镜像核质量关系的对称性

Symmetry between masses of mirror nuclei

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Jan. 2020

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Introduction

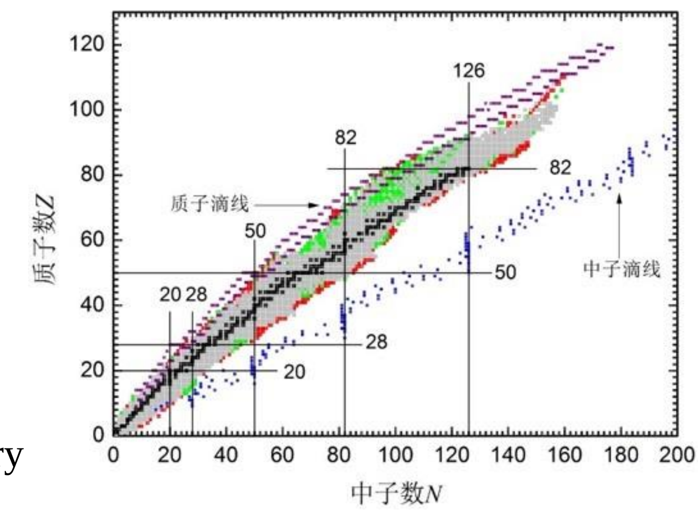
- Global model
  - Duflo-Zuker model

    J. Duflo and A. P. Zuker, Phys. Rev. C 52, R23 (1995)
  - Skyrme Hartree-Fock-Bogoliubov theory

    P. Möller , J. R. Nix, At. Data Nucl. Data Tables 59, 185 (1995)
  - Weizsäcker-Skyrme mass formula

    N. Wang, M. Liu and X. Z. Wu, Phys. Rev. C 81, 044322 (2010)
  - Spherical relativistic continuum Hartree-Bogoliubov theory

    X. W. Xia , Y. Lim, et al., At. Data Nucl. Data Tables 121, 1 (2018)

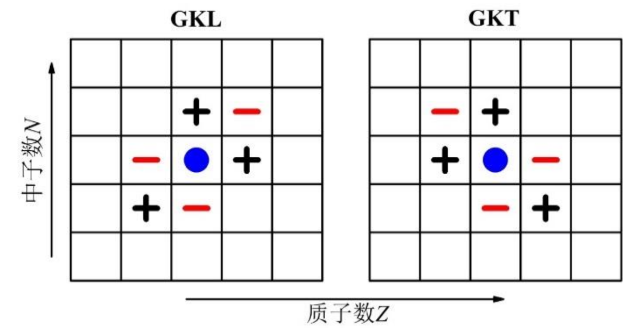


- Local mass formulas
  - Audi-Wasptra method

    G. Audi, A. H. Wapstra and C. Thibault, Nucl. Phys. A 729, 337 (2003)
  - Garvey-Kelson mass relations

    G. T. Garvey and I. Kelson, Phys. Rev. Lett. 16, 197 (1966)
  - Mass relation based on neutron-proton interaction

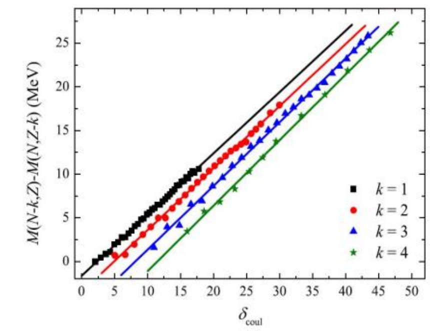
    G. J. Fu , et al., Phys. Rev. C 82, 034304 (2010)



Introduction

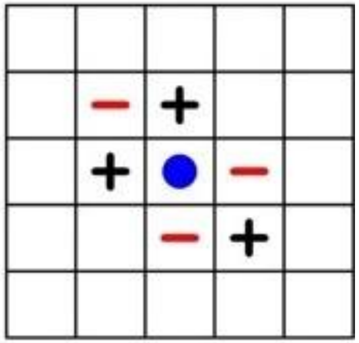
- Masses correlation between mirror nuclei

M. Bao, Y. Lu, Y. M. Zhao and A. Arima, Phys. Rev. C 94, 044323 (2016)



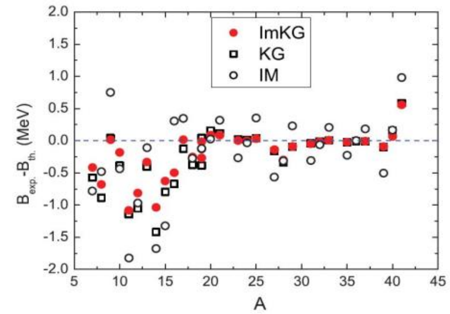
- Garvey-Kelson relations for nuclei with N = Z

$$M(N-1,Z+1)+M(N,Z-1)+M(N+1,Z)$$
$$-M(N-1,Z)-M(N,Z+1)-M(N+1,Z-1)=0$$



- Improved Garvey-Kelson mass relations

J. L. Tian, N. Wang, C. Li and J. J. Li, Phys. Rev. C 87, 014313 (2013)



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Neutron-proton interaction

- Residual neutron-proton interaction

$$V_{in-jp} = -M(N,Z) + M(N-i,Z) + M(N,Z-j) - M(N-i,Z-j)$$

- For (N - k, Z) and (N, Z - k) pair, we denote

$$\Delta V_{in-jp}(N-k,Z) = V_{in-jp}(N-k,Z) - V_{jn-ip}(N,Z-k) \qquad \boldsymbol{N = Z}$$

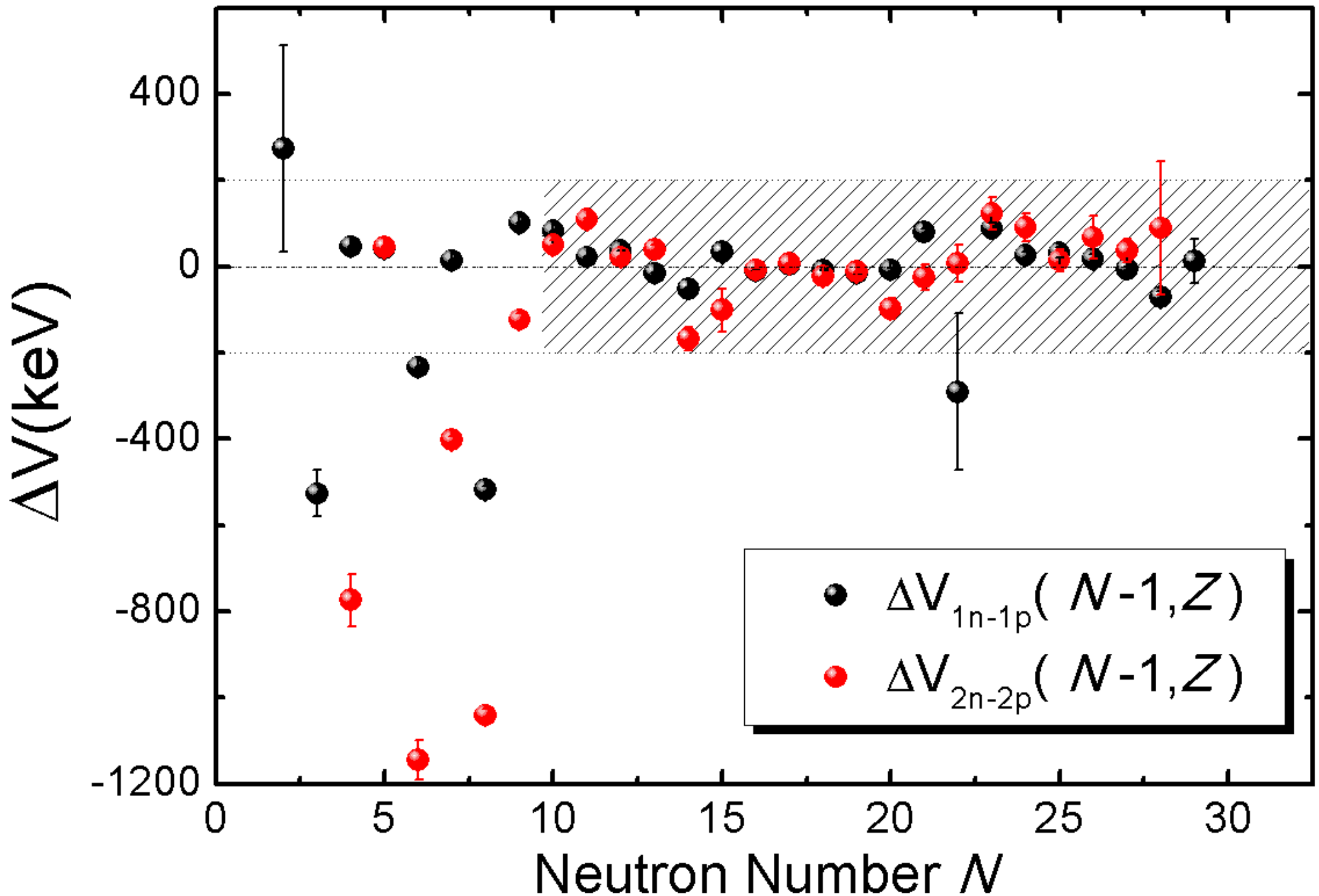
- Suppose that the neutron-proton interactions V_{1n-1p} are equal:

$$\boxed{\Delta V_{1n-1p}(N-k,Z) = 0}$$

J. Jänecke, Phys. Rev. C ***6****, 467 (1972);*

Y. H. Zhang, P. Zhang, X. R. Zhang N. Wang, et al., Phys. Rev. C ***98****, 014319 (2018)*

Neutron-proton interaction



Neutron-proton interaction

- The RMSD (in keV) and number of $\Delta V_{in-jp}(N-k,Z)$ with ^{44}V excluded

k = 1-3 / i , j = 1-2	σ_1	N_1	σ_2	N_2	σ_3	N_3
ΔV_{1n-1p}	43	19	64	16	133	5
ΔV_{2n-1p}	55	18	110	6	868	1
ΔV_{1n-2p}	43	19	76	17	136	5
ΔV_{2n-2p}	73	19	152	6	1071	1

M. Wang, G. Audi, F. G. Kondev, W. J. Huang, et al., Chin. Phys. C ***41****, 030003 (2016)*

Neutron-proton interaction

- Mass relations based on this work

$$M(N-2,Z) = M(N,Z-2) + M(N-1,Z) - M(N,Z-1)$$
$$+ M(N-2,Z-1) - M(N-1,Z-2)$$

$$M(N-3,Z) = M(N,Z-3) + M(N-1,Z) - M(N,Z-1) + M(N-2,Z-1)$$
$$- M(N-1,Z-2) + M(N-3,Z-2) - M(N-2,Z-3)$$

$$M(N-3,Z) = M(N,Z-3) + M(N-1,Z) - M(N,Z-1)$$
$$+ M(N-3,Z-1) - M(N-1,Z-3)$$

- Mass extrapolation : AME1995 ➡ AME2016 ($N \geqslant 10$)

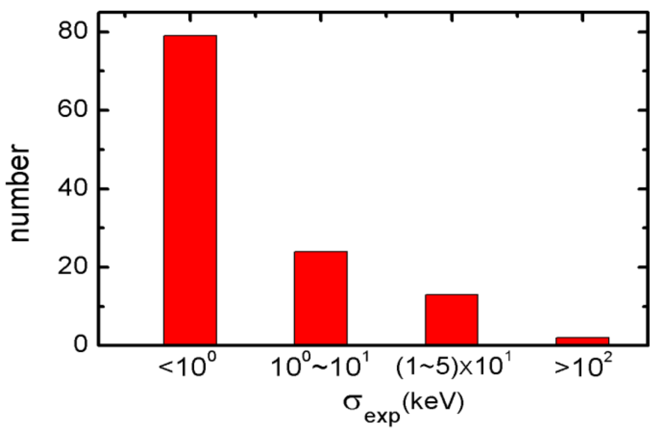
11 proton-rich nuclei

RMSD : **47** keV

Neutron-proton interaction

- Uncertainty of predictions

$$\sigma = \sqrt{\sigma_{th}^2 + \sum \sigma_{exp}^2}$$



- m_{pred} and σ_{pred}

$$m_{pred} = F\frac{m_1}{(\sigma_1)^2} + F\frac{m_2}{(\sigma_2)^2} + F\frac{m_3}{(\sigma_3)^2}$$

$$F = \frac{1}{\frac{1}{(\sigma_1)^2}+\frac{1}{(\sigma_2)^2}+\frac{1}{(\sigma_3)^2}} \qquad \sigma_{pred} = \sqrt{F}$$

N	Z	A	$mass_{pred}^{excess}$	σ_{pred}
27	30	57	-32778	45
28	31	59	-34019	60
29	31	60	-39988	60
29	32	61	-34001	92
30	32	62	-42328	70
30	33	63	-33832	125
31	33	64	-39666	102
31	34	65	-33484	136
32	32	66	-42059	116
32	35	67	-32935	137
33	35	68	-38712	90
33	36	69	-32755	171
34	36	70	-41579	142

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Separation energies

- Weizsäcker mass formula

$$B(N,Z) = a_{\mathrm{v}}A - a_{\mathrm{s}}A^{2/3} - a_{\mathrm{c}}Z^2A^{-1/3} - a_a(N-Z)^2A^{-1} + a_p\delta_{\mathrm{pair}}A^{-1/2}$$

- The relation between nuclear masses and the Coulomb energy for $N = Z$

$$M(N-1,Z) - M(N,Z-1) = a_c(A-1)^{2/3} + M_p - M_n$$

Namely $$\Delta_{\mathrm{m}}(N-k,Z) = M(N-k,Z) - M(N,Z-k)$$

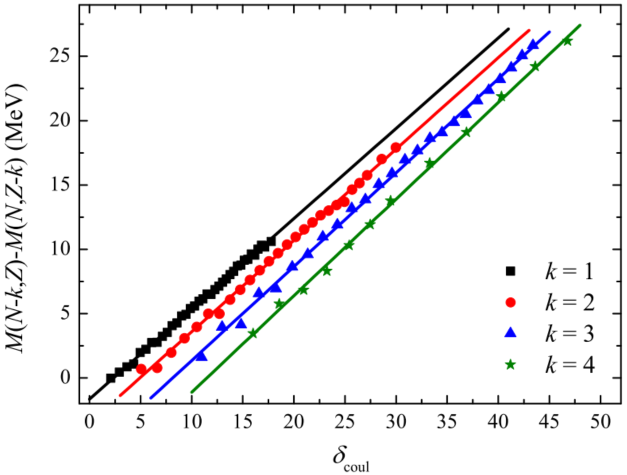
$$= a_c\delta_{\mathrm{coul}} + k\left(M_p - M_n\right)$$

where $\delta_{\mathrm{coul}} = k(A-k)^{2/3}$, $k = 1-4$

- RMSD values :134, 239, 309, 275 (in keV)

for $k = 1, 2, 3$, and 4, respectively.

M. Bao, Y. Lu, Y. M. Zhao and A. Arima, Phys. Rev. C 94, 044323 (2016)



Separation energies

- One-neutron (proton) separation energy $S_{\mathrm{n}}(N,Z)$, $S_{\mathrm{p}}(N,Z)$:

$$S_{\mathrm{n}}(N,Z)= M(N-1,Z)-M(N,Z)+M_n;$$

$$S_{\mathrm{p}}(N,Z)= M(N,Z-1)-M(N,Z)+M_{\mathrm{p}}$$

- We next define two quantities, Δ_n and Δ_p :

$$\Delta_{\mathrm{n}}(N-k,Z)= S_{\mathrm{n}}(N-k,Z)-S_p(N,Z-k)+(M_{\mathrm{p}}\text{-}M_n);$$

$$\Delta_{\mathrm{p}}(N-k,Z)= S_{\mathrm{p}}(N-k,Z)-S_{\mathrm{n}}(N,Z-k)+(M_{\mathrm{n}}\text{-}M_{\mathrm{p}})$$

- Finally, we obtain

$$\Delta_{\mathrm{n}}(N-k,Z)= M(N-1-\mathrm{k},Z)\text{-}M(N-\mathrm{k},Z)\text{-}M(N,Z-1-\mathrm{k})+M(N,Z-\mathrm{k})=a_c\delta_c^n+(M_{\mathrm{p}}\text{-}M_n);$$

$$\Delta_{\mathrm{p}}(N-k,Z)= M(N-\mathrm{k},Z-1)\text{-}M(N-\mathrm{k},Z)\text{-}M(N-1,Z-\mathrm{k})+M(N,Z-\mathrm{k})=a_c\delta_c^n+(M_{\mathrm{n}}\text{-}M_{\mathrm{p}})$$

where $\delta_c^{\mathrm{n}} = (k+1)(A-k-1)^{\frac{2}{3}} - k(A-k)^{\frac{2}{3}}$; $\delta_{\mathrm{c}}^{\mathrm{p}} = (k-1)(A-k-1)^{\frac{2}{3}} - k(A-k)^{\frac{2}{3}}$

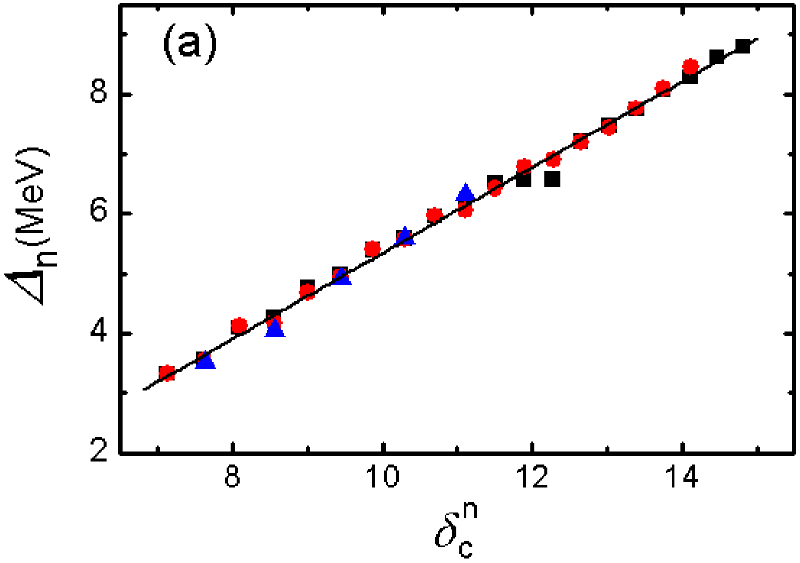
Separation energies

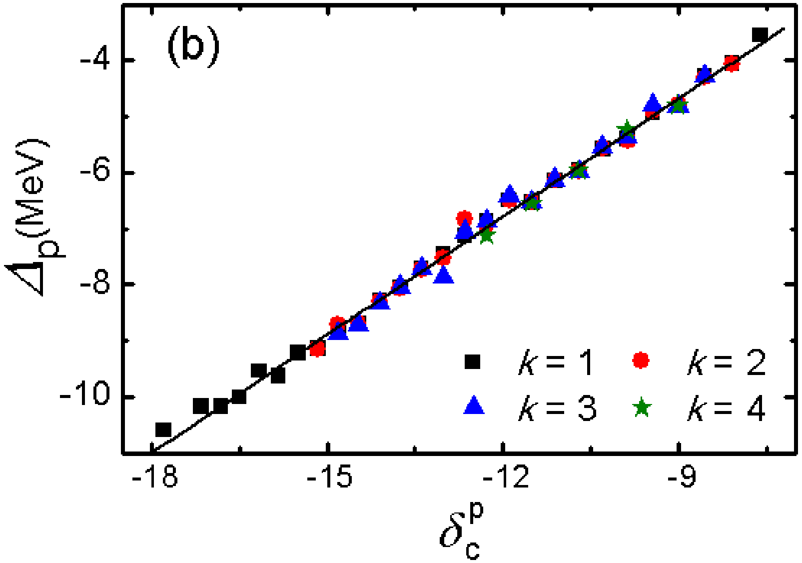
- We rewrite the simple relations in short as

$$\Delta = a_c \delta_c + C$$

Strong linear correlations between Δ and δ_c, independent of k :

$\Delta_{(N \geqslant 10)}$	RMSD	Number	a_c	C
Δ_n	113	46	718	-1833
Δ_p	132	68	702	+1637





Separation energies

- Mass relations based on this work

$$M(N-k,Z) = M(N-1-k,Z) - M(N,Z-1-k)$$
$$+ M(N,Z-k) - a_c\delta_c^n - C$$

$$M(N-k,Z) = M(N-k,Z-1) - M(N-1,Z-k)$$
$$+ M(N,Z-k) - a_c\delta_c^p - C$$

- Mass extrapolation : AME2003 ➡ AME2016 ($N \geqslant 10$)

  13 proton-rich nuclei RMSD : **102** keV (346 keV with Δ_m)

- We predict 58 nuclear masses for proton-rich nuclei with N=[10,50],

  and $(Z-N) \leqslant 4$

Contents

Summary

- We report two simple relations of masses between corresponding mirror nuclei for N⩾10.
- The neutron-proton interactions of two mirror nuclei are very close to each other, namely $\Delta V_{in-jp}(N-1, Z) \sim 0$.
- The difference between on-nucleon separation energies of two mirror nuclei, namely $\mathit{\Delta}_{\mathrm{n}}(\mathit{\Delta}_{\mathrm{p}})$, exhibits strong linear correlations with coulomb correction term.
- These correlations provide a remarkably accurate approach to predict 58 proton-rich nuclei.

谢 谢！