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SOME EXPERIMENTAL TESTS OF THE LUDERS THEOREM

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ABSTRACT

Some experimental consequences of the Luders theorem are discussed.

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SOME EXPERIMENTAL TESTS OF THE LUDERS THEOREM

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The recently observed violations of the principle of symmetry under space and space-time inversions may be easily accommodated in the existing theoretical framework by the readmission of various interaction terms or by the suppression of certain states. The violations of these symmetry principles may, however, signify a more fundamental defect in the current form of physical theory. In view of the conclusions of Landau and Pomeranchuk[1] and of the prevailing sentiment that the renormalization procedures are fundamentally unsatisfactory, the failure of the spatial symmetries casts an additional suspicion upon the current treatment of the space-time point.[2]

A recent theorem of Luders shows that for the usual types of field theory the product of time reversal (T), charge conjugation (C), and space inversion (P) must be a valid symmetry operation. As the validity of the usual treatment of the space-time point is assumed in the proof of this theorem, an inadequacy of the treatment may be reflected in a failure of the theorem. Regardless of the validity of the present treatment of space and time, a demonstrated violation of the Luders theorem would be of considerable theoretical importance, as it would imply the nonvalidity of at least one of the fundamental precepts of current physical theory.

Direct experimental tests of the Luders theorem are difficult because the two processes directly related by the theorem are time inverses of each other, and the time inverse of a weak (decay) process is not easily performed. If, however, the weak interaction is effective only in first order, the need for observing the time-inverse process may be circumvented by an appeal to the principle of detailed balance.[3] The Luders theorem in conjunction with the principle of detailed balance allows one to equate the transition rate for the process $\alpha \longrightarrow \beta$ to the transition rate for $\tilde{\alpha} \longrightarrow \tilde{\beta}$, where α and β represent eigenstates of the strong interactions and $\tilde{\alpha}$ and $\tilde{\beta}$ represent the corresponding CPT-inverse states. If the final states may be chosen as plane-wave states (i.e., if these are eigenstates of the strong reactions) then the CPT-inverse of a state is a state with the same momentum but with opposite spin and charge (more precisely a particle is changed to its antiparticle and its spin is reversed). A number of consequences of the Luders theorem may be immediately deduced. One of these is the equality of the reaction rates of the processes $\pi^+ \longrightarrow \mu^+ + \nu$ and $\pi^- \longrightarrow \mu^- + \nu$. Similarily the reaction rates of the two processes $\mu^\pm \longrightarrow e^\pm + \nu$ must be equal. These results have been obtained somewhat less directly by Lee, Oehme, and Yang.[4] Additional consequences are easily obtained. In particular the polarizations (spin expectation values) of the μ^+ and μ^- produced in the decay at rest of π^+ and π^- must be equal but opposite if the Luders theorem is valid. This result may be distinguished from the consequences of invariance under charge conjugation. If this latter invariance is maintained, one again finds the equality of the reaction rates for the two charge states, but the polarizations of the μ^+ and μ^- must now be

equal both in magnitude and in direction. A measurement of the relative polarizations of the μ^+ and μ^- produced from the decay of π^+ and π^- would therefore permit a decision as to whether it is invariance under C or under CPT that is preserved in the weak interactions[5] or whether both are violated.

Similar conclusions may be obtained from the measurement of the angular distributions and polarizations of the $e^{\pm}$ produced from the decay of polarized $\mu^{\pm}$. If the spins of the μ^+ and μ^- are oppositely aligned and CPT-invariance is maintained, then the angular distributions of the e^+ and e^- will be the same but their polarizations will be opposite. On the other hand, if charge-conjugation invariance is maintained and if the spins of the μ^+ and μ^- are aligned (as they would be if charge conjugation invariance were maintained in the production of the μ^+ and μ^- in $\pi^{\pm}$ decay), then the angular distribution of the e^+ and e^- would be identical, but their polarizations would be the same in both direction and magnitude.

The decay of long-lived neutral K particles (assumed unpolarized or of spin zero) can be analyzed in a similar way. If charge-conjugation invariance were maintained the long-lived K_0 would be an eigenstate of charge conjugation and would be its own charge-conjugate state. This would imply the equality of the reaction rates into any two final states that are charge conjugates of each other. (It is assumed that the short-lived component has decayed and therefore gives no interference effects.) The polarization of the μ^+ and μ^- obtained from the decay of the long-lived neutral K will therefore be the same in both sign

and magnitude if charge conjugation is maintained. If, on the other hand, the reaction is invariant under the product of charge conjugation and space inversion (i.e., under CP), as has been frequently suggested, then the components of polarizations of the μ^+ and μ^- that lie in the plane of production must be equal but opposite; the components of polarization perpendicular to the production plane must be equal both in sign and in magnitude. If in addition to CP invariance there is also invariance under CPT, then time-reversal invariance is required and, to the extent that final-state interactions are negligible, the components of polarization perpendicular to the plane of scattering must vanish.

Invariance under CPT, together with the assumption that the short lifetime of the neutral K^o is very small in comparison with the long lifetime, allows one to consider the long-lived K^o particle to be its own CPT-inverse. The transition rates into any two final states that are CPT-inverses of each other will then be equal and the polarizations of final μ^+ and μ^- must consequently be equal but opposite.

REFERENCES

1. L. D. Landau, Niels Bohr and the Development of Physics (McGraw-Hill, New York, 1955).

2. The role of the space-time point in current theories is that of an elementary unanalyzable parameter which provides the framework in which the theory is set. This may be distinguished from alternative treatments in which, for instance, space-time separations emerge as well-defined quantities only in a limiting case, much as the notions of simultaneity in time and simultaneous position and momentum become valid only in the classical limit of the relativistic quantum theory.

3. J. Blatt and V. Weisskopf, Theoretical Nuclear Physics (Wiley, New York, 1952).

4. T. D. Lee, R. Oehme, and C. N. Yang (to be published in the Physical Review).

5. It is frequently stated that the parity-violating experiments have also demonstrated that charge-conjugation invariance is violated. Actually it is P and the product PT that are violated. Therefore either C or CPT is violated. It seems premature to decide in favor of CPT, particularly since CPT is more intimately associated with the somewhat suspect properties of space-time than is C.