Title
TCP AS A SPACE REFLECTION

Author
Lubkin, Elihu.

Publication Date
1959-10-20

UCRL-8957

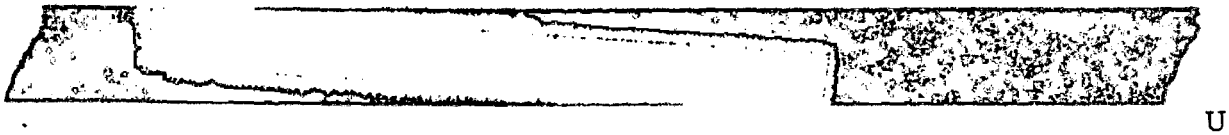
UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation Laboratory

BERKELEY, CALIFORNIA

DISCLAIMER



UCRL-8957

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

TCP AS A SPACE REFLECTION

Elihu Lubkin

October 20, 1959

Printed for the U. S. Atomic Energy Commission

UCRL-8957

TCP AS A SPACE REFLECTION*

Elihu Lubkin

Lawrence Radiation Laboratory
University of California
Berkeley, California

October 20, 1959

1.- The remark that parity conservation implies the impossibility of the experimental definition of a right-handed coordinate system was somewhat disturbing in the days before the discovery of parity nonconservation, because one would have liked to argue in the reverse direction, but one was blocked by the fallaciousness of the converse.[1] This very difficulty has been turned to advantage to show that the present experimental situation does not involve an experimental definition of a right-handed coordinate system, because the present situation is consistent with CP invariance.[2] In order to accept this conclusion, one must abandon a priori choice of sign of charge; this choice, if it is at all involved in the discussion of an experimental definition of right and left, must itself be part of the experiment.

If one oversimplifies the situation by accepting the conclusion--namely, that CP invariance be a reasonable substitute for P invariance in providing for left-right symmetry--merely on the ground that the factor P occurs once in CP, one is thereby led to the conjecture that TCP invariance alone may provide for left-right symmetry, in the sense that a theory which possesses TCP invariance must also satisfy the condition that an observer be incapable of experimentally defining a right-handed coordinate system, for indeed the factor P occurs once in TCP, as well as in P and in CP.

---

* This work was performed under the auspices of the U.S. Atomic Energy Commission.

This conclusion is valid only if one takes even greater care not to make any choice prior to the attempted experimental determination of a screw sense. In fact, one must not allow an a priori determination of a sense of time.

This may be seen most rapidly as follows. Consider a system which contains an observer, and its image under TCP. The notebooks of the TCP'ed observer will have the same text as those of the original observer; e.g., there will be no extra minus signs. But the coordinates employed by the TCP'ed observer differ objectively from those of the initial observer with regard to spatial orientation, sense of time, and sign of charge.* Consequently, for each asymmetry observed by the original observer, the objectively reversed asymmetry is seen by the TCP'ed observer, providing over-all symmetry with respect to choice of a screw sense, of a time sense, and of a sign of charge.

It is not necessary, of course, to explicitly consider time-reversed observers, and in the following the situation will be examined from the standpoint of the various asymmetries that may be seen by a single observer.

It is convenient to use proper Lorentz invariance to reduce all observables to proper Lorentz scalars. One then asks how these observables transform under pure space reflection or "parity," P; pure charge conjugation, C; and pure time reversal, T. Since these three operations commute and square to 1 in their action on the scalar observables, the operations they

---

* This comparison of the objective situations may be facilitated by considering the two relatively TCP'ed states as descriptions of only parts of a system observed by a super-observer to whom the operation does not apply.

induce on the scalar observables may be simultaneously diagonalized,* so that we may speak of eight types of proper Lorentz scalars, according to their behavior in regard to change of sign under the transformations of scalar observables induced by P, C, T. Convenient notation for these eight types of scalars is as follows: a 1+ scalar changes its sign under none of the three operations, a 1- scalar changes its sign under all of them, a P-, C-, or T- changes its sign only under the transformation induced by P, C, or T, respectively, and a P+, C+, or T+ does not change its sign under the transformation induced by P, C, or T, respectively, but does change its sign under the two other transformations.

Instead of considering the general conditions for an experimental definition of just an absolute screw sense to be impossible--a matter that is easily discussed in the present framework of the eight classes of proper Lorentz scalars--we will consider the general conditions for the impossibility of an experimental definition of either an absolute screw sense, or an absolute sign of charge, or an absolute sense of time. Bias introduced by the observer is easily eliminated by the free use of coordinate systems: thus, instead of considering a time-reversed observer, one may consider the use of a reversed time coordinate for a fixed observer.

The three impossibility conditions are then easily seen to be incompatible with the existence of a nonzero P-, C-, or T-. Since the conjoint existence of a nonzero 1- and a nonzero P+, C+, or T+ would give rise to the existence of a nonzero P-, C-, or T-, respectively, the three impossibility conditions allow either the conjoint existence of the

* Note that scalars so incomparable that they may not be added also cannot be expected to mix under an inversion operation, so that their existence does not really damage the classification argument.

nonzero types 1+, 1-, or the conjoint existence of the nonzero types 1+, P+, C+, T+. The parity asymmetries already discovered are of form T+. Therefore, the impossibility conditions and the present experimental situation limit the types to 1+, P+, C+, T+. This set coincides with that determined by the requirement of invariance under the transformation induced by TCP. Either from the previous argument using the TCP image of an observer, or from the observation that neither a P+ nor a C+ nor a T+ can determine a convention without a prior choice of another convention, one concludes that the impossibility conditions provide no further restriction on the possible types of nonzero proper Lorentz scalar observables than is imposed by TCP invariance.

That the left-right symmetry inherent in TCP invariance alone necessitates the contemplation of a time-reversed observer, or equivalently, the acceptance of coordinate systems with t running opposite to the usual sense, is easily shown in an example. Suppose a spinless particle A decays into particles B and C, and that B has spin, and is in fact totally longitudinally polarized. Further, suppose that the charge-conjugate decay involves the same longitudinal polarization of $\overline{B}$, so that CP invariance is violated. Then TCP invariance may still be maintained by allowing only the B and $\overline{B}$ particles of reverse helicity to be captured in the inverse processes $B + C \rightarrow A$, $\overline{B} + \overline{C} \rightarrow \overline{A}$. The only way to argue that a screw sense is not absolutely determined in this example is to admit the time-reversed description on a footing equal with the usual description, so that the capture reactions may be regarded as decays involving the opposite helicity.

2.- The three general indistinguishability conditions regarding screw sense, time sense, and sign of charge have been shown to impose no restriction beyond what is imposed by TCP invariance. If one seeks a general indistin-

guishability principle that rules out the possibility of nonzero P+ and C+ scalars, in conformity with the apparent validity of CP invariance, one must go beyond a requirement of left-right symmetry.

It is easy to find such a principle. The known existence of a nonzero T+ has already correlated choice of sign of charge with choice of a screw sense, so that the existence of a nonzero P+ or C+ would imply a correlation of all three choices. One may then postulate a principle of independence of choice of screw sense from choice of time sense to rule out the unobserved asymmetries.

Such a postulate may seem of questionable form, because the apparently similar postulate forbidding dependence of choice of sign of charge on choice of screw sense is wrong.

However, these two kinds of dependence are of quite different character. The charge-screw sense dependence may be viewed as an actual spatial structure of charge, in analogy to stereoisomerism in chemistry, and it may therefore be considered a welcome step in the unification of charge with space-time. But a time-screw sense dependence has no similar concretization, and would constitute, in more symmetric language, an orientation of 4-space. A rule forbidding dependence between screw sense and time sense is therefore an analogue of the rule forbidding an experimental definition of a screw sense, stepped up to four dimensions.

REFERENCES

1. The possibility of CP as a space reflection appears in the famous footnote of Wick, Wightman, and Wigner, Phys. Rev. 88, 104 (1952).

2. T. D. Lee and C. N. Yang, Phys. Rev. 105, 1671 (1957); L. Landau, Nuclear Phys. 3, 127 (1957); E. P. Wigner, Revs. Modern Phys. 29, 258 (1957).