Nuclear shapes from the stability and consistency of the SU(3) symmetry

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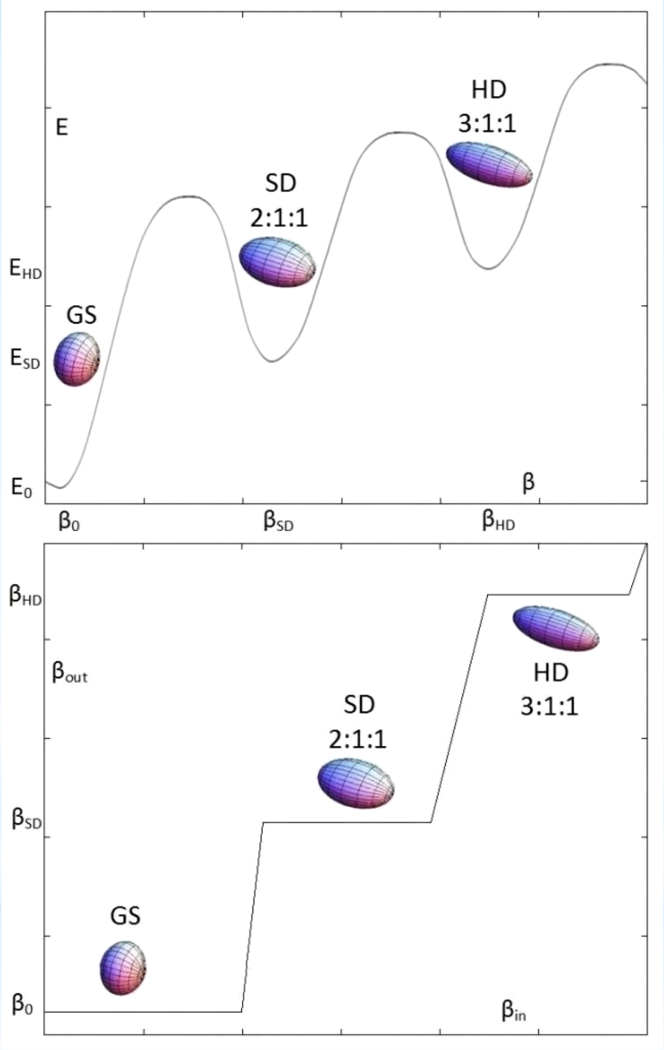
I. Introduction

Nuclear shapes in general, and shape isomers in particular, are from energy surface calculations of some structure model. Energy as a function of deformation parameters; local minima: shape isomers. E.g. GS,SD,HD…

Here: an alternative method. No energy surface. Investigate the stability and self-consistency of the SU(3) symmetry (or quadrupole deformation that is uniquely related to it).



E
HD
3:1:1
SD
2:1:1
GS
E_{HD}
E_{SD}
E_0
β
β_0
β_{SD}
β_{HD}
β_{HD}
β_{out}
HD
3:1:1
SD
2:1:1
β_{SD}
GS
β_0
β_{in}

Validity of SU(3) symmetry (deformation axis)

Spherical harmonic oscillator (HO):
SU(3) - degenerecy - shell structure

Deformed HO: symmetry-break down.

G. Rosensteel, J. P. Draayer, J. Phys. A 22 (1989) 1323.

HO with commensurable ratios: SU(3) recovers

How about more realistic interactions?

I. Inroduction

II. Quasidynamical SU(3) symmetry

III. Method of calculation

IV. Applications

V. Summary and conclusions

I. Quasidynamical SU(3) symmetry

P. Rochford, D.J. Rowe, J. Repka, J. Math. Phys. 29, 572 (1988).

Symmetry of the eigenvalue equation when neither the operator, nor the eigenvectors are symmetric.

Embedded representation: matrix elements of the group operators between vectors which are special linear combinations of bases of different irreps.
(For a subspace of the Hilbert space.)
Exact or approximate embedded representations.

$$\psi_{\alpha JM} = \Sigma_{\delta\lambda\mu K} C_{\alpha\delta\lambda\mu KJM} \phi_{\delta\lambda\mu KJM}$$

H: spherical, M-independent.
If it is also J-independent: approximate quasi-dynamical SU(3) symmetry.
Soft SU(3) band.

Adiabatic separation of rotational and intrinsic df.

Explains why some models are successful inspite of symmetry-breaking interactions.

II. Method of calculation

M. Jarrio, J.L. Wood, D.J. Rowe, Nucl. Phys. A528, 409 (1991).

- An asymptotic Nilsson state $|Nn_z\Lambda\Sigma>$ is an intrinsic state of a soft SU(3) band.
- For large prolate deformation $(\lambda\mu)$ from many-particle Nilsson state.

P.O. Hess et al, Eur. J. Phys. A15, 449 (2002).

Oblate and small deformations.
Expansion in terms of asymptotic Nilsson states.

Scenario

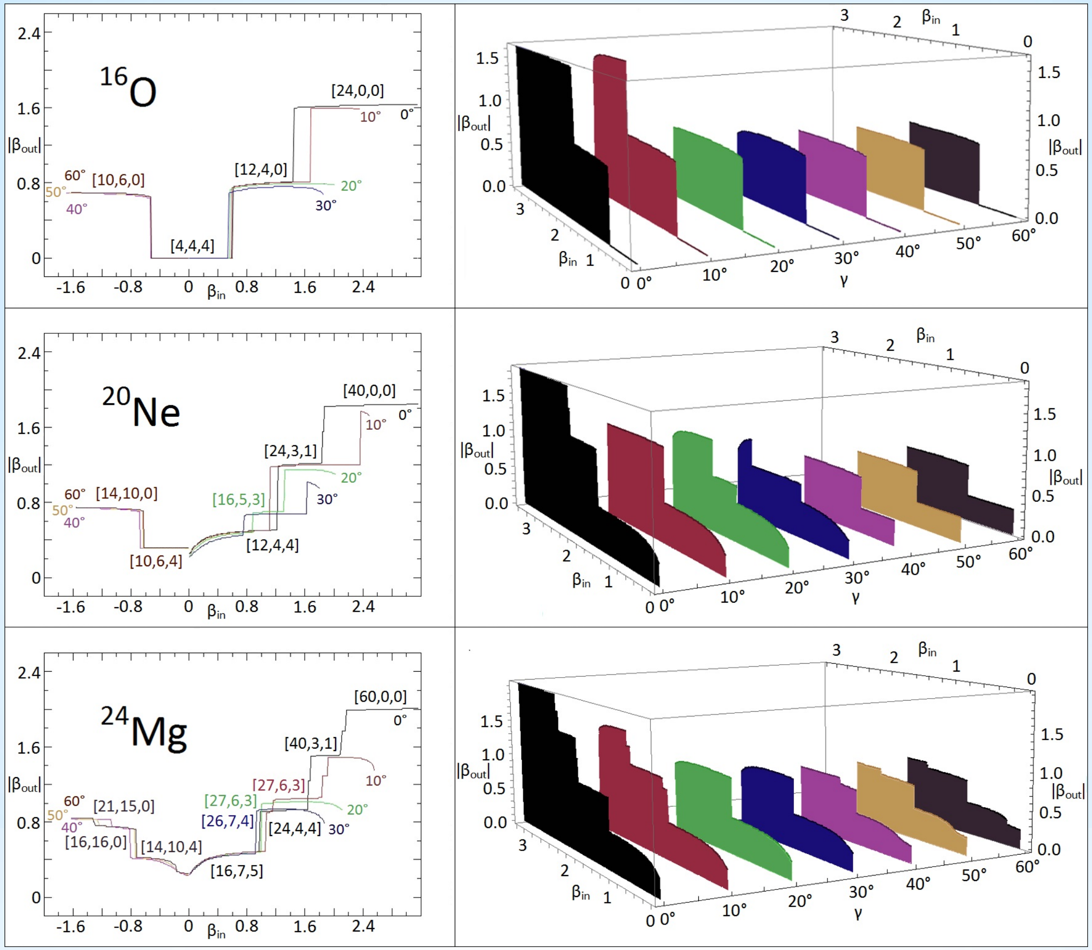
i) Nilsson orbitals
ii) Many-particle state
iii) Expansion in terms of asymptotic Nilsson states
iv) $(\lambda\mu)$ from the expansion
v) $$\beta^2 = \frac{16\pi}{5N_0^2}(\lambda^2 + \mu^2 + \lambda\mu), \gamma = arctan\left(\frac{\sqrt{3}\mu}{2\lambda + \mu}\right)$$

III. Application

$^{16}O \quad ^{20}Ne \quad ^{24}Mg$

G. Leander, S.E. Larsson, Nucl. Phys. A239, 93 (1975).
Nilsson model calculations.

W.D.M. Rae et al, Nucl. Phys. A 549, 431 (1992);
564, 252 (1993); 575, 61 (1994).
Alpha-cluster model calculations.


16O
[24,0,0]
[12,4,0]
[10,6,0]
[4,4,4]
20Ne
[40,0,0]
[24,3,1]
[14,10,0]
[16,5,3]
[12,4,4]
[10,6,4]
24Mg
[60,0,0]
[40,3,1]
[27,6,3]
[27,6,3]
[26,7,4]
[24,4,4]
[21,15,0]
[16,16,0]
[14,10,4]
[16,7,5]
|βout|
βin
γ

Nucl.	Nilsson $\omega_x : \omega_y : \omega_z (\epsilon, \gamma)$	Alpha	Shape	$\hbar\omega$	U(3)	SU(3)	(ϵ, γ)	a:b:c
^{16}O	1:1:1 (0,0)	tetrahed	GS	0	[4,4,4]	(0,0)	(0,0)	1:1:1
	4:2:1 (1.04,43)	2d(2:1)	SD	4	[12,4,0]	(8,4)	(0.83,19)	2.5:1.5:1
	4:4:1 (1.2,0)	$\alpha - ch$	$\alpha - ch$	12	[24,0,0]	(24,0)	(1.56,0)	4:1:1
^{20}Ne	2:2:1 (0.40,0)	bipyram	GS	0	[12,4,4]	(8,0)	(0.50,0)	1.6:1:1
	8:3:2 (1.17,50)	2d(3:2)	Tri$_{SD}$	4	[16,8,0]	(8,8)	(0.80,30)	2.6:1.8:1
		2d(3:1)	HD	8	[24,4,0]	(20,4)	(1.19,9)	3.4:1.4:1
	5:5:1 (1.25,0)	$\alpha - ch$	$\alpha - ch$	20	[40,0,0]	(40,0)	(1.76,0)	5:1:1
^{24}Mg	4:3:2 (0.45,20)	3d triax	GS	0	[16,8,4]	(8,4)	(0.51,19)	1.8:1.3:1
	(1.0,0)	3d cilsy	SD(p)	4	[24,4,4]	(20,0)	(0.91,0)	2.3:1:1
	3:1:1 (1.23,60)	2d(1:1)	SD(o)	4	[16,16,0]	(0,16)	(0.72,60)	2.3:2.3:1
	5:2:1 (1.26,42)	2d(2:1)	Tri	8	[28,8,0]	(20,8)	(1.07,16)	3.3:1.7:1
			HD$_{Tri}$	16	[40,4,0]	(36,4)	(1.46,5)	4.3:1.3:1
	6:6:1 (1.25,0)	$\alpha - ch$	$\alpha - ch$	32	[60,0,0]	(60,0)	(1.91,0)	6:1:1

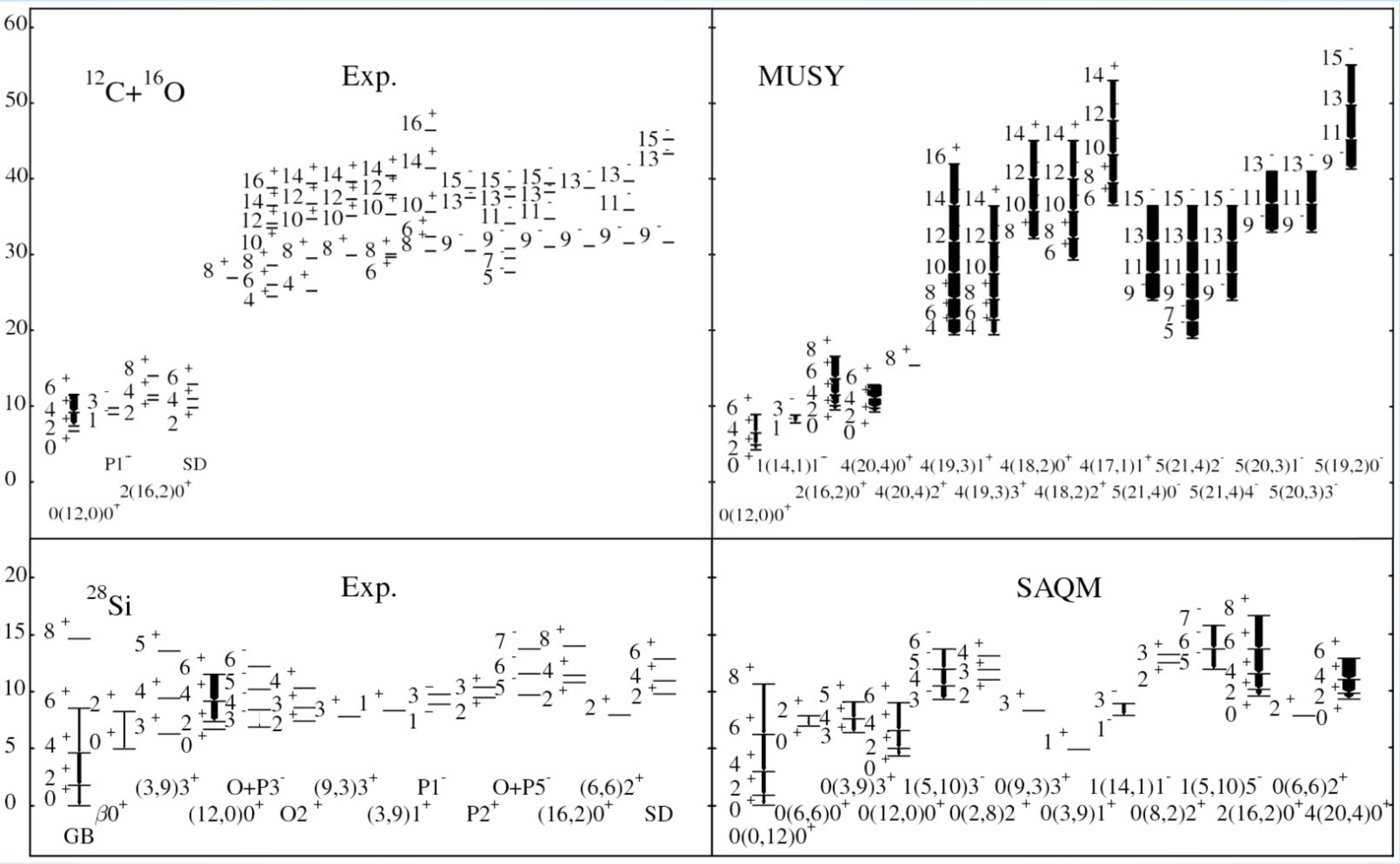
Comparison of shape isomers from different models.

Different methods, similar results.

Symmetry > selection rule >
> clusterization > reaction channel

Energy: from symmetry adapted (semimicroscopic algebraic) quartet and cluster models.

Energies: not only shape isomers, but detailed spectra. Multiconfigurational dynamical symmetry (MUSY).



(J. Cseh, G. Riczu, Phys. Lett. B 757 (2016) 312.)

V. Summary and conclusions

SU(3) seems to be valid even for realistic (Nilsson) Hamiltonians for commensurable major axes.

Stability and consistency of the SU(3) symmetry (or quadrupole deformation): alternative way for determining the shape isomers.

Selection rule for allowed clusterizations, and favored reaction channels.

Energies: related symmetry-based structure models.
Not only shape isomers, but detailed spectra.
MUSY: Spectra of different configurations in different energy windows. Predictive power.

J. Cseh, G. Riczu, J. Darai,

Phys. Lett. B 795 (2019) 160.

In previous studies:
A. Algora, Valencia
P.O. Hess, UNAM Mexico

Thank you for your attention!