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G. Parisi: A MECHANISM FOR CONFINEMENT IN 4 DIMENSIONAL YANG MILL'S THEORY. -

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We show the existence of a mechanism for confinement of charged particles in an SU(2) invariant Yang Mill's theory in a 4 dimensional space time.

It has been recently pointed out[1,2] that in a theory where gauge invariance is spontaneously broken, as in superconductors, isolated monopoles[3] cannot exist as separate entities, only monopole-antimonopole pairs may be present. One can hope that this observation may be used to construct a realistic model in which quarks are confined in zero triality states; however a model in which the fundamental fields are monopoles is rather artificial: there seems to be no compelling reason for introducing monopoles in the Lagrangian, unless one wants to put in confinement by hand. The aim of this note is to show that it is possible to use the same mechanism in the case of a pure Yang Mill's theory.

The idea is quite simple: we consider an SU(2) invariant Yang Mill's theory in which the fundamental fields are a triplet of gauge fields (A), a doublet of fermions fields (q) and a triplet of Higg's fields (ϕ). The fermions are isospinors and Higg's fields are isovectors. We fix our attention on the case in which the SU(2) simmetry is spontaneously broken in such a way that one Higg's field has vacuum aspectation value different from zero, only one gauge particle remain massless and the other two become massive.

In this situation t'Hooft has shown[4] that one can find solutions of the classical equations of motions which behaves like monopoles respect to the massless gauge field. In the quantum case one gets a spectrum of particles carrying monopole quantum number. For semplicity we assume that the spin zero monopole is the less massive. These monopoles are bound states of Higg's and Yang Mill's fields. One can try to break spontaneously the gauge invariance with respect to the massless field and to confine the monopoles. This solution is not satisfactory: the particles we confine would not be associated to any fundamental field and they would not be fermions. On physical grounds one would like to confine the particles which appear in the Lagrangian (i. e. q). Let us see how it can be done.

In the low momenta region we can forget how the monopoles have been introduced in the theory and neglect the exchange of the two massive Yang Mill's fields. What remains is a theory of charge $\pm 1/2$ fermions, charge ± 1 vectors and scalar monopoles interacting with an abelian gauge field. It is possible that, increasing the coupling costant, the mass of the monopole decrease, become equal to zero and finally the field ψ associated to the monopole aquire a vacuum aspectation value different from zero.

The best way to understand what happens in this situation is to use Dirac's argument of duality and to interchange magnetic with electric charge: the charged particles become "monopoles" and the monopoles become "charged". Now the "monopoles" (q and A) are fundamental particles of spin 1/2 and 1, gauge invariance is spontaneously broken by the presence of a "charged" composite field ψ having a vacuum aspectation value different from zero. The presence of a Meisner effect[1], as in superconductor, implies that the "monopoles" are confined and only states carrying zero "monopole" charge have a finite energy. The number of fermions in the allowed states is always even: any number of charge 1 vectors cannot compensate the charge of an odd number of charge 1/2 fermions.

Unfortunately we are unable to controll our assumptions using perturbation theory, however their realizability remains an open possibility. The crucial hypothesis is that the t'Hooft monopole (or any object carrying monopole quantum number) become massless for a particular value of the coupling costant; increasing the coupling costant the onset of spontaneously simmetry breaking avoids the presence of negative mass particles.

It is possible that in a pure Yang Mill's theory the charged particles are confined; no massless particles or long range forces are present. The confinement is an highly non linear phenomenum and the SU(2) simmetry is badly broken.

New problems arise in the realistic case (SU(3) simmetry): all the gauge particles must remain massless without complicating to much the structure of Higg's fields. Although it is possible that this additional difficulties forbid the construction of a theory of strong interactions based on this particular mechanism, it is still interesting to study the variety of ways in which confinement may be realized in a relativistic quantum field theory.

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(4) - G. t'Hooft, Nuclear Phys. B79, 276 (1974).