Quark imprisonment and vacuum repulsion *

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(Received 25 March 1974)

We describe a classical field theory in which infinitely long-range forces are present. These forces do not stem from a direct interaction among particles. They have their origin in a rather peculiar phenomenon, which we call vacuum repulsion.

It is commonly assumed that quarks are the fundamental constituents of the hadrons.[1] However, all quark-hunting done in these last years has given negative results. A possible explanation has been suggested by Johnson[2]: Quarks cannot escape from hadrons and do not exist as free particles because they are bounded by an infinitely long-range attractive force, whose strength does not decrease with increasing distance.

Unfortunately, a force mediated by a field normally decays at large distances like $1/r^2$. Moreover, a residual long-range dipole-dipole interaction should be present between bound states. The quanta which mediate this force should be emitted in processes like π^0 decay.

The aim of this note is to present a classical field-theory model in which the Johnson suggestion is realized. In this model there are particles which attract themselves with a force which is independent of the distance at large distances; the force between bound states exponentially decreases toward infinity and no massless particles are present.

The Lagrangian density is the same as in the Higgs model[3]:

$$\mathcal{L} = \tfrac{1}{2}(\partial_\mu - ieA_\mu)\phi^\dagger(\partial^\mu + ieA^\mu)\phi + \tfrac{1}{4}(\partial_\mu A_\nu - \partial_\nu A_\mu)(\partial^\mu A^\nu - \partial^\nu A^\mu) - \tfrac{1}{2}m^2\phi^\dagger\phi - \tfrac{1}{4}g(\phi^\dagger\phi)^2, \qquad (1)$$

where ϕ and A_μ are, respectively, scalar and vector fields. Pointlike particles are also present; they are magnetic monopoles[4] with respect to the charge to which the gauge field A_μ is coupled.

Let us consider the solutions of the associated Euler-Lagrange equation when m^2 is negative and no monopoles are present. The lowest-energy solution is characterized by[5] $|\phi| = (-m^2/g)^{1/2}$; the gauge symmetry is spontaneously broken. There are no excitations whose frequency spectrum extends to zero.[6] In the quantized version of the theory no massless particles are present; the Goldstone boson disappears and the gauge field acquires a mass.

In the static situation (fixed monopoles, $\dot\phi = \dot A_\mu = 0$) the Euler-Lagrange equations reduce to the Ginzburg-Landau equations for a three-dimensional superconductor.[7] In order to have an intuitive representation of the phenomena we shall first discuss the behavior of real monopoles inside a real superconductor. The conclusions can be readily extended to the relativistic case; the Higgs vacuum has the same properties as a superconducting medium.

A distinctive feature of superconductors is the Meisner effect.[8] Weak magnetic fields are completely shielded. Strong fields are not shielded, but their presence destroys superconductivity and increases the energy density. The net effect is a repulsive force between the superconductor and any possible magnetic source.

If we place a magnetic monopole inside a superconductor, the material is not able to shield the magnetic field of the monopole. It would rather concentrate it in a string[8] which, starting from the monopole, extends to the surface. The induced currents push the monopole inside the string with a force which is independent of the distance of the monopole from the surface. In the infinite-volume limit the string is infinite and may be oriented in an arbitrary direction. The single monopole state is characterized by an infinite energy and by the spontaneous breakdown of rotational invariance; the monopole is subjected to a constant force pointing in the same direction as the associated string.

A pair of particles has a finite energy only if the string starting from one particle ends on the other particle. The energy of a sufficiently long string is proportional to its length. The two components of the pair attract each other with an asymptotically constant force. This force is not originated by a direct interaction among the particles. A constant force is always present on the isolated monopole; the other particles choose only the direction in which this force is directed. There are no zero-frequency excitations which are associated with this long-range interaction; moreover, the force among magnetically neutral systems is completely shielded by the medium and decreases exponentially at large distances.

The same type of phenomena are present also in the relativistic case. Only names must be changed in the previous argument. The same conclusions should be valid in a hopefully existing quantum version of the model[9]; they are straightforward consequences of the Meisner effect.

It is tempting to identify the magnetic monopoles with quarks and the gauge field with the gluon. The observed zero-triality structure of the physical states may be reproduced assuming the existence of three groups of quarks having, respectively, magnetic charge 2, −1, −1.[10]

Although the model described in this note has no strong unrealistic feature, it seems to be too artificial. However, it is interesting to produce at least one field-theory model in which quarks are imprisoned inside zero-triality bound states.

The author wishes to thank B. Zumino for stimulating remarks. Fruitful discussions with N. H. Christ, A. H. Mueller, and D. Zwanziger are gratefully acknowledged.

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*This research was supported by the U. S. Atomic Energy Commission.

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