Investigation of the spin-orbit strengths on the prediction of the closed shells for superheavy nuclei based on Two Center Shell Model

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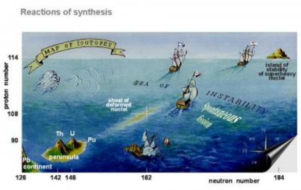


- The experimental study of heaviest nuclei can be guided by the theoretical analysis.$\Longrightarrow$ **JINR Superheavy Elements Factory $\Longrightarrow$ New era in SHN research.**
- The knowledge of the single-particle structure, location of the shell closures, and decay modes of heaviest nuclei

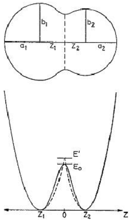
- Increasing stability of nuclei approaching $N = 184$, and indication quite a large shell effects behind **Z = 114** $\Longrightarrow$
  Relativistic and nonrelativistic mean-field models $Z = 120 - 126$, $N = 182 - 184$**?**
  Phenomenological model[1] **(**$Z = 126$**)?**
  Mic-mac models[2] predict $Z = 114$.

Our Aim

To investigate the role of spin-orbital strengths on the position of the magic shell and how they affect the description of low-lying states

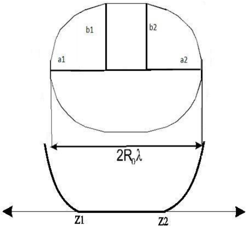
[1] S. Liran, A. Marinov, and N. Zeldes, Phys. Rev. C **62**, 047301 (2000)
[2] P. Möller, J.R. Nix, W.D. Myers, and W.J. Swiatecki, At. Data Nucl. Data Tables **59**, 185 (1995)

$$H = (-\hbar/2m)\nabla^2 + V(\rho, z) + V_{l,s} + V_{l^2}$$ [3]



- $\lambda = L/2R_0$,
- $\beta = a/b = \beta_1 = \beta_2$ the case,
- $\varepsilon = E_0/E' = 0$,
- $\eta = (A_1 - A_2)/(A_1 + A_2) = 0$

Other variables are fixed.



where the momentum-independent part is $V(\rho, z)$ and the momentum-dependent part consists of

$$V_{ls} = -\frac{2\hbar\kappa}{m\omega_0'}(\nabla V \times \mathbf{p})\,\mathbf{s}$$

$$V_{l^2} = -\kappa\mu\hbar\omega_0' l^2 + \kappa\mu\hbar\omega_0' \frac{N(N+3)}{2}\delta_{if}$$

- A weak dependence on $(N - Z)$ in the $\kappa_{n,p}$ and $\mu_{n,p}$ was introduced [a]
- It improved the description of spins and parities of the nuclear g.s.
- + a better order of the single-particle levels near λ_F

[a] G.G. A., N.V. A., and W. Scheid, PRC **81**, 024320 (2010)

[3] J. Maruhn and W. Greiner, Z. Phys. A **251**, 431 (1972)

$$H = (-\hbar/2m)\nabla^2 + V(\rho, z) + kV_{l,s} + V_{l^2}$$

In order to study the influence of *sl*-strengths in the region of SHN with the modified TCSM, we take the *sl*-term as kV_{ls} and study how the results depend on the coefficient k varying from 0.8 to 1.2. The value $k = 1$ corresponds to the parameters defined in Eqs. for κ and μ .

Note

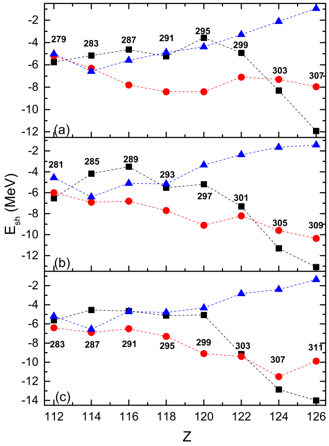
The larger shell correction energy $|E_{sh}|$ in the g.s., the greater the stability of SHN with respect to spontaneous fission and $\alpha-$decay.

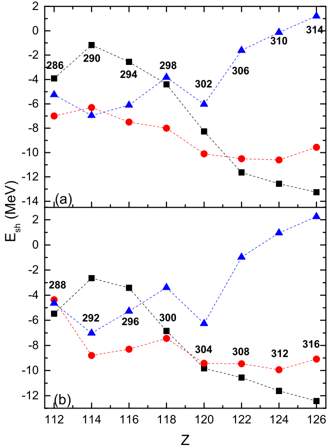
$$E = E_{LDM} + \delta E_{mic}$$

- The Coulomb and surface energies
- The shell E_{sh} and pairing corrections

Position of shell closure

$k = 0.8$ (squares), 1.0 (circles), and 1.2 (triangles)



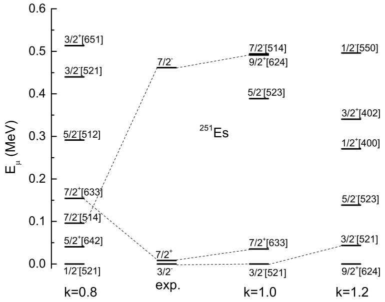


The stability of the nuclei with $Z > 120$ decreases with increasing k

The strength of spin-orbit interaction is crucial to define the position of the shell closures in nuclei beyond Pb. The 20% variation of the sl-strength can strongly shift the position of the minimum of E_{sh}.

Dependence of 1qp-spectra on sl-strength

$$E_\mu = \sqrt{(e_\mu - e_F)^2 + \Delta^2} - \sqrt{(e'_\mu - e_F)^2 + \Delta^2}$$



Briefly

- The experimental energies, spins, and parities are well described (within 250 keV) with $k = 1.0$.
- The calculated results obtained at $k = 0.8$ and 1.2 are less consistent with the experimental data – the g.s. spins and parities can not be reproduced.
- In most cases, the E_{qp}-spectra become denser with $k = 0.8$ or 1.2.
- At $k = 1$ we have the best description of low-lying 1qp-states.

SUMMARY

- As shown, the quality of the description of low-lying 1qp-states crucially depends on the sl-strength. The sl-strength taken in the modified TCSM at $k = 1$ allows us to describe well the low-lying 1qp-spectra in heavy nuclei.
- At $k = 0.8$ and 1.2 the calculated spectra are less consistent with the experimental data. So the choice of the TCSM parameters in [4] was optimal.
- At $k = 1$ the strongest shell effects are found for the nuclei with $Z = 120$ or 124 and 126 at N approaching 184. However, the variation of the value of E_{sh} in the isospin chains is relatively small, which confirms the results of self-consistent calculations [5]

[4] A.N. Kuzmina, G.G. Adamian, N.V. Antonenko, and W. Scheid, Phys. Rev. C **85**, 014319 (2012)

[5] G.G. Adamian, L.A. Malov, N.V. Antonenko, H. Lenske, K. Wang, and S.-G. Zhou, Eur. Phys. J. A **54**, 170 (2018)

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- With decreasing spin-orbit strength ($k = 0.8$) the p-shell closure is shifted to $Z = 126$. For larger sl-interaction ($k = 1.2$), the nuclei with $Z = 114$ are calculated to have the largest values of shell-correction energy.
- The shell effect at $N = 184$ is quite strong and interplays with p-shell effects. The shell effect at $N = 174$ is less pronounced in the calculations with in the TCSM.
- The results obtained clearly demonstrate that the next doubly magic nucleus beyond ^{208}Pb is probably at $Z \geq 120$. Thus, our microscopic-macroscopic treatment qualitatively leads to results close to those of the self-consistent microscopic treatments.

[4] A.N. Kuzmina, G.G. Adamian, N.V. Antonenko, and W. Scheid, Phys. Rev. C **85**, 014319 (2012)

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Thank you!