(\epsilon_1 + \epsilon_2)\left|\frac{\partial\epsilon}{\partial\rho}\right|^{-1}\left|\frac{\partial V}{\partial P}\right|^{-1}.$$

We note that (1) and (3) show that the electric field becomes stronger in a rarefaction shock wave and weaker in a compression wave. The latter is simplest to understand by analyzing the case $E_{\perp} = 0$, in which we can see, from the condition for the continuity of $D_{\parallel}$, that the ratio of E on the two sides of the continuity is the inverse of the ratio of $\epsilon(\rho)$. With decreasing (increasing) ρ, ϵ also decreases (increases) in a rarefaction (compression) wave, and this leads to an increase (decrease) of the electric field.

The author thanks A. I. Saet for a discussion of the result.

[1] L. D. Landau and E. M. Lifshitz, Elektrodinamika sployshnykh sred (Electrodynamics of Continuous Media), Fizmatgiz, 1959.
[2] L. D. Landau and E. M. Lifshitz, Mekhanika sploshnykh sred (Mechanics of Continuous Media), Fizmatgiz, 1956.
[3] L. D. Landau and E. M. Lifshitz, Teoriya polya (Field Theory), Fizmatgiz, 1965.
[4] A. A. Ansel'm, JETP 14, 364 (1944).
[5] P. W. Bridgman, The Physics of High Pressure, Bell, 1931.
[6] L. Bergmann, Ultrasonics and Their Scientific and Technical Applications, Bell, 1938.

THE $\Sigma^+ \to p\gamma$ DECAY

V. I. Zakharov and A. B. Kaidalov
Submitted 22 June 1966
ZhETF Pis'ma 4, No. 7, 273-276, 1 October 1966

We calculate in this letter the imaginary amplitude of the $\Sigma^+ \to p\gamma$ decay, an amplitude connected with the existence of real intermediate states $\Sigma^+ \to n\pi^+(p\pi^0) \to p\gamma$ [1]. The result is discussed from three different points of view: the possibility of obtaining information on the mechanism of the $\Sigma^+ \to n\pi^+$ decay from the study of the $\Sigma^+ \to p\gamma$ decay, the degree of violation of unitary symmetry in the $\Sigma^+ \to p\gamma$ decay, and the possible magnitude of the difference in the probabilities of the decays $\Sigma^+ \to p\gamma$ and $\overline{\Sigma^+} \to \bar{p}\gamma$ in the case when CP invariance is strongly violated in strangeness-changing electromagnetic transitions.

1. The magnitude of the imaginary part depends strongly on whether the $\Sigma^+ \to n\pi^+$ decay proceeds via an s- or a p-wave. This is connected with the fact that the largest of all the amplitudes of pion photoproduction on a proton with total angular momentum I = 1/2 is the s-wave amplitude in the production of charged mesons $\gamma p \to n\pi^+$.

If the s-wave is large in the $\Sigma^+ \to n\pi^+$ decay, then

$$W^s_{\min} = (1.95 \pm 0.25) \times 10^{-3}. \qquad (1)$$

If the p-wave is large in the $\Sigma^+ \to n\pi^+$ decay, then

$$W^p_{min} = (1.4 \pm 0.8) \times 10^{-4}, \tag{2}$$

where W_{min} is the probability of the $\Sigma^+ \to p\gamma$ decay with Re $M(\Sigma^+ \to p\gamma) = 0$ in units of the probability of the $\Sigma^+ \to n\pi^+$ decay. In calculating (1) and (2) we used the phase-shift analysis of photoproduction reported by Nelipa [2] and the customary assumptions concerning the $\Sigma \to N\pi$ decays [3].

If it turns out experimentally that $W_{exp} < W^s_{min}$, this means that the $\Sigma^+ \to n\pi^+$ decay proceeds via a p-wave. At the present time the experimental data are quite uncertain, for different measurements lead to results ranging from ~1 x 10^{-3} to 3.7 x 10^{-3} (detailed references can be found in [4]).

If $W^s_{min} < W_{exp}$, then limitations arise on the possible value of the "up-down" symmetry of γ-quantum emission in the decay of polarized hyperons.

The matrix element of the $\Sigma^+ \to p\gamma$ decay is

$$M(\Sigma^+ \to p\gamma) = \varphi^+_p\{iA(\vec{\sigma}\cdot\vec{e}) + B\vec{\sigma}\cdot[\vec{n} \times \vec{e}]\}\varphi_\Sigma,$$

where $\vec{n}$ is a unit vector in the γ-quantum momentum direction and $\vec{e}$ is the γ-quantum polarization vector.

The parameter α is defined in terms of A and B as

$$\alpha = \frac{2\mathrm{Re}(A^*B)}{(|A|^2 + |B|^2)}$$

and its possible limits are

$$-1 + \frac{W^s_{min}}{W_{exp}} \leq \alpha - \frac{2\ \mathrm{Im}\ A\ \mathrm{Im}\ B}{W_{exp}} \leq 1 - \frac{W^s_{min}}{W_{exp}}\ . \tag{3}$$

The advisability of verifying (3) depends on the degree to which W_{exp} is close to W^s_{min}.

2. In the unitary-symmetry limit, the masses of Σ^+ and p are equal, the matrix element is hermitian, and the imaginary part is equal to zero. Expressions (1) and (2) can be approximately written

$$W_{min} \approx \sigma^+_{ph}/2\pi \quad \frac{a^2}{a^2 + b^2}(\Delta m)^2,$$

where σ^+_{ph} is the cross section for the production of π^+ on the proton, Δm the mass difference between Σ^+ and p, and a and b are amplitudes of the s- and p-waves in the $\Sigma^+ \to n\pi^+$ decay. Since $\sigma^+_{ph} \sim \alpha/\mu^2$ (~10^{-28} cm^2), where μ is the pion mass, we have

$$W_{min} \approx \frac{\alpha}{2\pi}\left(\frac{\Delta m}{\mu}\right)^2 \frac{a^2}{a^2 + b^2} \qquad (\alpha = 1/137),$$

i.e., the parameter for violation of unitary symmetry in the $\Sigma^+ \to p\gamma$ decay is, generally speaking, the ratio $\Delta m/\mu$ and not $\Delta m/M$, where M is the mass of the nucleon or of even heavier particles (quarks), as is customarily assumed.

If $a \approx 0$, then the imaginary part is relatively small. This circumstance, however, is "accidental" with respect to unitary symmetry. In particular, in other radiative decays such as $\Lambda \to n\gamma$ and $\Xi^- \to \Sigma^-\gamma$, where the s-wave predominates in the main non-leptonic decays, there are no grounds for assuming that the violation of SU(3) is small.

3. It was assumed above that CP invariance is conserved in weak interaction at least with accuracy of α. Several models have been recently proposed [5], in which CP invariance is strongly broken (~ 1) only in weak electromagnetic transitions. The comparison of the probabilities of the decays $\Sigma^+ \to p\gamma$ and $\overline{\Sigma^+} \to \bar{p}\gamma$ is one of the possible experiments with which to check on these models.

The difference between these probabilities is due to "interference" between the CP-even imaginary part obtained above and the CP-odd imaginary part. Using (1) and (2) and assuming that the probability of the $\Sigma^+ \to p\gamma$ decay is 3.7×10^{-3}, we can obtain the following limitations on the possible difference between the probabilities of the decays $\Sigma^+ \to p\gamma$ and $\overline{\Sigma^+} \to \bar{p}\gamma$:

$$0 \le r \le 6.5, \tag{4}$$

if the s-wave is large in the $\Sigma^+ \to n\pi^+$ decay, and

$$0.35 \le r \le 2 \tag{5}$$

if the p-wave is large in the $\Sigma^+ \to n\pi^+$ decay, with $r = W(\overline{\Sigma^+} \to \bar{p}\gamma)/W(\Sigma^+ \to p\gamma)$.

It follows from (4) and (5) that this difference can be appreciable.

The authors thank I. Yu. Kobzarev and L. B. Okun' for continuous interest in the work and I. Ya. Pomeranchuk for useful discussions.

[1] M. Kawaguchi and K. Nishijima, Progr. Theor. Phys. 16, 177 (1956).

[2] N. F. Nelipa, Nucl. Phys. 61, 689 (1965).

[3] M. Gell-Mann and A. H. Rosenfeld, Ann. Rev. Nucl. Sci. 7, 407 (1958).

[4] G. Quareni et al., Nuovo Cimento 40, 928 (1965).

[5] B. A. Arbuzov and A. T. Filippov, Phys. Lett. 20, 537 (1966).

Erratum

In the article by D. A. Kirzhnits and M. A. Livshitz, Vol. 4, No. 2, p. 46, line 24, should read: "Kirzhnits [4] obtained..." in lieu of "Landau [3] obtained..."