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Authors
Shaw, G.L.
Bland, R.W.
Fonda, L.
et al.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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G.L. Shaw, R.W. Bland, L. Fonda, H.S. Matis,
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SCENARIO FOR COLD FUSION BY FREE QUARK CATALYSIS

G.L.Shaw[1], R.W.Bland[2], L.Fonda[3], H.S.Matis[4], H.G.Pugh[4], M.Shin[1] & R.Slansky[5]

ABSTRACT

Fleischmann and Pons have reported the astonishing results of watts of power from cold deuteron fusion without large amounts of radiation. We present a scenario in which small numbers of free stable $\bar{u}\bar{u} = Q$ anti-diquarks (electric charge of - 4/3, mass of a few GeV, and short range strong repulsion with hadrons) catalyze the deuteron fusion. The reaction channel $He^4 + Q$ dominates. We predict bursts of neutrons with a 3-body energy spectrum. However, independently from the findings of these experiments, the Q catalysis is attractive in that it could provide large power production, with relatively low radioactivity, if this kind of matter is found and accumulated.

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[1] Physics Department, University of California, Irvine, CA 92717, USA

[2] Physics and Astronomy Department, San Francisco State Univ., San Francisco CA 94132, USA

[3] Department of Theoretical Physics, University of Trieste, Trieste 34100, Italy

[4] Nuclear Science Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

[5] Los Alamos National Laboratory, Los Alamos, NM 87545, USA

The astonishing recent report by Fleischmann and Pons, FP [1], of cold fusion of deuteron + deuteron (d + d) giving watts of power without large amounts of radiation, seems to require new physics. Although there are conflicting reports from other laboratories [2] (in general reporting detection of neutrons but small production of energy), and our knowledge of the details of the FP experiment is sketchy, we would like to present here a testable scenario that may be consistent with the general nature of the FP experiment. No attempt is made to explain precise details.

We shall speculate whether it is possible that the d+d fusion be catalyzed by the presence of anti-diquarks which, being negatively charged and massive, can effectively screen the d-d Coulomb barrier. These particles are predicted by the glow model [3] of broken QCD to be free stable bound states of two anti-upquarks: $\bar{u}\bar{u}$, and therefore to have electric charge $-4/3$ and a mass of perhaps a few GeV. These $\bar{u}\bar{u}$ particles, which we shall denote by Q in the following, have a strong repulsive barrier at short distance for interaction with other hadrons, leading to a suppression of production of neutrons and tritons.

The catalytic cold fusion reaction processes for Q with deuterons would be [4]

$$
\begin{aligned}
(Q\,d\,d)_{\text{molecule}} &\rightarrow He^4 + Q + 23.9\ \text{MeV} && \text{(i)} \\
&\rightarrow He^3 + n + Q + 3.3\ \text{MeV} && \text{(ii)} \qquad (1) \\
&\rightarrow t + p + Q + 4.0\ \text{MeV} && \text{(iii)}
\end{aligned}
$$

As we shall see, the $He^4 + Q$ process (i) proceeds very rapidly, and at a rate of more than 10^4 times faster than the competing three-body channels (ii) and (iii). In contrast to catalysis by muons [5], in the Q catalysis first of all the Q cannot be treated as a spectator and second the fusion processes (1), in particular (i), proceed by a strong final state interaction. Thus a two-body versus three-body transition probability estimate gives the suppression of (ii) and (iii) by a large factor with respect to (i). We shall also see that the concentration of free Q's in nature in order to explain the FP results, is consistent with present limits and would be measurable.

We stress that, if the $Q = \bar{u}\bar{u}$ particles exist in nature, the considerations made and the conclusions obtained in this paper are rather general and model independent. For the sake of definiteness, the discussion follows the glow model [3] of broken QCD, which specifically predicts their existence.

The glow model was introduced in order to provide a theoretical framework consistent with the standard ideas in GUTs (such as SU(5), SO(10) or E(6)) which would allow for the observation of free quarks, as reported by the laboratory of Fairbank [6]. SU(3)-color is spontaneously broken to SO(3)-glow via a color 27 of Higgs (which is contained in the adjoint X adjoint of these GUTs). Five of these eight QCD gluons acquire a mass m(g) which would have to be less than 100 MeV in order not to violate various experimental constraints [3]. The remaining three gluons remain massless and provide a confining force for SO(3)-glow non-singlets. In contrast to a single gluon or a single quark which are glow non-singlets and thus are confined, a diquark in an SU(3)-color 6 has an SO(3)-glow singlet and thus can be free. It is not possible to determine definitively from present theoretical and experimental results whether the exact local symmetry in nature is SU(3)-color X U(1)-em, in which case particles with color are confined, or SO(3)-glow X U(1)-em so that fractionally charged glow-singlet diquarks can be free, produced either in the big-bang [7] or preferentially in relativistic heavy-ion collisions [3].

Zweig [4] discussed the diquark catalysis of fusion in 1978, in particular, the d+d fusion processes (1). What was required was to have a stable anti-diquark $\bar{u}\bar{u}$ state (which we define as Q) since the electric charge - 4/3 on the Q is necessary for the formation of a ddQ molecule. Other models of broken QCD [8] allow for free quarks. However, the glow model [3] specifically has diquarks as the lowest state of a free fractionally charged quark system. Further, since the mass of an upquark is less than that of a downquark, we expect the most stable anti-diquark is indeed $\bar{u}\bar{u}$ = Q.

In our scenario, the properties of the Q are:

(a) Q has a charge Z = - 4/3.
(b) Q is stable.
(c) The Q mass m_Q is roughly a few GeV.
(d) The interaction of a quark with another quark is the usual linear confining potential (slope of 1 GeV/f) out to a distance of roughly 1/m(g) (several fermis) then falling exponentially to 0; this then provides a strong, short-range repulsive barrier for Q interactions with ordinary hadronic matter. (Just as it is very difficult to produce free quarks, it is very difficult to get them back together !)

Now let us consider the ddQ catalysis reactions given by (1), contrasting it with ddμ catalysis (replace Q with a μ in (1)). The interesting phenomenon of muon catalysis of p+d fusion was observed by Alvarez et al. [9] over 30 years ago. A pdμ molecule is formed, and the large mass of the μ relative to the electron confines the p+d to a small enough distance to effect the rapid penetration of the Coulomb barrier.

Much work has been done recently on understanding μ catalysis of d+d and d+t fusions. The slowest part of the cycle is the time for formation of the ddμ and dtμ molecules, and the rates are enhanced by molecular resonances [5]. A few hundred d+t fusions can occur in a μ lifetime of 2 microseconds (while this is a surprisingly large number, it is still too small, as yet, to use μ catalysis as an energy source).

In contrast, for a free anti-diquark Q with its $Z = -4/3$ (compared to $Z = -1$ for the μ) and mass of a few GeV (compared to 0.1 GeV for the μ), both the molecular formation of ddQ and the fusion processes (1) should proceed at a much faster rate than for the analogous case with the Q replaced by a μ. In particular, the dQ molecule has a charge -1/3 and can therefore form the ddQ molecule by Coulomb attraction, in contrast to the μ case where the dμ molecule has a charge 0. This makes an enormous difference ! Under ideal conditions, perhaps such as having a high deuteron concentration as in the experiments of FP, the time for the fusion cycle (1) per Q is incredibly short (note that the upper time limit appearing in [4] is useless). We have estimated this time to be of the order of 10^{-10} s. (Detailed calculations are still in progress on this point. Collision times, temperature related, may play a role.) Now, as we will argue, the He^4 + Q channel (i) will dominate over the three body channels (ii) and (iii) by a large factor. Thus, to produce a net energy of a few watts, FP need to have 10^{12} fusions/s which would require roughly 100 Q's active on the average in the catalysis. We shall return to examine this concentration of Q's. First we give the simple phase space argument concerning the suppression of reactions (ii) and (iii).

In contrast to μ catalysis, in the Q catalysis given by Eq.(1) the Q cannot be treated as a spectator. The key argument is that its mass is comparable to the other final products and in the He^4 + Q channel (i) the relevant share of 23.9 MeV of binding energy can be transferred to the Q via the QCD strong repulsion described in (d) above, rather than electromagnetically as for the μ catalysis (which transition probability is then depressed by a factor α^2). Thus to compare the reaction rates (i) versus (ii) and (iii), we evaluate the ratio R of the two-body versus the three-body total transition probabilities. Using the usual N-body phase space

$$\text{N-body phase space} = \delta^3(\text{total momentum})\,\delta(\text{total energy})\,\prod_i \{d^3k_i(2\pi)^{-3}(2E_i)^{-1}\}$$

and integrating the transition probabilities over all dynamical variables, taking of course only S-waves for the calculations, we get

$$R = (m_{int})^2 \int(\text{2-body phase space}) / \int(\text{3-body phase space})$$

$$= N(m_Q)\,[\Delta_2 E(\text{GeV})]^{1/2}/[\Delta_3 E/m_{int}]^2 \qquad (2)$$

where $\Delta_2 E(\text{GeV})$ is the energy released in the two body process (i) expressed in GeV, $\Delta_3 E$ is the corresponding energy for the three body processes (ii) or (iii); m_{int} is the relevant interaction mass; $N(m_Q)$ is a very slowly varying function of m_Q which has a value of approximately 10^2 in the relevant m_Q region. Introducing the values of the energies released in processes (1) we get

$$R \cong 10^6\,\{m_{int}(\text{GeV})\}^2 \qquad (3)$$

Reasonable estimates for the strong interaction mass m_{int} within 0.1 and 0.3 GeV yield a value between 10^4 and 10^5 for the dominance of the $He^4 + Q$ channel with respect to the neutron or triton channels. Note that we expect the electromagnetic process in which the Q, in reaction (ii) of Eq. (1), comes off bound to the He^3 (thus being lost for the catalytic process) to be greatly suppressed.

If this scenario is relevant for the FP experiments giving watts of power from d+d fusion, there would then be 10^{12} He^4 produced per second from (i), along with roughly 10^7-10^8 neutrons per second from (ii) and 10^7-10^8 tritons per second from (iii). We have argued before that, roughly, 100 active Q's may be necessary to give a few watts of power; this means that neutrons and tritons are predicted to be produced according to

$$N(\text{neutrons and tritons}) \cong 10^5\text{-}10^6\ /\text{s}/Q \qquad (4)$$

(In contrast, if (ii) and (iii) dominated, then FP would have produced 10^{13} n's and t's per second.) Furthermore, in the three-body channel (ii) the energy of the neutron is not unique as in the case of μ catalysis where the μ is a spectator.

Consider now the concentration of Q's in nature necessary to explain the FP results. Q's in some concentration might be left over from the big-bang giving a general level of occurance in matter and/or a more concentrated amount C(S) in specific materials (which seems more likely). In the FP experiments, the roughly 1cm^3 rod has 10^{23} atoms of palladium. Thus, if the Q's were present in palladium, the presence of 100 active Q's (not bound to a heavy nucleus) would require a specific concentration of at least $1Q/10^{21}$Pd atoms.

Note that the Q need not be on a Pd atom since, as stressed by Lackner and Zweig [10], a "quarked" atom can have quite different chemical properties from the atom without the quark. Thus it might be that the "quarked" atom behaves similarly to a Pd atom, but has different, perhaps significantly less, mass and charge, so that it may be possible to free the Q from the atom and make it available for the catalytic fusion.

A second possibility is that the Q's were present in the D_2O and were concentrated then by FP near the Pd rod. Assuming that a few liters of D_2O was involved over some time in the course of the FP experiment, this would require a concentration of $1Q/10^{24}$ D_2O molecules.

In general, searches for free quarks involve null measurements on as much as 10 mg of material [11] giving a concentration less than $1Q/10^{21}$ molecules, and thus are compatible with the C(Pd) and $C(D_2O)$ needed concentrations. (Note that although no quark search has been made using Pd, Fairbank and collaborators [6] found evidence for free quarks on little spheres of the transition metal niobium at a level as large as 1quark/10^{19}Nb molecules.)

The above needed concentration of $C(D_2O)$ could be tested by the SFSU-LBL-LANL-UCI quark search collaboration: As in the searches [12] and [13], at accelerators, for free quarks produced in high energy collisions, tanks of liquid were used to stop secondaries, and any charged atoms were collected electrostatically on gold-coated electrodes. The Au coatings were dissolved in a small drop of mercury which was then tested for quarks in the San Francisco State University automated Millikan apparatus. These published negative findings can be used here to set limits on the Q concentration in these liquids. In [12], tanks containing 180 kg of liquid argon were used, and about 1% of the mercury was measured; this gives a limit of $C(Ar) < 1Q/10^{25}$ Ar atoms. Similarly, in [13], tanks of liquid nitrogen were used, giving a limit of $C(N_2) < 1Q/10^{25}N_2$ molecules. Thus, we should be readily able to use this collection and detection method on tanks of D_2O to test whether Q's are present at the needed level of $1Q/10^{24}D_2O$ molecules.

A few points are worth noting concerning the Q catalysis scenario in the other cold fusion experiments [2]. As already pointed out, roughly 100 active Q's are necessary in order to obtain watts of power. Consider, on the other hand, the extreme case in which, at a given time, only one Q is active in an experimental apparatus. Then a large, localized in time, burst of neutrons, separated in time by 10^{-5} - 10^{-6} seconds, according to Eq.(4), would be expected since the Q, after having catalyzed a number of fusions, might then escape from the reaction region (and thus the thickness of the transition metal electrode may play a role) or become trapped by a nucleus with $Z > 1$.

Finally, another important prediction of this paper is that the neutrons should not have a fixed energy of 2.45 MeV, but should have a three-body energy spectrum.

In conclusion, we would however like to point out that, independently from the Fleischmann-Pons and similar experiments (and the various attempts to a theoretical understanding of this phenomenon), the anti-diquark catalysis is very interesting as it can provide [4], in the long run, a way to get large energy production via cold d+d fusion (if the anti-diquarks $Q = \bar{u}\bar{u}$ exist at all and one has been able to properly accumulate them). Furthermore, the radioactivity would be much less than that obtained in hot fusion since the He^4+Q reaction channel dominates.

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720