Fractionally charged particles and quark confinement

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A new class of fractionally charged particles, which are bound systems of fractionally charged, conventional quarks and new electrically neutral quarks rather than free quarks, is proposed. The feasibility of a search for such particles with use of accelerators is analyzed. Their cosmological evolution is briefly discussed.

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One of the noteworthy properties of quarks is their fractional electric charge. This property is generally used in experiments on the search for free quarks.[1] The development of quantum chromodynamics, however, helped to identify another aspect of a free quark—the color degrees of freedom. The absence of quarks in a free state is an example of color confinement in this sense; therefore, the existence of fractionally charged particles would seem to contradict absolute confinement.[2,3] Our goal in this paper is to show that the existence of fractionally charged free particles is consistent with absolute quark confinement.

If, in fact, new, electrically neutral quarks exist, then their bound systems with conventional quarks must be the fractionally charged particles. Such a possibility was considered in the context of a hypothesis recently proposed by Okun'.[4] He suggested that the Y matter of new Y particles, which interact with ordinary particles (0 particles) only gravitationally, have their own Y interactions which are analogous to the weak, electromagnetic or strong interaction of ordinary particles. The X particles, which have 0-particle interactions as well as Y interactions, have been analyzed in addition to the Y particles. The hypothesis of Okun'[4] can be realized, for example, in the context of the unified gauge model

$$G_{OXY} = G_{W-S} \times SU(3)_c \times G_Y , \qquad (1)$$

where $G_{W-S} = SU(2)\times U(1)$ is the gauge group of the ordinary weak and electromagnetic interaction,$SU(3)_c$ is the gauge symmetry of the strong color interaction, and G_Y is the new gauge symmetry corresponding to the common Y interaction. A spontaneous violation of G_Y to $U(1)_{YEM}$ in the scheme (1) gives rise to the new, long-range interaction—the hypothetical "Y electromagnetism" which is associated with the new, totally conserved "Y electric charge." G_Y in the scheme (1) corresponds to the Y analog of the ordinary, weakly electromagnetic interaction. The Y fermions, which interact only with the gauge bosons G_Y (Y bosons), are the Y particles (Y leptons) and the colored fermions, which interact with the Y bosons, are the X particles (X quarks). All the known quarks and leptons, which are the 0 particles, do not interact directly with the Y bosons (W_{Y,γ_Y}).

The scheme (1) is similar to the scheme[5] with a strong, common interaction. It was shown in Ref. 5 that such a scheme is inconsistent with the case in which G_{W-S} and G_Y are exactly symmetrical—in this case the 0- and X-quark mesons are degenerate with respect to the mass,[1)] a $\pi - \pi_Y$ mixing occurs, etc. However, according to current concepts (see Ref. 7), the mass of the bare quarks is apparently associated with the parameters of spontaneous violation of G_{W-S} and hence of G_Y. These parameters can differ greatly in both groups; for example, the lightest X quark can have a mass $m_x \gtrsim 20$ GeV, so that the degeneration effects[5] do not apply here. The scheme (1) is consistent with the experimental evidence for asymmetrical spontaneous violation of G_{W-S} and G_Y.

We shall assume that quark confinement is absolute. In addition to ordinary hadrons produced by ordinary quarks, the scheme (1) predicts the existence of $0\bar{X}$ and $X\bar{X}$ mesons as well as $00X$, $0XX$, and XXX baryons—white, bound states of X quarks. It is easy to see that the $0\bar{X}$ mesons and the $00X$ and $0XX$ baryons are fractionally charged particles (fractons).

The fractons (X hadrons) in the scheme (1) are produced mainly in the hadronic processes because of the two-gluon mechanism $gg \rightarrow x\bar{x}$. The pairs of X quarks in e^+e^- annihilation into hadrons can be produced because of the transitions via the $2g$ states only and the probability of such transitions is suppressed at least by the factor $a_c^2(m_X^2) \sim 4 \times 1^{-2}$. The $X\bar{X}$ mesons and XXX baryons, whose properties are similar to those of gluonium, may contain a sea of light 0-quark pairs, whereas, in the 0 hadron, the contribution of X-quark pairs to the sea is negligible because of the large mass of X quarks.

The contribution of Y interactions to the processes with 0 particles may be connected with the $2g \rightarrow 2_{y_Y}$ or $3 \rightarrow y_Y$ transitions via the virtual X-quark pairs. Such a contribution is strongly suppressed at momenta $\ll m_x$, which is analogous to the Θ interactions.[7]

According to the scheme (1), a search for fractionally charged particles should be conducted in hadronic processes at high energies. This prediction is qualitatively inconsistent with the scheme with fractionally charged free quarks,[8] according to which a search for free quarks should be conducted in the processes of e^+e^- annihilation into hadrons.

The lightest XX and X0 mesons and $X00$, $XX0$, and XXX baryons are absolutely stable. According to the theory of the hot universe, such particles should have been formed in the early stages of cosmological evolution and should have remained until now in surrounding matter. The calculations of quenched concentration of quarks in the early universe[9] set a lower limit that is several orders of magnitude greater than the constraints imposed on the abundance of relict quarks.[1] One would think that a similar contradiction should exist for the $X0$, $X00$, and $XX0$ hadrons. However, in contrast with free quarks, the fractons have Y interactions, which can reduce the relative fraction content in matter as the inhomogeneities are formed. Such a reduction may be associated with the fact that 1) the fractons may be distributed more uniformly than the 0 matter, 2) the fractons may be condensed principally into inhomogeneities of the Y matter, and 3) an additional annihilation of fractons [for example, (uX)

$+ (uuX) \to \pi^+ + p]$ can occur in the case of charge symmetry of the X quarks, $n_X = n_{\bar{X}}$, in the inhomogeneities of 0 matter. Such annihilation can be effective even at low temperatures and also if the 0 nuclei contain a large fraction of X hadrons, because the "Y electromagnetic" attraction of X and $\bar{X}$ quarks can compensate for the Coulomb repulsion of 0 nuclei. The effects 1–3 can reduce the fracton content in matter to a value consistent with the existing constraints on the concentration of fractionally charged particles[1] at a quenched concentration of fractons corresponding to the calculations.[3]

Other type of fractons–$(\bar{u}_Y Q_Y)$-type "Y hadrons"-can be produced as a result of absolute confinement of Y color. Here $\bar{u}_Y - Y$ are quarks which have no common interactions with the 0 particles other than the gravitational interaction and $Q_Y - Y$ are color states with a fractional electric charge. These can be produced within the framework of a broader symmetry group than the I group which includes the Y-color interaction,

$$G_{OXY} = G_{W-S} \times SU(3)_c \times G_Y \times G_{Yc} \tag{2}$$

Such fractons, which exist as fractionally charged leptons (X leptons) with a new, strong interaction, can be produced in electromagnetic processes (for example, in e^+e^- annihilation).

The fracton hypothesis is an interesting alternative of the interpretation of the experimental evidence for the existence of fractionally charged particles.[10]

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1)The masses of fractionally charged "hydrons" in the scheme[6] are close to the masses of ordinary hadrons, a fact that was rejected[6] by observations.

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