*CONSERVATION OF COMBINED PARITY AS A FUNDAMENTAL SYMMETRY LAW OF NATURE**

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Usp. Fiz. Nauk 68, 159-163 (May, 1959)

THE various properties of space-time are expressed in physics in the form of fundamental laws. Thus the homogeneity of space-time in the absence of gravity leads to the laws of conservation of energy, momentum, and angular momentum. The fundamental principle of the special theory of relativity-invariance of the laws of physics under proper Lorentz transformations — reflects another property of space-time. The requirement of invariance under inversion of the space and time coordinates also reflects a property of space-time. We note that the restrictions imposed on field theory by the most general properties of space-time ought to be the same for all types of interactions.

Let us consider in more detail the requirements of invariance under the inversion of space and time coordinates, and also under the operation of charge conjugation. As is well-known, experiments suggested by Lee and Yang[1] have shown that space parity P is not conserved in weak interactions. So the question arises as to what the symmetry properties of space-time actually are. At first it was attempted to make the neutrino responsible for parity nonconservation in weak interactions. These attempts failed when it was discovered that parity is not conserved in many neutrinoless decays of elementary particles. It was pointed out by Landau,[2] and Lee and Yang[5] that combined parity is conserved in weak interactions. The proposal of Landau[2] consisted of the assumption that space is symmetric and the asymmetry found is due to the particles, or better, to their electric charge. However this separation of the properties of the particles from those of space is not convincing. Thus, the properties of space-time manifest themselves in the form of a restriction imposed on the velocity of motion of all particles. In the same manner, it seems to us, the properties of space-time are mirrored in the transformation properties of the operators describing elementary particles. Complex units exist in nature which do not satisfy the requirements of invariance under space inversion. In connection with this statement, it seems appropriate to relate the properties of space-time under inversion to the properties of the elementary particles, namely: at each stage of development the properties of space-time under inversion manifest themselves in the behavior of those particles which, at that stage of development, are considered to be elementary ones.

It follows from this approach that parity nonconservation in weak interactions implies that space-time is not symmetric under inversion of space coordinates. In view of this the law of conservation of combined parity should be considered as the fundamental symmetry law of nature; i.e., all theories should be invariant under the transformation of combined inversion. Originally[3,4] this law was formulated as the hypothesis that only combined parity is conserved in strong, electromagnetic, and weak interactions.

The combined inversion transformation PC consists of the operation of inversion of space coordinates P, and the transformation of particle into antiparticle C. It follows from the Pauli-Lüders theorem that quantities invariant under combined inversion are also invariant under the operation of time reversal. Consequently the fundamental symmetry law of nature may be formulated as the law of invariance of the theory under time reversal (in the Wigner sense).

Before discussing the question of parity conservation in strong interactions, let us note a peculiarity of the mathematical apparatus describing elementary particles. The strong interaction Lagrangians of mesons and baryons, assuming the validity of the Gell-Mann and Nishijima classification of elementary particles, may be divided into two classes.[6] In the first class we put all those interactions which contain at least one vertex at which the fermion does not change any of its characteristics (mass, electric charge, strangeness). All interactions of π mesons with nucleons and π mesons with Ξ hyperons (and also electromagnetic interactions) belong here. In the second class we put those interactions which contain only vertices at which the fermion changes at least one

*Report at the All-Union Conference on Quantum Field Theory and Elementary Particles Theory in Uzhgorod, October 3, 1958.

of its characteristics (mass, electric charge, strangeness). Interactions of π mesons with Λ and Σ hyperons as well as all interactions of K mesons with baryons belong here. The form of the interaction Lagrangian for the first class is determined by the behavior of the field operators under the operations P and PC (or T), whereas for the second class it is fully determined by the behavior of the field operators under the operation P alone.

The basic assumption of our concept may be formulated as follows: the law of conservation of combined parity reflects the fundamental properties of space-time. Conservation of space parity for specific interactions is a consequence of additional invariance requirements. Indeed, it has been shown[3,4,7] that for quantum electrodynamics invariance under space inversion is a consequence of the requirements of invariance under combined inversion PC and under gauge transformations. By this precept parity conservation for renormalizable electromagnetic interactions follows from the law of conservation of electric charge.*

For renormalizable pseudoscalar or scalar meson theory, it has been shown[3,4,7,11] that invariance under space inversion P follows from the requirement of invariance under combined inversion PC and from isotopic invariance. In this way parity conservation in meson theories is a consequence of the hypothesis of charge independence.

It has further been shown[9,4] that the requirement of invariance under combined inversion PC of a renormalizable and isotopic invariant Lagrangian for the K-meson—baryon and the $\Sigma\pi\Lambda$ interactions does not lead to parity conservation. Thus the requirements of PC and isotopic invariance lead to parity conservation for interaction Lagrangians of the first class, and do not lead to parity conservation for interaction Lagrangians of the second class. It is quite possible that it will be necessary to introduce some additional invariance requirements which will lead to parity conservation for specific Lagrangians of the second class. We note that a renormalizable Lagrangian describing the interaction of baryons and mesons which is invariant under combined inversion is unique. Indeed, since the behavior of the π-meson field operator under PC is known, the terms of the interaction Lagrangian belonging to the first class are fully determined; and for interactions belonging to the second class there exists only one form of interaction Lagrangian which is invariant under PC.

We limit our considerations to the case of renormalizable theories. It must be noted that the division of interaction Lagrangians into renormalizable and nonrenormalizable parts is based on a series expansion of the S matrix in powers of the coupling constant. However, as is well-known,[10] there is a significant physical difference between renormalizable and nonrenormalizable theories, since the interaction Lagrangian of nonrenormalizable theories represents a "truncated" nonlocal interaction expressed in the form of a local interaction.

In the study of parity nonconservation in strong interactions by analyzing baryon-meson collisions, one must keep in mind that the effect due to strong interactions must be larger than the parity nonconserving contribution from virtual processes involving weak interactions. Since we follow the classification of interactions given by Gell-Mann, the example of Zel'dovich[8] is not a case of parity nonconservation in electromagnetic interactions, but is, from our point of view, an illustration of the effect of virtual weak interaction processes on the electromagnetic interaction.

Let us now discuss the problem of experimental verification of parity nonconservation in strong interactions. Isotopic invariance leads to parity conservation when applied to PC-invariant interaction Lagrangians of the first class. We therefore consider first the interactions of those particles whose interaction Lagrangians belong to the second class. To verify parity conservation in the production of K mesons and hyperons we consider the process $\pi + N \rightarrow K + Y$ followed by the decay $Y \rightarrow N + \pi$ (Y is either a Λ or Σ hyperon). It has been shown[12] that if parity is not conserved in the production of K mesons and hyperons, then a longitudinal component may appear in the hyperon polarization vector. This could lead to an asymmetry in the distribution of the π mesons produced in the hyperon decay (in the center of mass system) with respect to a plane perpendicular to the production plane and passing through the direction of motion of the incident π meson, as well as with respect to a plane perpendicular to the production plane and perpendicular to the direction of motion of the incident π meson. Furthermore,[12,13] if the hyperon is longitudinally polarized, then an asymmetry should appear with respect to at least one of the above-mentioned planes.*

*We note that Zel'dovich[8] refers to a nonrenormalizable interaction.

*The author is grateful to Prof. Drell for sending a preprint and for communicating his ideas on the question of PC conservation.

An analysis of the experimental data[14] and a study[15] of the above mentioned asymmetry in the reaction $\pi^- + p \rightarrow \Lambda^0 + K^0$ at 1.1 Bev performed by the Berkeley bubble chamber group* did not reveal parity nonconservation in the production of K mesons and hyperons, however, the experimental accuracy was quite low. In connection with these experiments it should be noted that since nothing is known about the longitudinal polarization (if it exists), it is possible that it varies (in magnitude and in sign) with the hyperon production angle, and thus the effect is washed out when an angular integration is performed. It would therefore be of interest to study this process in a narrow interval of hyperon production angle. Of analogous interest are the reactions

$$K^- + p \rightarrow Y + \pi, \quad \Sigma^- + p \rightarrow \Lambda + n$$

and others.

A study of the reaction[16]

$$\pi^- + p \rightarrow \Sigma^- + K^+ + \pi^0.$$

is quite promising. If parity is not conserved in the production of K mesons and hyperons then there will be an asymmetry in the K-meson distribution with respect to a plane passing (in the center of mass system) through the directions of motion of the incident π meson and of the hyperon. The advantage of this, and the analogous reactions

$$K^- + d \rightarrow p + \Lambda^0 + \pi^-, \quad \pi^- + p \rightarrow Y^0 + K^+ + \pi^-$$

lies in the fact that the asymmetry does not depend on longitudinal polarization. It is possible that parity nonconservation will appear at very high energies, when three or more mesons are produced.

A more detailed study of parity nonconservation was carried out by scattering polarized nucleons on nucleons and nuclei. The analysis by Heer et al[17] of the polarization experiment of Chamberlain et al[18] shows that the quantity F^2, which characterizes the degree of parity nonconservation, is less than or equal to 3×10^{-2}. Jones et al[19] found $F^2 \leq 3.6 \times 10^{-6}$ by measuring the longitudinal polarization of a neutron beam of 350 Mev. Heer et al[17] found $F^2 \leq 2 \times 10^{-3}$ by studying parity nonconservation in the production of π^+ mesons on aluminum by polarized 209-Mev protons. Parity conservation was verified much more accurately in nuclear reactions. Thus Tanner[20] found $F^2 \leq 4 \times 10^{-8}$ and Wilkinson[21] determined $F^2 \leq 1 \times 10^{-7}$ on the average from several reactions.

*The author is grateful to Prof. Steinberger and Prof. Good for sending preliminary results of the measurements.

If isotopic invariance is valid then parity nonconservation in nucleon-nucleon collisions and in nuclear reactions can appear as a consequence of virtual processes involving K mesons and hyperons and as a consequence of nonlocal interactions. It follows from the estimate of Drell et al[13] that the contribution of K-meson forces to the nucleon-nucleon potential is small, and therefore (to a high degree of accuracy) parity conservation in nucleon-nucleon interactions does not imply parity conservation for processes involving K mesons and hyperons (i.e., for interaction Lagrangians of the second class).

In conclusion we note that the experimental discovery of parity nonconservation in strong interactions described by Lagrangians of the second class would not only validate the ideas outlined above, but would also contribute to a deeper penetration of the mysteries of nature. For example, the appearance of parity nonconservation in pion-nucleon scattering would indicate either a violation of the charge independence hypothesis or the existence of a nonlocal interaction. Also the appearance of parity nonconservation in nucleon-nucleon interactions would in addition make possible an estimate of the contribution of K-meson—hyperon forces.

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Translated by A. M. Bincer