Isospin Symmetry Violation in *sd* Shell Nuclei

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1. Compilation of Experimental Data:
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2. Mirror Energy Difference :
Silvia M. Lenzi[⋆]

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Outline

Construction of INC Hamiltonian

Isospin Conserving Nucl. Hamiltonian (USD/USDB/USDA) ⇐ **Perturbation theory**

⇓

Solve eigenvalue prob.

⇓

Nucl. wave function, $|\psi^T\rangle$

⇓

Assume $V^{pp} \neq V^{nn} \neq V^{pn}$ ⇐ **Nolen-Schiffer anomaly**

⇓

Evaluate $\langle \psi^T | V_{INC} | \psi^T \rangle$ ⇐ **Short Range Correlation $V_{coul}, V_{\pi}, V_{\rho}$**

Short Range Correlation ⇐

1. Unitarity Correlation Operator Method (UCOM)

2. Jastrow-type SRC:

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a. Miller-Spencer
b. CD-Bonn
c. Argonne V18
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⇓

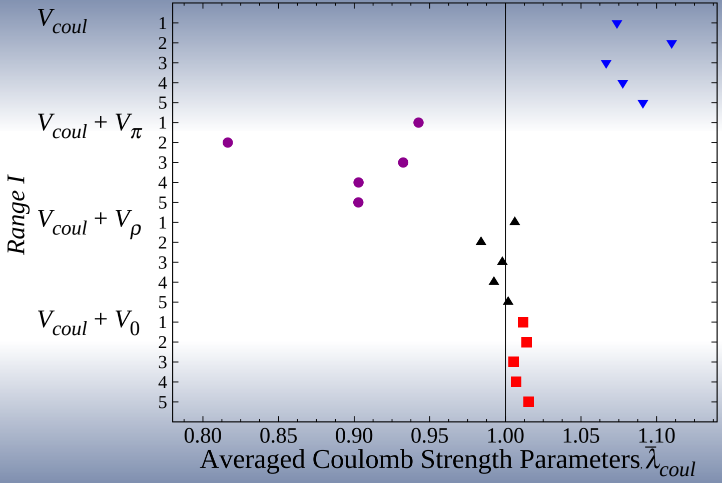
Fit Strength Parameters $\lambda_{coul}^{(q)}, \lambda_{\pi}^{(q)}, \lambda_{\rho}^{(q)}, \lambda_{0}^{(q)}$ to reproduce newly compiled exp. IMME *b* & *c* coeff. [1]. ⇐ **Exp. IMME *b* & *c* coef.**

⇒ **Charge-dependent Hamiltonian**

$$H_{CD}^{iv+it} = \sum_{q=1,2} \left(\lambda_{coul}^{(q)} V_{coul}^{(q)} + \lambda_{\pi}^{(q)} V_{\pi}^{(q)} + \lambda_{\rho}^{(q)} V_{\rho}^{(q)} + \lambda_{0}^{(q)} V_{0}^{(q)} \right) + H_{CD}^{1b}$$

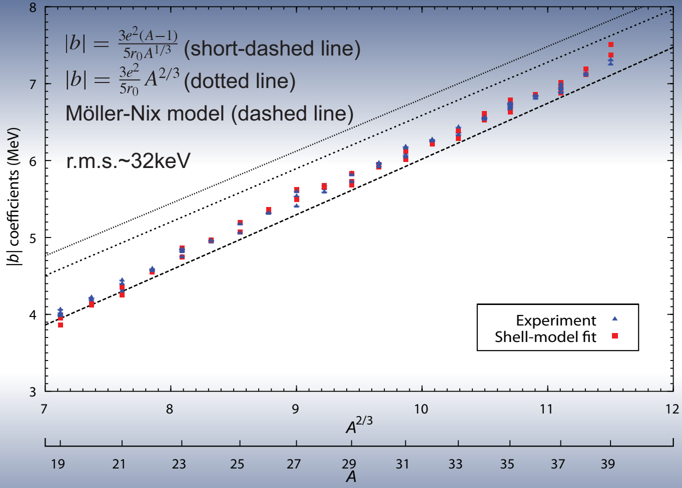
[1] Y. H. L., B. Blank, N. A. Smirnova, J. B. Bueb, M. S. Antony, *accepted by ADNDT*.

Coulomb Strength



[1] Y. H. L., N. A. Smirnova, E. Caurier Phys. Rev. C 87 (2013) 054304.

Comparison of Shell-Model Fit, Möller-Nix model[1], Experimental, and Uniformly Charged Sphere *b* coefficients[2]



[1] P. Möller and J. Nix, At. DataNucl. Data Tables 39 (1988) 213.
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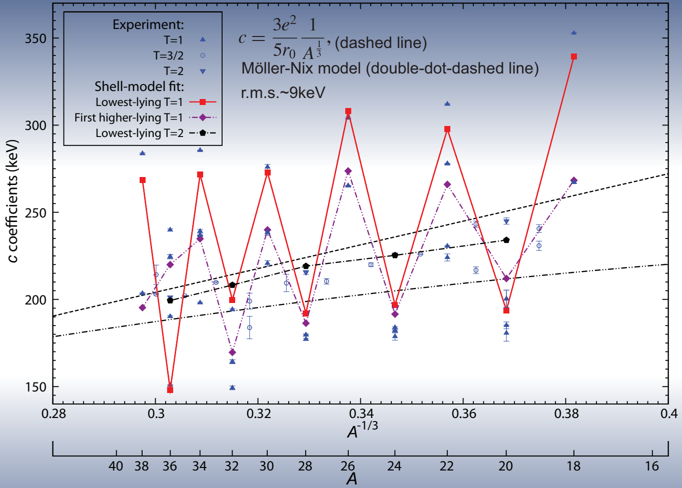

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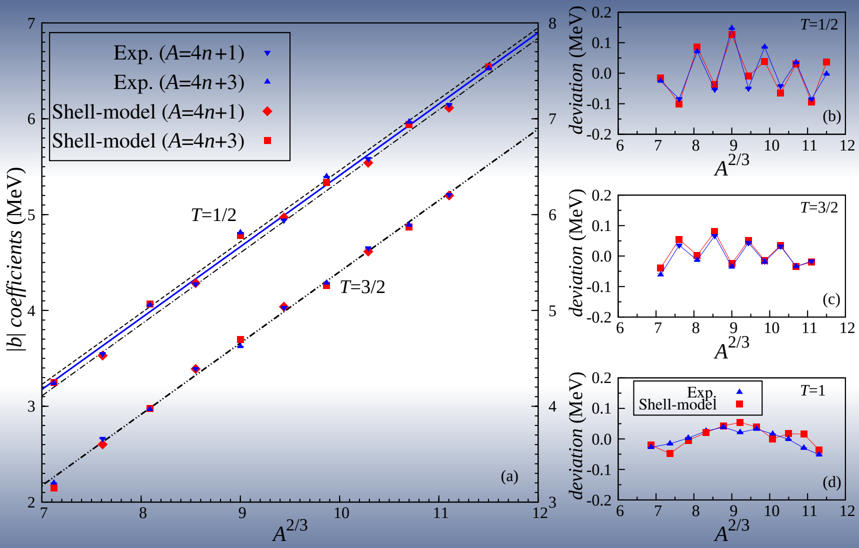
Staggering Behavior of IMME *b* coefficients

Doublet ($T = 1/2$) and Quartet ($T = 3/2$)



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Staggering Behavior of IMME coefficients

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Vector and Tensor Coulomb Energies*

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(Received 7 March 1966)

Vector and tensor Coulomb energies have been extracted from the known experimental Coulomb energy differences between isobaric doublets and triplets in light nuclei. The vector Coulomb energy essentially depends linearly on A within a given shell and shows discontinuities at major shell closures and superimposed weak oscillations. The tensor Coulomb energy exhibits a pronounced oscillatory structure. The characteristic A dependence of both Coulomb energies is discussed and the oscillations in particular are related to Coulomb pairing effects.

I. INTRODUCTION

PRECISE values for the masses of proton-rich light nuclei with $T_z=-1$ have recently been measured[1] by various nuclear reactions. In addition, excitation energies for states with $T=1$ in several self-conjugate nuclei have also been measured[1] using high-resolution γ-ray detectors. These new data together with the older data can be used to derive Coulomb energy differences for the isobaric doublets and triplets up to $A=43$. The Coulomb energy differences are related to the vector and tensor Coulomb energies and also to the coefficients in

in the $T_z=0$ nuclei are indicated in column 5. The data result from measurements of Q values of various types of nuclear reactions, from measurements of maximum β^+ end-point energies and from measurements of the energies of associated γ rays.

Table II lists the few cases in light nuclei with $T>1$, where two or more Coulomb energy differences between ground-state isobaric analog states for a given A and T are known experimentally.

III. THE VECTOR AND TENSOR COULOMB

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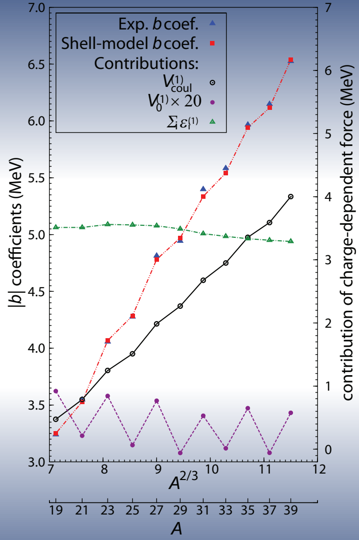

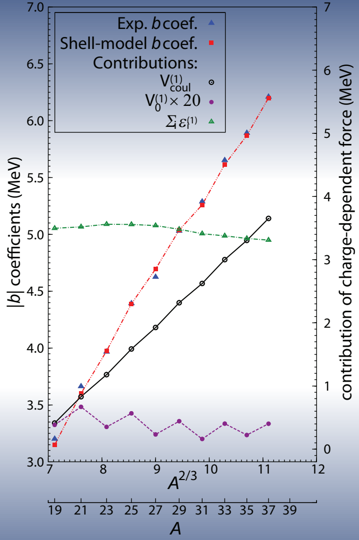

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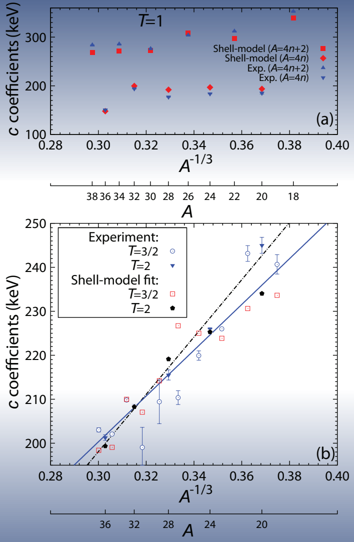
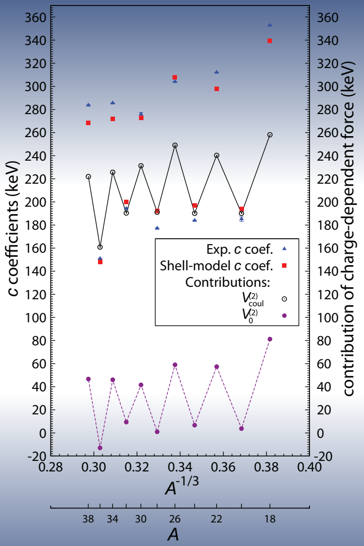
Staggering Behavior of IMME *c* coefficients

Triplet ($T = 1$)

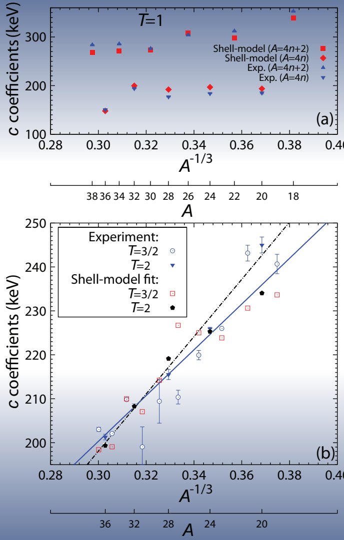


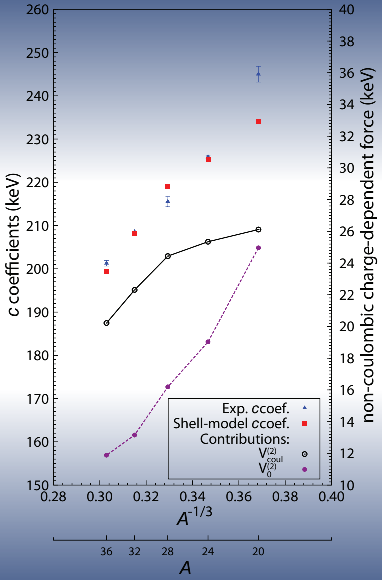


[1] Y. H. L., N. A. Smirnova, E. Caurier Phys. Rev. C 87 (2013) 054304.

Staggering Behavior of IMME *c* coefficients

Quintet ($T = 2$)





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Isobaric Multiplet Mass Equation (IMME)

Why the IMME can be cubic and of higher order ?

- possible three and more nucleon interactions

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$$\mathscr{M}(\alpha, T, T_z) = a(\alpha, T) + b(\alpha, T)T_z + c(\alpha, T)T_z^2$$

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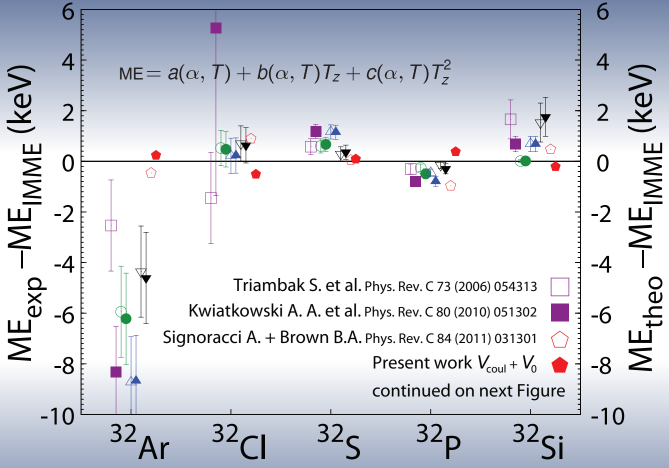
IMME of Quadratic Form, $a + bT_z + cT_z^2$, ($A = 32$)



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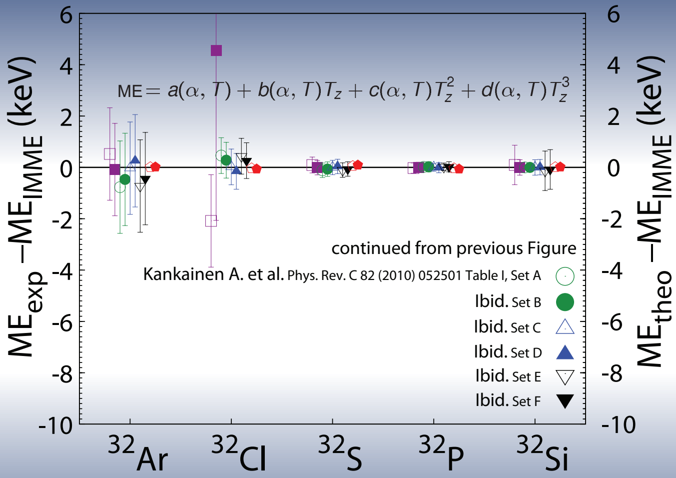
IMME of Cubic Form, $a + bT_z + cT_z^2 + dT_z^3$, $(A = 32)$



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IMME of Cubic Form, $a + bT_z + cT_z^2 + dT_z^3$, ($A = 32$)

Do we need d coefficient ?

	d (keV)	$\frac{\chi^2}{n_{quadr.}}$	$\frac{\chi^2}{n_{cubic}}$
Triambak *et. al.* PRC 73 (2006) 054313	0.54 (16)	13.1	0.77
Kwiatkowski *et. al.* PRC 80 (2009) 051302	1.00 (9)	31	0.48
Kankainen *et. al.* PRC 82 (2010) 052501 Set A	0.52 (12)	9.9	0.86
Ibid. Set B	0.60 (13)	12.3	0.31
Ibid. Set C	0.90 (12)	28.3	0.002
Ibid. Set D	1.00 (13)	30.8	0.09
Ibid. Set E	0.51 (15)	6.5	0.74
Ibid. Set F	0.62 (16)	8.3	0.28
Signoracci & Brown PRC 84 (2011) 031301	0.39	1.09	0.005
Lam, Smirnova, Caurier PRC 87 (2013) 054304	-0.19	0.26	0.02

Theoretical IMME b, c, d, and e coefficients of $A = 32, J^\pi = 0^+, T = 2$ Quintets.

	b, c (keV)	b, c, d (keV)	b, c, e (keV)	b, c, d, e (keV)
Exp. values quoted in Signoracci & Brown[1]	−5471.9 (3) 208.6 (2) $\chi^2/n = 64.282$	−5473.1 (3) 207.2 (3) 0.93 (12) $\chi^2/n = 0.005$	−5471.1 (3) 205.5 (5) 0.61 (10) $\chi^2/n = 4.525$	−5473.0 (5) 207.1 (6) 0.92 (19) 0.02 (16)
Theoretical values in Signoracci & Brown[1]: **USD**	−5417.7 209.1 $\chi^2/n = 2.177$	−5419.0 209.1 0.39 $\chi^2/n = 0.003$	−5417.7 209.0 0.03 $\chi^2/n = 0.434$	−5419.0 209.0 0.39 0.03
Present works[2]: **USD**	−5464.38 207.59 $\chi^2/n = 0.2563$	−5463.75 207.59 −0.19 $\chi^2/n = 0.01685$	−5464.38 207.39 0.045 $\chi^2/n = 0.4958$	−5463.75 207.39 −0.19 0.045

[1] A. Signoracci and B. A. Brown Phys. Rev. C 84 (2011) 031301.

[2] Y. H. L., N. A. Smirnova, E. Caurier Phys. Rev. C 87 (2013) 054304.

IMME of Cubic/Quartic Form, $a + bT_z + cT_z^2 + dT_z^3 + eT_z^4$

Other *sd*-shell quintet *b*, *c*, *d* and *e* coefficients.

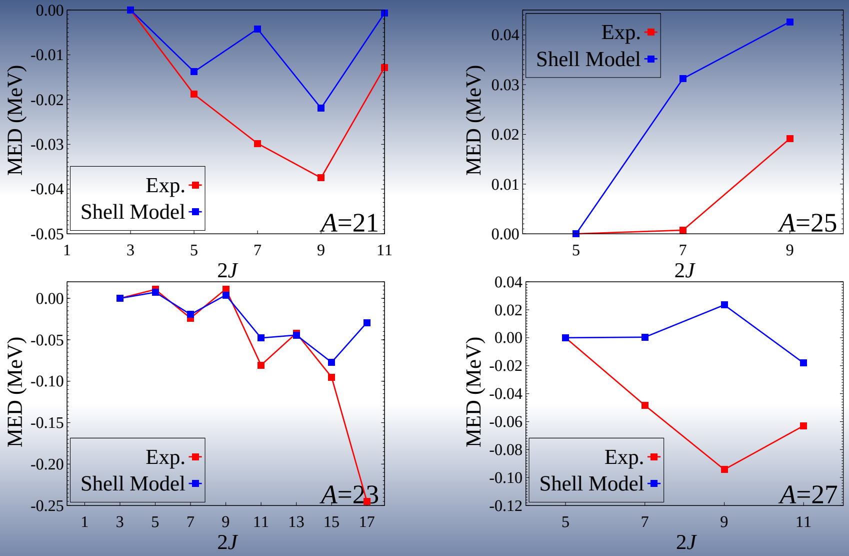
	b, c (keV)	b, c, d (keV)	b, c, e (keV)	b, c, d, e (keV)
$A = 24$	-4179.00	-4178.95	-4179.00	-4178.95
	224.31	224.31	219.71	219.71
		-0.02		-0.02
			1.039	1.039
	$\chi^2/n = 8.882$	$\chi^2/n = 4.439$	$\chi^2/n = 0.00076$	
$A = 28$	-4869.74	-4869.57	-4869.74	-4869.57
	216.84	216.84	204.53	204.53
		-0.05		-0.05
			2.78	2.78
	$\chi^2/n = 63.570$	$\chi^2/n = 31.767$	$\chi^2/n = 0.0070$	

[a] Present calculations use V_{coul} (UCOM) and V_0 combination.

[b] All $\frac{\chi^2}{n}$ are calculated by assuming uncertainty ± 1 keV for every mass excess.

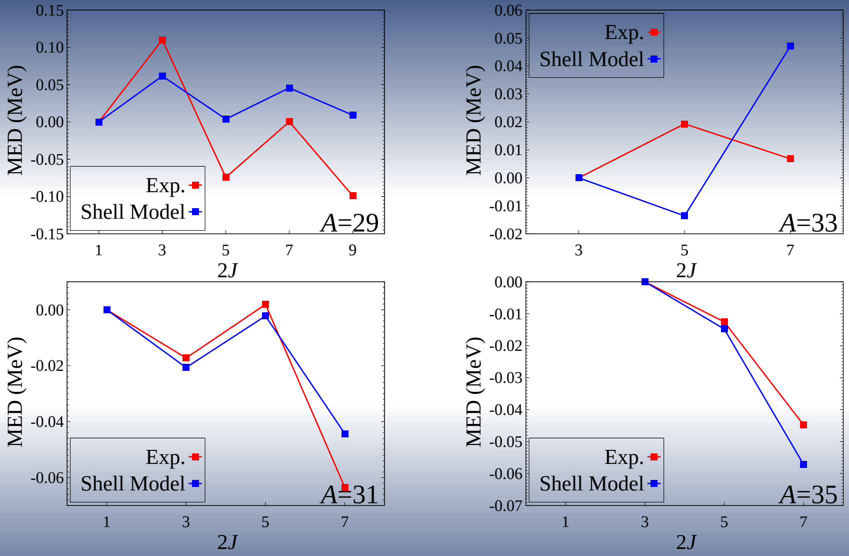
[1] Y. H. L., N. A. Smirnova, E. Caurier (in preparation).

Doublet ($T = 1/2$)



[1] See seminars of S. M. Lenzi

Doublet ($T = 1/2$)



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Summary

- We have developed a set of **precise INC Hamiltonians** which reproduce experimental mass splitting *accurately*, paying particular attention to **Short Range Correlation**.
- IMME b coefficients are fitted with root mean square (rms) deviation $\sim$33 keV and about 1% deviate from exp. values. rms of c coefficients is about $\sim$9 keV.
- We have also compiled the **new exp. IMME coefficients** with **710 data points**.
- V_{coul} should be coupled with effective charge-dependent forces of nuclear origin.
- For the **first** time, we successfully separate **contributions from various charge-dependent forces to isovector and isotensor energies**.
  - The staggering effect is **mainly due to V_{coul}** and charge-dependent force of nuclear origin resembles the staggering trend.
- The **existence of d coefficient** is confirmed for $A = 32$ quintet, and we also verify the possibility of **non-zero e coefficient** for $A = 24$ and 28 quintets. However, more precise experimental masses are required to affirm our results.

Perspective

- The construction of **INC Hamiltonians of other shell spaces, e.g.** ***psd*, *psdpf*, *sdpf*, *pf*, and *pfg* -shell spaces**, is in progress.
- The construction of the Wigner's supermultiplet formalism for **quintet staggering effect** in *sd*-shell nuclei is in progress.
- The calculation of **quartet ($A = 23, 25, 29, 31, 35, 37$) d coefficients** is in progress.
- The survey of TBME of V_{coul} based on Woods-Saxon basis will be tested.

Acknowledgements

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- S. Triambak,
  TRIUMF / Univ. of Delhi, India.
- Calin A. Ur,
  INFN Sezione di Padova, Italy.
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