Relativistic Mean Field Theory for Hypernuclei*

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Abstract The results of relativistic mean field (RMF) calculations are presented for some of strange, charmed and bottom hypernuclei and compared to each other. The calculation includes single particle energies and other static properties of hypernuclei with different flavours. The potential well depths and coupling constants of these flavoured baryons are estimated and the results show rich behaviour. A search for charmed hypernucleus with atomic number $A \geqslant 100$ is suggested. Possible influences of different baryons impurities on the core nucleus are also examined.

Key words flavoured nuclei, heavy baryon-nucleus potential, single-particle spectra, relativistic mean field model

1 Introduction

The study of hypernuclei is of great scientific interest, it gives indeed a new dimension to the traditional world of nuclei by revealing the existence of a new type of nuclear matter. It contains baryon with strange S, namely, Λ-hyperon ($S = -1$), Σ-hyperon ($S = -1$), Ξ-hyperon ($S = -2$) and so on. A large number of Λ-hypernuclei have been observed and systematic studies for these Λ hypernuclei known at present have provided the binding energies B of the Λ-single particle states in nuclei[1—3]. B varies linearly with mass number A with a slope of about 1 MeV/(unit of A) and saturates at about 23 MeV for the heavy hypernuclei. This behavior suggests a simple model in which the Λ particle is confined in a potential well with a radius equal to the nuclear radius. The potential well depth may extract from these binding energy data, and much of what we know of the ΛN interaction comes from studies of the Λ-nucleus potential. Comparing with the Λ-hypernuclei, we know very few to other hypernuclei. Moreover, a recent experiment gives the negative answer on the existence of Σ-hypernuclei[4]. This kind of situation is stimulating more theoretical efforts and experimental measurements to understand the physics of hypernuclei.

On the other hand, it is generally agreed that hypernuclei represent the first kind of flavoured nuclei (with new quantum numbers), in the direction of other exotic nuclear systems, such as charmed and bottom hypernuclei. In fact, soon after the discovery of charmed particles Λ_c, it had been suggested that, in analogy with the strange nuclei, there should also exist the charmed nuclei[5—8].

The Λ_c- nucleus potential describes the behavior of a charmed baryon Λ_c in the nuclear medium. Early works for charmed hypernuclei achieved different estimates about the binding energy and the potential well depth. Dover and Kahana[5] proposed that "the Λ_c- nucleus potentials are seen to be comparable in depth to the nucleon-nucleus potential". Batusov et al.[8] advanced that the binding energy of a charmed baryon Λ_c seems to be as large as that of Λ in hypernuclei. Bandō and Nagata[6] made a theoretical estimate of Λ_c hypernuclei and the calculated potential depth for Λ_c is 2/3 of that for Λ. Up to now, the Λ_c- nucleus potential is still unclear because the experimental information on the potential is absent. However, from the existing experimental data, indeed there are some signs expressing the existence of Λ_c hypernuclei[8—10]. Now, in the Japan Hadron Facility (JHF), the experiment to search for the charmed and the bottom hypernuclei (Λ_c-, Λ_b- hypernuclei) is becoming realistic. Careful estimates of the possible bound states of such

exotic nuclei are needed.

In this work, we study some of strange, charmed and bottom hypernuclei within the framework of the RMF model. Our aim is to examine their potential well depths and single particle energies. Due to a hyperon behaves as an impurity in nuclei, we also consider the additions of the different baryons to some closed-shell nuclei and observe the influence of different baryons impurities on the core nucleus.

The RMF model used in our calculations is described in the following section. In Sec.3 we present results of the calculations. The summary and conclusions are drawn in Sec. 4.

2 The model

Because the relativistic mean-field model is a very standard theory that have been widely used to describe finite nuclei, nuclear matter and hypernuclei, all the formulations and the methods of numerical calculations have been clearly given in Refs.[11—15]. Here we only make a short description on the inputs in our calculations.

For the nucleonic sector, the NL-SH force parameters by Sharma et al.[12] are used in the calculation. In the case of the hyperons and the heavy flavored baryons, labeled as

$$Y = \Lambda, \Xi^-, \Xi^0, \Lambda_c^+, \Lambda_b, \Xi_c^+, \text{ or } \Xi_c^0,$$

Lagrangian density

$$L_Y = \bar{\psi}_Y (i\gamma^\mu \partial_\mu - m_Y - g_{\sigma Y}\sigma - g_{\omega Y}\gamma^0\omega_0 - \frac{1}{2}g_{\rho Y}\gamma^0\tau_{3,Y}\rho^0 - e\gamma^0 Q_Y A_0)\psi_Y. \quad (1)$$

is used to describe the flavored baryon and its couplings to the σ-, ω-, and ρ-meson fields, where eQ_Y is the electric charge of the hyperons. The Λ, Λ_c^+ and Λ_b are isoscalar baryons which have isospin and charge zero and therefore cannot couple to the ρ-meson field and the electromagnetic field. To properly describe the properties of Λ hypernuclei, parametrization about Λ hyperon is taken from Ref.[13], where a tensor coupling term $+ f_{\omega\Lambda}\bar{\psi}_\Lambda\sigma^{i0}\partial_i\omega_0\psi_\Lambda/2m_Y$ of vector meson is also included, here $\sigma^{i0} = (i/2)\{\gamma^i, \gamma^0\}$, $i = 1,2,3$.

With an quark model approximation[16] that the light unflavored ($S = C = B = 0$) meson fields couple to u,d quarks only, coupling constants of hyperons to the vector meson fields have the following quantitative relations

$$\frac{1}{3}g_{\omega N} = g_{\omega\Xi^-} = g_{\omega\Xi^0} = g_{\omega\Xi_c^0} = g_{\omega\Xi_c^+},$$

$$g_{\rho N} = g_{\rho\Xi^-} = g_{\rho\Xi^0} = g_{\rho\Xi_c^0} = g_{\rho\Xi_c^+},$$

$$\frac{2}{3}g_{\omega N} = g_{\omega\Lambda} = g_{\omega\Lambda_c^+} = g_{\omega\Lambda_b}. \quad (2)$$

The coupling constants to the scalar meson fields can be determined by the experimental information—the optical potential. It turns out that the scalar and the vector coupling constants of a hyperon are strongly correlated to its depth of the potential well in saturation nuclear matter[17,18]

$$U_Y = g_{\sigma Y}\sigma^{eq} + g_{\omega Y}\omega_0^{eq}. \quad (3)$$

Using these parametrization of RMF theory, one can make quantitative stus on various properties of hypernuclei, such as the singleparticle energy levels, binding energy per baryon, r.m.s. radii of baryons distributions, etc.

3 Results of calculations

It is well known that the potential well depth of Λ hyperon in nuclear matter is about -30MeV, so we can choose $U_Y = -30\text{MeV}$ to obtain the coupling constant $g_{\sigma\Lambda}$. Then all the field equations are solved self-consistently in the mean filed approximation for finite nuclei. The calculated Λ single-particle energies are in good agreement with the experiments[19], and the observed very small spinorbit splitting for Λ hypernuclei is also consistent with the earlier phenomenological analysis.

However, experimental data on Ξ hypernuclei are very little, and, there is even no experimental data available on Λ_c^+, Λ_b, Ξ_c^+ and Ξ_c^0 yet, their depth of U_Y in nuclear matter is not known. Dover et al.[5] estimated that the Λ_c^+-nucleus potential is comparable in depth to the nucleon-nucleus potential, while Bando et al.[6] 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 by employing the OBE potentials derived from the Nijmegen model. D. Starkov et al.[20] reported that, roughly, $V_{\Lambda_c^+ N}(r) \approx kV_{\Lambda N}(r)$, $k \approx 0.8$, where $V_{\Lambda_c^+ N}$ and $V_{\Lambda N}$ are Λ_c^+-N and Λ-N potential, respectively. The value of k is intermediate between 1 as reported by Rufa et al.[21] and 0.5 as assumed by Tan et al.[19] and Shen et al.[22] on the basis of the 2π-exchange alone. Λ_c^+ has a positive electric charge, whereas Λ or Λ_b is neutral, therefore, the Coulomb effects may play a non-negligible role in hypernuclei. On the other hand, the large mass of Λ_c^+ and Λ_b means that it may be more strongly bound than Λ.

To investigate the effects of various values of hyperon-nucleus potential U_Y, we actually choose $U_Y = -40, -30,$

Table 1. Hyperon single-particle energies(in MeV) in core nucleus ^{16}O.

	$_{\Lambda}^{16}$O(exp)	$_{\Lambda}^{17}$O	$_{\Lambda_c^+}^{17}$F			$_{\Lambda_b}^{17}$O			
			-40	-30	-20	-40	-30	-20	-10
$1s_{1/2}$	-12.5	-12.3	-23.3	-13.0	-4.91	-35.9	-22.4	-12.1	-5.1
$1p_{3/2}$	-2.5	-2.5	-13.9	-6.4	-0.9	-28.6	-18.0	-9.5	-3.9
$1p_{1/2}$	$(1p)$	-2.2	-13.4	-6.0	-0.6	-28.5	-17.9	-9.4	-3.8
$1d_{5/2}$			-5.2	-0.1		-22.2	-13.3	-6.5	-2.2
$2s_{1/2}$			-4.5			-20.9	-12.5	-5.8	-0.6
$1d_{3/2}$			-4.4			-22.0	-13.2	-6.4	-2.2
$1f_{7/2}$						-16.0	-8.7	-3.4	-0.3

-20, -10MeV for Λ_c^+ and Λ_b, compare the results of the single-particle energies in core nuclei ^{16}O, ^{90}Zr and ^{208}Pb, which is respectively presented in Tables 1, 2, 3. The results for Λ hyperon in the corresponding nuclei are also given as comparison. The experimental data are taken from Refs. [24,25]. It can be seen that Λ_c^+ would not bind to any of these three nuclei if Λ_c^+ potential well depth in nuclear matter is less then 10MeV. When $U_{\Lambda_c^+} = -20$MeV, it begins to bind to ^{16}O and ^{90}Zr, but not yet to ^{208}Pb, while Λ_b can bind to all of the three nuclei with U_{Λ_b} ranging from -40MeV to -10MeV. It can also be seen that, the change of potential well depth will result in a large movement for the single-particle energies. When U_Y goes deeper, the single-particle energies of Λ_c^+ or Λ_b increases significantly. We can conclude that the repulsive Coulomb interaction between the Λ_c^+ and protons leads a considerable lowering to the binding energy of Λ_c^+ in nuclei. Besides, a small spin-orbit splitting of Λ- and Λ_c^+-hypernuclei is also observed, while the similar splitting for Λ_b-hypernuclei is almost zero. A small level spacing of Λ_b single-particle energies has been obtained and compared with those of Λ and Λ_c^+. Just as the suggestion by Tsushima et al.[16], this may be a consequence of the heavier mass, and the small level spacing would make much more difficulties to distinguish the states in an experiment, or imply some new phenomena. The results of Λ_c^+ and Λ_b single-particle energies in Ref.[16] are very close to ours at the value of $U_Y = -30$ MeV.

Now we make a brief discussion on theoretical results of Λ_c^+ hypernuclei systematically. The $1s_{1/2}$ Λ_c^+ binding energies as a function of atomic numbers are given in Fig.1, where the proton numbers are set to be equal to the neutron number for all the nuclides. The solid and dashed lines
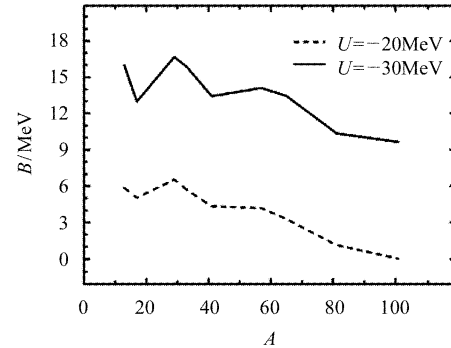

Fig.1. Λ_c^+ binding energies as a function of atomic number for $1s_{1/2}$ configuration computed with $U_Y = -30$MeV(solid line) and -20MeV(dashed line).

Table 2. Hyperon single-particle energies(in MeV) in core nucleus ^{90}Zr.

	$_{\Lambda}^{89}$Y(exp)	$_{\Lambda}^{91}$Zr	$_{\Lambda_c^+}^{91}$Nb			$_{\Lambda_b}^{91}$Zr			
			-40	-30	-20	-40	-30	-20	-10
$1s_{1/2}$	-22.1	-22.4	-21.7	-11.5	-1.9	-34.2	-23.5	-13.6	-5.5
$1p_{3/2}$	-16.0	-16.3	-18.6	-8.9	-0.1	-31.1	-21.0	-11.8	-4.4
$1p_{1/2}$	$(1p)$	-16.2	-18.5	-8.8		-31.1	-21.0	-11.8	-4.4
$1d_{5/2}$	-9.5	-9.6	-14.6	-5.5		-27.9	-18.3	-9.8	-2.9
$2s_{1/2}$		-7.6	-12.2	-3.2		-27.0	-17.5	-9.1	-2.0
$1d_{3/2}$	$(1d)$	-9.4	-14.4	-5.3		-27.9	-18.3	-9.8	-2.9
$1f_{7/2}$	-2.5	-2.7	-10.0	-1.6		-24.6	-15.5	-7.7	-1.2

Table 3. Hyperon single-particle energies(in MeV) in core nucleus ^{208}Pb.

	$^{208}_{\Lambda}$Pb(exp)	$^{209}_{\Lambda}$Pb	$^{209}_{\Lambda_c}$Bi		$^{209}_{\Lambda_b}$Pb			
			-40	-30	-40	-30	-20	-10
$1s_{1/2}$	-26.5	-24.7	-15.1	-5.4	-36.9	-26.5	-13.1	-5.1
$1p_{3/2}$	-21.3	-21.0	-13.8	-4.2	-34.8	-24.8	-11.6	-3.9
$1p_{1/2}$	$(1p)$	-21.0	-13.7	-4.2	-34.8	-24.8	-11.5	-3.9
$1d_{5/2}$	-17.0	-16.5	-11.7	-2.4	-32.8	-23.0	-9.9	-2.5
$2s_{1/2}$		-14.5	-9.1		-32.5	-22.5	-9.3	-2.0
$1d_{3/2}$	$(1d)$	-16.4	-11.6	-2.3	-32.8	-23.0	-9.8	-2.5
$1f_{7/2}$	-12.0	-11.4	-9.1	-0.2	-30.7	-21.1	-8.1	-1.2

correspond to $U_{\Lambda_c^+} = -30$MeV and -20MeV, respectively. From the figure, we can see that the binding energies of Λ_c^+ decrease as the nuclei get heavier. When the atomic number exceeds 100, Λ_c^+ cannot bind to the nuclei if $U_{\Lambda_c^+} = -20$MeV. This suggests that, it appears preferable to search for Λ_c^+-hypernuclei in the medium-heavy systems.

When a baryonic impurity (a baryon different from nucleons) is added to an ordinary nucleus, its static properties may be affected. In order to observe the universal effects of impurities in nuclear core, we make a unified RMF calculation. In this work, typical hypernuclei between $^{7}_{Y}$Li and $^{209}_{Y}$Pb are selected, where $Y = \Lambda, \Xi^-, \Xi^0, \Lambda_c^+, \Lambda_b, \Xi_c^+$ or Ξ_c^0.

Dover and Gal[25] analyzed the old emulsion data on Ξ^- hypernuclei, concluded a nuclear potential well depth of $U_\Xi = -21 — -24$MeV. Fukuda et al.[26] fitted to very low energy part of Ξ^- hypernuclear spectrum data in ^{12}C(K$^-$, K$^+$)X reaction in experiments E224 at KEK, estimated the value of

U_Ξ between -16 and -20MeV. Recently, E885 at AGS[27] indicated a potential depth of $U_\Xi = -14$MeV or less. Here we choose $U_{\Xi^-} = U_{\Xi^0} = -14$MeV to determine $g_{\sigma\Xi}$. The results of Λ_c^+ and Λ_b single-particle energies in Ref.[16] are very close to the corresponding result with $U_\Lambda = -30$MeV, so we adopt $U_{\Lambda_c^+} = U_{\Lambda_b} = -30$MeV. In addition, our calculations show that Ξ_c^+-hypernuclei are very unlikely to be formed if $|U_{\Xi_c^+}| \leqslant 14$MeV, so $U_{\Xi_c^0} = U_{\Xi_c^+} = -16$MeV is adopted here, making reference to the experimental data of Ξ hypernuclei.

The calculated results of Λ, Ξ^- and Ξ^0 hypernuclei are shown in Table 4, results of ordinary nuclei are also given for comparison. $-E/A$ is the binding energies (in MeV) per baryon, r_{ch} is the r.m.s. charge radius, and r_Λ, r_n and r_p are calculated r.m.s. radii (in fm) of Λ hyperon, neutron and proton distributions, respectively. All the hyperons are at their $1s_{1/2}$ configuration in the hypernuclei. It can be found

Table 4. Binding energy per baryon(in MeV), and r.m.s. radii of baryons(in fm).

^AZ	$-E/A$	r_{ch}	r_y	r_n	r_p	^AZ	$-E/A$	r_{ch}	r_y	r_n	r_p
^{6}Li	5.67	2.52		2.32	2.37	^{16}O	8.04	2.70		2.55	2.58
$^7_\Lambda$Li	5.63	2.43	2.49	2.25	2.29	$^{17}_\Lambda$O	8.33	2.71	2.45	2.55	2.58
$^7_{\Xi^-}$Li	5.02	2.43	3.85	2.35	2.28	$^{17}_{\Xi^-}$O	7.98	2.68	2.89	2.57	2.55
$^7_{\Xi^0}$Li	4.86	2.55	4.43	2.27	2.41	$^{17}_{\Xi^0}$O	7.77	2.73	3.11	2.54	2.60
^{8}Be	5.42	2.48		2.30	2.34	^{40}Ca	8.52	3.46		3.31	3.36
$^9_\Lambda$Be	5.72	2.44	2.35	2.28	2.30	$^{41}_\Lambda$Ca	8.77	3.46	2.77	3.31	3.36
$^9_{\Xi^-}$Be	5.12	2.43	3.29	2.33	2.28	$^{41}_{\Xi^-}$Ca	8.67	3.44	2.95	3.33	3.34
$^9_{\Xi^0}$Be	4.93	2.50	3.69	2.27	2.36	$^{41}_{\Xi^0}$Ca	8.48	3.47	3.13	3.30	3.38
^{12}C	7.47	2.46		2.30	2.32	^{208}Pb	7.90	5.51		5.71	5.45
$^{13}_\Lambda$C	7.90	2.45	2.18	2.28	2.31	$^{209}_\Lambda$Pb	7.99	5.51	4.13	5.71	5.45
$^{13}_{\Xi^-}$C	7.34	2.43	2.80	2.32	2.29	$^{209}_{\Xi^-}$Pb	7.99	5.50	3.76	5.72	5.44
$^{13}_{\Xi^0}$C	7.12	2.48	3.05	2.27	2.34	$^{209}_{\Xi^0}$Pb	7.94	5.51	4.17	5.70	5.45

Table 5. Binding energy per baryon(in MeV), and r.m.s. radii of baryons(in fm), with the contribution of ρ meson fields.

^{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	2.52		2.32	2.37	^{16}O	8.04	2.70		2.55	2.58
$^{7}_{\Lambda c}$Li	5.99	2.42	1.88	2.23	2.28	$^{17}_{\Lambda c}$O	8.33	2.72	2.04	2.56	2.59
$^{7}_{\Lambda b}$Li	7.04	2.37	1.39	2.19	2.22	$^{17}_{\Lambda b}$O	8.87	2.71	1.57	2.56	2.58
$^{7}_{\Xi^0 c}$Li	5.17	2.38	2.59	2.37	2.24	$^{17}_{\Xi^0 c}$O	7.97	2.68	2.39	2.58	2.55
$^{7}_{\Xi^- c}$Li	4.90	2.59	2.97	2.22	2.46	$^{17}_{\Xi^- c}$O	7.71	2.74	2.55	2.53	2.61
^{8}Be	5.42	2.48		2.30	2.34	^{40}Ca	8.52	3.46		3.31	3.36
$^{9}_{\Lambda c}$Be	6.00	2.43	1.79	2.25	2.29	$^{41}_{\Lambda c}$Ca	8.64	3.47	2.48	3.32	3.37
$^{9}_{\Lambda b}$Be	6.99	2.38	1.28	2.21	2.23	$^{41}_{\Lambda p}$Ca	8.94	3.46	1.94	3.32	3.36
$^{9}_{\Xi^0 c}$Be	5.24	2.40	2.38	2.34	2.26	$^{41}_{\Xi^0 c}$Ca	8.56	3.44	2.70	3.33	3.34
$^{9}_{\Xi^- c}$Be	4.96	2.53	2.61	2.24	2.39	$^{41}_{\Xi^- c}$Ca	8.35	3.48	2.89	3.30	3.38
^{12}C	7.47	2.46		2.30	2.32	^{208}Pb	7.90	5.51		5.71	5.45
$^{13}_{\Lambda c}$C	8.13	2.43	1.59	2.26	2.29	$^{209}_{\Lambda c}$Pb	7.89	5.51	4.65	5.71	5.45
$^{13}_{\Lambda b}$C	7.90	2.44	2.13	2.28	2.30	$^{209}_{\Lambda b}$Pb	7.99	5.51	3.64	5.71	5.45
$^{13}_{\Xi^0 c}$C	7.42	2.41	2.13	2.33	2.27	$^{209}_{\Xi^0 c}$Pb	7.90	5.50	4.26	5.72	5.44
$^{13}_{\Xi^- c}$C	7.13	2.49	2.29	2.26	2.35	$^{209}_{\Xi^- c}$Pb	–	–	–	–	–

Table 6. Binding energy per baryon(in MeV), and r.m.s. radii of baryons(in fm), without the contribution of ρ meson fields.

^{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	2.52		2.32	2.37	^{16}O	8.04	2.70		2.55	2.58
$^{7}_{\Xi^-}$Li	5.08	2.47	3.37	2.29	2.33	$^{17}_{\Xi^-}$O	8.02	2.70	2.73	2.55	2.58
$^{7}_{\Xi^0}$Li	4.89	2.49	3.82	2.30	2.35	$^{17}_{\Xi^0}$O	7.79	2.71	2.98	2.55	2.58
$^{7}_{\Xi^0 c}$Li	5.32	2.45	2.21	2.27	2.31	$^{17}_{\Xi^0 c}$O	8.03	2.71	2.20	2.55	2.58
$^{7}_{\Xi^- c}$Li	5.00	2.48	2.45	2.28	2.34	$^{17}_{\Xi^- c}$O	7.74	2.71	2.41	2.55	2.58
^{8}Be	5.42	2.48		2.30	2.34	^{40}Ca	8.52	3.46		3.31	3.36
$^{9}_{\Xi^-}$Be	5.18	2.46	2.96	2.29	2.32	$^{41}_{\Xi^-}$Ca	8.69	3.46	2.83	3.31	3.36
$^{9}_{\Xi^0}$Be	4.97	2.47	3.29	2.30	2.33	$^{41}_{\Xi^0}$Ca	8.48	3.46	3.12	3.31	3.36
$^{9}_{\Xi^0 c}$Be	5.37	2.45	2.07	2.28	2.31	$^{41}_{\Xi^0 c}$Ca	8.58	3.46	2.52	3.31	3.36
$^{9}_{\Xi^- c}$Be	5.05	2.46	2.27	2.28	2.32	$^{41}_{\Xi^- c}$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
$^{13}_{\Xi^-}$C	7.40	2.45	2.58	2.29	2.31	$^{209}_{\Xi^-}$Pb	7.98	5.51	4.83	5.71	5.44
$^{13}_{\Xi^0}$C	7.16	2.46	2.82	2.29	2.32	$^{209}_{\Xi^0}$Pb	7.92	5.51	4.34	5.71	5.45
$^{13}_{\Xi^0 c}$C	7.54	2.44	1.87	2.28	2.30	$^{209}_{\Xi^0 c}$Pb	7.93	5.51	3.94	5.71	5.45
$^{13}_{\Xi^- c}$C	7.20	2.45	2.04	2.29	2.31	$^{209}_{\Xi^- c}$Pb	–	–	–	–	–

that, for lighter Λ-hypernucleus, size of the core nucleus in a hypernucleus is smaller than the one in free space, i.e., both the values of r_n and r_p get smaller in hypernucleus. Although there are only a bit of shrinkage in the core nucleus due to the presence of Λ impurity, the glue-like role of Λ is obtained, in agreement with KEK-PS E419 experiment. It can be seen from the table that the effect of Λ on nuclear core is gradually decreasing with increasing mass number. The above RMF results have revealed the universality of the shrinkage effect in lighter Λ hypernuclei, however, situation of Ξ hypernuclei is quite different. By adding a Ξ⁻ hyperon into nuclei, the r.m.s. radii of neutrons become a little larger, while those of protons become much smaller; Contrary to the Ξ⁻ hypernuclei, adding a Ξ⁰ hyperon will cause the proton r.m.s. radii to become larger, and the neutron ones to become smaller. Obviously that the common explanation[28]

for the shrinkage does not suit the case of Ξ^- and Ξ^0 now. Both Λ and Ξ^0 hyperon are neutral, hence the origin of the above difference cannot be owed to their Coulomb potential.

To see the effects of heavy flavored baryons impurities on nuclear core, results of Λ_c^+, Λ_b, Ξ_c^0 and Ξ_c^+ hypernuclei are shown in Table 5, results of ordinary nuclei are also given. We can see that both r_n and r_p become smaller when a Λ_c^+ or Λ_b is added to a lighter nucleus. That is to say these two hyperons play the glue-like role in lighter nuclei. But, for other heavier nuclei, such as ^{17}O, r_n and r_p become a little larger than that in ordinary nuclei. While a Ξ_c^0 is added to a nucleus, the situation is the same as a Ξ^- hyperon; The effects of Ξ_c^+ is the same as of a Ξ^0.

Different behavior of Λ (Λ_c^+, Λ_b), Ξ^- (Ξ_c^0) and $\Xi^0(\Xi_c^+)$ in-nuclear impurities is believed to come from the differences of their third isospin component, which couples with the ρ meson fields in RMF model. After eliminating contributions of the ρ mesons, the RMF results are shown in Table 6. Now we find that both the r.m.s. radii of protons and neutrons reduce when adding a Ξ^- (Ξ_c^0) or $\Xi^0(\Xi_c^+)$ hyperon to the nuclei, the same as the situation of adding a Λ hyperon. It is also seen that, the effects of heavy flavored baryons on heavier nuclei is very little.

If the contribution of ρ mesons is ignored, we obtain the same nuclear shrinkage by adding a Ξ^- (Ξ_c^0) or $\Xi^0(\Xi_c^+)$ to lighter nuclei. So we can conclude that, the ρ meson field plays an important role, and the different behavior of the $\Lambda(\Lambda_c^+, \Lambda_b)$, Ξ^- (Ξ_c^0) and $\Xi^0(\Xi_c^+)$ impurities is due to their different third component of isospin.

4　Summary and conclusions

Within the framework of the RMF model, we have performed comprehensive calculations of three kind of flavored nuclei (strange, charmed and bottom hypernuclei), using consistent force parameters NL-SH for the nucleonic sector. The potential well depths and coupling constants of these flavored baryons are estimated and the results show rich and colorful behavior.

The effects of different baryons impurities on the core nucleus are also examined. It is shown that for lighter Λ hypernuclei, unlike the conclusion of Ref. [29], the glue-like role of the Λ impurity is universal—Λ has the same effects on the core proton distribution and the neutron one. Our results of heavy flavored hypernuclei show that both hyperons Λ_c^+ and Λ_b play the glue-like role as Λ does in lighter hypernuclei; but the effects of Ξ or Ξ_c hyperon on the core nucleus are different. The results suggest that, for Ξ^- or Ξ_c^0 hypernuclei, the proton distribution has a little shrinkage effect, whereas the neutron distribution shows a little swell. For Ξ^0 or Ξ_c^+ hypernuclei the trend of the variety is contrary to the above.

Although our results for charmed and bottom hypernuclei should be regarded as a qualitative estimate, they may exhibit some general features that may remain valid after we learn more about the interaction between flavored baryon and nucleon.

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超核的相对论平均场计算*

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摘要　利用相对论平均场方法计算了奇异、粲和底超核的部分性质，包括各种不同味的超核的单粒子能量以及其他一些静态性质，并对结果进行了比较．对各种味的重子的势阱深度和耦合常数做了估计，得到丰富的结果．建议寻找质量数大于100的粲超核．同时探讨了不同重子杂质对原子核芯性质的可能影响．

关键词　不同味的原子核　重味重子－核势　单粒子谱　相对论平均场方法