Chiral Symmetry Breaking and Stability of Quark Droplets

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The stability of strangelets, which are finite volume droplets of quark matter with strangeness, has been one of the most interesting topics in the quark and hadron physics [1]. We discuss how chiral symmetry breaking affects the stability of the finite volume strangelets. As an effective theory of QCD, we consider a four-quark interaction of the Nambu–Jona-Lasinio (NJL) model for chiral symmetry breaking. The quarks are assumed to exist only inside the strangelets. To consider quark confinement, we impose the MIT bag boundary condition at the surface of the strangelet. With these assumptions, we use the lagrangian [2, 3]

$$\mathcal{L}=\bar{\psi}(i\partial\!\!\!/-m^0)\psi+\frac{G}{2}\sum_{a=0}^{8}\left[\left(\bar{\psi}\lambda^a\psi\right)^2+\left(\bar{\psi}i\gamma_5\lambda^a\psi\right)^2\right]-\frac{1}{2}\bar{\psi}\psi\delta(r-R), \quad (1)$$

where $\psi=(u,d,s)^t$ is the quark field, and $m^0=\mathrm{diag}(m_u^0,m_d^0,m_s^0)$ current quark mass matrix. The second term is the NJL point-like interaction term invariant under $U(N_f)_L\times U(N_f)_R$, in which λ^a $(a=0,\cdots,8)$ is the Gell-Mann matrices normalized by $\mathrm{tr}\lambda^a\lambda^b=2\delta^{ab}$. We assume that the strangelet has a spherical shape with a bag radius R. The last term of Eq. (1) is a confinement term in the MIT bag model, where r is a distance from the center of the bag.

The non-perturbative dynamics in the NJL interaction causes chiral symmetry breaking, in which $\bar{q}q$ condensate takes a non-zero expectation value. To investigate the $\bar{q}q$ condensate inside the bag, we use the mean field approximation for the scalar channel. For a given baryon number A, we obtain the energy E, the radius R and the strangeness S of the strangelets by taking a variation of R and S with respect E.

In Fig. 1(a), we show the energy per baryon number E/A as a function of the baryon number A. The solid and dashed lines are the results by discrete energy level and the Multiple Reflection Expansion (MRE). In the calculation by the discrete energy levels, we derive the nucleon mass 1.1 GeV as an averaged value of nucleon and delta as a quark droplet with baryon number $A=1$. We also obtain the bag radius $R=0.76$ fm. In Fig. 1(b), we show the strangeness fraction $r_s=|S|/3A$ for the quark droplets with baryon number A. For the quark droplets with $10\lesssim A\lesssim 10^3$, there is a finite strangeness in the quark droplets. Therefore, the ground state of the quark droplets is strangelet. However, the energy of such strangelets is larger than the nucleon mass. Therefore, we conclude that the strangelets are not absolutely stable objects as compared with nucleons.

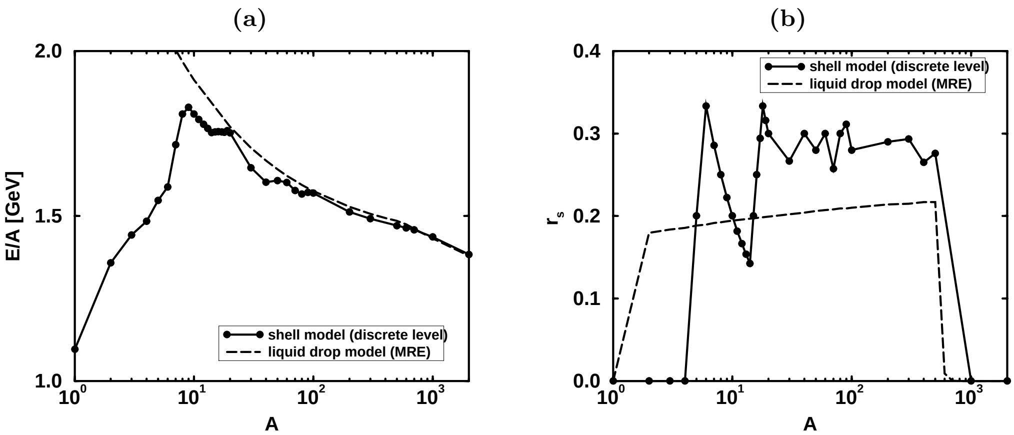

Figure 1: (a) The energy per baryon number E/A as a function of baryon number A. (b) The strangeness fraction r_s as a function of baryon number A. The solid line is by the discrete energy level, and the dashed line is the MRE method.

References

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