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Spectroscopic factors in the projected shell model

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2012-12-14 Beijing Xiangshan

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- Definition of the spectroscopic factor.
- The Projected Shell Model（PSM）.
- Relevant Formulae in the PSM.
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Definition

Wigner-Eckhart Theorem

$$\langle JM|T_{jm}|J'M'\rangle = \langle J'M'jm|JM\rangle\langle J||T_j||J'\rangle$$

Spectroscopic Factors:

$$\begin{aligned} S_j &= |\langle \Psi^{A\sigma_f}_{I_f M_f}||c^\dagger_j||\Psi^{A-1,\sigma_i}_{I_i M_i}\rangle|^2 \\ &= \frac{2I_i+1}{2I_f+1}|\langle \Psi^{A-1,\sigma_i}_{I_i M_i}||\tilde{c}_j||\Psi^{A\sigma_f}_{I_f M_f}\rangle|^2 \end{aligned}$$

$$\tilde{c}_{jm} = (-1)^{j+m} c_{j-m}$$

PRL **102,** 062501 (2009) PHYSICAL REVIEW LETTERS week ending 13 FEBRUARY 2009

Survey of Excited State Neutron Spectroscopic Factors for $Z = 8$–28 Nuclei

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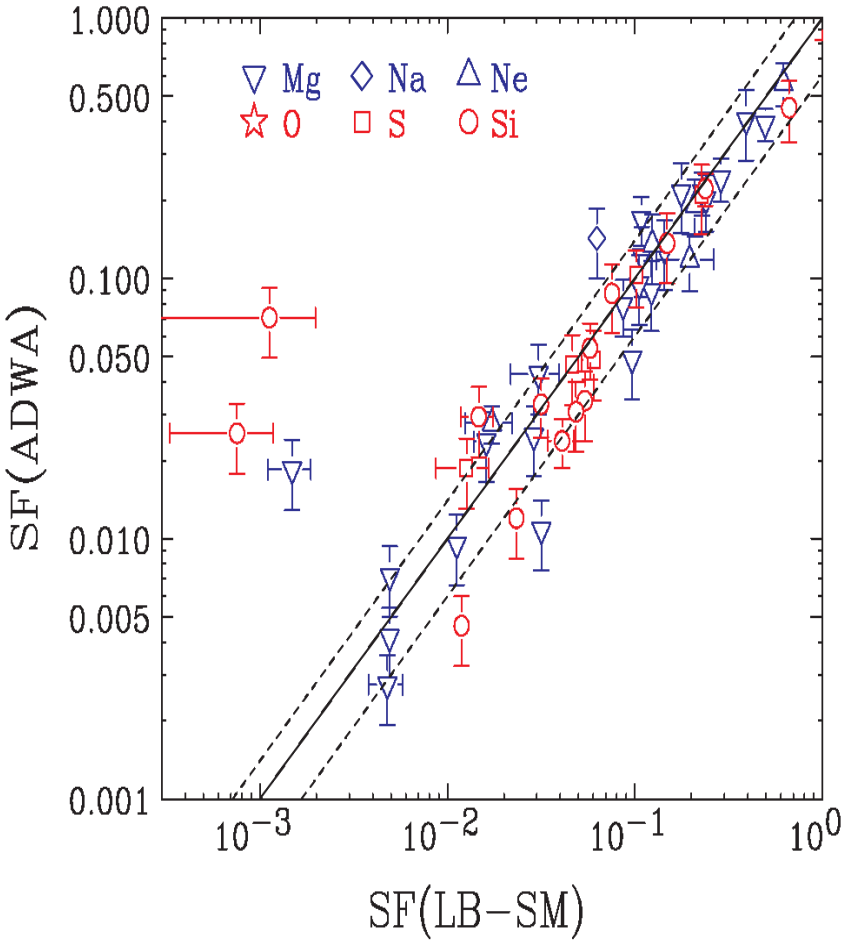
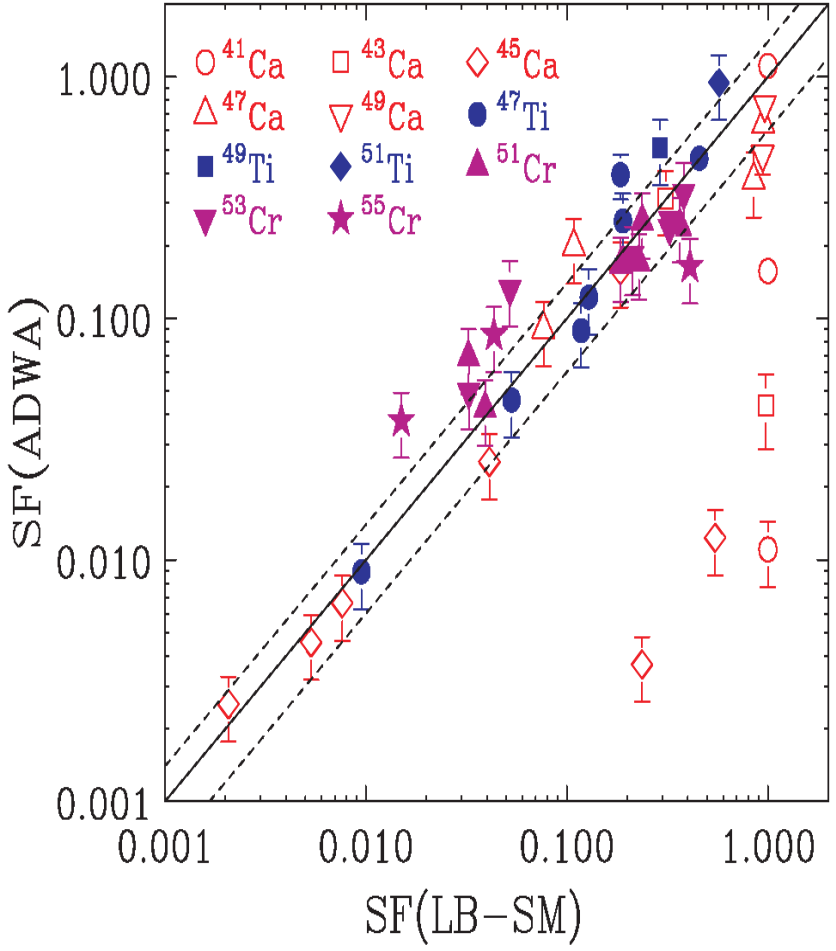




USDA and USDB

GXPF1A

The Projected Shell Model (PSM)

The nuclear wave function is assumed to be

$$|\Psi^{\sigma}_{IM}\rangle = \sum_{K\kappa} f^{\sigma}_{IK\kappa} \hat{P}^{I}_{MK} |\kappa\rangle,$$

Where,

$$\hat{P}^{I}_{MK} = \frac{2I+1}{8\pi^2} \int d\Omega \, D^{I}_{MK}(\Omega) \, \hat{R}(\Omega)$$

$f^{\sigma}_{IK\kappa}$'s are to be determined by the eigenvalue equation

$$\sum_{K'\kappa'} (H^{I}_{K\kappa,K'\kappa'} - E^{\sigma}_{I} N^{I}_{K\kappa,K'\kappa'}) f^{\sigma}_{IK\kappa'} = 0$$

$$H^{I}_{K\kappa,K'\kappa'} = \langle\kappa|HP^{I}_{KK'}|\kappa'\rangle,$$

$$N^{I}_{K\kappa,K'\kappa'} = \langle\kappa|P^{I}_{KK'}|\kappa'\rangle.$$

Relevant Formulae in the PSM

$$\langle \Psi^{A\sigma_f}_{I_f M_f} || c^\dagger_j || \Psi^{A-1,\sigma_i}_{I_i M_i} \rangle = \sum_{K_f \kappa_f, K_i \kappa_i} f^{A\sigma_f}_{I_f M_f} f^{A-1\sigma_i}_{I_i M_i} \mathbb{R}_{I_f K_f \kappa_f, I_i K_i \kappa_i}$$

$$\mathbb{R}_{I_f K_f \kappa_f, I_i K_i \kappa_i} = \sum_m \langle I_i K_f - m, jm | I_f K_f \rangle \langle \kappa^A_f | c^\dagger_{jm} P^{I_i}_{K_f - m, K_i} | \kappa^{A-1}_i \rangle$$

$$\langle \Psi^{A-1,\sigma_i}_{I_i M_i} || \tilde{c}_j || \Psi^{A\sigma_f}_{I_f M_f} \rangle = \sum_{K_f \kappa_f, K_i \kappa_i} f^{A\sigma_f}_{I_f M_f} f^{A-1\sigma_i}_{I_i M_i} \mathbb{S}_{I_i K_i \kappa_i, I_f K_f \kappa_f}$$

$$\mathbb{S}_{I_i K_i \kappa_i, I_f K_f \kappa_f} = \sum_m \langle I_f K_i - m, jm | I_i K_i \rangle \langle \kappa^{A-1}_i | \tilde{c}_{jm} P^{I_f}_{K_i - m, K_f} | \kappa^A_f \rangle$$

Symmetry Check: Very useful to confirm the correctness of the code!

$$\langle \Psi^{A\sigma_f}_{I_f M_f} || c^\dagger_j || \Psi^{A-1,\sigma_i}_{I_i M_i} \rangle = (-1)^{j + I_i - I_f} \sqrt{\frac{2I_i + 1}{2I_f + 1}} \langle \Psi^{A-1,\sigma_i}_{I_i M_i} || \tilde{c}_j || \Psi^{A\sigma_f}_{I_f M_f} \rangle$$

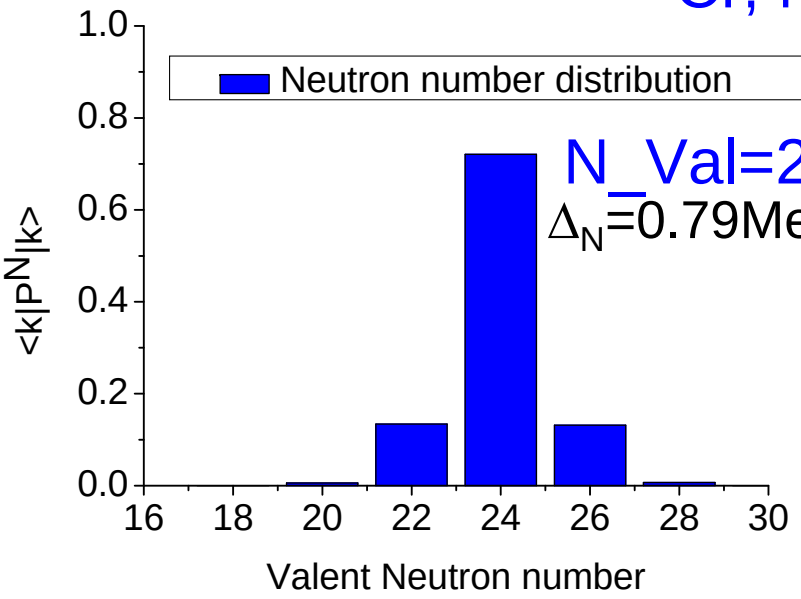
Improvement of PSM——Particle number projection

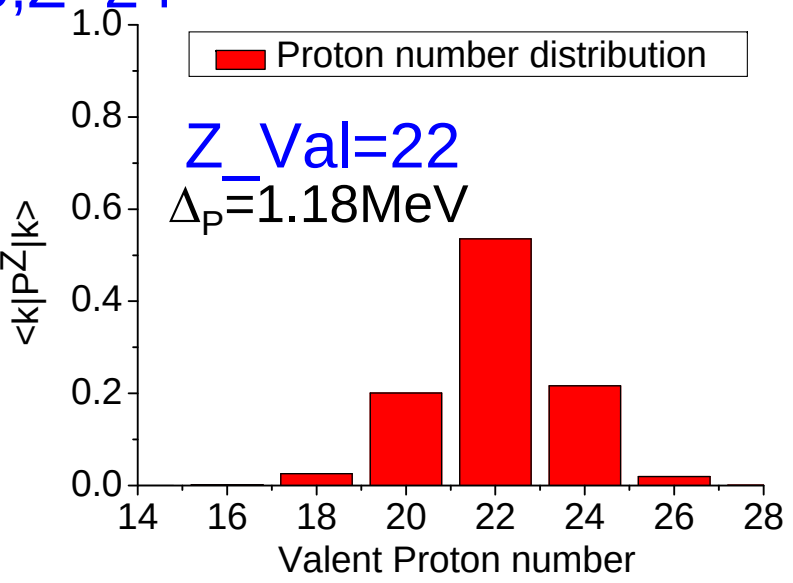
$$|\kappa^{NZ}\rangle = \hat{P}^N \hat{P}^Z |\kappa\rangle$$

$$\hat{P}^N = \frac{1}{2\pi}\int_0^{2\pi} d\phi e^{i(\langle N\rangle - \hat{N})\phi}$$

$$|\kappa\rangle = \sum_{NZ} |\kappa^{NZ}\rangle \Leftrightarrow \sum_{NZ}\langle\kappa|\kappa^{NZ}\rangle = \sum_{NZ}\langle\kappa|\hat{P}^N\hat{P}^Z|\kappa\rangle = 1$$

^{50}Cr, N=26,Z=24

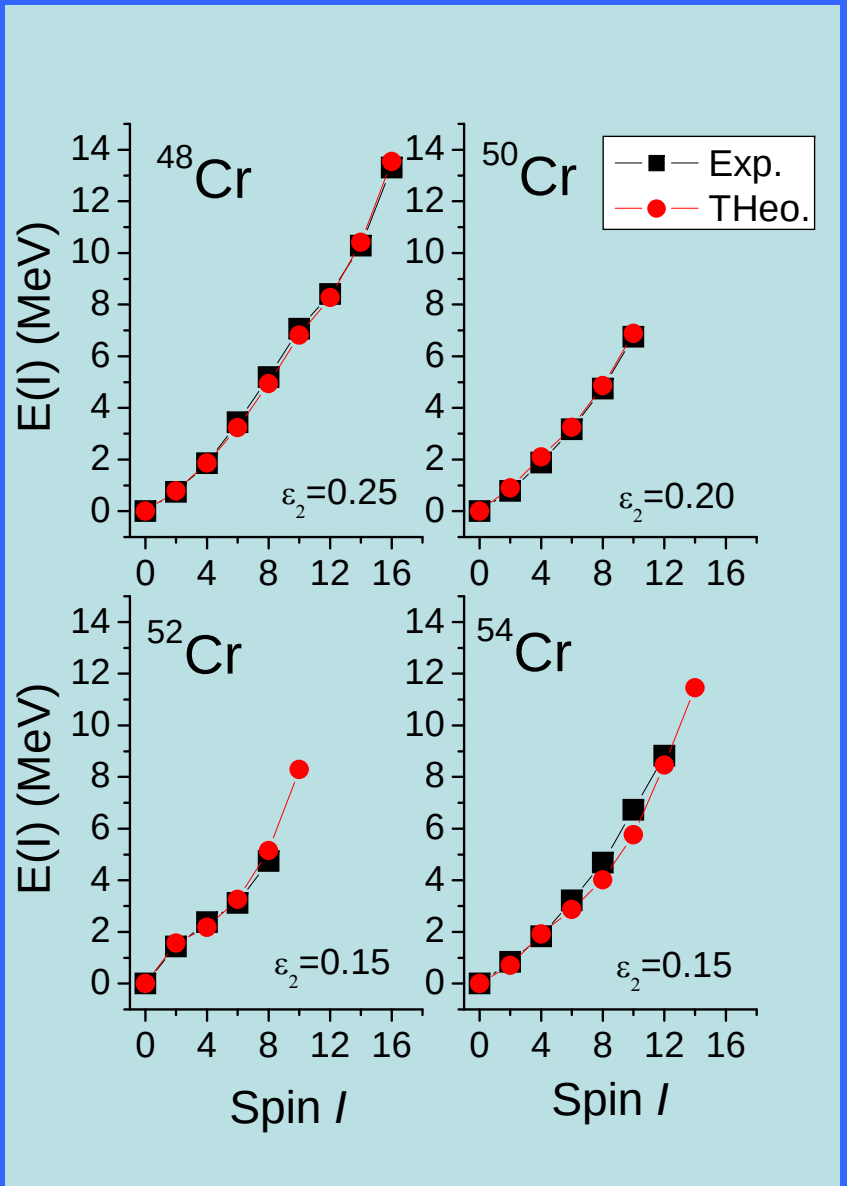


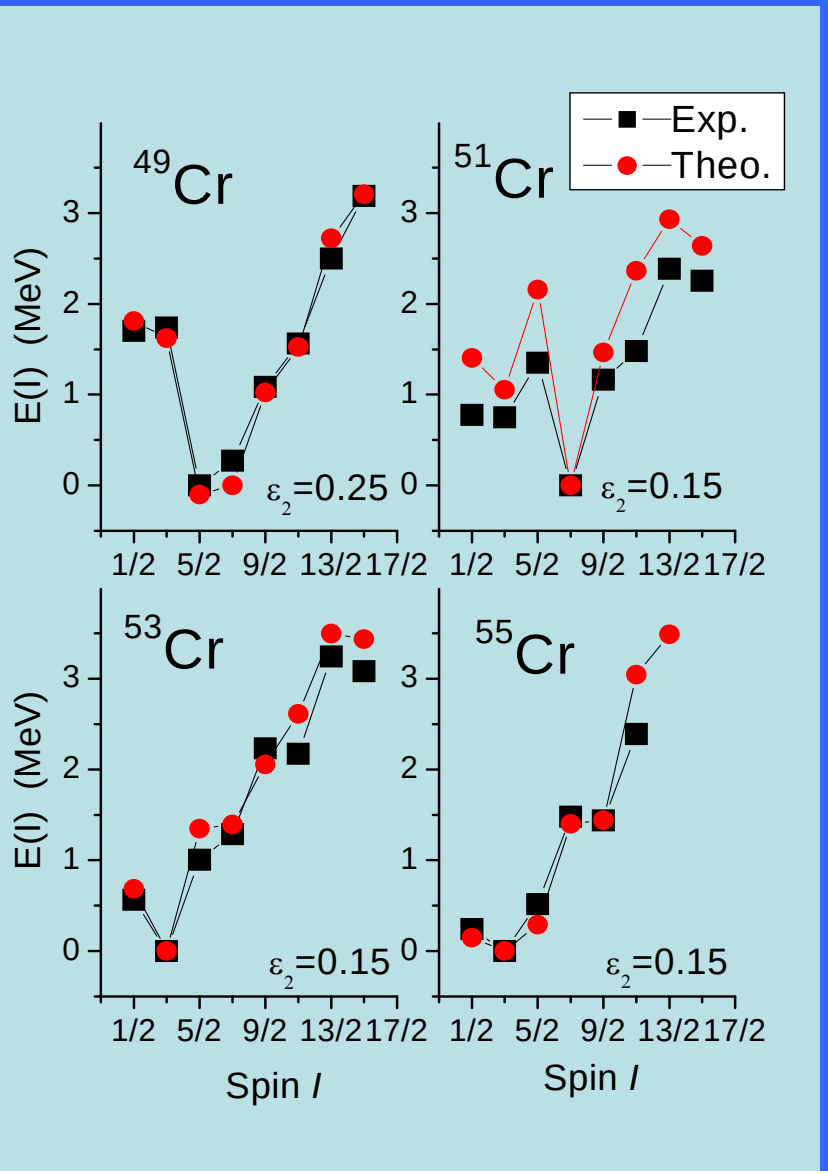


PSM description of the Yrast states in Cr isotopes

Data are taken from Nuclear Data Sheets

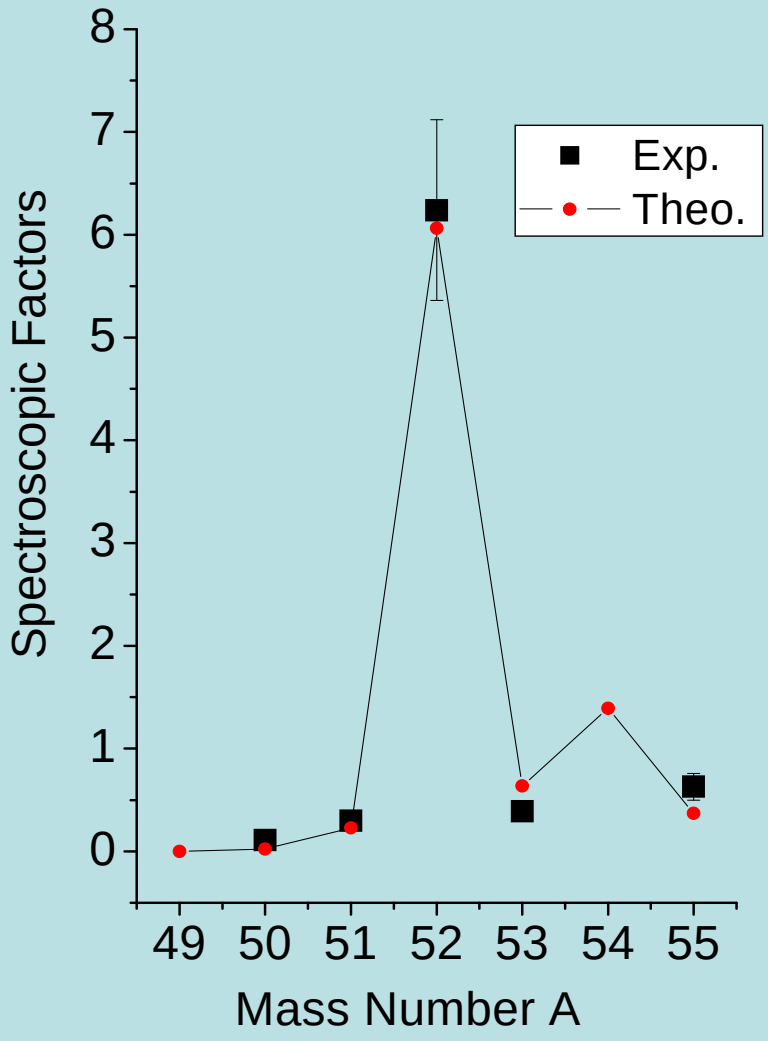
The parameters are taken from Hara&Sun&Mizusaki PRL83 1922(1999)





The Calculated S-Factors

Data taken from Tsang et al PRL95,222501(2005)



Nucleus	*lj*	Exp.	PSM
^{49}Cr	5/2	-----	0.00
^{50}Cr		0.11±0.02	0.02
^{51}Cr	f7/2	0.30±0.08	0.23
^{52}Cr		6.24±0.88	6.06
^{53}Cr	p3/2	0.39±0.03	0.64
^{54}Cr		-----	1.39
^{55}Cr	p3/2	0.63±0.13	0.37

Summary and outlook

Summary：

1. For the first time, the particle number projection (PNP) has been applied to the Projected Shell Model.
2. Based on the improved PSM wavefunctions(with PNP), the code for the calculations of the spectroscopic factors has been established.
3. The spectroscopic factors of the ground states in the Cr isotopes has been calculated and compared with the experimental data. Good agreements have been achieved.

Outlook:

1. Only limit to axial symmetry, will be extended to the triaxial and octupole cases。
2. Cooperation and application。

Thanks