Properties of the Alpha Decay Chain Nuclei of $^{310}126$, $^{292}120$ and $^{298}114$ *

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The properties of the α decay nuclei of $^{310}126$, $^{292}120$ and $^{298}114$ are investigated in the deformed relativistic mean-field model. The nuclear properties are investigated with the TMA and NL-Z2 parameter sets, and compared with Moller's result [At. Data Nucl. Data Tables 59 (1995) 185]. The results show that the α decay energy increases systematically with the increasing proton number. Meanwhile, the a decay energy has a minimum value at the point of shell closure. It is also found that among the three nuclei, $^{292}120$ is more possible to be the next doubly magic nucleus.

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In the late 1960s, Nilsson *et al.* predicted that there is a stable island of superheavy nucleus (SHN) around the nucleus $Z = 114$ and $N = 184$, wherein the nuclear lifetime is longer than their neighbourhoods.[1] Since then great efforts have been made to investigate SHN by physicists and chemists. Especially in the past several years, a series of superheavy nuclei were produced.[2−6] Some of famous Laboratories such as GSI in Germany, Dubna in Russian, Berkeley in the USA and Riken in Japan have made great efforts to search for new superheavy elements. At the same time, a series of theoretical investigations on the production and structure of SHN have been carried out.[7−16] Among them, the theoretical results using the refined macro-micro models, such as the Yukawa-plus exponential model with Woods-Saxon single-particle potentials[7] or the finite-range droplet model with folded-Yukawa single-particle potentials,[8,9] confirmed the prediction of $^{298}114$ for the next spherical doubly magic nucleus. However, most of the self-consistent models found the more proton-rich $^{292}120$ or even $^{310}126$[10−14] are the possible nuclei for that. Recently, the study of superheavy nuclei using the cranked Hartree-Fock theory has been performed, which predicted that the $^{292}120$ are most possible to be the next doubly magic nuclei.[15]

Up to now, the element $Z = 114$ has been produced, and the occurance of $Z = 116$ is to be proven further. Therefore, the investigation of the properties of SHN in details becomes necessary. In this Letter, we apply the deformed relativistic mean field (DRMF) to study the properties of the α decay nuclei of $^{310}126$, $^{292}120$ and $^{298}114$, and to predict the next possible doubly magic nucleus by systematical analyses, which is an important subject for many nuclear physicists for a long time. The TMA parameter has been proven to be very reliable for the predictions of SHN.[16] We use this parameter to obtain reasonable results for further theoretical investigation of the production of superheavy nuclei, because the data of nuclei with $Z \geq 115$ are still absent.

The RMF approach has been extensively used to study the bulk properties of β-stable and β-unstable nuclei.[17−22] The formalism of DRMF theory for finite nuclei can be found in Ref. [18]. We start from the local Lagrangian density for a nucleon-meson many-body system, and solve the Dirac equation for nucleons and the Klein–Gordon equations for the mesons. In the numerical calculations, the effect of the pairing interaction has been added by the Bardeen-Cooper-Schrieffer (BCS) formalism. The oscillator quantum numbers for the fermion spinors and boson fields are taken to be $N_f = N_b = 20$.

There are more than ten parameter sets for RMF equations, which are suitable for different kinds of nuclei. In this work, we use the TMA parameter set which was developed more recently.[23] This parameter set includes the A-dependent coefficients in the coupling constants while any other set of parameter has not. Therefore, the surface effects of the finite nuclei throughout the chart of nuclei can be considered reasonably. It is suggested that any model on superheavy nuclei should be tested first with a known nucleus ^{264}Hs for the further discussion on superheavy nuclei.[13] Table 1 shows the ground-state properties of ^{264}Hs, where the results from other parameters are given for comparison. The results of parameter NL1 is also given there. From Table 1 it can be seen clearly that our calculated result of binding energy is better than the other parameters, compared to the experimental data. The difference between the theoretical results with TMA and the experimental data is ap-

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proximately 0.2%, the same as for ^{208}Pb. It is shown that the parameter TMA can be reliably applied to the range of superheavy nuclei.

Table 1. Ground-state properties of ^{264}Hs. The results of parameters NL-Z, PL-40, NL-SH, and TM1 are from Ref. [13]. The results of NL1 are calculated by our DRMF model with $N_f = N_b = 20$. The input pairing gaps are both $\Delta p = \Delta n = 11.2\,\mathrm{MeV}/\sqrt{A}$.

Parameter set	E_B (MeV)	$\delta B/B$ (%)	Q_2 (fm^2)	β_2
NL-Z	1931.32	−0.24	1074	0.29
PL-40	1931.34	−0.24	1072	0.29
NL-SH	1939.14	−0.64	904	0.24
TM1	1938.66	−0.62	945	0.25
NL1	1937.07	−0.54	1076.92	0.29
TMA	1930.64	−0.20	920.64	0.25
Expt	1926.72			

Alpha decay is one of the most predominant modes of decay of superheavy nuclei.[24] Because many superheavy nuclei are identified by the observation of a series of α decays, the α decay plays a key role for the study of superheavy nuclei. In the following we discuss α decays based on the calculated results.

^{310}126 nucleus

In Table 2 the results of the properties of the α decay chain nuclei of ^{310}126 are listed. Because of lack of experimental data, we compare our results with Moller's result.[25] The binding energies are plotted in Fig. 1 and the a decay energies are plotted in Fig. 2. From Fig. 1 it can be seen that the calculations with the parameter TMA agree with Ref. [25] very well up to ^{302}122, and for the nuclei above ^{306}124, the discrepancies increase a little. This might be due to the fact that the binding energies of the superdeformation ground state are much larger than the corresponding ones under normal deformation for the nuclei above ^{306}124. For the nuclei from ^{286}114 to ^{302}122, the binding energies of ground state with superdeformation are in fact not much larger than their binding energies with normal deformation. For the nuclei from ^{286}114 to ^{314}128, it was considered that they have normal deformation instead of superdeformation,[25] this could be the reason for the discrepancy of nuclei above ^{306}124. Despite this, the largest discrepancy is less than 0.5%. In Fig. 2, the comparison of the α decay energies of the ^{310}126 α decay chain nuclei is made. It clearly demonstrates that the α decay energies increase with the increase of the proton Z. From Fig. 2 it is also clarified that ^{310}126 can not be the next doubly magic nucleus because the present calculations show that the α decay energy is neither maximal nor minimal at ^{310}126 although there is a maximal α decay energy for ^{310}126 in Ref. [25].

Table 2. Properties of the a decay chain nuclei of ^{310}126.

Nuclei	E_B (MeV)	β_n	β_p	R_n	R_p	Q_α	E_B (MeV)[25]	Q_α[25]
^{314}128	2158.976	0.62	0.65	6.885	6.783	15.079	2148.555	16.83
^{310}126	2145.755	0.59	0.62	6.833	6.723	13.906	2137.085	17.11
^{306}124	2131.361	0.58	0.61	6.798	6.679	13.727	2125.796	16.331
^{302}122	2116.788	0.53	0.55	6.723	6.591	13.34	2113.827	14.051
^{298}120	2101.828	0.53	0.56	6.694	6.557	11.203	2099.578	13.361
^{294}118	2084.731	0.50	0.53	6.648	6.501	11.442	2084.639	12.281
^{290}116	2067.873	0.48	0.50	6.607	6.450	10.153	2068.62	11.121
^{286}114	2049.726	0.48	0.49	6.573	6.407	10.684	2051.441	9.401
^{282}112	2032.110	0.17	0.18	6.376	6.252	10.713	2032.542	9.421
^{278}110	2014.523	0.19	0.19	6.353	6.155	10.427	2013.663	10.41
^{274}108	1996.650	0.20	0.21	6.332	6.128	8.843	1995.773	9.471

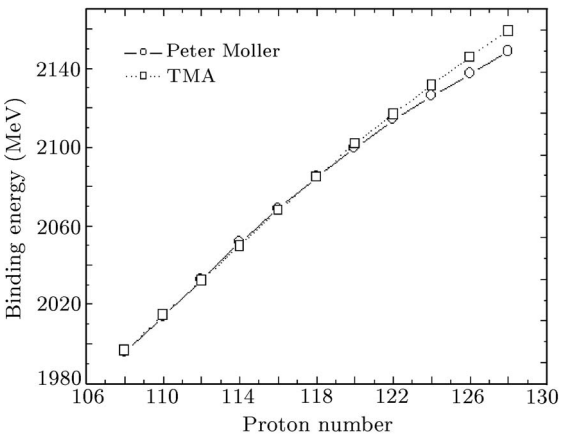


Fig. 1. Binding energy of the ^{310}126 alpha decay chain nuclei.

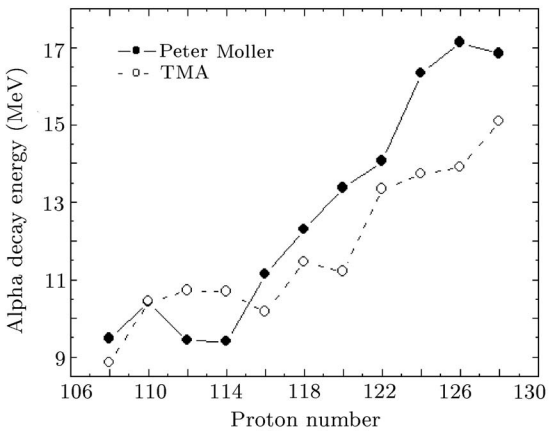


Fig. 2. The alpha decay energy of the ^{310}126 alpha decay chain nuclei.

$^{292}120$ *nucleus*

The binding energy and the α decay energy of these nuclei are plotted in Figs. 3 and 4. From Fig. 3 it can be seen that the present calculations for binding energy with parameters of TMA and NL-Z2 agree very well with Ref. [25]. Figure 4 shows a very good upward trend with the increasing proton number. For the parameter TMA at $Z = 120$, the α decay energy is less than its neighbouring nuclei $Z = 122$ and 118. To confirm whether $^{292}120$ is a doubly magic nucleus, its α decay chain is also calculated using the parameter NL-Z2. This parameter set is also widely used in the investigation of SHN. Figure 4 shows the α decay energy decreases more obviously at $^{292}120$. It can also be seen from Fig. 4 that for the parameter TMA and NL-Z2, the a decay energy increase slowly with the increase of proton number or neutron number, and Q_α decrease obviously at $^{292}120$. This illuminates the stability of $^{292}120$.

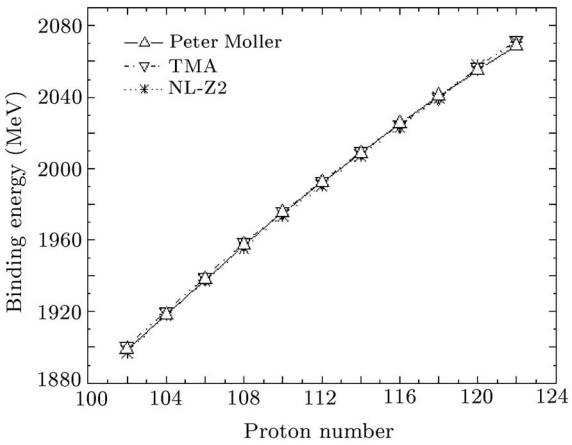


Fig. 3. Binding energy of $^{292}120$ alpha decay nuclei.

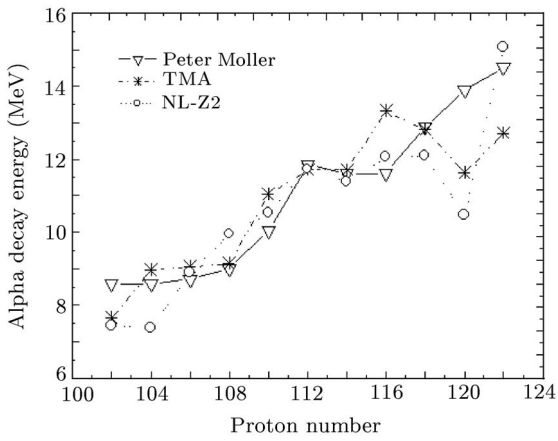


Fig. 4. Alpha decay energy of the $^{292}120$ alpha decay nuclei.

$^{298}114$ *nucleus*

The binding energies and the α decay energies are plotted in Figs. 5 and 6. Figure 5 shows the good agreement between the present work with parameter TMA and Ref. [25]. The α decay energies in Fig. 6 also display a well upward trend for both the theoretical calculations. At $Z = 114$ the Q_α is neither maximum nor minimum. This means that there is no shell structure at $Z = 114$, $N = 184$. It has been found in the investigations of Lalazssis *et al.*[24] that the $N = 184$ neutron shell disappears with the increase of proton number from 108 to 114. Our results are consistent with the above conclusion.

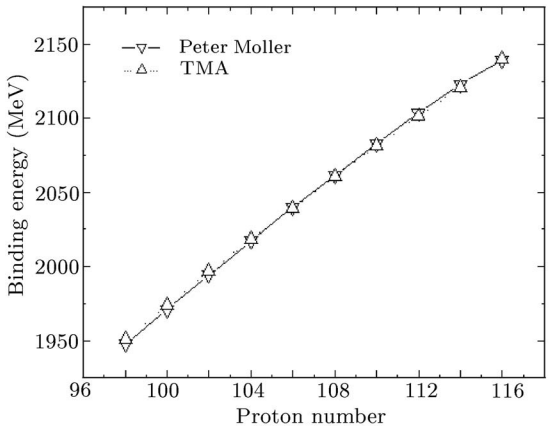


Fig. 5. Binding energy of $^{298}114$ alpha decay chain nuclei.

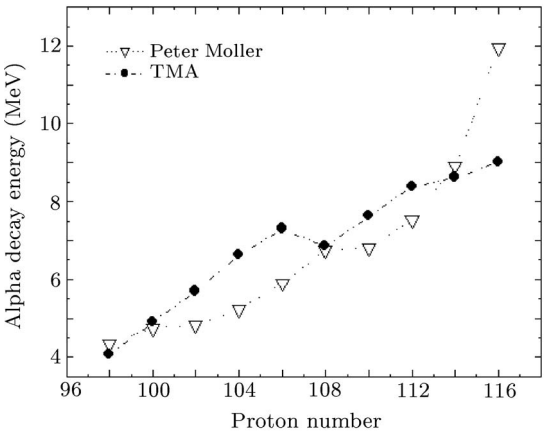


Fig. 6. Alpha decay energy of $^{298}114$ alpha decay chain nuclei.

In summary, we have reported the recent investigations of the properties of the three superheavy nuclei $^{310}126$, $^{292}120$ and $^{298}114$ respectively. The deformed relativistic mean field approach is used with the parameter set TMA. By comparing the results from DRMF calculations and the data in Ref. [25] for the three nuclei series, it is found that there is overall agreement of the binding energies, which means the RMF model is also valid for such a kind of superheavy

nuclei. Our study finds that $^{310}126$ and $^{298}114$ are not the next doubly magic nuclei; while for $Z = 120$ and $N = 172$, the a decay energy is less than its neighbouring nuclei, that is, $^{292}120$ is more stable than its neighbouring nuclei. It is also shown in our calculations that the α decay energy increases steadily in the α decay series with the increasing proton and neutron numbers. Our results agree well with others.[15,25,26]

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