Effect of different baryon impurities

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We demonstrate the different effects of different baryon impurities on the static properties of nuclei within the framework of the relativistic mean-field model. Systematic calculations show that Λ_c^+ and Λ_b have the same attracting role as the Λ hyperon does in lighter hypernuclei. Ξ^- and Ξ_c^0 hyperons have the attracting role only for the proton distribution and have a repulsive role for the neutron distribution. On the contrary, Ξ^0 and Ξ_c^+ hyperons attract surrounding neutrons and reveal a repulsive force to the protons. We find that the different effects of different baryon impurities on the nuclear core are due to the different third components of their isospin.

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I. INTRODUCTION

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

In-medium hyperon interactions have been studied nonrelativistically and relativistically by several groups—e.g., Hjorth-Jensen and co-workers [3], Keil *et al.* [4], Vretenar *et al.* [5], Schaffner and co-workers [6,23], and Mareš and co-workers [7]. Different from their works, our work focuses on the effect of different baryon impurities on the nuclei. In the present work, first we will study whether we can obtain this shrinkage of Λ hypernuclei within relativistic mean-field (RMF) model. After that, it is natural to think whether other baryons have the attracting role as Λ does. In order to obtain a more profound understanding of the effect of strange impurities on the nuclear core, it is necessary to consider other impurities, such as Σ and Ξ or even heavy-flavored baryons. However, a new experiment at KEK [8] shows that a strongly repulsive Σ-nucleus potential is required to reproduce the observed spectrum. So we have reason to believe that the Σ hyperon does not have any attracting role and cannot make the nucleus shrink. Next in mass are Ξ^- and Ξ^0 hyperons. Experimental evidence suggested that the binding energy of a Ξ hyperon in nuclear matter is negative [9]. Therefore we will consider Ξ hypernuclei in this work. In the mid 1970s and 1980s, theoretical estimations [10–15] predicted a rich spectrum and a wide range of atomic numbers for charmed and bottom nuclei. Now that 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 Λ_c^+, Λ_b, Ξ_c^0, and Ξ_c^+. By analogy with Σ hyperons, here we do not consider Σ_c (Σ_c^{++}, Σ_c^+, Σ_c^0) hypernuclei. A different effect of different baryons impurities (Λ, Ξ^-, Ξ^0, Λ_c^+, Λ_b, Ξ_c^0, or Ξ_c^+) on the nuclear core is revealed in the present work.

II. RMF MODEL

To accomplish these, the relativistic mean-field model is used. The RMF model has been used to describe nuclear matter, finite nuclei, and hypernuclei successfully. Here, we start from a Lagrangian density of the form

$$\mathcal{L} = \mathcal{L}_{Dirac} + \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho + \mathcal{L}_A, \tag{1}$$

with

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

$$\mathcal{L}_\sigma = \frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - g_{\sigma N}\overline{\Psi}_N\sigma\Psi_N - g_{\sigma Y}\overline{\Psi}_Y\sigma\Psi_Y - \frac{1}{3}b\sigma^3 - \frac{1}{4}c\sigma^4,$$

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

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

$$\mathcal{L}_A = -\frac{1}{4}H_{\mu\nu}\cdot H^{\mu\nu} - e\overline{\Psi}_N\gamma_\mu q_N A^\mu\Psi_N - e\overline{\Psi}_Y\gamma_\mu q_Y A^\mu\Psi_Y, \tag{2}$$

with

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

TABLE I. 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, and $m_\rho=763$ 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, $U_\Lambda=U_{\Lambda_c^+}=U_{\Lambda_b}=-30$ MeV, $U_\Xi=U_{\Xi_c}=-16$ 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
Λ	6.4686	8.63	0	0	0
Ξ	3.2619	4.315	4.383	0	0

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

$$H_{\mu\nu}=\partial_\nu A_\mu-\partial_\mu A_\nu, \tag{3}$$

where the mesons fields are denoted by $\sigma,\omega_\mu,\rho_\mu$ and their masses by m_σ,m_ω,m_ρ, respectively. Ψ_N and Ψ_Y are the nucleon and hyperon fields with corresponding masses m_N and m_Y, respectively, and $Y=\Lambda$, Ξ^-, Ξ^0, Λ_c^+, Λ_b, Ξ_c^0, or Ξ_c^+. Here A_μ is the electromagnetic fields. q_N and q_Y are nucleon charge and hyperon charge in units of the proton charge e. The Lagrangian for the scalar meson includes phenomenological nonlinear self-interaction and is treated in the mean-field and 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 I. The center-of mass correction $E_{\text{c.m.}}=-\frac{3}{4}41A^{-1/3}$ 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 rms charge radius (r_{ch}) for ordinary nuclei—i.e., the nuclei without the hyperon. The results are shown in Table II, the experimental results are also given for comparison. From Table II, it can be found that the properties of finite nuclei can be well described with this parametrization. For the hyperon sector, it has been shown in Refs. [6,21–23] that the two coupling ratios $g_{\sigma\Lambda}/g_{\sigma N}$ and $g_{\omega\Lambda}/g_{\omega N}$ of the Λ are connected to the Λ potential depth U_Λ in nuclear matter by the relation

TABLE II. Binding energy per baryon, $-E/A$ (in MeV), and rms charge radius r_{ch} (in fm). The experimental data of rms charge radii are taken from [27].

	$-E/A$		r_{ch}			$-E/A$		r_{ch}	
A_Z	RMF	Expt.	RMF	Expt.	A_Z	RMF	Expt.	RMF	Expt.
^{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

$$U_\Lambda=g_{\sigma\Lambda}\sigma^{eq}+g_{\omega\Lambda}\omega_0^{eq}=m_N\left[\frac{m_N^*}{m_N}-1\right]\frac{g_{\sigma\Lambda}}{g_{\sigma N}}+\frac{g_{\omega N}^2}{m_\omega^2}\rho_0\frac{g_{\omega\Lambda}}{g_{\omega N}}, \tag{4}$$

where σ^{eq} and ω_0^{eq} are the values of σ and ω_0 fields at saturation, and $m_N^*/m_N=0.597$ and $\rho_0=0.146$ fm^{-3} for the set NL-SH. Hence, for simplicity, similar to Ref. [24], in an approximation where the ω,ρ 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

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

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

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

Λ, Λ_c^+, and Λ_b are isoscalar baryons, and do not couple with the ρ 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 depth well will be somewhat smaller [(10–20)%]. It is well known that the potential well depth of Λ hyperon in nuclear matter is about −30 MeV, so we use $U_\Lambda=-30$ MeV to obtain the coupling constant $g_{\sigma\Lambda}$. However, the experimental data on Ξ hypernuclei are very few. Dover and Gal [25] analyzed old emulsion data on Ξ^- hypernuclei and concluded a nuclear potential well depth of $U_\Xi=-21$ to −24 MeV. Fukuda *et al.* [26] fitted the very-low-energy part of Ξ^- hypernuclear spectrum in the ^{12}C(K$^-$,K$^+$)X reaction and estimated the value of U_Ξ to be between −16 and −20 MeV. Recently, E885 at the AGS [9] have indicated a potential depth of $U_\Xi=-14$ MeV or less. Note that these Ξ potential depth data are estimated based on Woods-Saxon potentials. Here, we choose $U_{\Xi^-}=U_{\Xi^0}=-16$ MeV to fix $g_{\sigma\Xi}$. Because there are no experimental data on Λ_c^+, Λ_b, Ξ_c^+, and Ξ_c^0 hypernuclei, the depths of their potential well U_Y in nuclear matter are not known yet. Reference [11] estimated that the Λ_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. Reference [14] reported the relation between the Λ_c^+N potential and ΛN potential, roughly $V_{\Lambda_c^+N}(r)\simeq kV_{\Lambda N}(r)$, with $k\approx 0.8$. Here, we adopt $U_{\Lambda_c^+}=U_{\Lambda_b}=-30$ MeV, the same as the depth of the Λ potential well, to fix the coupling constants of Λ_c^+ and Λ_b to the scalar meson. Because our calculations show that Ξ_c^+ hypernuclei are very unlikely to be formed if $|U_{\Xi_c^+}|\leqslant 14$ MeV, so here $U_{\Xi_c^0}=U_{\Xi_c^+}=-16$ MeV is chosen. The obtained coupling constants for hyperons are displayed in Table I.

TABLE III. Binding energy per baryon, $-E/A$ (in MeV), rms charge radius r_{ch} (in fm), and rms radii of the 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 $U_\Lambda = -30$ MeV and $U_\Xi = -16$ MeV. The experimental data of the ordinary nuclear rms 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
^{6}Li	5.67	2.51		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	5.09	2.41	3.50	2.35	2.27	$^{17}_{\Xi^-}$O	8.06	2.68	2.73	2.58	2.55
$^7_{\Xi^0}$Li	4.92	2.55	3.90	2.25	2.41	$^{17}_{\Xi^0}$O	7.85	2.73	2.89	2.53	2.60
^{10}B	6.22	2.46		2.29	2.32	^{40}Ca	8.52	3.46		3.31	3.36
$^{11}_\Lambda$B	6.63	2.44	2.57	2.28	2.30	$^{41}_\Lambda$Ca	8.77	3.46	2.77	3.31	3.36
$^{11}_{\Xi^-}$B	6.14	2.42	2.76	2.32	2.27	$^{41}_{\Xi^-}$C	8.71	3.44	2.84	3.33	3.34
$^{11}_{\Xi^0}$B	5.92	2.49	2.98	2.26	2.35	$^{41}_{\Xi^0}$Ca	8.52	3.47	2.98	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	7.44	2.42	2.60	2.32	2.28	$^{209}_{\Xi^-}$Pb	8.00	5.50	3.72	5.72	5.44
$^{13}_{\Xi^0}$C	7.21	2.48	2.77	2.27	2.34	$^{209}_{\Xi^0}$Pb	7.95	5.51	4.10	5.70	5.45

III. EFFECT OF DIFFERENT BARYON 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 baryon impurities on the nuclear core, a unified RMF calculation is needed and careful tests should be done. Hence in our calculations typical hypernuclei between ^7_YLi and $^{209}_Y$Pb are selected, where $Y = \Lambda$, Ξ^-, Ξ^0, Λ_c^+, Λ_b, Ξ_c^0, or Ξ_c^+.

Our calculated results for Λ, Ξ^-, and Ξ^0 hypernuclei are shown in Table III 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 rms charge radius, and r_Y, r_n, and r_p are the calculated rms radii (in fm) of hyperon, neutrons, and protons distributions, respectively. Hyperon is at its $1s_{1/2}$ configuration for all hypernuclei. From Table III, it can be found that for lighter Λ 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 rms 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 $^7_\Lambda$Li. The attracting role of Λ is obtained in agreement with the KEK-PS E419 experiment. The attracting role of Λ is also seen in $^9_\Lambda$Be and $^{13}_\Lambda$C hypernuclei. The above RMF results reveal the universality of the shrinkage effect for lighter Λ hypernuclei. But the situation for Ξ hypernuclei is different. It is particularly of interest to observe a quite different effect caused by Ξ hyperon impurities.

From Table III, we find that, by adding a Ξ^- hyperon, the rms radii of the neutrons become a little larger, while the rms radii of the protons become much smaller, comparing with those in the normal nuclei. Contrary to the Ξ^- hypernuclei, the rms radii of the protons become larger and those of the neutrons become smaller in the Ξ^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 Ξ^- and Ξ_0 hyperons on the nuclear core is different from Λ hyperons. Note that Λ, Ξ^-, and Ξ^0 are different particles from protons and neutrons; they are all not constrained by Pauli exclusion. It is obvious that the common explanation [1] for the Λ shrinkage does not suit the case of Ξ^- and Ξ^0. Otherwise, both Λ and Ξ^0 hyperons are neutral, and hence the origin of the above difference cannot be attributed to the Coulomb potential. There must be some other source that we do not recognize.

Next, let us see the effect of heavy-flavored baryon impurities on the nuclear core. The results of Λ_c^+, Λ_b, Ξ_c^0, and Ξ_c^+ hypernuclei are shown in Table IV with $U_{\Lambda_c^+} = U_{\Lambda_b} = -30$ MeV and $U_{\Xi_c} = -16$ MeV. The results for ordinary nuclei are also given. The configuration of heavy-flavored baryons is $1s_{1/2}$ for all hypernuclei. From Table IV, it can be seen 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, Λ_c^+ and Λ_b have the same attracting role as Λ does in lighter nuclei. While a Ξ_c^0 is added to a nucleus, the situation is the same as adding a Ξ^- hyperon, and r_n becomes larger and r_p becomes smaller. The effect of adding a Ξ_c^+ on the nuclear core is the same as Ξ^0, and r_p becomes larger and r_n becomes smaller. Our calculations show that the effect of Ξ_c^0 or Ξ_c^+ on the nuclear core has a similar trend as using -28 MeV $< U_{\Xi_c} \leqslant -16$ MeV. From Table III and IV, it can be seen that the effect of baryon impurities on the nuclear core is gradually decreasing with increasing mass number.

In order to understand the different behavior of Λ (or Λ_c^+ or Λ_b), Ξ^- (or Ξ_c^0), and Ξ^0 (or Ξ_c^+) impurities in the nuclei,

TABLE IV. Binding energy per baryon, $-E/A$ (in MeV), rms charge radius r_{ch} (those of the nucleons, in fm), and rms 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 hyperons is $1s_{1/2}$ for all hypernuclei. The results of Λ_c^+ and Λ_b hypernuclei are given with $U_{\Lambda_c^+}=U_{\Lambda_b}=-30$ MeV. The results of Ξ_c hypernuclei are given with $U_{\Xi_c}=-16$ 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
$^{7}_{\Lambda_c^+}$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
$^{7}_{\Xi_c^0}$Li	5.17	2.38	2.59	2.37	2.24	$^{17}_{\Xi_c^0}$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
^{10}B	6.22	2.46		2.29	2.32	^{40}Ca	8.52	3.46		3.31	3.36
$^{11}_{\Lambda_c^+}$B	6.87	2.43	1.70	2.26	2.29	$^{41}_{\Lambda_c^+}$Ca	8.64	3.47	2.48	3.32	3.37
$^{11}_{\Lambda_b}$B	7.86	2.36	1.11	2.19	2.21	$^{41}_{\Lambda_b}$Ca	8.94	3.46	1.94	3.32	3.36
$^{11}_{\Xi_c^0}$B	6.14	2.41	2.24	2.33	2.26	$^{41}_{\Xi_c^0}$Ca	8.56	3.44	2.70	3.33	3.34
$^{11}_{\Xi_c^+}$B	5.86	2.50	2.42	2.25	2.36	$^{41}_{\Xi_c^+}$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
$^{13}_{\Xi_c^0}$C	7.42	2.41	2.13	2.33	2.27	$^{209}_{\Xi_c^0}$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	-	-	-	-	-

we make an inspection of their isospin. Λ (or Λ_c^+ or Λ_b), Ξ^- (or Ξ_c^0), and Ξ^0 (or Ξ_c^+) have different isospin third components, which may be responsible for their different behavior. The third component of the isospin works through the coupling of baryons with the ρ mesons in the RMF model. We may imagine if the couplings of ρ mesons to Ξ^-, Ξ_c^0, Ξ^0, and Ξ_c^+ are omitted from the RMF calculation, the above-mentioned different behavior of Ξ^- (Ξ_c^0) and Ξ^0 (Ξ_c^+) from Λ could disappear. After eliminating the contribution of the ρ mesons, the RMF results are shown in Table V with $U_\Xi=U_{\Xi_c}=-16$ MeV. From Table V, we find that the rms radii of both protons and neutrons reduce when adding any one of these baryons to the lighter nuclei, which is the same as the situation of adding a Λ hyperon. It is also seen that the effect of baryon 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 ρ mesons. The same conclusion can be obtained with -28 MeV$<U_\Xi<-10$ MeV or -28 MeV$<U_{\Xi_c}<-16$ MeV. While Λ_c^+, Λ_b, and Λ, Ξ_c^0, and Ξ^-, Ξ_c^+, and Ξ^0 have the same isospin third component, so they have a similar effect on the nuclear core.

So we can conclude that the ρ mesons play an important role and the different behavior of Λ (or Λ_c^+ or Λ_b), Ξ^- (or Ξ_c^0), and Ξ^0 (or Ξ_c^+) impurities is due to their different isospin third components. Although the changes are small, in the different responses of r_p and r_n to adding a Ξ^- (Ξ_c^0) or Ξ^0(Ξ_c^+) hyperon it may be interesting to know the kind of properties of the two-body ΞN ($\Xi_c N$) interaction. Probably the isospin $T=0$ interaction is attractively large, while the $T=1$ interaction is repulsive and small. However, the rms radius is reduced only for one kind of nucleons, but the rms radius of the other kind of nucleons become larger. It seems that the nuclei may swell somewhat when adding a Ξ^- (Ξ_c^0) or Ξ^0(Ξ_c^+) hyperon. That is very different from the nuclear shrinkage induced by a Λ in lighter hypernuclei.

IV. SUMMARY AND CONCLUSION

Within the framework of the RMF theory, we investigate the effect of different baryon impurities on the nuclear core. The shrinkage effect induced by a Λ hyperon impurity is obtained. It is found that other lighter Λ hypernuclei also have this shrinkage effect besides loosely bound $^{6}_{\Lambda}$Li. Both Λ_c^+ and Λ_b have the attracting role as Λ does in lighter hypernuclei. We also study the effect of Ξ or Ξ_c hyperons on the nuclear core. It is found that by adding a Ξ^- or Ξ_c^0 hyperon to the nucleus, r_n, the rms radius of the neutrons, becomes a little larger, while r_p, the rms radius of the protons, becomes smaller by comparing with that in the core

TABLE V. Binding energy per baryon, $-E/A$ (in MeV), rms charge radius r_{ch} (those of the nucleons, in fm), and rms radii of the hyperon, neutron, and proton, r_y, r_n, and r_p (in fm), respectively, without the contribution of the ρ mesons. The configuration of hyperons is $1s_{1/2}$ for all hypernuclei. The results of Ξ and Ξ_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
$^{7}_{\Xi^-}$Li	5.17	2.46	3.07	2.28	2.31	$^{17}_{\Xi^-}$O	8.11	2.70	2.58	2.55	2.57
$^{7}_{\Xi^0}$Li	4.97	2.48	3.38	2.29	2.34	$^{17}_{\Xi^0}$O	7.87	2.71	2.77	2.55	2.58
$^{7}_{\Xi_c^0}$Li	5.32	2.45	2.21	2.27	2.31	$^{17}_{\Xi_c^0}$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
^{10}B	6.22	2.46		2.29	2.32	^{40}Ca	8.52	3.46		3.31	3.36
$^{11}_{\Xi^-}$B	6.21	2.44	2.54	2.28	2.30	$^{41}_{\Xi^-}$Ca	8.73	3.45	2.73	3.31	3.35
$^{11}_{\Xi^0}$B	5.97	2.45	2.73	2.29	2.31	$^{41}_{\Xi^0}$Ca	8.52	3.46	2.96	3.31	3.36
$^{11}_{\Xi_c^0}$B	6.26	2.44	1.97	2.28	2.30	$^{41}_{\Xi_c^0}$Ca	8.58	3.46	2.52	3.31	3.36
$^{11}_{\Xi_c^+}$B	5.93	2.45	2.15	2.28	2.31	$^{41}_{\Xi_c^+}$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	7.51	2.45	2.40	2.29	2.31	$^{209}_{\Xi^-}$Pb	8.03	5.50	3.56	5.71	5.44
$^{13}_{\Xi^0}$C	7.26	2.45	2.57	2.29	2.31	$^{209}_{\Xi^0}$Pb	7.92	5.51	4.24	5.71	5.45
$^{13}_{\Xi_c^0}$C	7.54	2.44	1.87	2.28	2.30	$^{209}_{\Xi_c^0}$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	-	-	-	-	-

nucleus, whereas when adding a Ξ^0 or Ξ_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 Λ hyperon. We find that the ρ mesons play an important role, the different effect of $\Lambda(\Lambda_c^+, \Lambda_b)$, Ξ^- (Ξ_c^0), and Ξ^0 (Ξ_c^+) on the nuclear core is due to their different isospin third components. Although the changes are small, in the different responses of r_p and r_n to adding a Ξ^- (Ξ_c^0) or Ξ^0 (Ξ_c^+) it may be interesting to know the kind of properties of the two-body ΞN ($\Xi_c N$) 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 Λ and Ξ hypernuclei; the coupling between ΞN and $\Lambda\Lambda$ channels in Ξ hypernuclei is not taken into consideration. In addition, we should mention that the coupling constants of Ξ^-, Ξ^0, Λ_c^+, Λ_b, Ξ_c^+, and Ξ_c^0 cannot unambiguously be determined, due to a shortage of reliable experimental data. In order to get a definite conclusion, more reliable information is required.

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[1] K. Tanida *et al.*, Phys. Rev. Lett. **86**, 1982 (2001).

[2] K. Tanida *et al.*, Nucl. Phys. **A684**, 560 (2001).

[3] I. Vidaña, A. Polls, A. Ramos, L. Engvik, and M. Hjorth-Jensen, Phys. Rev. C **62**, 035801 (2000); I. Vidaña, A. Polls, A. Ramos, M. Hjorth-Jensen, and V. G. J. Stokes, *ibid.* **61**, 025802 (2000); I. Vidaña, A. Polls, A. Ramos, and M. Hjorth-Jensen, Nucl. Phys. **A644**, 201 (1998); M. Hjorth-Jensen, A. Polls, A. Ramos, and H. Muether, *ibid.* **A605**, 458 (1996).

[4] C. Keil, H. Lenske, and C. Greiner, J. Phys. G **28**, 1683 (2002); C. Keil and H. Lenske, Phys. Rev. C **66**, 054307 (2002); C. M. Keil, F. Hofmann, and H. Lenske, *ibid.* **61**, 064309 (2000).

[5] D. Vretenar, W. Pöschl, G. A. Lalazissis, and P. Ring, Phys. Rev. C **57**, R1060 (1998).

[6] J. Schaffner and I. N. Mishustin, Phys. Rev. C **53**, 1416 (1996); M. Rufa, J. Schaffner, J. A. Maruhn, H. Stöcker, W. Greiner, and P.-G. Reinhard, *ibid.* **42**, 2469 (1990); J. Schaffner, C. B. Dover, A. Gal, C. Greiner, and H. Stöcker, Phys. Rev. Lett. **71**, 1328 (1993).

[7] J. Mareš and B. K. Jennings, Phys. Rev. C **49**, 2472 (1994); S. Marcos, R. J. Lombard, and J. Mareš, *ibid.* **57**, 1178 (1998); J. Mareš and B. K. Jennings, Nucl. Phys. **A585**, 347c (1995); E. D. Cooper, B. K. Jennings, and J. Mareš, *ibid.* **A585**, 157c (1995); R. J. Lombard, S. Marcos, and J. Mareš, Phys. Rev. C

51, 1784 (1995).
[8] H. Noumi *et al.*, Phys. Rev. Lett. **89**, 072301 (2002).
[9] P. Khaustov *et al.*, Phys. Rev. C **61**, 054603 (2000).
[10] S. Iwao, Lett. Nuovo Cimento Soc. Ital. Fis. **19**, 647 (1977); R. Gatto and F. Paccanioni, Nuovo Cimento A **46**, 313 (1978); N. N. Kolesnikov *et al.*, Sov. J. Nucl. Phys. **34**, 957 (1981); C. B. Dover *et al.*, Phys. Rev. C **27**, 2085 (1983).
[11] C. B. Dover and S. H. Kahana, Phys. Rev. Lett. **39**, 1506 (1977).
[12] H. Bando and S. Nagata, Prog. Theor. Phys. **69**, 557 (1983).
[13] H. Bando and M. Bando, Phys. Lett. **109B**, 164 (1982).
[14] N. I. Starkov and V. A. Tsarev, Nucl. Phys. **A450**, 507c (1986).
[15] S. A. Bunyatov, V. V. Lyukov, N. I. Starkov, and V. A. Tsarev, Sov. J. Part. Nucl. **23**, 253 (1992).
[16] http://jkj.tokai.jaerigo.jp/.
[17] www.gsi.de/GSI-future
[18] P.-G. Reinhard, Rep. Prog. Phys. **52**, 439 (1989).
[19] M. M. Sharma, M. A. Nagarajan, and P. Ring, Phys. Lett. B **312**, 377 (1993).
[20] M. Bender, K. Rutz, P.-G. Reinhard, and J. A. Maruhn, Eur. Phys. J. A **7**, 467 (2000).
[21] J. Schaffner, C. Greiner, and H. Stöcker, Phys. Rev. C **46**, 322 (1992).
[22] N. K. Glendenning and S. A. Moszkowski, Phys. Rev. Lett. **67**, 2414 (1991).
[23] J. Schaffner *et al.*, Ann. Phys. (N.Y.) **235**, 35 (1994).
[24] K. Tsushima and F. C. Khanna, Phys. Rev. C **67**, 015211 (2003); Prog. Theor. Phys. Suppl. **149**, 160 (2003).
[25] C. B. Dover and A. Gal, Ann. Phys. (N.Y.) **146**, 309 (1983).
[26] T. Fukuda *et al.*, Phys. Rev. C **58**, 1306 (1998).
[27] I. Angeli, At. Data Nucl. Data Tables **87**, 185 (2004).