REMARKS CONCERNING C-INVARIANCE VERIFICATION IN EXPERIMENTS WITH COLLIDING e^+e^- BEAMS

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1. Baier [1] and Pais and Treiman [2] proposed to verify C-invariance in hadron production reactions accompanying e^+e^- collisions. If we confine ourselves to the case of self-conjugate final states, then in the absence of polarization of the initial particles, C invariance should lead to the following relation for the differential cross sections of the process of annihilation of an electron-positron pair into hadrons, summed over the polarizations of the final particles, regardless of the approximation in α,

$$d\sigma(p, k_i) = d\sigma(-p, k_i').$$ (1)

Here $\vec{p}$ is the electron c.m.s. momentum, $\vec{k}_i$ the momentum of the final particle f_i, and $\vec{k}_i'$ the momentum of the particle f_i that is charge-conjugate to the particle f_i.

The most rigorous verification of C invariance would be an experimental investigation of Eq. (1). More realistic, however, is an analysis of the cross sections integrated over the momenta of all the final particles, with the exception of the momenta $\vec{k}$ and $\vec{k}'$, corresponding to the given particle and its antiparticle [2]. If the number of particles in the final state is n > 3, then these cross sections depend on five independent variables: the particle and antiparticle energies E and $\bar{E}$, $z = \cos\theta$, $\bar{z} = \cos\bar{\theta}$ (where θ is the angle between $\vec{p}$ and $\vec{k}$ and $\bar{\theta}$ the angle between $\vec{p}$ and $\vec{k}'$), and ϕ, the azimuthal angle between the planes $(\vec{p}, \vec{k})$ and $(\vec{p}, \vec{k}')$[1]).

In this case, C-invariance leads to the relation [2]

$$d\sigma(E, \bar{E}, z, \bar{z}, \cos\phi) = d\sigma(\bar{E}, E, -\bar{z}, -z, \cos\phi).$$ (2)

2. In [3], Pais and Treiman considered the question of verifying C invariance in pp and e^+e^- annihilation in the case when the initial particles are polarized. We note that the question of allowance for polarization of the initial particles in electron-positron collisions is of considerable interest, since the radiation in prolonged motion in the magnetic field of storage rings can lead to the occurrence of transverse polarization of the electrons and positrons [4, 5]. As shown in [3], in the one-photon approximation, when the annihilation occurs only from the triplet state, all the results of [2], and particularly formulas such as (1) and (2), hold regardless of the polarization state of the initial particles. The authors have assumed, however, that owing to the corrections to the single-photon approximation, with accuracy up to 1%, these relations do not hold, and they have therefore considered the cross sections averaged over the angle ϕ for the case n > 3 (formulas (7) and (8) of [3]). Formulas (1) and (2), in the opinion of the authors of [3], are suitable for the case n = 3 (e.g., $e^+e^- \to \pi^+\pi^-\pi^0$, $e^+e^- \to kk\pi^0$) with polarized initial particles only in the one-photon approximation.

3. Our remark is that by virtue of the conservation of the helicity of the ultrarelativistic electrons (γ_5 invariance of the electromagnetic interactions) [6] the annihilation occurs only from the triplet state with the projection of the angular momentum on $\vec{p}$ ± 1. Consequently, the contribution of the interference of the singlet state with the triplet state to the cross section for the process of annihilation into hadrons is of the order of

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[1])If n = 3, the angle ϕ is not an independent variable.

smallness $\alpha m_e/\varepsilon$ (ε – energy of initial electron (positron), m_e – electron mass), and not of the order of α as assumed by the authors of [3][2]).

Therefore formulas (1) and (2) can be used, with the indicated accuracy, to verify C-invariance in the annihilation of a polarized electron-positron pair (including the case n = 3). This circumstance may be important from the experimental point of view. The differential cross section of the process of e^+e^- annihilation into hadrons, summed over the polarizations of the final particles, accurate to terms $\sim m_e/\varepsilon$, can be written in the c.m.s. in the form

$$d\sigma_{\zeta^{(1)}\zeta^{(2)}} = d\sigma_0 (1 + \zeta_3^{(1)}\zeta_3^{(2)}) + a_1(\zeta_3^{(1)} + \zeta_3^{(2)}) +$$
$$+ a_2(\zeta_1^{(1)}\zeta_1^{(2)} - \zeta_2^{(1)}\zeta_2^{(2)}) + a_3[\zeta_1^{(1)}\zeta_2^{(2)} + \zeta_2^{(1)}\zeta_1^{(2)}]. \tag{3}$$

Here $d\sigma_0$ is the differential cross section of the processes with unpolarized initial particles, $\vec{\zeta}^{(1)}$ ($\vec{\zeta}^{(2)}$) is the electron (positron) polarization vector, a_i are real functions, $a_i = a_i(p, k_i)$ or $a_i = a_i(E, \bar{E}, z, \bar{z}, \cos\phi)$, and the z axis is directed along the electron momentum.

By virtue of C invariance, in analogy with (1) and (2), we obtain for a_i the relations

$$a_i(p, k_i) = a_i(-p, k_i'), \tag{4}$$
$$a_i(E, \bar{E}, z, \bar{z}\phi) = a_i(\bar{E}, E, -\bar{z}, -z\phi). \tag{5}$$

If the momenta $\vec{k}$ and $\vec{k}'$ lie in the zy plane, then it follows from invariance against reflections of the x axis that

$$a_{1,3} = 0. \tag{6}$$

the quantities $d\sigma_0$ and a_i satisfy in the single-photon approximation the relations (5), (7), and (8) of [2].

4. Vainshtein and Khriplovich [7], considering the question of production of resonances with positive charge parity in colliding-beam experiments, have shown that the charge asymmetry in the angular distribution in the reaction $e^+e^- \to \pi^+\pi^-$ at a total energy 2ε equal to the mass of the f meson ($I^{pc} = 2^{++}$) can reach 20%. Our remark is that if CP invariance holds then the influence of the resonances with positive charge parity, but with CP parity equal to -1 (these may be, e.g., the resonances A1 (1070), A3 (1640), in the case $I^{pc} = 2^{-+}$, which is not excluded experimentally [8]) on the behavior of the cross section $e^+e^- \to 3\pi$ at energies equal to the masses of these resonances can be neglected. In fact, accurate to terms (m_e/ε), the initial state is CP-even [9], and in the case when the CP invariance holds, production of resonances with CP = -1 is forbidden. We note also that by virtue of helicity conservation, production of resonances with I = 0 in colliding-beam experiments is forbidden with accuracy $(m_e/\varepsilon)^2$. For the same reason, decays of the resonances with CP = -1 or I = 0 into e^+e^- and $\mu^+\mu^-$ pairs are subject to additional hindrance (proportional to $(m_\mu/M)^2$, where M is the resonance mass).

[2])The quantities $X^{(-)}$ and $X^{(+)}$ of [3] are related by the equation $X^{(-)} \sim \alpha m_e/\varepsilon X^{(+)}$.

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COOPERATIVE TUNNEL EFFECT IN CRYSTALS

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In crystals consisting of one-dimensional molecular chains, alternation of the internuclear distances can occur both as the result of configuration instability and as a consequence of the energy features of the packing of the molecules in the crystal.

The purpose of the present paper is to show that in systems of this type, when the three-dimensional interaction is important, one can observe the effect of ordered localization of the electrons over the atomic centers; this effect is due to a cooperative process. If each center of the chain supplies the system with one electron, then ordered localization of electron pairs may arise[1].

We separate in the crystal an infinite chain $(A)_\infty$ consisting of weakly-coupled groups of atoms (complexes) A, which supply one electron for the formation of the bond in the chain. The real potential function of the chain V will be approximated by a one-dimensional potential V' (see the figure), which separates a pair of complexes A-A with a tunneling pair of electrons. Such an approximation is natural and is the limiting case of alternation. The exchange interaction between the electron pairs will be taken into account later. To describe the electron system V', we use the quasispin formalism proposed by
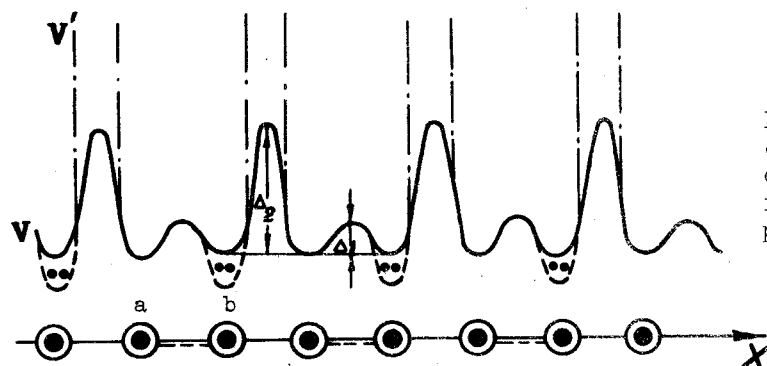
Potential curve for a polyene chain $(A)_\infty$. The dashed line denotes the potential curve in the case of a cooperative process.

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[1] In the case when two neighboring centers deliver to the system one electron, ordered localization of one electron will take place.