Shell quenching revisited

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Introduction

Proper understanding and modelling of the formation of heavy elements in nature happening through the r-process, i.e. a combination of rapid neutron captures, inverse photodisintegrations, and slower β^--decays, β-delayed processes as well as fission and possibly interactions with intense neutrino fluxes, requires the knowledge of nuclear properties far from stability and a detailed prescription of the astrophysical environment. The investigations with radioactive ion beams have played a pioneering role in exploring the characteristics of nuclear structure in terms of masses and β-decay properties. In recent times experiments have produced highly unstable nuclei with magic neutron (proton) numbers and information about their β-decay properties, related to the location and height of r-process peaks have been obtained. Recent works focus on the evolution of shell effects at large distances from the valley of stability [1].

It is actually the beta-decay rate rather than the neutron-capture rate is inversely proportional to nuclear abundances. Presumably, the slowest beta-decays will be in conjunction with magic numbers, so the highest abundances will thus be associated with magic numbers. The evolution of these magic numbers along the nuclear chart plays an important role in the abundance of nuclei. Quenching of the N = 82 shell due to a softening of the neutron potential [2] has been invoked to explain this abundance deficiency [3] and experimental evidence for a reduced shell gap for N = 82, Z - 50 has been presented [4,5]

With the inclusion of tensor interaction in Skyrme Hartree Fock theory the splitting of spin-orbit partners of single particle states of shell closed nuclei gets modified [6-8]. As a result, the shell gap which is the energy difference between the last filled hole state and first unfilled particle state changes with increase of neutron/proton number. This raises the question whether this development could provide a possible scenario to understand the r-path abundance deficiency trough below the A ~ 130 peak in astrophysical network calculations [9].

Formalism

After inclusion of tensor interaction the expressions for proton (- neutron) spin-orbit potential in Skyrme Hartree-Fock theory is

$$V_{SO}^{q} = \frac{1}{2r}\left\{\begin{matrix}\left(\left(C_0^J - C_1^J\right)J_0(r) + 2C_1^J\, J_q(r) - \right. \\ \left(C_0^{\nabla J} - C_1^{\nabla J}\right)\frac{d\rho_0}{dr} - 2C_1^{\nabla J}\,\frac{d\rho_q}{dr}\end{matrix}\right\}\mathbf{L}\,.\,\mathbf{S} \tag{1}$$

$$C_0^{\nabla J} = -\frac{3}{4}\,W_0. \tag{2}$$

The final spin-orbit potential component is given by

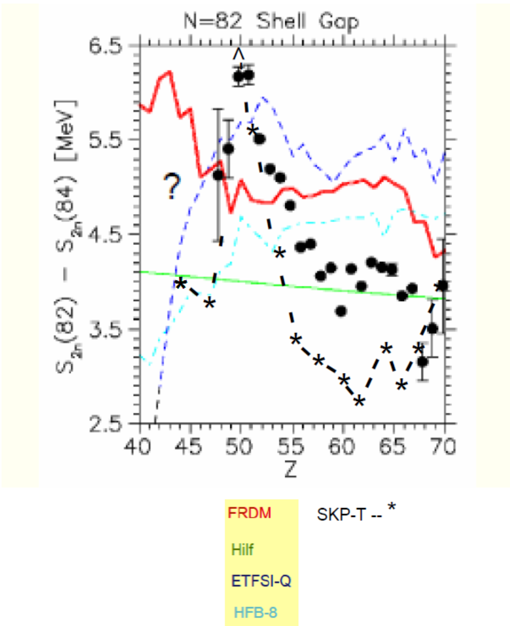
$$V_{s.o.}^{q} = \frac{W_0}{2r}\left(2\frac{d\rho_q}{dr} + \frac{d\rho_{q'}}{dr}\right) + \left(\alpha\frac{J_q}{r} + \beta\frac{J_{q'}}{r}\right) \tag{3}$$

where $J_{q(q')}$ (r) is the proton or neutron spin-orbit density.

Using a set of force parameters (SKP) in SKHF along with BCS prescription for pairing which has shown the best reproduction of observed splitting of shell model states of ^{40}Ca, ^{56}Ni, ^{48}Ca and ^{208}Pb, the tensor coupling coefficients were optimized. In fig. 1 we present the shell gap given by S_{2n}(N=82) – S_{2n}(N=84) for a series of nuclei with Z = 44 – 70. Inclusion of tensor interaction in the SKHF theory gives a better reproduction of the experimental situation compared to other theoretical approaches. In Table we present the single particle spectrum of ^{1132}Sn along with the experimental values.

Results

The reduction of shell gap below Z = 50 indicates shell quenching effect which was pointed out earlier by Dobaczewski et al. The importance of tensor interaction in the study of development of shell structure through meanfield type of calculation has been studied [10]. Study of abundance of nuclei near r-path in SKHF theory with the inclusion of tensor interaction is in progress.



References:

[1] H. Grawe et al, Eur. Phys. J. A 25, s01, 357(2005)
[2] J. Dobaczewski et al., Phys. Rev. Lett. 72, 981 (1994).
[3] A. L. Goodman and J. Borisowicz, Nucl. Phys., A 295, 333 (1978)
[4] B. Pfeifer et al., Nucl. Phys. A 693, 282 (2001).
[5] H. Grawe, Acta Phys. Pol. B 34, 2267 (2003)
[6] D. Vautherin and D.M. Brink, Phys. Lett. B 32, 149 (1970); Phys. Rev. C 5, 626 (1972)
[7] F. Stancu, D.M. Brink and H. Flocard, Phys. Lett., B 68, 108 (1977)
[8] M. Zalewski et al, Phys. Rev. C 80, 064307 (2009)
[9] I. Dillmann et al., Phys. Rev. Lett. 91, 162503 (2003)
[10 R. Bhattacharya, Nucl. Phys. A 913, 1 (2013)

TABLE I

Single particle spectrum of ^{132}Sn

nlj	$-E_{nlj}$	
	Th.(SKP)	Expt.
$1f_{5/2}$	18.28	18.97
$1g_{9/2}$	14.67	15.38
$1g_{7/2}$	9.17	9.68
$2d_{5/2}$	8.95	8.72
$1h_{11/2}$	7.05	6.89
Neutron		
$1g_{7/2}$	8.57	9.72
$2d_{5/2}$	9.55	8.95
$3s_{1/2}$	7.80	7.62
$2f_{5/2}$	7.76	7.53
$2d_{3/2}$	7.55	7.29
$2f_{7/2}$	2.25	2.63

Experimental values are taken from Grawe et al [1]