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E.V. Shuryak

ON THE EXISTENCE OF STABLE QUARK MATTER

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НОВОСИБИРСК

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ABSTRACT

This work contains some discussion of why the stable quark matter (SQM) may exist, how to look for it and what its concentration may be in the Universe, if it is produced by pulsars. Some speculations conserning its possible applications for energy production from neutron convertion into SQM are also given.

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This paper considers the question of whether the minimal energy per baryon (E/A) corresponds to atomic nuclei, or to «stable quark matter» (SQM). In view of new ideas and recent experimental discoveries the latter possibility seems more probable, than it was considered before, and now it is probably reasonable to attract attention of specialists in various fields of physics to this question and to searches for SQM. Apart from purely scientific interest, its importance is seen from the fact that, if such matter exists and if it can absorb neutrons, one may get energy from their «burning» in nuclear reactors.

E. Witten has recently pointed out several important facts [1], in particular: (i) transition of ordinary nuclei into SQM is practically impossible: it contains about 1/3 of strange quarks; (ii) a particle of SQM has electric potential of the order of 10 MeV, preventing absorbtion of ordinary matter under normal conditions; (iii) an active source of SQM should be pulsars, which, if SQM exists, are made of it up to the surface.

The last conclusion is especially intriguing after recent observation of muons [2], correlated in direction and time with pulsar Cygnus X-3. Not going into detailed discussion of these date we just state, that they suggest existance of some unknown neutral hadron with mass of about few GeV and lifetime not smaller than about 10 years, needed to reach Earth. The first candidate proposed [3], the «dihyperon» H with strangeness and baryonic number $S=A=2$, is unable to do the job [4]. However, clusters of SQM with $A>2$ can be considered. (In particular, the «magic» one with the closed shell value $S=A=6$.)

But why SQM is so «strange»? The first (obvious) reason [1] is that the strange quark mass $m_s \simeq 150$ MeV is smaller than Fermi energies $E_F \simeq 300$ MeV, so their production decreases the kinetic energy. The second (perturbative) reason, is that one-gluon exchange energy is positive and stronger for u, d quarks than for s. The third (nonperturbative) one is due to the fact, that interaction of s quarks with vacuum fluctuations is much weaker than for u, d ones (see e. g. comparison of π and K sum rules [5]), thus the «vacuum pressure» on strange matter is smaller than on ordinary one with the same density. Estimates are still uncertain, but on the order-of-magnitude level each of these effects separate strange and nonstrange matter by about 50 MeV, reaching in sum 100—200 MeV.

Unfortunately, it is not so far possible to give accurate estimates for the absolute values of E/A in these cases, so that we cannot say whether it is below its value in nuclei, $(E/A)_{Nucl} \simeq 930$ MeV, or not. There exist some observational restrictions, in particular, stability of nuclei implies that the nonstrange quark matter is surely unbound. Another important restriction is that the largest mass of a stable quark star should be at least as large as $1.4-1.6\ M_{\odot}$ (in unite of the Sun mass), because such pulsars are already observed. In the simplest bag-type model for quark matter with some effective vacuum pressure B_{eff} these two bounds are approximately $50 < B_{eff} < 80$ MeV/fm^3.

What may be the concentration of SQM in Universe? If its source are pulsars in close binaries, some estimates can be obtained. If the accreting matter produces a fraction x of SQM matter flying away [3], then, after a time period about the age of Universe, its weight concentration reaches about $10^{-8}x$. Other estimates can be based on muon data mentioned above. The observed flux $(7 \cdot 10^{-11}/\mathrm{sec \cdot cm^2})$ can be converted into absolute outcome of particles in TeV region. If at least the same amount of SQM is radiated below MeV energies and it is trapped gently by matter, and if all 10^5 binary pulsars in our Galaxy do the same since its formation, the produced fraction of SQM reaches 10^{-10}. (Unfortunately, in air and liquids heavy SQM atoms fall down, thus much smaller fraction can be expected on Earth.) These estimates produce surprisingly large numbers, exceeding feasible experimental limits, so the search for SQM is not unreasonable.

How can one find SQM? At $Z < 100$ it is in the form of ordinary atoms, but about ten times heavier [6]. So, the natural method is the mass-spectrometry, and the natural place is heavy fractions in isotop-separating devices. Another possibility is provided by molecule spectroscopy. Looking for new molecule vibration frequencies which differ by the factor 2 from those of ordinary diatomic molecules, one may find molecules containing heavy SQM-made nuclei. (The most intriguing are the spectra of the stars-companions of pulsars, which may contain large admixture of SQM.)

Activation of heavy ions above the Coulomb barrier was suggested in [7]. However, the negative result is not quite convincing, since strong interaction expel the ordinary matter before weak decay takes place, unless the following condition is satisfied

$$(3/2)\,(E_F^u + E_F^d) < (E/A)_{Nucl}. \qquad (1)$$

(E_F^u, E_F^d are Fermi energies for u, d quarks in SQM.) Because in SQM $E_F^u < E_F^d$, analogous condition that neutrons «stick» to it

$$E_F^u + 2E_F^d < (E/A)_{Nucl} \qquad (2)$$

is even stronger. If convertion of a neutron into SQM produces tens of MeV or more, such processes can probably be separated from background nuclear reactions, and therefore used for SQM search.

If SQM exists and (2) is valid, then this reaction may produce energy by «burning» of neutrons in power reactors. However, in order to do so one needs macroscopic amount of SQM, while we may only hope to find a tiny concentration of this «pulsar ash» somewhere in Universe. Can it be multiplied in laboratory?

Estimates show, that this problem seems to be solvable. The grouth of SQM atoms under the flux j is given by

$$A(t) = [A^{1/3}(0) + t/t_0]^3 \qquad (3)$$

where $t_0 = 3/j\sigma_0$ and cross section assumed to be $\sigma = \sigma_0 A^{2/3}$ with $\sigma_0 \simeq 10^{-26}\mathrm{cm}^2$. Neutron fluxes are too low, but keeping SQM in storage ring at energy of several MeV/A with beam going through gas target or thin foil (such that Coulomb losses are about 10 eV and can be compensated, while their fluctuations being cooled down), one may in principle reach $t_0 \simeq 1$ sec, and, according to (3), do obtain macroscopic amount of SQM in the time of about a year.

Concluding this paper let me note once more, that existence of SQM does not contradict either to our theoretical knowledge nor to experimental facts (some puzzles can even be explained, as discussed above). If so, it is a problem of great scientific and practical importance. No doubts, in the nearest future feasible experimental limits on SQM concentration on Earth, Moon, meteorites etc. will be established. It is quite probable that ideas considered above on how to search for SQM and how to use it later will be considered as too naive by specialists in the particular fields involved. However, my major aim is to attract their attention to this important problem.

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E.V.Shuryak

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