The effect of different baryons impurities

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Abstract

We demonstrate the different effect of different baryons impurities on the static properties of nuclei within the framework of the relativistic mean-field model. Systematic calculations show that $\Lambda^+$ and $\Lambda^0$ has the same attracting role as $\Lambda$ hyperon does in lighter hypernuclei. $\Xi^-$ and $\Xi^0$ hyperon has the attracting role only for the protons distribution, and has a repulsive role for the neutrons distribution. On the contrary, $\Xi^0$ and $\Xi^+$ hyperon attracts surrounding neutrons and reveals a repulsive force to the protons. We find that the different effect of different baryons impurities on the nuclear core is due to the different third component of their isospin.

PACS numbers:21.80.+a, 21.10.Dr, 24.10.Jv

1 Introduction

Change of bulk properties of nuclei under the presence of strange impurities, like the lambda hyperon ($\Lambda$), is an interesting subject in hypernuclear physics. Since a $\Lambda$ does not suffer from Pauli blocking in $\Lambda$ hypernuclei, it can locate at the center of a nucleus, then $\Lambda$ attracts surrounding nucleons ($\Lambda$ has the additional attraction provided by - stronger net attraction - induced attraction) and makes the nucleus shrink\cite{1, 2}. Recently, the experiment KEK-PS E419 has found clear evidence for this shrinkage of $^7\Lambda$Li hypernucleus\cite{1, 2}.

In-medium hyperon interactions have been studied non-relativistically and relativistically by several groups, e. g. Hjorth-Jensen et al.\cite{3}, Lenske et al.\cite{4}, Ring and Vretenar.\cite{5}, Schaffner et al.\cite{6, 23}, Mare\v{s} et al.\cite{7}. Different from their works, our work focus on the effect of different baryons impurities on the nuclei. In the present work, first we will study whether we can obtain this shrinkage of $\Lambda$ hypernuclei within relativistic mean-field (RMF) model. After that, it is natural to think whether other baryons have the attracting role as $\Lambda$ does. In order to obtain a more profound understanding of the effect of strange impurities on nuclear core, it is necessary to consider other impurities, such as $\Sigma$ and $\Xi$, or even heavy flavored baryons. However, a new experiment at KEK \cite{8} shows that a strongly repulsive $\Sigma$-nucleus potential is required to reproduce the observed spectrum. So, we have reason to believe that $\Sigma$ hyperon does not have any attracting role and can not make nucleus shrink. Next in mass are $\Xi^-$ and $\Xi^0$ hyperons. Experimental evidence suggested that the binding energy of a $\Xi^-$ hyperon in nuclear matter is negative\cite{9}. Therefore we will consider $\Xi$ hypernuclei in this work. In mid 70’s and 80’s, the theoretical estimations\cite{10, 11, 12, 13, 14, 15} predicted a rich spectrum and a wide range of
atomic numbers for charmed and bottom nuclei. Now, heavy flavored hadrons can be studied at both the Japan Hadron Facility (JHF) [16] and GSI future accelerator [17], the experimental search for charmed nuclei is becoming realistic and would be realized. Therefore, We also investigate the heavy flavored baryons impurities, such as $\Lambda$, $\Xi$, $\Sigma$ hyperon, here we do not consider $\Sigma$. By analogy with $\Sigma$ hyperon, here we do not consider $\Sigma$ for the RMF model. The RMF model has been used to describe nuclear matter, finite nuclei, and hypernuclei successfully. Here, we start from a

$$\mathcal{L} = \mathcal{L}_{\text{Dirac}} + \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho + \mathcal{L}_A$$

(1)

with

$$\mathcal{L}_{\text{Dirac}} = \bar{\Psi}_N (i\gamma^\mu \partial_\mu - m_N) \Psi_N + \bar{\Psi}_Y (i\gamma^\mu \partial_\mu - m_Y) \Psi_Y$$

$$\mathcal{L}_\sigma = -\frac{1}{2} \gamma_\mu \partial_\mu \sigma - \frac{1}{2} m_\sigma^2 \sigma^2 - g_{\sigma\rho} \bar{\Psi}_N \sigma \Psi_N - g_{\sigma Y} \bar{\Psi}_Y \sigma \Psi_Y - \frac{1}{3} \beta \sigma^3 - \frac{1}{4} \sigma^4$$

$$\mathcal{L}_\omega = -\frac{1}{4} F_{\mu\nu} \cdot F^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu - g_{\omega Y} \bar{\Psi}_N \gamma_\mu \omega^\mu \Psi_N - g_{\omega Y} \bar{\Psi}_Y \gamma_\mu \omega^\mu \Psi_Y$$

$$\mathcal{L}_\rho = -\frac{1}{4} G_{\mu\nu} \cdot G^{\mu\nu} + \frac{1}{2} m_\rho^2 \rho_\mu \rho^\mu - g_{\rho Y} \bar{\Psi}_N \gamma_\mu \rho^\mu \cdot \mathbf{I} \Psi_N - g_{\rho Y} \bar{\Psi}_Y \gamma_\mu \rho^\mu \cdot \mathbf{I} \Psi_Y$$

$$\mathcal{L}_A = -\frac{1}{4} H_{\mu\nu} \cdot H^{\mu\nu} - e \bar{\Psi}_N \gamma_\mu q_N A^\mu \Psi_N - e \bar{\Psi}_Y \gamma_\mu q_Y A^\mu \Psi_Y$$

(2)

with

$$F_{\mu\nu} = \partial_\nu \omega_\mu - \partial_\mu \omega_\nu,$$

$$G_{\mu\nu} = \partial_\nu \rho_\mu - \partial_\mu \rho_\nu,$$

$$H_{\mu\nu} = \partial_\nu A_\mu - \partial_\mu A_\nu,$$

(3)

where the mesons fields are denoted by $\sigma, \omega, \rho$, and their masses by $m_\sigma, m_\omega, m_\rho$, respectively. $\Psi_N$ and $\Psi_Y$ are the nucleon and hyperon fields with corresponding masses $m_N$ and $m_Y$, respectively, and $Y = \Lambda, \Xi, \Xi^0, \Lambda^+, \Lambda_b$, $\Xi^0$ or $\Xi^+$. $A_\mu$ is the electromagnetic fields. $q_N$ and $q_Y$ are nucleon charge and hyperon charge in the unit of the proton charge $e$. The Lagrangian for the scalar meson includes phenomenological non-linear self-interaction, and is treated in the mean-field and the no-sea approximations [18]; the contributions of anti(quasi)particles and quantum fluctuations of mesons fields are thus neglected.

The parametrization (NL-SH) of the nucleonic sector adopted from Ref. [19] is displayed in table 1. The center-of-mass correction $E_{\text{c.m.}} = -\frac{1}{2} \frac{1}{4} A^{1/3}$ MeV is used for the RMF forces NL-SH[20], where $A$ is the atomic number. First of all, to check the validity of these parameters, we calculate the binding energy per baryon ($-E/A$) and r.m.s. charge radius ($r_{\text{ch}}$), for ordinary nuclei, i.e. the nuclei without the hyperon. The results are shown in Table 2, the experimental results are also given for comparison. From table 2, it can be found that the properties of finite nuclei can be well described with this parametrization. For the hyperon sector, it has been
turned out in Ref. [21, 22, 6, 23] that the two coupling ratios \( g_{\sigma \Lambda} / g_{\sigma N} \) and \( g_{\omega \Lambda} / g_{\omega N} \) of the \( \Lambda \) are connected to the \( \Lambda \) potential depth \( U_{\Lambda} \) in nuclear matter by the relation

\[
U_{\Lambda} = g_{\sigma \Lambda} \sigma^{eq} + g_{\omega \Lambda} \omega^{eq}_0 = m_N \left( \frac{m_N^*}{m_N} - 1 \right) \frac{g_{\sigma \Lambda}}{g_{\sigma N}} + \frac{g_{\omega \Lambda}^2}{m_\omega^2} \rho_0 \frac{g_{\omega \Lambda}}{g_{\omega N}},
\]

where \( \sigma^{eq} \) and \( \omega^{eq}_0 \) are the values of \( \sigma \) and \( \omega \) fields at saturation, and \( m_N^*/m_N = 0.597, \rho_0 = 0.146 \text{fm}^{-3} \) for the set NL-SH. Hence, for simplicity, similar to Ref. [24], in an approximation where the \( \omega, \rho \) fields couple only to the \( u \) and \( d \) quarks, provided the strange, beauty and charm quarks in the baryons act as spectators when coupling to the vector mesons, the coupling constants of hyperons to the vector fields in the native quark-counting model are obtained as

\[
\begin{align*}
g_{\omega \Xi^-} &= g_{\omega \Xi^0} = g_{\omega \Xi^+_c} = g_{\omega \Xi^{+}_c} = \frac{1}{3} g_{\omega N}, \\
g_{\rho \Xi^-} &= g_{\rho \Xi^0} = g_{\rho \Xi^+_c} = g_{\rho \Xi^{+}_c} = g_{\rho N}, \\
g_{\omega \Lambda^+_c} &= \frac{2}{3} g_{\omega N},
\end{align*}
\]

\( \Lambda, \Lambda^+_c \) and \( \Lambda_b \) are isoscalar baryons, and don’t couple with \( \rho \) meson. Then we fix the scalar coupling constants to the potential depth of the corresponding hyperon in normal nuclear matter. Note that \( U_Y \) is the relativistic potential depth. The absolute value of the nonrelativistic schrödinger equivalent potential potential depth well will be somewhat smaller\((10 - 20)\% \). It is well known that the potential well depth of \( \Lambda \) hyperon in nuclear matter is about \(-30 \text{ MeV} \), so we use \( U_{\Lambda} = -30 \text{ MeV} \) to obtain coupling constant \( g_{\sigma \Lambda} \). However, the experimental data on \( \Xi \) hypernuclei are very little. Dover and Gal[25] analyzed old emulsion data on \( \Xi^- \) hypernuclei, concluded a nuclear potential well depth of \( U_{\Xi} = -21 \sim -24 \text{ MeV} \). Fukuda et al[26] fitted the very low energy part of \( \Xi^- \) hypernuclear spectrum in the \( ^{12}\text{C}(K^-, K^+)X \) reaction, and estimated the value of \( U_{\Xi} \) to be between \(-16 \) and \(-20 \text{ MeV} \). Recently, E885 at the AGS [9] indicates a potential depth of \( U_{\Xi} = -14 \text{ MeV} \) or less. Note that these \( \Xi \) potential depth data are estimated based on Woods-Saxon potentials. Here, we choose \( U_{\Xi^-} = U_{\Xi^0} = -16 \text{ MeV} \) to fix \( g_{\sigma \Xi} \). Because there are no experimental data on \( \Lambda^+_c, \Lambda_b, \Xi^+_c \) and \( \Xi^0 \) hypernuclei, the depths of their potential well \( U_Y \) in nuclear matter are not known yet. Ref. [11] estimated the \( \Lambda^+_c \) nucleus potential was comparable in depth to the nucleon-nucleus potential. While Ref. [12] suggested \( U_{\Lambda^+_c} / U_{\Lambda} \approx 2/3 \) and \( U_{\Lambda_b} / U_{\Lambda} \approx 1 \) within the framework of the lowest-order Brueckner theory. Ref. [14] reported the relation between \( \Lambda^+_c N \) potential and \( \Lambda N \) potential, roughly \( V_{\Lambda^+_c N}(r) \approx kV_{\Lambda N}(r) \), with \( k \approx 0.8 \). Here, we adopt \( U_{\Lambda^+_c} = U_{\Lambda_b} = -30 \text{ MeV} \), the same as the depth of \( \Lambda \) potential well, to fix the coupling constants of \( \Lambda^+_c \) and \( \Lambda_b \) to the scalar meson. Because our calculations show that \( \Xi^{+}_c \) hypernuclei are very unlikely to be formed if \( |U_{\Xi^{+}_c}| \leq 14 \text{ MeV} \), so here \( U_{\Xi^{+}_c} = -16 \text{ MeV} \) is chosen. The obtained coupling constants for hyperons are displayed in table 1.

### 3 The effect of different baryons impurities

When a baryon impurity (a baryon different from nucleons) is added to an ordinary nucleus, the static properties of the nucleus will be affected. In order to observe the universality of the effect of baryons impurities on nuclear core, an unified RMF calculation is needed and careful tests should be done. Hence in our calculations typical hypernuclei between \( ^7\text{Li} \) and \( ^{209}\text{Pb} \) are selected, where \( Y = \Lambda, \Xi^-, \Xi^0, \Lambda^+_c, \Lambda_b, \Xi^{+}_c \) or \( \Xi^0_c \).
Our calculated results for $\Lambda$, $\Xi^-$ and $\Xi^0$ hypernuclei are shown in table 3 with $U_\Lambda = -30$ and $U_\Xi = -16$ MeV. The theoretical results for ordinary nuclei are also given for comparison. In the table, $-E/A$ (in MeV) is the binding energies per baryon, $r_{ch}$ is the r.m.s. charge radius, and $r_Y$, $r_n$ and $r_p$ are the calculated r.m.s. radii (in fm) of hyperon, neutrons and protons distributions, respectively. Hyperon is at its 1s$_{1/2}$ configuration for all the hypernuclei. From table 3, it can be found that for lighter $\Lambda$ hypernuclei, the size of the core nucleus in a hypernucleus is smaller than the core nucleus in free space, i.e., the values of both $r_n$ and $r_p$ in a hypernucleus are less than those in the corresponding ordinary nucleus. For instance, the r.m.s. radius $r_n$ ($r_p$) of neutrons (protons) decreases from 2.32 fm (2.37 fm) in $^6$Li to 2.25 fm (2.29 fm) in $^\Lambda_3$Li. The attracting role of $\Lambda$ is obtained in agreement with experiment KEK-PS E419. The attracting role of $\Lambda$ is also seen in $^9_\Lambda$Be and $^{13}_\Lambda$C hypernuclei. Above RMF results reveal the universality of the shrinkage effect for lighter $\Lambda$ hypernuclei. But the situation for $\Xi$ hypernuclei is different. It is particularly interesting to observe a quite different effect caused by $\Xi$ hyperon impurity.

From table 3, we find: by adding a $\Xi^-$ hyperon, the r.m.s. radii of the neutrons become a little larger, while the r.m.s. radii of the protons become much smaller, comparing with that in the normal nuclei. Contrary to the $\Xi^-$ hypernuclei, the r.m.s. radii of the protons become larger and that of the neutrons become smaller in the $\Xi^0$ hypernuclei. In fact, by calculations, it is found that the same conclusion is drawn with $-28$ MeV $< U_\Xi < -10$ MeV. The effect of $\Xi^-$ and $\Xi_b$ hyperon on nuclear core is different from $\Lambda$ hyperon. Note that $\Lambda$, $\Xi^-$ and $\Xi^0$ are different particles from proton and neutron, they are all not constrained by the Pauli exclusion. It is obviously that the common explanation[1] for the $\Lambda$ shrinkage does not suit the case of $\Xi^-$ and $\Xi^0$. Otherwise, both $\Lambda$ and $\Xi^0$ hyperon are neutral, hence the origin of the above difference can not be attributed to the Coulomb potential. There must be some other source that we don’t recognized.

Next, let us to see the effect of heavy flavored baryons impurities on the nuclear core. The results of $\Lambda^+_c$, $\Lambda_b$, $\Xi^0_c$ and $\Xi^+_c$ hypernuclei are shown in table 4 with $U_{\Lambda^+_c} = U_{\Lambda_b} = -30$ MeV and $U_\Xi = -16$ MeV. The results for ordinary nuclei are also given. The configuration of heavy flavored baryon is 1s$_{1/2}$ for all hypernuclei. From table 4, it can be seen that both $r_n$ and $r_p$ become smaller when a $\Lambda^+_c$ or $\Lambda_b$ is added to a lighter nucleus. That is to say $\Lambda^+_c$ and $\Lambda_b$ have the same attracting role as $\Lambda$ does in lighter nuclei. While a $\Xi^0_c$ is added to a nucleus, the situation is the same as adding a $\Xi^-$ hyperon, $r_n$ becomes larger, and $r_p$ becomes smaller. The effect of adding a $\Xi^+_c$ on nuclear core is the same as a $\Xi^0$ does, $r_p$ becomes larger, and $r_n$ becomes smaller. Our calculations show that the effect of $\Xi^0_c$ or $\Xi^+_c$ on nuclear core has the similar trend as using $-28$ MeV $< U_{\Xi_c} < -16$ MeV. From table 3 and 4, it can be seen that the effect of baryons impurities on nuclear core is gradually decreasing with increasing mass number.

In order to understand the different behavior of $\Lambda$ (or $\Lambda^+_c$, or $\Lambda_b$), $\Xi^-$ (or $\Xi^0_c$) and $\Xi^0$ (or $\Xi^+_c$) impurities in the nuclei, we make an inspection of their isospin. $\Lambda$ (or $\Lambda^+_c$, or $\Lambda_b$), $\Xi^-$ (or $\Xi^0_c$) and $\Xi^0$ (or $\Xi^+_c$) have different isospin third component, which may be responsible for their different behavior. The third component of isospin works through the coupling of baryon with the $\rho$ mesons in the RMF model. We may imagine if the couplings of $\rho$ mesons to $\Xi^-$, $\Xi^0_c$, $\Xi^0$ and $\Xi^+_c$ are omitted from the RMF calculation, the above mentioned different behavior of $\Xi^-$ ($\Xi^0_c$) and $\Xi^0$ ($\Xi^+_c$) from $\Lambda$ could disappear. After eliminating the contribution of the $\rho$ mesons, the RMF results are shown in table 5 with $U_\Xi = U_{\Xi_c} = -16$ MeV. From table 5, we find the r.m.s. radii of both the protons and neutrons reduce when adding anyone of these baryons to the lighter nuclei, which is the same as the situation of adding a $\Lambda$ hyperon. It is also seen that the effect of baryons impurities on the heavier nuclei is very little. The nuclear shrinkage
induced by these baryons is obtained in lighter nuclei when ignoring the contribution of the \( \rho \) mesons. The same conclusion can be obtained with \(-28\) MeV \(< U_\Xi < -10\) MeV or \(-28\) MeV \(< U_\Xi < -16\) MeV. While \( \Lambda^+_c, \Lambda_b \) and \( \Lambda, \Xi^0, \Xi^- \) have the same isospin third component, so they have the similar effect on the nuclear core.

So, we can conclude that the \( \rho \) mesons play an important role, and the different behavior of \( \Lambda \) (or \( \Lambda^+_c, \Lambda_b \)), \( \Xi^- \) (or \( \Xi^0 \)) and \( \Xi^0 \) (or \( \Xi^+ \)) impurities is due to their different isospin third component. Although the changes are small, the different response of \( r_p \) and \( r_n \) to adding a \( \Xi^- \) (or \( \Xi^0 \)) or \( \Xi^0 \) (or \( \Xi^+ \)) hyperon may be interesting to know what kind of properties of the two-body \( \Xi N (\Xi_cN) \) interaction. Probably the isospin \( T = 0 \) interaction is attractively large, while the \( T = 1 \) interaction is repulsive and small. However the r.m.s. radius is reduced only for one kind of nucleons, but the r.m.s radius of the other kind of nucleons become larger. It seems that the nuclei may swell somewhat when adding a \( \Xi^- \) (or \( \Xi^0 \)) or \( \Xi^0 \) (or \( \Xi^+ \)) hyperon. That is very different from the nuclear shrinkage inducing by a \( \Lambda \) in lighter hypernuclei.

4 Summary and conclusion

Within the framework of the RMF theory, we investigate the effect of different baryons impurities on the nuclear core. The shrinkage effect induced by a \( \Lambda \) hyperon impurity is obtained. It is found other lighter \( \Lambda \) hypernuclei also have this shrinkage effect besides loosely bound \( ^6_\Lambda \text{Li} \). Both \( \Lambda^+_c \) and \( \Lambda_b \) have the attracting role as \( \Lambda \) does in lighter hypernuclei. We also study the effect of \( \Xi \) or \( \Xi_c \) hyperon on the nuclear core. It is found that: by adding a \( \Xi^- \) or \( \Xi^0 \) hyperon to the nucleus, \( r_n \), the r.m.s. radius of the neutrons becomes a little larger, while, \( r_p \), the r.m.s. radius of the protons becomes smaller by comparing with that in the core nucleus. Whereas when adding a \( \Xi^0 \) or \( \Xi^+_c \) hyperon, \( r_p \) becomes a little larger and \( r_n \) becomes smaller. And this is very different from the nuclear shrinkage induced by a \( \Lambda \) hyperon. We find that the \( \rho \) mesons play an important role, the different effect of \( \Lambda (\Lambda^+_c, \Lambda_b) \), \( \Xi^- \) (or \( \Xi^0 \)), \( \Xi^0 \) (or \( \Xi^+_c \)) on the nuclear core is due to their different isospin third component. Although the changes are small, the different response of \( r_p \) and \( r_n \) to adding a \( \Xi^- \) (or \( \Xi^0 \)) or \( \Xi^0 \) (or \( \Xi^+_c \)) may be interesting to know what kind of properties of the two-body \( \Xi N (\Xi_cN) \) interaction. Probably the isospin \( T = 0 \) interaction is attractively large, while the \( T = 1 \) interaction is repulsive and small.

The present work only focuses on the pure \( \Lambda \) and \( \Xi \) hypernuclei, the coupling between \( \Xi N \) and \( \Lambda \Lambda \) channels in \( \Xi \) hypernuclei isn’t taken into consideration. In addition, we should mention that the coupling constants of \( \Xi^- \), \( \Xi^0 \), \( \Lambda^+_c \), \( \Lambda_b \), \( \Xi^+_c \) and \( \Xi^0 \) can not unambiguously be determined, due to be short of reliable experimental data. In order to get determinate conclusion, more reliable information are required.

ACKNOWLEDGEMENTS

This work was supported in part by China postdoctoral science foundation (2002032169), National Natural Science Foundation of China (10275037) and China Doctoral Programme Foundation of Institution of Higher Education (20010055012).
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Table 1: The coupling constants used in the calculations. The parametrization (NL-SH) of the nucleonic sector adopted from Ref. [19], where $m_\sigma = 526.059$ MeV, $m_\omega = 783$ MeV, $m_\rho = 763$ MeV. The vector coupling constants for the hyperons are taken from the native quark-counting model. The scalar coupling constants for the hyperons are fixed to the potential depth of the corresponding hyperon in normal nuclear matter, $U_\Lambda = U_{\Lambda^+} = U_{\Lambda^0} = -30$ MeV, $U_\Xi = U_{\Xi^0} = -16$ MeV.

|      | $g_{\sigma B}$ | $g_\omega B$ | $g_{\rho B}$ | $b$(fm$^{-1}$) | $c$   |
|------|---------------|---------------|---------------|---------------|------|
| $N$  | 10.444        | 12.945        | 4.383         | -6.9099       | -15.8337 |
| $\Lambda$ | 6.4686       | 8.63          | 0             | 0             | 0    |
| $\Xi$ | 3.2619        | 4.315         | 4.383         | 0             | 0    |
Table 2: Binding energy per baryon, $-E/A$ (in MeV), and r.m.s. charge radius $r_{ch}$ (in fm). The experimental data of r.m.s. charge radii are taken from [27].

| $^A$Z  | $-E/A$ ($\text{MeV}$) | $r_{ch}$ (fm) | $-E/A$ ($\text{MeV}$) | $r_{ch}$ (fm) |
|--------|----------------------|---------------|----------------------|---------------|
|        | RMF      | EXP.     | RMF      | EXP.     | RMF      | EXP.     | RMF      | EXP.     |
| $^6$Li  | 5.67     | 5.33     | 2.51     | 2.54     | $^{16}$O  | 8.04     | 7.98     | 2.70     | 2.70     |
| $^{10}$B | 6.22     | 6.48     | 2.46     | 2.43     | $^{40}$Ca | 8.52     | 8.55     | 3.46     | 3.48     |
| $^{12}$C | 7.47     | 7.68     | 2.46     | 2.47     | $^{208}$Pb| 7.90     | 7.87     | 5.51     | 5.50     |
Table 3: Binding energy per baryon, -E/A (in MeV), r.m.s. charge radius r_{ch} (in fm), r.m.s. radii of hyperon, neutron and proton, r_y, r_n and r_p (in fm), respectively. The configuration of hyperons is 1s_{1/2} for all hypernuclei. The results of Λ and Ξ hypernuclei are given with U_Λ = -30 MeV and U_Ξ = -16 MeV. The experimental data of the ordinary nuclear r.m.s. charge radii are taken from [27].

| A \ Z | -E/A | r_{ch} | r_y  | r_n  | r_p  | A \ Z | -E/A | r_{ch} | r_y  | r_n  | r_p  |
|-------|------|--------|------|------|------|-------|------|--------|------|------|------|
| 6Li   | 5.67 | 2.51  | 2.32 | 2.37 | 16O  | 8.04 | 2.70  | 2.55  | 2.58 |
| 7\n\n7Li | 5.63 | 2.43  | 2.49 | 2.25 | 2.29 | 17O  | 8.33 | 2.71  | 2.45 | 2.55 | 2.58 |
| 7\n\n7Li | 6.09 | 2.41  | 3.50 | 2.35 | 2.27 | 17O  | 8.06 | 2.68  | 2.73 | 2.58 | 2.55 |
| 7\n\n7Li | 4.92 | 2.55  | 3.90 | 2.25 | 2.41 | 17O  | 7.85 | 2.73  | 2.89 | 2.53 | 2.60 |
| 10B   | 6.22 | 2.46  | 2.29 | 2.32 |        | 19\n\n20Ca | 8.52 | 3.46  | 3.31 | 3.36 |
| 11B   | 6.63 | 2.44  | 2.57 | 2.28 | 2.30 | 1\n\n20Ca | 8.77 | 3.46  | 2.77 | 3.31 | 3.36 |
| 1\n\n20Ca | 6.14 | 2.42  | 2.76 | 2.32 | 2.27 | 1\n\n20Ca | 8.71 | 3.44  | 2.84 | 3.33 | 3.34 |
| 1\n\n20Ca | 5.92 | 2.49  | 2.98 | 2.26 | 2.35 | 20\n\n20Ca | 8.52 | 3.47  | 2.98 | 3.30 | 3.38 |
| 12C   | 7.47 | 2.46  | 2.30 | 2.32 |        | 20\n\n208Pb | 7.90 | 5.51  | 5.71 | 5.45 |
| 13C   | 7.90 | 2.45  | 2.18 | 2.28 | 2.31 | 20\n\n209Pb | 7.99 | 5.51  | 4.13 | 5.71 | 5.45 |
| 1\n\n209Ca | 7.44 | 2.42  | 2.60 | 2.32 | 2.28 | 20\n\n209Pb | 8.00 | 5.50  | 3.72 | 5.72 | 5.44 |
| 1\n\n209Pb | 7.14 | 2.48  | 2.77 | 2.27 | 2.34 | 20\n\n209Pb | 7.95 | 5.51  | 4.10 | 5.70 | 5.45 |

Table 4: Binding energy per baryon, -E/A (in MeV), r.m.s. charge radius r_{ch}(those of the nucleons, in fm), r.m.s. radii of the charmed baryon(or bottom), neutron and proton, r_y, r_n and r_p (in fm), respectively, including the contribution of the ρ mesons. The configuration of hyperon is 1s_{1/2} for all hypernuclei. The results of Λ_c^± and Λ_b hypernuclei are given with U_Λ_c^± = U_Λ_b = -30 MeV. The results of Ξ_c hypernuclei are given with U_Ξ_c = -16 MeV.

| A \ Z | -E/A | r_{ch} | r_y  | r_n  | r_p  | A \ Z | -E/A | r_{ch} | r_y  | r_n  | r_p  |
|-------|------|--------|------|------|------|-------|------|--------|------|------|------|
| 7\n\n7Li | 5.99 | 2.42  | 1.88 | 2.23 | 2.28 | 17\n\n17O | 8.33 | 2.72  | 2.04 | 2.56 | 2.59 |
| 7\n\n7Li | 7.04 | 2.37  | 1.39 | 2.19 | 2.22 | 17\n\n17O | 8.87 | 2.71  | 1.57 | 2.56 | 2.58 |
| 7\n\n7Li | 5.17 | 2.38  | 2.59 | 2.37 | 2.24 | 17\n\n17O | 7.97 | 2.68  | 2.39 | 2.58 | 2.55 |
| 7\n\n7Li | 4.90 | 2.59  | 2.97 | 2.22 | 2.46 | 17\n\n17O | 7.71 | 2.74  | 2.55 | 2.53 | 2.61 |
| 10B   | 6.22 | 2.46  | 2.29 | 2.32 |        | 19\n\n20Ca | 8.52 | 3.46  | 3.31 | 3.36 |
| 11B   | 6.87 | 2.43  | 1.70 | 2.26 | 2.29 | 1\n\n20Ca | 8.64 | 3.47  | 2.48 | 3.32 | 3.37 |
| 1\n\n20Ca | 7.86 | 2.36  | 1.11 | 2.19 | 2.21 | 1\n\n20Ca | 8.94 | 3.46  | 1.94 | 3.32 | 3.36 |
| 1\n\n20Ca | 6.14 | 2.41  | 2.24 | 2.33 | 2.26 | 1\n\n20Ca | 8.56 | 3.44  | 2.70 | 3.33 | 3.34 |
| 1\n\n20Ca | 5.86 | 2.50  | 2.42 | 2.25 | 2.36 | 20\n\n20Ca | 8.35 | 3.48  | 2.89 | 3.30 | 3.38 |
| 12C   | 7.47 | 2.46  | 2.30 | 2.32 |        | 20\n\n208Pb | 7.90 | 5.51  | 5.71 | 5.45 |
| 13C   | 8.13 | 2.43  | 1.59 | 2.26 | 2.29 | 20\n\n209Pb | 7.89 | 5.51  | 4.65 | 5.71 | 5.45 |
| 1\n\n209Pb | 7.90 | 2.44  | 2.13 | 2.28 | 2.30 | 20\n\n209Pb | 7.99 | 5.51  | 3.64 | 5.71 | 5.45 |
| 1\n\n209Pb | 7.42 | 2.41  | 2.13 | 2.33 | 2.27 | 20\n\n209Pb | 7.90 | 5.50  | 4.26 | 5.72 | 5.44 |
| 1\n\n209Pb | 7.13 | 2.49  | 2.29 | 2.26 | 2.35 | 20\n\n209Pb | -    | -    | -    | -    | -    |
Table 5: Binding energy per baryon, $-E/A$ (in MeV), r.m.s. charge radius $r_{ch}$ (those of the nucleons, in fm), r.m.s. radii of the hyperon, neutron and proton, $r_y$, $r_n$ and $r_p$ (in fm), respectively, without the contribution of the $\rho$ mesons. The configuration of hyperon is $1s_{1/2}$ for all hypernuclei. The results of $\Xi$ and $\Xi_c$ hypernuclei are given with $U_\Xi = U_{\Xi_c} = -16$MeV.

| $^A$Z | $-E/A$ | $r_{ch}$ | $r_y$ | $r_n$ | $r_p$ | $^A$Z | $-E/A$ | $r_{ch}$ | $r_y$ | $r_n$ | $r_p$ |
|-------|--------|---------|------|-----|-----|-----|--------|---------|------|-----|-----|
| $^6$Li | 5.67   | 2.51    | 2.32 | 2.37|     | $^{16}$O | 8.04   | 2.70    | 2.55 | 2.58|     |
| $^7$Li | 5.17   | 2.46    | 3.07 | 2.28| 2.31| $^{17}$O | 8.11   | 2.70    | 2.58 | 2.55| 2.57|
| $^7$Li | 4.97   | 2.48    | 3.38 | 2.29| 2.34| $^{17}$O | 7.87   | 2.71    | 2.77 | 2.55| 2.58|
| $^7$Li | 5.32   | 2.45    | 2.21 | 2.27| 2.31| $^{17}$O | 8.03   | 2.71    | 2.20 | 2.55| 2.58|
| $^7$Li | 5.00   | 2.48    | 2.45 | 2.28| 2.34| $^{17}$O | 7.74   | 2.71    | 2.41 | 2.55| 2.58|
| $^{10}$B | 6.22   | 2.46    | 2.29 | 2.32|     | $^{40}$Ca | 8.52   | 3.46    | 3.31 | 3.36|     |
| $^{11}$B | 6.21   | 2.44    | 2.54 | 2.28| 2.30| $^{41}$Ca | 8.73   | 3.45    | 2.73 | 3.31| 3.35|
| $^{11}$B | 5.97   | 2.45    | 2.73 | 2.29| 2.31| $^{41}$Ca | 8.52   | 3.46    | 2.96 | 3.31| 3.36|
| $^{11}$B | 6.26   | 2.44    | 1.97 | 2.28| 2.30| $^{41}$Ca | 8.58   | 3.46    | 2.52 | 3.31| 3.36|
| $^{11}$B | 5.93   | 2.45    | 2.15 | 2.28| 2.31| $^{41}$Ca | 8.35   | 3.46    | 2.87 | 3.31| 3.36|
| $^{12}$C | 7.47   | 2.46    | 2.30 | 2.32|     | $^{208}$Pb | 7.90   | 5.51    | 5.71 | 5.45|     |
| $^{13}$C | 7.51   | 2.45    | 2.40 | 2.29| 2.31| $^{209}$Pb | 8.03   | 5.50    | 3.56 | 5.71| 5.44|
| $^{13}$C | 7.26   | 2.45    | 2.57 | 2.29| 2.31| $^{209}$Pb | 7.92   | 5.51    | 4.24 | 5.71| 5.45|
| $^{13}$C | 7.54   | 2.44    | 1.87 | 2.28| 2.30| $^{209}$Pb | 7.93   | 5.51    | 3.94 | 5.71| 5.45|
| $^{13}$C | 7.20   | 2.45    | 2.04 | 2.29| 2.31| $^{209}$Pb | -      | -       | -    | -   | -   |