About Fractons: further investigations- several models

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I. HIGHER-DIMENSIONAL-STRUCTURES RELIC FRACTIONALLY-CHARGED PARTICLES

In [1], the $SO(10)$ gauge symmetry has been demonstrated to break at the string level.

-"Wilsonian particle", '*uniton*': heavy down-like quark (standard down-like charge assignment):
- fractional charge under the $U(1)_{Z'}$ symmetry:
  $\Rightarrow$ the uniton may be stable.

Symmetry broken as

- $SO(10) \rightarrow SU(3) \times SU(2) \times U(1)^2$;
$\Rightarrow$ exotic matter states
- classified according to the patterns of the $SO(10)$ symmetry breaking;

- in $SU(3) \times SU(2) \times U(1)^2$ type models,
one also obtains states with:
- regular charges under the Standard Model gauge group, but
- with fractional charges under the $U(1)_{Z'}$ symmetry;

- fractionally charged $SU(3)_C \times SU(2)_L$ singlets:
in $SO_(6) \times SO_(4)$ these states are doublets of $SU(2)_R$ with zero $U(1)_C$ charge and an $SU(3)_C$ singlet in the quartets of $SU(4)$ with zero $U(1)_L$ charge:
in standard-like models these states are $SU(3)_C \times SU(2)_L$ singlets with electric charge $Q_{em} = \pm 1/2$, i.e.:

- $SO(10) \rightarrow SO(6) \times SO(4)$:
- fractionally-charged standard-like-model states,
  - $SU(3)_C \times SU(2)_L$ singlets with $Q_{em} = \pm\frac{1}{2}$,and
  - (fractional) charge under $U(1)_Y$:
    $[(1,0);(1,\pm1)]_{(\pm1/2,\mp1/2,\pm1/2)}$ where the pedices denote the $U(1)_Y$ charge ,
    $[(1,\pm3/2);(1,0)]_{(\pm1/2,\pm1/2,\pm1/2)}$;

- $SO(10) \rightarrow SU(5) \times U(1)$:
- exotic states,
- $SU(3)_C \times SU(2)_L$ singlets with $Q_{em} = \pm\frac{1}{2}$
  $[(1,\pm3/4);(1,\pm1/2)]_{(\pm1/2,\pm1/4,\pm1/2)}$;

-$SO(10) \rightarrow SU(3) \times SU(2) \times U(1)^2$:
- standard-model singlets with nontrivial $U(1)_{Z'}$;

- heavy particles:
- (low energy limit) $SU(2)_L$ doublets and singlets, which are
- $SU(3)$ singlets
  $(1,2)_0, (1,1)_{1/2}$,
- lepton-like,
- fractional electric charge $Q_{em} = \pm 1/2$;

- fractionally charged vector- like quarks:
  $(3,1)_{1/6}$ (*sexton*, color triplet),
  - which can interact with u and d quarks and origin stable baryons and stable mesons;
    - with fractional electric charge of $\pm 1/2$ and $\pm 3/2$
    - lower bound for the masses [3]:
      - $M \sim \frac{eV}{{Y_0}^{FC}} > 10^{-19} GeV$ - ${Y_0}^{FC}$ relic density of fractionally-charged matter
        ${Y_0}^{FC} < 10^{-19} {Y_0}^{B} < 10^{-19} \frac{eV}{m_p} \sim 10^{-28}$;
      - experimental searches for free quarks in various materials:
        upper bound on the number density of fractionally-charged-particles smaller than $10^{-19} \sim 10^{-26}$;
        - experimental constraints: densities of fractionally charged bound states have suppressed densities.

Differently from E. Nardi and E. Roulet, Phys. Lett. B245 (1990) 105.

- Sexton σ: Charge = 1/6, and
- fractionally charged leptons,

  - *confinement temperature*, the sexton σ can form:
    - neutral color singlet bound states,
    - charged color singlet bound states,
      $\sigma\sigma\sigma$, $\sigma\sigma q$, $qq\sigma$, $\bar{q}\sigma$, and
    - the corresponding antiparticles
      $\bar{\sigma}\bar{\sigma}\bar{\sigma}$, $\bar{\sigma}\bar{\sigma}\bar{q}$, $\bar{q}\bar{q}\bar{\sigma}$, $q\bar{\sigma}$,
      - with q ordinary quarks.

- integer-charged final states can reconvert into fractionally charged states,
  - due to the presence of a large amount of ordinary particles;
- cooling temperature (expansion of the universe):
  - possibility for the remaining fractional hadrons to form:
    - bound states of integer charge with fractionally-charged-heavy leptons
      $(1,2)_0$ and $(1,1)_{1/2}$ with $Q_{em} = T_3 + Y$,
    $\rightarrow$
    neutral heavy hydrogen-type bound states $B_{1/2} + L_{-1/2}$, which can capture an electron at a temperature of a few eV, whose cross-section is calculated to be extremely small.

-$SO(10)$ symmetry breaking of $SU(3) \times SU(2) \times U(1)^2$
  $\Rightarrow SU(3)_c \times SU(2)L \times U(1)_Y$ singlet with non-standard $U(1)_{Z'}$ charge,
  - interactions with the Standard Model states vanish to all orders of non-renormalizable terms if the $SU(3)_H$ is left unbroken, but
  - $U(1)_{Z'}$ should be broken between the weak scale and the Planck scale:
  - W-singlet W_s:
    - interaction is suppressed by $1/{M^2}_{Z'}$,
    - (can be classified as WIMP);
    - can annihilate into:
      - two light Standard Model fermions, and
      - their superpartners;
    - further conditions on the W-singlet: mass (wrt $M_{Z'}$) and inflation;
    - can be a strongly interacting particle.

II. FURTHER ANALYSIS OF THE SO(18) MODEL

In citeDong:1982wq, the breaking of the SO(18) supersymmetric model has been analyzed to be possible through several mechanisms.

The generalized charge operator Q' for states is obtained as
$Q' = Q + \sqrt{2}aT_3^{L'} + \sqrt{2}bT_3^{R'} + \sqrt{2}cT_3^{L''} + \sqrt{2}dT_3^{R''}$,
as fractionally charged color singlet particles
where the parameters a, b, c and d appear in the definition of the generalized electric charged operator Q' of the 256-dimensional irreducible representations.

- 'model 1':
  parameters of the generalized charge operator: $a = c = 0$, $b = 1/3$, $d = 2/3$
  - color singlets with charge $Q = 1/3, 2/3, 4/3, 5/3, 2$, or
  - with right-handed current.

- 'model 2':
  because of the symmetry, cannot have $SU(3)_c \times SU(2) \times U(1)$ invariant masses
  parameters of the generalized charge operator: $a = c = 0$, $b = d = 1/3$;
  - i.e., six generations of ordinary fermions which can not acquire (because of the symmetry breaking) $SU(3)_c \times SU(2) \times U(1)$ invariant masses, and
  - ten generations of non-standard fermions, among which also fractionally-charged color-singlet particles: $Q = 1/3, 2/3, 4/3, 5/3$;

The color singlets can acquire masses because, in these two models, the symmetry G' is not needed.
The color singlets predicted
- do not interact with usual quarks via the gauge bosons: **stable**;
- experimental observation has bee proposed [4];
- under the hypotheses they have
  unstandard properties like charge, color, or weak isospin,
  provided that they are not prohibitively massive,
  experimental observation has been proposed in [5];
  - experiment cancelled [6].

III. MORE ABOUT FCHAMP'S

FCHAMP's have been further analyzed also in [7].

- FCHAMP's:

-leptons with:
- fractional e.m. charge,
- electroweak charge,
- with non-trivial hypercharge $U(1)_Y$,
- no strong interactions, and
- of mass m and charge $Q_L \simeq 2$;

  - Early Universe: possibility to retrieve items of information about FCHAMP's for:
  - thermal production,
  - annihilation,
  - survival,
  - cosmological constraints from primordial nucleosynthesis,
  - cosmological constraints form microwave-background-radiation, and
  - abundance on Earth;

IV. DOUBLY-CHARGED MASSIVE STABLE PARTICLES

In [7], the detection of stable particles with $Q_{em} = 2$ has been revised.

- XY gauginos and warped extra dimensional models:

  - GUT parity, and
  - effective TeV-scale supersymmetric grand unification;

- doubly-charged leptons within 'modern' walking
technicolor models (Minimal Walking Technicolor):
  - (predictions of large Flavour-Changing Neutral Currents (FCNC's) and a great variety of technimesons rejected because no experimental evidence was produced);
  - walking behaviour: slow running of the technicolour gauge coupling over an extended range

  - masses expected to exceed 100 GeV,
  - lightest technibaryon stable,
  - electric charges of the UU, UD, and DD
    equal $n + 1$, n, and $n - 1$, respectively, n arbitrary real number;

  - fourth family of leptons:
  - new 'neutrino' ν' and a new 'electron' e',
  - hypercharges $(-(3y - 1)/2)$ and $-(3y + 1)/2)$, resp.:
    for the analysis in [7], the simplest choice $y = 1$ has been perfomed,
    for $y = 1$, electric charges of the new leptons -1 and -2, resp;

  - two kinds of stable doubly-charged particles:
    - technibaryon UU^{++}, and
    - technilepton e'^{++}.

- Doubly-charged Higgs bosons in $L-R$;

- (Higgs triplets containing) doubly-charged Higgs bosons $\Delta^{++}{}_R$ and $\Delta^{++}{}_L$
(amplitudes of the vector boson fusion processes proportional to v_{L-R} VEV's of the neutral members of the scalar triplets);
- $\Delta^{++}{}_L$ suppressed;
- the doubly-charged Higgs boson quasi-stable for very small Yukawa couplings;

- doubly-Charged Higgsinos in the $L-R$ supersymmetric model:

- *with doubly charged Higgs bosons*, doubly charged Higgsinos can be long-lived enough to be detected;

- doubly-charged leptons in the framework of almost-commutative geometry:

- no other SM gauge charges;
- stable **because of** the absence of mixing with light fermions.

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[1] S. Chang, C. Coriano and A. E. Faraggi, Nucl. Phys. B **477** (1996), 65-104 doi:10.1016/0550-3213(96)00371-9 [arXiv:hep-ph/9605325 [hep-ph]].
[2] F. X. Dong, T. S. Tu, P. .Y Xue and X. J. Zhou, Annals Phys. **145** (1983), 1 doi:10.1016/0003-4916(83)90170-7
[3] Particle Data Group, Review of Particle Properties, Phys. Rev. D50 (1994) 1;
and 1995 off-year partial update 1996 http://pdg.lbl.gov/.
[4] L. L. CHAU, ISABELLE Proceeding of the 1981 Summer Workshop, BNL 745, Vol. 2, 1981.
[5] A. ALI et al., ISABELLE Proceeding of the 1981 Summer Workshop, BNL 503, Vol. 2, 1981.
[6] Brookhaven National Laboratory (2004), "The long road from ISABELLE to RHIC". U.S. Department of Energy;
Frederick E. Mills (1973). "ISABELLE Design Study" (PDF). IEEE Transactions on Nuclear Science. 20 (3): 1036-1038.
[7] B. Acharya *et al.* [MoEDAL], Int. J. Mod. Phys. A **29**, 1430050 (2014) doi:10.1142/S0217751X14300506 [arXiv:1405.7662 [hep-ph]].