

DEUTERON COLD FUSION BY ANTI-DIQUARK CATALYSIS

LUCIANO FONDA and GORDON L. SHAW

International Center for Theoretical Physics, Trieste 34100, Italy
Physics Department, University of California, Irvine, CA 92717, USA

Received 13 October 1989

UDC 539.128

Original scientific paper

We discuss the possibility that deuteron cold fusion be catalysed by a free stable bound state of two anti-upquarks (electric charge of $-4/3$, mass of a few GeV, and short range strong repulsion with hadrons). The reaction leading to the direct formation of He^4 dominates. Bursts of neutrons, with a 3-body energy spectrum, are predicted. The proposed anti-diquark catalysis is attractive in that it could provide large power production, with relatively low radioactivity, if this kind of quark matter is found and accumulated.

The recent alleged discovery of cold fusion of deuteron + deuteron ($d + d$) by Fleischmann and Pons¹⁾, has given rise to a flourishing of experiments on the subject, notably by Jones et al.²⁾, Scaramuzzi et al.³⁾ and many others, which have left by and large the phenomenon unexplained or, even worse, in many cases have shed serious doubts on its actual occurrence.

Assuming the optimistic point of view that something has actually been observed in the above experiments, we have speculated⁴⁾ whether it is possible that the $d + d$ fusion be catalysed by the presence of quark-like particles which, being negatively charged and massive, can effectively screen the $d-d$ Coulomb barrier. Negatively charged quark-like particles (if stable and not confined) could form «triatomic molecules» with pairs of deuterons and therefore catalyse a fusion reaction between these nuclei in a manner analogous to fusion catalysed by muons.

The original suggestion of quark catalysed fusion goes back to 1969 to a paper by Marshall Libby and Thomas⁵⁾ where they made some rough estimates of the effect of quark catalysis on the energy production of the Sun. Salpeter⁶⁾ then showed that this effect would be negligible in the Sun. In 1978 Zweig⁷⁾, one of the

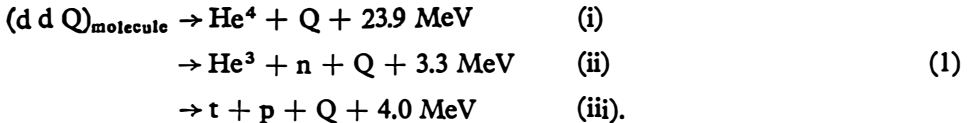
two originators of the quark picture, revived this quark catalysed fusion idea by applying it to the problem of power production for our planet.

Among all quark-like particles previously considered for catalysis purposes, the best candidate appears to us to be the bound state $\bar{u}\bar{u}$ of two anti-upquarks, whose charge is $Z = -4/3$. We shall denote this quark-like particle $\bar{u}\bar{u}$ by Q in the following.

The electric charge $-4/3$ on the Q is necessary for the formation of a ddQ molecule. The existence, as a free state, of this quark-like particle is predicted by the 'glow model' of broken QCD⁹⁾. According to this model, this particle acquires, through a symmetry breaking mechanism, a mass of perhaps a few GeV. In our scenario, the properties of the Q are then:

- (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 zero; 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!)

The catalytic cold fusion reaction processes for Q with deuterons is then as follows:



In contrast to catalysis by muons¹⁰⁾, in our quark catalysis first of all the Q cannot be treated as a spectator and second the fusion processes (1) (in particular (i), as also shown in Fig. 1) proceed by a strong final state interaction. Thus, as we shall see, a two-body versus three-body transition probability estimate gives the suppression of (ii) and (iii) by a large factor with respect to (i).

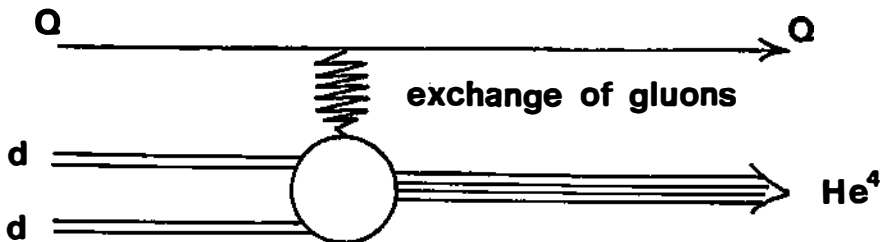


Fig. 1. Strong hadronic coupling formation of He^4 in Q catalysis. The initial state consists of the 'triatomic molecule' ddQ .

Let us compare the ddQ catalysis reactions given by (1), with dd μ catalysis (replace Q with a μ in (1))¹¹⁾. Much work has been done recently on understanding μ catalysis of d + d and d + t fusions¹⁰⁾. The slowest part of the cycle is the time of formation of the dd μ and dt μ molecules. The rate of formation is enhanced by molecular resonant processes which are temperature dependent, the optimal temperature being around 1800 K. At room temperature, a few hundred d + t fusions can occur in a μ lifetime of 2 microseconds¹²⁾. 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 formation of the ddQ molecule 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 d μ molecule has a charge 0. This makes an enormous difference! Under ideal conditions, when deuterons are highly concentrated, the time for the fusion cycle (1) per Q is incredibly short. We have estimated this time to be of the order of 10^{-10} s. (Note that the upper time limit appearing in Ref. 7 is wrong. Detailed calculations are still in progress on this point. Collision times, temperature related, may play a role.) In Fig. 2 we compare the μ and Q catalytic fusion cycles.

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 $\text{He}^4 + \text{Q}$ channel (i) the relevant share of 23.9

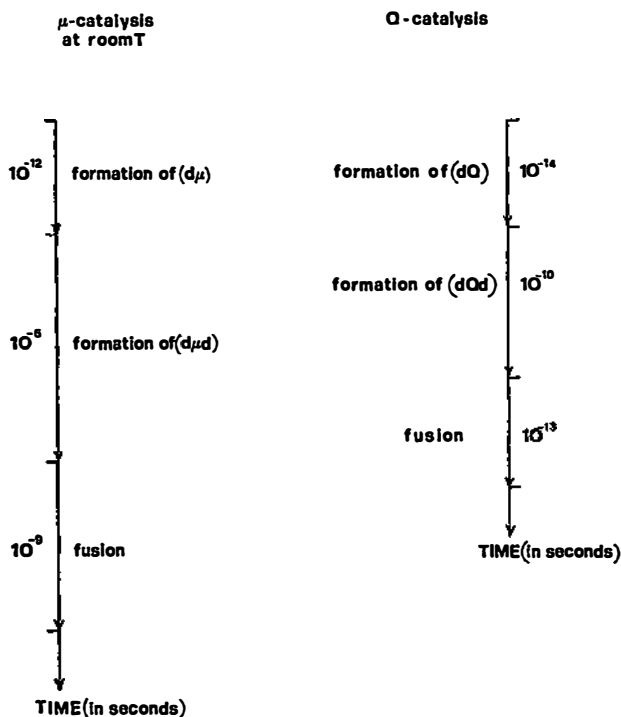


Fig. 2. Fusion cycles for μ and Q catalyses.

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 N -body phase space = $\delta^3(\text{total momentum}) \delta(\text{total energy}) \Pi_i \{d^3k_i (2\pi)^{-3} (2E_i)^{-1}\}$ and integrating the transition probabilities over all dynamical variables, taking of course only S-waves for the calculations, we get

$$R = (m_{int})^2 \int (2\text{-body phase space}) / \int (3\text{-body phase space}) = N(m_Q) [\Delta_2 E (\text{GeV})]^{1/2} / [\Delta_3 E / m_{int}]^2 \tag{2}$$

where $\Delta_2 E$ (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

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

Reasonable estimates for the strong interaction mass m_{int} within 0.1 and 0.3 GeV yield a very large value for the dominance of the $\text{He}^4 + \text{Q}$ channel with respect to the neutron or triton channels:

$$R \cong 10^4 - 10^5. \tag{4}$$

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.

How is it possible that the Q's be present in transition metals? A possible scenario is that the Q is primordially bound to He^4 . The »quarked« atom He^4Q , having chemical properties similar to hydrogen¹³⁾, can then be concentrated in transition metals. Note that the strong repulsive barrier for Q interactions with ordinary hadronic matter (see point (d) above) will substantially reduce the He^4Q binding energy, thus making possible the liberation of the Q from the »quarked« atom, and therefore making it available for the catalytic fusion, as a result of some non-equilibrium process in the transition metal. Once the Q is liberated, it will undergo the catalytic process until it will eventually get sequestered on a very deep energy level of a heavy transition metal atom or escape from the region of interaction (thus the thickness of the transition metal electrode may play a role).

This means that a large, localized in time, burst of neutrons is predicted in this scenario. According to our estimated time for the fusion cycle (1), we have the following rates of production:

$$N(\text{He}^4) \cong 10^{10}/\text{s/Q} \tag{5}$$

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

In the burst, the neutrons should then be separated in time by 10^{-5} – 10^{-6} seconds¹⁴⁾.

Finally, another important prediction of this paper is that the neutrons should not have a fixed energy of 2.45 MeV, but, according to reaction (ii) of (1), must instead have a three-body energy spectrum.

Had Fleischmann and Pons been right, they would have obtained 10^{12} He⁴ per second, along with roughly 10^7 – 10^8 neutrons and tritons per second. Therefore 100 active Q's at any given time would have been needed to give the few watts of power allegedly obtained in their experiments. This can be considered as an upper limit for the concentration of Q's. In Ref. 4 we concluded that the concentration of Q's in nature necessary to explain the Fleischmann-Pons results, is not inconsistent with the present experimental null measurements in searches for free quarks¹⁵⁾. Q's in some concentration might be left over from the big-bang¹⁶⁾. A reasonable scenario is that the Q's are highly concentrated in specific materials¹³⁾, in particular perhaps in the transition metals. Thus, it is of great interest to perform¹⁷⁾ searches for free quarks in transition metals.

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, 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 He⁴ + Q reaction channel dominates.

References

- 1) M. Fleischmann and S. Pons, *J. Electroanal. Chem.* **261** (1989) 301;
- 2) S. E. Jones, E. P. Palmer, J. B. Czirr, D. L. Decker, G. L. Jensen, J. M. Thorne, S. F. Taylor and J. Rafelski, *Nature* **338** (1989) 737;
- 3) A. De Ninno, A. Frattolillo, G. Lollobattista, L. Martinis, M. Martone, L. Mori, S. Podda and F. Scaramuzzi, *Il Nuovo Cimento* **101A** (1989) 841;
- 4) G. L. Shaw, R. W. Bland, L. Fonda, H. S. Matis, H. G. Pugh, M. Shin and R. Slansky, *Il Nuovo Cimento* **102A** (1989) 1441;
- 5) L. Marshall Libby and F. J. Thomas, *Nature* **222** (1969) 1238;
- 6) E. E. Salpeter, *Nature* **225** (1970) 165;
- 7) G. Zweig, *Science* **201** (1978) 973;
- 8) R. Slansky, T. Goldman and G. L. Shaw, *Phys. Rev. Lett.* **47** (1981) 887;
G. L. Shaw and R. Slansky, *Phys. Rev. Lett.* **50** (1983) 1967;
- 9) 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. 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. 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 nonsinglets 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 experiment 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 or in relativistic heavy-ion collisions. Other models of broken QCD allow for free quarks, however, the 'glow model' specifically has diquarks as the lowest state of a free fractionally charged quark system.

- 10) S. E. Jones, *Nature* **321** (1986) 127;
- 11) The interesting phenomenon of muon catalytic fusion was first observed by Alvarez et al. (*Phys. Rev.* **105** (1957) 1127) for the $p + d$ system. A $pd\mu$ molecule is formed, and the large mass of the μ confines the $p + d$ to a small enough distance to effect the tunneling of the Coulomb barrier;
- 12) While this is a surprisingly large number, it is still too small, as yet, to use μ catalysis as an energy source;
- 13) K. S. Lackner and G. Zweig, *Phys. Rev.* **D28** (1983) 1671;
- 14) In contrast, if (ii) and (iii) dominated, we would have produced 10^{10} neutrons and tritons per second and per Q;
- 15) M. Marinelli and G. Morpurgo, *Phys. Rep.* **85** (1982) 162 and references therein; D. Liebowitz, M. Binder and K. O. H. Ziock, *Phys. Rev. Lett.* **50** (1983) 1640; P. F. Smith et al., *Phys. Lett.* **153B** (1985) 188; R. G. Milner et al., *Phys. Rev. Lett.* **54** (1985) 1472; D. C. Joyce et al., *Phys. Rev. Lett.* **51** (1983) 731; M. L. Savage et al., *Phys. Lett.* **167B** (1986) 481;
- 16) E. W. Kolb, G. Steigman and M. S. Turner, *Phys. Rev. Lett.* **47** (1981) 1357;
- 17) G. S. LaRue, J. D. Phillips and W. M. Fairbank, *Phys. Rev. Lett.* **46** (1981) 967.

DEUTERONSKA HLADNA FUZIJA POMOĆU ANTI-DVOKVARKOVSKJE KATALIZE

LUCIANO FONDA i GORDON L. SHAW

International Center for Theoretical Physics, Trieste, Italy

Physics Department, Univ. of California, Irvine, CA 32717, USA

UDK 539.128

Originalni znanstveni rad

Diskutirana je mogućnost katalize deuteronske hladne fuzije slobodnim stabilnim vezanim stanjima 2 antikvarka. Predložena kataliza pruža mogućnost velike proizvodnje energije sa relativno malo radioaktivnosti, ako se taj oblik kvarkovske materije može naći i akumulirati.