LOCAL GAUGE SYMMETRY AND CONFINEMENT IN QUANTUM CHROMODYNAMICS

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A nonabelian color gauge theory of quarks and gluons has been proposed as the basis for a fundamental theory of hadrons. We would like to focus on those features of this theory , quantum chromodynamics,which lead to confinement /1/ . We will also discuss a transverse lattice formulation of the theory which we use as a basis for calculation of properties of the hadronic bound states.

Quantum chromodynamics is a theory based on local gauge invariance. In order to define the quantum theory we must make a choice of gauge as not all degrees of freedom of the gauge fields are dynamical. Physics may appear much different for gauge dependent quantities but there exist a common physical subspace for all choices of gauge. We note that a confinement picture of hadrons is necessarily gauge dependent.

In order to focus on physical quantities we must eliminate two of the form components of the vector potentials. This is most convenient in an axial gauge where the vector potentials $\vec{A}_z = 0$ and $\vec{A}_t$ is dependent. $\vec{A}_x$ and $\vec{A}_y$ are the two indepednent degrees of freedom.

The lagrangian for a nonabelian gauge theory is given by

$$\mathcal{L} = -\frac{1}{4}\vec{G}_{\mu\nu}^{2} \tag{1}$$

where

$$\vec{G}_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + g A_\mu \times A_\nu .$$

In the axial gauge, canonical quantization leads to the hamiltonian density

$$\mathcal{H} = \frac{1}{2}\vec{P}_\alpha^{\,2} + \frac{1}{2}(\partial_z \vec{A}_\alpha)^2 + \frac{1}{4}\vec{G}_{\alpha\beta}^{\,2} + \frac{1}{2} g^2 \vec{J}_0 \frac{1}{\partial_z^2}\vec{J}_0 \tag{2}$$

where $\alpha = x, y$. P_α is the conjugate momentum and J_0 is the color charge density

$$\vec{J}_0 = \frac{1}{g}\vec{D}_\alpha \vec{P}_\alpha = \frac{1}{g}\partial_\alpha \vec{P}_\alpha + \vec{A}_\alpha \times \vec{P}_\alpha . \tag{3}$$

We note that there exists a linear longitudinal potential between the color charge densities in this gauge. The hamiltonian of Eq. (2) has a residual transverse gauge symmetry generated by the conserved charges

$$Q(\Lambda) = \int dz \int dx_\perp \, \vec{P}_\alpha (\vec{D}_\alpha \Lambda) \tag{4}$$

where

$$\Lambda = \Lambda(x_\perp).$$

The question of color confinement depends duextly how this residual symmetry is realized. If the transverse gauge symmetry is spontaneously broken, the global charge "color" is not confined and the colored gluons emerge as "plasma" excitations. The linear "coulomb" potential in E(2) is screened to a I/r potential, etc. Hence perturbation theory calculation assume a broken symmetry ground state. If a second symmetric phase could also exist, the linear longitudinal potential would confine the transverse color and only color singlet states would result. In either case, the matrix elements of gauge charges between physical states is zero. We note that either phase could, in principle, result dynamically as there exists nontrivial longitudinal dynamics /2/ .

As the residual symmetry is local in $x_\perp$ we do not know how to study the symmetry phase directly in the continuum theory. Hence, we have reformulated the gauge theory on a transverse lattice where the gauge charges become the color charge at each site. The transverse gauge fields $A_{n\alpha}$ are associated with links on the lattice /3/ . The longitudinal gauge fields $A_{n\beta}$ and the quarks are associated with sites on the lattice. We note that only x and y are made discrete while z and t remain continuous.

The lagrangian of eq. (1) becomes

$$\mathcal{L} = \sum_{n\mu\nu} \left[-\frac{1}{4} \vec{G}_{\mu\nu}^{2} \right] + \sum_{n\alpha} TR \left[D_\mu M_{n\hat{\alpha}} D_\mu M^{+}_{n\hat{\alpha}} \right]$$
$$+ \sum_{n\alpha\beta} \frac{g^2}{q^2} TR \left[M_{n\hat{\alpha}} M_{n+\hat{\alpha},\beta} M^{+}_{n+\hat{\beta},\hat{\alpha}} M^{+}_{n\hat{\beta}} \right] \quad (5)$$
$$+ \sum_{n\alpha} V(M_{n\alpha})$$

where D_μ is the longitudinal covariant derivative with coupling strength, g/q and $V(M_{n\alpha})$ is a local potential chosen such that $M_{n\alpha} M^{+}_{n\alpha} = 1/g^2$ in the continuous limit. We have chosen to write the lagrangian in terms of linear degrees of freedom for the transverse gluons as we expect these to be generated in any case in the symmetrical phase [4].

We again quantize the theory by eliminating the longitudinal degrees of freedom in favour of coulomb potential. Hadrons are formed as bound states of quarks and the symmetric phase gluons.

With E.Rabinovich we are using the transverse lattice theory to compute properties of the hadronic bound states. We hope in the near future to report the results of these calculations.

References

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BOUND AND RESONANT STATES IN THE NUCLEON-ANTINUCLEON SYSTEM

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A possibility of existence of relatively long living quasinuclear states of the $N\bar{N}$ system was shown theoretically in 1969-1970 (L.N.Bogdanova, O.D.Dalkarov et al., see references in reviews [1-3]). Later the same authors have considered production of NN systems in interactions of antiprotons ($\bar{p}$) with deuterium and the electromagnetic transitions of $p\bar{p}$ atoms to the levels of the NN quasinuclear system accompanied by hard (the average energy of about 100 MeV) γ radiation with a discrete spectrum.

The starting points of the theory of quasinuclear states are a) the choise of the interaction potential of nonrelativistic N and $\bar{N}$ and b) use of the fact that the $N\bar{N}$ annihilation distances are of the order of the nucleon Compton wave-length, whereas the mean radius of the $N\bar{N}$ quasinuclear state must be of the order of the nuclear range, i.e. about 1 fm.

The $N\bar{N}$ potential for euristical calculations was represented by one of the OBEP versions satisfactory fitting the nucleon-nucleon scattering at nonrelativistic energies. The NN channel was transformed into $N\bar{N}$ channel by G conjugation. The change of the sign of the forces is determined by G-parity of the light meson which is exchanged between the interacting fermions. In the OBEP version used the π, η, ρ and ω meson exchanges are taken into account as well as the exchange by two "effective" scalar bosons (pseudoscalar and isovector) introduced in order to substitute the two and three-pion exchange disgrams.

The ω -meson exchange plays a special role in the $N\bar{N}$ interaction. The dimensionless constant of $N\bar{N}$ interaction is large (about 20). So, the sign of the $N\bar{N}$ forces corresponds to attraction, the NN forces being repulsive. The