Stability of strangelet at finite temperature

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Abstract

Using the quark mass density- and temperature dependent model, we have studied the thermodynamical properties and the stability of strangelet at finite temperature. The temperature, charge and strangeness dependences on the stability of strangelet are investigated. We find that the stable strangelets are only occurred in the high strangeness and high negative charge region.

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I. INTRODUCTION

The study of small lumps of strange quark matter, called strangelets, plays an important role for research the quark gluon plasma (QGP) in recent relativistic heavy ion collision (RHIC) experiments. The reason is that although many signatures of QGP such as $J/\Psi$ suppression, strangeness enhancement, thermal dilepton electromagnetic radiation, etc., have been found \cite{1,2}, but it is still ambiguous because these signatures can also be explained by hadron gas \cite{3}. To search an unambiguous signature of QGP is the key for RHIC experiments. The strangelet, as was argued by Greiner et. al \cite{4}, is a good candidate which could serve as an unambiguous signature for the QGP.

The essential problem for detectability of strangelet in RHIC experiments is to study its stability during the formation of QGP. Employing MIT bag model, many authors discussed this problem \cite{5-8}. They came to the same conclusion that the electric charge and the strangeness fraction are of vital important to the experimental searches of strangelets because these two elements affect a change of stability remarkably. But the effect of charge on stability is different for different authors. Jaffe and his co-workers \cite{5-7} argued that the strangelet is slightly positive charged. They considered strong and weak decay by nucleon and hyperon emission together and concluded that the stable strangelets will have a low but positive change to mass ratio. Contrary to Jaffe et. al, after considering the initial condition of possible strangelet production in RHIC carefully, Greiner and his co-workers \cite{8} argued that strangelets are most likely highly negative charged. Here we hope to emphasize that above discussions are limited in the framework of MIT bag model and at zero temperature.

Since the quark deconfinement phase transition can occur at high temperature or/and high density only, it is of interest to extend the investigation for the stability of strangelets to finite temperature. This is the objective of this paper.

However, MIT bag model is a permanent quark confinement model because the confined boundary condition does not change with temperature. In principle, one can not use this model to study the phase transition of QCD directly. The best that we can do is to employ a model which can almost reproduce the properties of strange quark matter obtained by MIT bag model, but in which the quark confinement is not permanent. The quark mass density- and temperature-dependent model (QMDTD) \cite{9,10} suggested by us is one of such candidates.

Many years ago, a quark mass density-dependent model (QMDD) was suggested by Fowler, Raha and Weiner \cite{11} and then it was employed by many authors to discuss the properties of strange quark matter \cite{12-14}. According to the QMDD model, the masses of $u, d$ quarks and strange quarks (and the corresponding anti-quarks) are given by

\begin{equation}
    m_q = \frac{B}{3n_B}, \quad (q = u, d, \bar{u}, \bar{d}),
\end{equation}

\begin{equation}
    m_s, \bar{s} = m_{s0} + \frac{B}{3n_B},
\end{equation}

where $n_B$ is the baryon number density, $m_{s0}$ is the current mass of the strange quark and $B$ is the vacuum energy density. As was proved by ref. \cite{13}, the properties of strange matter in the QMDD model are nearly the same as those obtained in the MIT bag model. In fact, it is not surprised if one notices that the confinement mechanism of MIT bag model is almost the same as that of QMDD model \cite{9}.
But when we employ the QMDD model to discuss the properties of strangelet, a lot of difficulties emerge [9,10]. At first, the radius of strangelet decreases as the temperature increases; Secondly, it can not mimic the correct phase diagram of QCD because the temperature $T$ tends to infinite when $n_B \rightarrow 0$. To overcome these difficulties, we suggest a QMDTD model [10]. Instead of a constant $B$ in QMDD model, we argue that $B$ is a function of temperature and introduced an ansatz [10]

$$B(T) = B_0 \left[1 - a \left(\frac{T}{T_c}\right) + b \left(\frac{T}{T_c}\right)^2\right], \quad 0 \leq T \leq T_c,$$

$$B(T) = 0, \quad T > T_c,$$  \hspace{1cm} (3)

where $B_0$ is the vacuum energy density inside the bag (bag constant) at zero temperature, $T_c = 170$MeV is the critical temperature of quark deconfinement phase transition, and $a, b$ are two adjust parameters. Since $B$ is zero when $T = T_c$, a condition

$$1 - a + b = 0$$  \hspace{1cm} (5)

is imposed and only one parameter $a$ can be adjusted. As pointed out by ref. [10], in order to satisfy two physical conditions of strangelet at finite temperature, namely, (1), the radius of the strangelet must increases when the temperature rises, (2), the energy of the strangelet must increases when the temperature rises, the parameter $a$ is restricted in a small range:

$$0.65 \leq a \leq 0.8.$$  \hspace{1cm} (6)

In this paper, we fix the value of two parameters $a, b$ in this suitable range

$$a = 0.65, \quad b = -0.35.$$  \hspace{1cm} (7)

With these parameters set, we use the QMDTD model to discuss the thermodynamical properties of strangelet, especially, to investigate the stability of strangelet via strong hadron emission and weak hadronic decay. We will study the effects of temperature, charge and strangeness fraction on the stability and hope that our study can have impact to the detectability of the strangelet.

The organization of this paper is as follows. In the following section, we give the formulæ of thermodynamical calculations for QMDTD model. The results of thermodynamical properties of strangelet are presented in section 3. In section 4, we will discuss the stability of strangelet via possible strong and weak decays. The last section is a summary.

**II. THERMODYNAMICAL FORMULÆ**

To calculate the dynamical and thermodynamical quantities of the strangelet, we must look for the density of states first. The density of states of a spherical cavity in which the free particles be contained can be expressed as

$$\rho(k) = \frac{dN(k)}{dk},$$  \hspace{1cm} (8)
where \( N(k) \) is the total number of particle states and can be written in terms of dimensionless variable \( kR \) as

\[
N(k) = A(kR)^3 + B(kR)^2 + C(kR),
\]

where \( R \) is the radius of the bag. The three terms of the right hand side of Eq. (9) refer to the contributions of the volume, surface and curvature, respectively. The coefficients \( A, B \) and \( C \) are expected to be very slow varying functions of \( kR \), and their expressions are model dependent. For MIT bag model, these coefficients have been obtained by numerical calculations in our previous paper [10]. The volume term \( A \) is a constant, and it has the value of

\[
A = \frac{2g}{9\pi},
\]

where \( g \) is the total degeneracies. For example, it is the total number of spin and color degrees of freedom for a quark with flavor treated separately. The surface term \( B \) is

\[
B \left( \frac{m}{k} \right) = \frac{g}{2\pi} \left\{ \frac{1}{3} - \frac{k}{m} \tan^{-1} \left( \frac{k}{m} \right) - \frac{\pi}{2} \right\},
\]

where \( m \) is the mass of quark. Equations (10) and (11) are in good agreement with the ones given by multi-reflection theory [17,18]. The curvature term \( C \) can not be evaluated by this theory except for the two limiting case: \( m \to 0 \) and \( m \to \infty \). Madsen proposed that

\[
\tilde{C} \left( \frac{m}{k} \right) = \frac{g}{2\pi} \left\{ \frac{1}{3} + \frac{k}{m} + \frac{\pi}{2} \right\}.
\]

But as was pointed out by ref. [16], the best fit of numerical data for curvature term is

\[
C \left( \frac{m}{k} \right) = \tilde{C} \left( \frac{m}{k} \right) + \left( \frac{m}{k} \right)^{1.45} \frac{g}{3.42 \left( \frac{m}{k} - 6.5 \right)^2 + 100}.
\]

Now we are in the position to calculate the thermodynamical quantities of strangelets for QMDTD model. The thermodynamical potential \( \Omega \) is

\[
\Omega = \sum_i \Omega_i = - \sum_i \frac{g_i T}{(2\pi)^3} \int_0^\infty dk \frac{dN_i}{dk} \ln \left( 1 + e^{-\beta (\varepsilon_i(k) - \mu_i)} \right),
\]

where \( i \) stands for \( u, d, s \) (or \( \bar{u}, \bar{d}, \bar{s} \) ) quarks, \( g_i = 6 \) for quarks and antiquarks. \( \frac{dN_i}{dk} \) is the density of states for various flavor quarks, it is given by eqs.(8)-(13). \( \mu_i \) is the corresponding chemical potential (for antiparticle \( \mu_i = -\mu_i \)).

\[
\varepsilon_i(k) = \sqrt{m_i^2 + k^2}
\]

is the single particle energy and \( m_i \) is mass for quarks and antiquarks.

According to the QMDTD model [9,10], the masses of quarks are
\[
m_{u,a,d,d} = \frac{B_0}{3n_B} \left[ 1 - a \left( \frac{T}{T_c} \right) + b \left( \frac{T}{T_c} \right)^2 \right], \quad 0 \leq T \leq T_c, \\
m_{u,a,d,d} = 0, T \geq T_c, \\
m_{s,s} = m_{s0} + \frac{B_0}{3n_B} \left[ 1 - a \left( \frac{T}{T_c} \right) + b \left( \frac{T}{T_c} \right)^2 \right], \quad 0 \leq T \leq T_c, \\
m_{s,s} = 0, T \geq T_c,
\]

where \( m_{s0} \) is the current mass of the strange quark matter, \( n_B \) is the baryon number density

\[
n_B = A/V,
\]

and \( A \) is the baryon number of the strangelet, \( V = \frac{4}{3} \pi R^3 \) is the volume of the strangelet.

Using the standard statistical treatment, and noticing that \( \Omega \) is not only a function of temperature, volume and chemical potential, but also of density, it can be proved that the total pressure \( p \) and the total energy density \( \varepsilon \) are given by

\[
p = -\frac{1}{V} \frac{\partial (\Omega/n_B)}{\partial (1/n_B)} \bigg|_{T,\mu_i} = -\frac{\Omega}{V} + \frac{n_B}{V} \frac{\partial \Omega}{\partial n_B} \bigg|_{T,\mu_i},
\]

\[
\varepsilon = \frac{\Omega}{V} + \sum_i \mu_i n_i - \frac{T}{V} \left( \frac{\partial \Omega}{\partial T} \right)_{\mu_i,n_B}.
\]

The number density of each particle can be obtained by means of

\[
n_i = -\frac{1}{V} \frac{\partial \Omega}{\partial \mu_i} \bigg|_{T,n_B}.
\]

At finite temperature, we must include the contributions of the anti-particles, therefore, the baryon number for \( i \) quark is given by

\[
\Delta N_i = (n_i - \bar{n}_i) \times V = \frac{g_i}{(2\pi)^3} \int_0^\infty dk \frac{dN_i}{dk} \left( \frac{1}{\exp[\beta(\varepsilon_i - \mu_i)] + 1} - \frac{1}{\exp[\beta(\varepsilon_i + \mu_i)] + 1} \right).
\]

The strangeness number \( S \) of the strangelet reads

\[
S = \Delta N_s,
\]

the baryon number \( A \) of the strangelet satisfies

\[
A = \frac{1}{3}(\Delta N_u + \Delta N_d + \Delta N_s).
\]

The electric charge \( Z \) of the strangelet is

\[
Z = \frac{2}{3} \Delta N_u - \frac{1}{3} \Delta N_d - \frac{1}{3} \Delta N_s.
\]
At finite temperature, the stability condition of strangelets for the radius reads

$$\frac{\delta F}{\delta R} = 0.$$  \hfill (26)

where the free energy $F$ of strangelet is,

$$F = E - T\tilde{S},$$  \hfill (27)

$E = \varepsilon V$ is the total energy, and

$$\tilde{S} = \sum_i \tilde{S}_i = -\sum_i \frac{\partial \Omega}{\partial T}_{\mu_i,n_B}$$  \hfill (28)

is the entropy.

Given strangeness number, baryon number and electric charge, for any strangelet, we can calculate chemical potentials for $u, d, s$ quarks self-consistently by the equations (23),(24),(25) and (26). Then the thermodynamic potential, free energy and the stable radius of the strangelet at finite temperature can be obtained self-consistently.

### III. THERMODYNAMICAL PROPERTIES OF STRANGELET

The numerical calculations have been done with the parameters set:

$$B_0 = 170\text{MeVfm}^{-3}, m_{s0} = 150\text{MeV}, T_c = 170\text{MeV},$$  \hfill (29)

and the possible area for strangelet in our calculations is chosen as

$$S > 0,$$  \hfill (30)

$$Z \geq -A,$$  \hfill (31)

$$S + Z \leq 2A.$$  \hfill (32)

We calculate the free energy of the strangelet first. Figure 1 shows the free energy per baryon $F/A$ in a $S - Z$ plane for all possible strangelets with $A = 5$ and $T = 20\text{MeV}$. This is a set of downward protruding curves. The corresponding curves but for $T = 50\text{MeV}$ are shown in figure 2. Comparing these two figures, we find that the positions of dots appeared in figure 2 are lower than the corresponding positions (with the same strangeness number $S$ and charge $Z$) in figure 1. For example, for $S = 3$ and $Z = -2$, the free energy per baryon of the dot is $F/A = 1064.9\text{MeV}$ in figure 1, but reads $F/A = 898.9\text{MeV}$ in figure 2. For fixed $S$ and $Z$, the free energy of the strangelet decreases when temperature increases. This result is reasonable because the entropy increases with the temperature, the term $T\tilde{S}$ in eq.(27) increases considerably and $F$ decreases. We will see in the next section this result affects on the decay of the strangelet remarkably.

To illustrate our result transparently, we draw the $F/A$ vs $S$ curves for fixed $A = 5, Z = -5$ but different temperatures $T = 20\text{MeV}$ and $50\text{MeV}$ in figure 3, respectively. We find that the minimum of these two curves are located at the same strangeness $S = 4$ but with different free energies.. The whole curve for $T = 20\text{MeV}$ is located on the upper position.
of the curve for $T = 50\text{MeV}$. We also draw the $F/A$ vs $S$ curve for $A = 10, Z = -10$ and $T = 50\text{MeV}$ in figure 4. Compared with figure 3, the shape of the curve in figure 4 almost does not change except the position of the minimum is changed to $S = 8$. These results are similar to that one given by [20].

Now we turn to study the charge and strangeness dependences of the radius of strangelet. We draw $F/A$ vs $S$ curves with fixed $A = 5, Z = 1$ and $T = 50\text{MeV}$ but different $S = 2, 6$ and 9 in figure 5, respectively. The stable radiiues given by Eq. (26) for different strangeness are different. Figure 5 shows that the stable radius changes from 1.64fm to 1.615fm when strangeness number changes from 2 to 9. The same curves for $A = 5, Z = -4$ and $T = 50\text{MeV}$ but different $S = 2, 14$ are shown in figure 6. We see that the stable radius become 1.67fm for $S = 2$ and 1.62fm for $S = 14$. Therefore, we come to a conclusion that the stable radius of strangelet decreases when $S$ increases.

To illustrate the charge dependence of the stable radius, we draw $F/A$ vs $S$ curves with fixed $A = 5, S = 2$ and $T = 50\text{MeV}$ but different electric charge $Z = 1, 5$ and 8 in figure 7, respectively. The stable radius increases from 1.64fm to 1.69fm when the electric charge rises from 1 to 8. The same curves for $A = 5, S = 9$ and $T = 50\text{MeV}$ but different charge $Z = 1, -4$ are shown in figure 8. We see that the stable radius changes from 1.615fm to 1.605fm when $Z$ decreases from 1 to $-4$. We find that the stable radius of strangelet increases with electric charge.

IV. STABILITY OF THE STRANGELET

In this section, we follow the line of ref. [8] to investigate the stability of the strangelet and extend their study to finite temperature by using the QMDTD model.

A. Strong decay and unstable strangelet

As was pointed out by refs. [21,22], small clusters of strange matter are most favoured for detection. As two examples, hereafter we study two cases with $A = 5$ and $A = 10$, respectively.

Instead of the binding energy at zero temperature, we calculate the free energy per baryon of the possible strangelet at finite temperature first. Figure 9 and 10 show the free energy per baryon of all possible strangelets as a function of the strangeness $S$ at the temperature $T = 50\text{MeV}$ but for $A = 5$ and $A = 10$, respectively. The solid lines in these two figures connect the masses of the nucleon, $\Lambda, \Xi$ and $\Omega$. As a first cut for potential candidates of stable strangelets, these ones lying above this line can (or probably will) completely decay to the pure hadron state via strong processes, and only these ones beneath the line will be possible for metastable or stable strangelets [8].

We consider the influence of temperature now. As shown in last section, the free energy per baryon increases when temperature decreases. The positions of the dots will raise and many dots will across the line and become unstable when temperature decreases. Figure 11 shows this result clearly. The figure 11 is the same as figure 9 except for temperature $T = 20\text{MeV}$. Comparing these two figures, we find many dots across the line when temperature
decreases from 50MeV to 20MeV. At low temperature, more strangelets can decay to the pure hadronic state by strong process.

Here we must emphasize that although any strangelet initially formed under this line can not decay to a pure hadron state, it is still possibly unstable because it can decay to a hadron and another strangelet changing baryon number, strangeness number and charge \[8\]. We will look for possible strong decays, i.e. single baryon \{n, p, Λ, Σ^+, Σ^-, Ξ^0, Ξ^- and Ω\} emission and mesonic decays at the finite size configuration at finite temperature.

The baryon number \(A\), strangeness number \(S\) and electric charge \(Z\) are conserved in the strong process. A general expression of a strong baryon decay for a strangelet \(Q(A, S, Z)\) can be written as

\[Q(A, S, Z) \rightarrow Q(A - 1, S - S_x, Z - Z_x) + x(1, S_x, Z_x).\] (33)

And this process is allowed if the free energy balance of the corresponding reaction is

\[F(A, S, Z) > F(A - 1, S - S_x, Z - Z_x) + m_x.\] (34)

where \(F\) stands for the total free energy of the strangelet and \(x\) stands for a baryon with strangeness number \(S_x\) and electric charge \(Z_x\). Our results of numerical calculation are shown in figures 12, 13 and 14. For \(A = 5\) and \(T = 50\)MeV, all strangelets including the ones lying above the lines of figure 9 and the ones which satisfy the inequality (34) are drawn by the circles in figure 12. These strangelets can strong decay and are unstable. The unstable strangelets for \(A = 10\) and \(T = 50\)MeV are drawn by circle in figure 13. Figure 12 and figure 13 show that the strangelets with small strangeness number \(S\) and situated in the left side of the figure are unstable.

To study the temperature effect, the same figure for \(A = 5\) and \(T = 20\)MeV are shown in figure 14. Comparing figure 12 and figure 14, we find that many strangelets become unstable when temperature decreases. Lower temperature is in favour of the strong decay of the strangelet.

B. Weak decay and metastable strangelet

According to the definition of Greiner et. al \[8\], ”a strangelet is called metastable in the following if its energy lies under the correspond (free) hadronic matter of the same baryon number, charge and strangeness, and if it can not emit a single hadron or multiple hadrons by strong processes.” At finite temperature, instead of energy, we use free energy. A metastable strangelet can then only decay via weak process like the nonleptonic (hadronic) decays. In this sub-section, we study all possible weak hadronic decay for metastable strangelets.

In the weak process, the baryon number \(A\) and the electric charge \(Z\) are conserved, but the strangeness number \(S\) is not conserved. For the weak decay, \(\Delta S = \pm 1\). Therefore, a general expression of a weak baryon decay for a strangelet \(Q(A, S, Z)\) can be written as

\[Q(A, S, Z) \rightarrow Q(A - 1, S - S_x - 1, Z - Z_x) + x(1, S_x, Z_x).\] (35)

This process is allowed if the free energy balance of the corresponding reaction is

\[F(A, S, Z) > F(A - 1, S - S_x - 1, Z - Z_x) + m_x.\] (36)
The metastable strangelets which satisfy the inequality (36) are shown in figure 12, 13 and 14 with filled circle. We find that they are almost situated in the area with negative charge (or slightly positive charge) and high strangeness number. In particular, high strangeness is in favour of the stability of strangelet. As shown in figures 12, 13 and 14, a minimal strangeness \( S_c \) above which \( (S > S_c) \) strangelets are metastable or stable exists. The values of the minimal strangeness \( S_c \) are 5 in figure 12 \((A = 5, T = 50\text{MeV})\) and 10 in figure 13 \((A = 10, T = 50\text{MeV})\). Defining strangeness fraction \( f_s \) as

\[
  f_s = \frac{S}{A},
\]

(37)

Greiner and his co-workers had predicted that there exists a critical \( f_{sc} \) at zero temperature and pointed that the metastable or stable strangelets could only be found above this value \( f_s > f_{sc} \). Our results strongly support their prediction and extend it to the finite temperature. We obtained \( f_{sc} = 1 \) at \( T = 50\text{MeV} \). This value does not depend on the baryon numbers. But as shown in figure 14, \( f_{sc} \) depends on the temperature. It becomes \( f_{sc} = \frac{10}{5} = 2 \) at \( T = 20\text{MeV} \).

Now we turn to discuss the charge dependence of the stability of strangelet. As shown in figures 12, 13 and 14, higher negative charge is in favour of the metastable and/or stable strangelets. A maximal charge, which is \( Z_m = 1 \) in figure 12 \((A = 5, T = 50\text{MeV})\), \( Z_m = 6 \) in figure 13 \((A = 10, T = 50\text{MeV})\) and \( Z_m = -3 \) in figure 13 \((A = 5, T = 20\text{MeV})\), respectively, exists. The strangelets would be stable or metastable when \( Z \leq Z_m \). Defining charge fraction \( f_z \) as

\[
  f_z = \frac{Z}{A},
\]

(38)

We find that the maximal charge fraction depends on not only the temperature but also the baryon number \( A \). For example, \( f_{zm} \) equals to \( \frac{1}{5} \) for \( A = 5 \) and \( \frac{6}{10} \) for \( A = 10 \) when \( T = 50\text{MeV} \).

C. Stable strangelet

The strangelet which is stable against both strong and weak decay is called stable strangelet. The stable strangelets are shown in figure 12, 13 and 14 by filled squares. We find that only a few strangelets can not decay via strong and weak reactions and be completely stable. For example, as shown in figure 12, for \( A = 5 \) and \( T = 50\text{MeV} \), in total 128 strangelets, only 4 strangelets are stable \((Z = -3, S = 12), (Z = -4, S = 13), (Z = -4, S = 14) \) and \( (Z = -5, S = 15) \).

Finally, we hope to emphasize that the high negative charge and the high strangeness are in favour of the stable strangelets obviously at finite temperature. The stable strangelets in figures 12, 13 and 14 are all highly negative charged. The conclusion given by Greiner et. al at zero temperature is still correct at finite temperature.
V. SUMMARY

In summary, by using the QMDTD model, we have studied the thermodynamical properties and the stability of strangelets at finite temperature. We obtain:

(1), For fixed strangeness and charge, free energy per baryon decreases as the temperature increases. The stable radius of the strangelet decreases when the strangeness increases or the charge decreases.

(2), The higher temperature is in favour of the stability of the strangelets. Comparing figure 12 with figure 14, we see clearly that the total area of metastable and stable strangelets expands when the temperature increases.

(3), The higher negative charge and higher strangeness number are in favour of the stability of the strangelets. The stable strangelets are highly negative charged and have high strangeness.

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VII. FIGURE CAPTIONS

Figure 1. The dots stand for the free energy per baryon $F/A$ in a $S - Z$ plane for all possible strangelets with $A = 5$ and $T = 20\text{MeV}$.

Figure 2. The same as figure 1, but for the temperature $T = 50\text{MeV}$.

Figure 3. The free energy per baryon $F/A$ as functions of strangeness number $S$ with $A = 5$ and $Z = -5$, the two lines represent the temperature $T = 20\text{MeV}$ and $50\text{MeV}$, respectively.

Figure 4. The free energy per baryon $F/A$ as a function of strangeness number $S$ with $A = 10$, $Z = -10$ and $T = 50\text{MeV}$.

Figure 5. The free energy per baryon $F/A$ as functions of radius $R$ with $A = 5$, $Z = 1$ and $T = 50\text{MeV}$, the three lines represent the strangeness number $S = 2, 6$ and 9, respectively.

Figure 6. The free energy per baryon $F/A$ as functions of radius $R$ with $A = 5$, $Z = -4$ and $T = 50\text{MeV}$, the two lines represent the strangeness number $S = 2$ and 14, respectively.

Figure 7. The free energy per baryon $F/A$ as functions of radius $R$ with $A = 5$, $S = 2$ and $T = 50\text{MeV}$, the three lines represent the electric charge $Z = 1, 5$ and 8, respectively.

Figure 8. The free energy per baryon $F/A$ as functions of radius $R$ with $A = 5$, $S = 9$ and $T = 50\text{MeV}$, the two lines represent the electric charge $Z = -4$ and 1, respectively.

Figure 9. The dots stand for the free energy per baryon $F/A$ with various strangeness numbers $S$ for all possible strangelets with baryon number $A = 5$ at temperature $T = 50\text{MeV}$. The masses of nucleon, $\Lambda, \Xi$ and $\Omega$ are represented by the filled squares, respectively.

Figure 10. The same as figure 9, but for baryon number $A = 10$.

Figure 11. The same as figure 9, but for temperature $T = 20\text{MeV}$. 
Figure 12. The electric charge $Z$ as a function of the strangeness number $S$ for unstable strangelets (open circles), metastable strangelets (filled circles) and stable strangelets (filled squares) with baryon number $A = 5$ at temperature $T = 50\text{MeV}$.

Figure 13. The same as figure 12, but for baryon number $A = 10$.

Figure 14. The same as figure 12, but for temperature $T = 20\text{MeV}$.
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Figure 1

A = 5, T = 20

F/A (MeV)
$A=5, T=50$

Figure 2
Figure 3:

\[ A = 5 \]

- \( T = 50 \text{ MeV}, Z = -5 \)
- \( T = 20 \text{ MeV}, Z = -5 \)

Graph showing the relationship between \( F/A(\text{MeV}) \) and \( S \) for different temperatures and nuclear charges.
Figure 5

$T=50, A=5, Z=1$

$S=9$

$S=6$

$S=2$
Figure 6

Z = -4, T = 50, A = 5

S = 2

S = 14
$S=2, T=50, A=5$

**Figure 7**
Figure 8

S=9, T=50, A=5

Z=1

Z=-4

F/A (MeV)

R (fm)
Figure 9

$T=50$

$A=5$
Figure 10

T = 50
A = 10
Figure 11

$F/A\text{(MeV)}$ vs $S$

$T=20$

$A=5$

$\Omega$
Figure 12

A=5, T=50MeV

- unstable strangelet
- metastable strangelet
- stable strangelet

Z

S

Figure 12
Figure 13

A=10, T=50 MeV

- unstabile strangelet
- metastable strangelet
- stable strangelet

Z

S

Figure 13
Figure 14

A=5, T=20MeV

- unstable strangelet
- metastable strangelet
- stable strangelet

Z

S

Figure 14