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Spontaneous Symmetry Breaking in Local Gauge Quantum Field Theory; the Higgs Mechanism

F. Strocchi* **

Joseph Henry Laboratories of Physics, Princeton University, Princeton, New Jersey 08540, USA

Abstract. Spontaneous symmetry breakings in indefinite metric quantum field theories are analyzed and a generalization of the Goldstone theorem is proved. The case of local gauge quantum field theories is discussed in detail and a characterization is given of the occurrence of the Higgs mechanism versus the Goldstone mechanism. The Higgs phenomenon is explained on general grounds without the introduction of the so-called Higgs fields. The basic property is the relation between the local internal symmetry group and the local group of gauge transformations of the second kind. Spontaneous symmetry breaking of c-number gauge transformations of the second kind is shown to always occur if there are charged local fields. The implications about the absence of mass gap in the Wightman functions and the occurrence of massless particles associated with the unbroken generators in the Higgs phenomenon are discussed.

1. Introduction

The discovery [1] that local internal symmetries in QFT (i.e. symmetries of the equations of motion or of the Hamiltonian) may fail to give rise to global symmetries of the theory because of vacuum instability suggested a simple powerful mechanism to understand symmetry breaking in elementary particle physics. Unfortunately, it was soon realized [2] and proved [3] quite generally in the framework of axiomatic (positive metric) QFT that such a mechanism requires the existence of massless particles (Goldstone bosons) with the quantum numbers of the generator of the local internal symmetry and there does not seem to be any candidate for such particles. A genuine Goldstone mechanism is therefore excluded from elementary particle physics. Actually, the only massless boson existing in nature is the photon and it is associated with an unbroken internal symmetry (gauge transformations of the first kind).

It was later shown [4] that a spontaneous symmetry breaking may occur without implying the existence of massless particles provided one is dealing with gauge field theories (Higgs phenomenon). This is not a counterexample to the

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** On leave from Scuola Normale Superiore INFN, I-56100 Pisa, Italy