The nature of the $G(1590)$ meson

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(Submitted 4 April 1985)
Pis'ma Zh. Eksp. Teor. Fiz. **42**, No. 7, 297–300 (10 October 1985)

The properties of the $G(1590)$ meson recently discovered at the Institute of High Energy Physics are analyzed by using a model based on the assumption that the interaction between hadrons is carried by their confined components (by the virton spinor and vector fields). The available experimental data support the assertion that the $G(1590)$ meson is a scalar gluonium.

The existence of a pure gluon state (gluonium) has recently been the subject of active discussion. The $G(1590)$ meson, which was recently discovered[1–3] at the Institute of High Energy Physics, may be the scalar 0^{++} gluonium.

The existence of the $G(1590)$ meson has been established in the study of the exclusive $\pi^- p$ reactions, in which 2η mesons are produced in the final state:

$$\pi^- p \to G\,(1590) n \to \eta\eta n .$$

The basic characteristics[1–3] of this meson are as follows: (a) the quantum numbers $I^G(J^{PC}) = 0^+(0^{++})$, the mass $m_c = (1592 \pm 25)$ MeV, and the total width $\Gamma_t = 210 \pm 40$ MeV; (b) the decays $G \to K\bar{K}$ are suppressed in comparison with $G \to \eta\eta$; and (c) the measured ratio is

$$R_{\rm exp} = \frac{\mathrm{Br}\,(G \to \eta\eta')}{\mathrm{Br}(G \to \eta\eta)} = 2.7 \pm 0.8 .$$

The simultaneous suppression of the decays of the G meson into pions and kaons is difficult to explain from the standpoint of the quark model. This phenomenon appears

 0021-3640/85/190367-05$01.00

to be reasonable, on the other hand, if it is assumed that the G meson is a bound state consisting of two gluons.[2] The decay into $\eta\eta(\eta\eta')$ mesons occurs because η and η' mesons have gluon admixtures[4] which account for the marked difference between the masses of the η and η' mesons.[5]

The question of the existence of gluonium and the study of its properties has been pursued theoretically by many investigators.[6] The basic difficulty in describing the physics of gluonium is the absence of a dynamic scheme which would make it possible to quantitatively estimate in a self-consistent way the characteristic features of gluonium: its mass and decay widths. In contrast with quark physics of mesons and baryons, which has a wealth of experimental data, a theory of the bound states of gluons can hardly give even an intuitive understanding of their nature, since no reliable experimental data indicating the existence of gluonium have so far been obtained. In the confinement region, all that is known about the constituent gluons and constituent quarks is that they have not been observed experimentally.

From this standpoint, the ability of the virton-quark model[7] to describe many effects of low-energy quark physics makes it possible to use the ideas and methods of this model to describe gluonium. In complete analogy with the assumption concerning the behavior of the quark propagator in the confinement region, we assume that the gluon in the given region can also be described by the virton field, that is propagator is an integral function, and that the coupling constant for the coupling of the G meson with gluons can be determined from the connectedness condition.[7]

Accordingly, we can write the free Lagrangian of the constituent gluon field

$$\mathcal{L}_0^B = -\frac{1}{2}B^\mu(x)Z_B(\Box)B_\mu(x), \tag{1}$$

where the operator $Z_B(\Box)(\Box = -\partial^\mu\partial_\mu)$ is expressed in a highly simplified form which satisfies the conditions necessary for constructing the S matrix[7]:

$$Z_B(\Box) = \frac{1}{L_B^2}\exp\left(-\frac{L_B^2}{4}\Box\right). \tag{2}$$

Consequently, we can write the Green's function of the constituent gluon field

$$D_B(x) = -iZ_B^{-1}(\Box)\delta(x) = \int\frac{d^4k}{(2\pi)^4 i}\widetilde{D}_B(-k^2)e^{ikx},$$
$$\widetilde{D}_B(-k^2) = L_B^2\exp\left(\frac{L_B^2k^2}{4}\right). \tag{3}$$

The parameter L_B which characterizes the scale of the hadron interactions is taken to be $L_B = L_q = L = 1/250$ MeV.

We will assume below that $G(1590)$ meson is a bound state consisting of two constituent gluons described by Lagrangian (1). The interaction Lagrangian can be written in the standard form

$$\mathcal{L}_G(x) = \frac{g_G}{\sqrt{32}} G(x) F^i_{\mu\nu}(x) F_i^{\mu\nu}(x), \tag{4}$$

where $F^i_{\mu\nu}(x) = \partial_\mu B^i_\nu(x) - \partial_\nu B^i_\mu(x)$, $i = 1, 2, \dots 8$.

The coupling constant g_G can be determined from the connectedness condition,

$$Z_G(m_G L, g_G) = 1 + \Sigma'_G(m_G^2) = 0, \tag{5}$$

where $\Sigma(P^2)$ is the mass operator for gluonium (the corresponding diagram is shown in Fig. 1a). The external hadron momenta are typically[7] ignored in the calculations of the diagrams.

The numerical value of the effective coupling constant for the coupling of the G meson with gluons, calculated from condition (5), is

$$h_G = \frac{g_G^2}{(4\pi L)^2} = 0.0104. \tag{6}$$

According to these arguments, we can add the terms, which take into account the gluon admixture, to the Lagrangian for the interaction of the $\eta\eta'$ mesons with quarks[7]:

$$\mathcal{L}_P = \frac{g_P}{\sqrt{2}} [\bar{q}_a i \lambda_P \gamma^5 q_a + \frac{\kappa_P}{4} F^i_{\mu\nu} \tilde{F}_i^{\mu\nu}] P(x). \tag{7}$$

Here

$$\tilde{F}^i_{\mu\nu} = \frac{1}{2} \epsilon_{\mu\nu\alpha\beta} F^{\alpha\beta, i}, \quad P = \eta, \eta',$$

$$\lambda_\eta = - \mathrm{diag}(\sin\delta_P, \sin\delta_P, \sqrt{2}\cos\delta_P),$$

$$\lambda_{\eta'} = \mathrm{diag}(\cos\delta_P, \cos\delta_P, -\sqrt{2}\sin\delta_P), \; \delta_P = \theta - \theta_I, \; \theta = -11^\circ.$$

The mass operator of the pseudoscalar mesons in this case is determined by the diagrams in Figs. 1a and 1b. The condition under which the renormalization constant for the renormalization of the wave functions of the η and η' mesons vanishes therefore determines the coupling constants g_P and κ_P only partially. These coupling constants can be determined uniquely by making the widths of the decays $P \to \gamma\gamma$ agree with the experiment (see Fig. 1c). In the absence of the gluon terms in (7) ($\kappa_P = 0$),

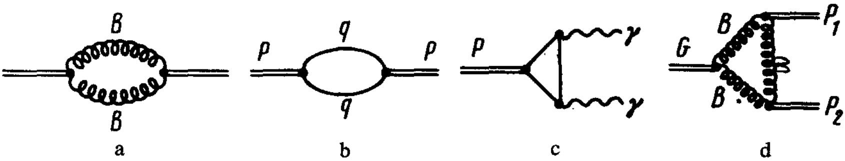

FIG. 1.

the corresponding widths will be too high in the virton-quark model. Standard calculations give the following values for the coupling constants:

$$h_{\eta'} \equiv \left(\frac{g_{\eta'}}{4\pi}\right)^2 = 0.0617\,, \qquad \kappa_{\eta'} = 0.316\,,$$
$$h_{\eta} \equiv \left(\frac{g_{\eta}}{4\pi}\right)^2 = 0.0804, \qquad \kappa_{\eta} = 0.131\,. \tag{8}$$

The decays of the G meson into 2π and $K\bar{K}$ are forbidden in this case. The transitions $G \to \eta\eta(\eta\eta')$ occur because of the addition of a gluon to Lagrangian (7), as illustrated by the diagram in Fig. 1d. The invariant amplitude is

$$M_{inv}(G \to P_1 P_2) = \frac{2^{15}\sqrt{2}}{9}\,\frac{\pi}{L}\sqrt{h_G h_{P_1} h_{P_2}}\,\kappa_{P_1}\kappa_{P_2}(\mu_G^2 - \mu_{P_1}^2 - \mu_{P_2}^2),\quad \mu^2 = \left(\frac{mL}{2}\right)^2 \tag{9}$$

if the external meson momenta are ignored. Substituting the numerical values of the coupling constants in (8), we find

$$\Gamma(G \to \eta\eta') = \frac{1}{8\pi}\,\frac{P^*_{G\eta\eta'} M^2_{inv}(G \to \eta\eta')}{m_G^2} = 160\ \text{MeV},$$
$$\Gamma(G \to \eta\eta) = \frac{1}{16\pi}\,\frac{P^*_{G\eta\eta} M^2_{inv}(G \to \eta\eta)}{m_G^2} = 80\ \text{MeV}, \tag{10}$$

in good agreement with the experimental data for the total decay width and for the ratio

$$R = \Gamma(G \to \eta\eta')/\Gamma(G \to \eta\eta).$$

The analysis of the scalar G-meson decays based on the dynamic scheme for gluon confinement proposed above shows unambiguously that if this meson exists and has the features outlined above, then it must be a gluonium. Here the channels for the decays $G \to \eta\eta(\eta\eta')$ would be the principal channels.

We wish to thank G. V. Efimov for many discussions.

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Translated by S. J. Amoretty