2000/9/25 物理学会 於 新潟大学

ニルソン模型でみる
原子核の偏長変形優勢の起源

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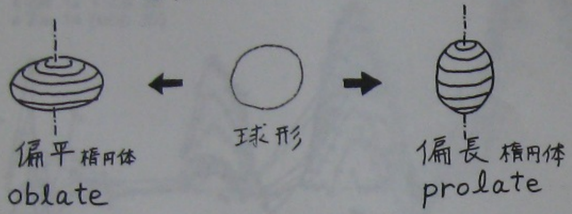


原子核の基底状態での変形は、
偏長形が圧倒的に多いらしい。

その起源は？

1. 巨視的効果（液滴模型）

- わずかに偏長優位 ← クーロン反発

慣性モーメント
∞ 角運動量射影によるエネルギーゲイン
（清水良文氏）

2. 微視的効果（殻効果）…· 主因

偏長優勢に寄与する殻効果を生ずる一体ポテンシャル

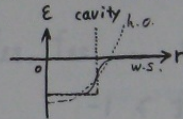
● 調和振動子ポテンシャル

→ やや偏長優位へ

· Mottelson (1979) Nikko
· Castel et al. Phys. Lett. B236 (1990) 121

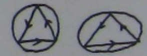
(NB)
$\langle E \rangle = \langle T \rangle + \langle V \rangle$
$\langle V \rangle$ ← 飽和性により変形によらない
$\langle T \rangle$ → 等方的速度分布で最小

● Woods-Saxon型動径依存性 ～ $\vec{l}^2$ポテンシャル



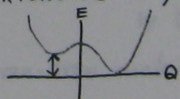
· H. Frisk　Nucl. Phys. A511 (1990) 309.

「cavity中の周期的古典軌道長は
$R_\perp^2 R_{/\!/}$ = 一定 を課すと、偏平で変化が小さい」



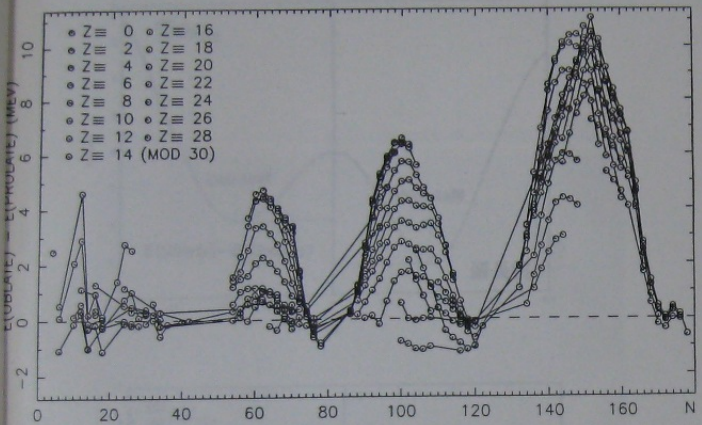
● スピン・軌道ポテンシャル

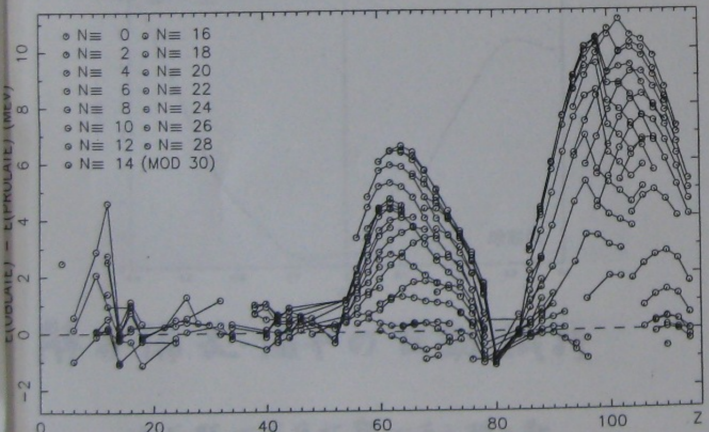
· extensive Skyrme HF calculation



E(偏平) − E(偏長) プロット

「偏長優勢は N, Z > 50 で急に出現する
主殻が high-j intruder を含む





Nilsson Model

- $$U(\vec{r}) = \frac{1}{2} m \left(\omega_\perp^2 x^2 + \omega_\perp^2 y^2 + \omega_{/\!/}^2 z^2 \right)$$
$$+ 2\hbar\omega_0 r_t^2 \sqrt{\frac{4\pi}{9}}\, \varepsilon_4 Y_{40}(\hat{r})$$
$$+ f_{ls} \cdot 2\kappa\hbar\omega_0\, \vec{l}_t \cdot \vec{s}$$
$$- f_{ll} \cdot \kappa\mu\hbar\omega_0 \left(\vec{l}_t^{\,2} - \langle \vec{l}_t^{\,2} \rangle_N \right)$$

- volume conservation requirement:

$$\begin{cases} \omega_\perp = \omega_0 \left(1 + \frac{1}{3}\varepsilon_2\right) \\ \omega_{/\!/} = \omega_0 \left(1 - \frac{2}{3}\varepsilon_2\right) \end{cases}$$, adjust ω_0 such that $\omega_\perp^2 \omega_{/\!/} = \text{constant}$

- f_{ll}, f_{ls} : reduction factors

$$-1 \leq f_{ls}, f_{ll} \leq 1$$

Nilsson-Strutinsky Method

ε_4 : optimized for each ε_2

$\tilde{\Delta} = 13/\sqrt{A}$ (MeV)

Nicra → reduction to $\left\{ \begin{array}{l} \text{non-rotating} \\ \text{axially symmetric} \end{array} \right\}$ cases

by Y. R. Shimizu very fast

1834 even-even nuclei $8 \leq Z \leq 126$, $8 \leq N \leq 184$

p-drip line ~ n-drip line

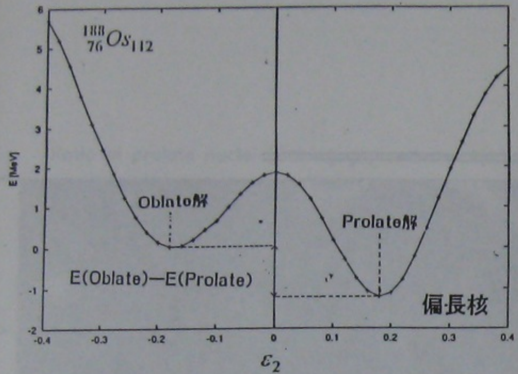
$\Delta f_{ls} = \Delta f_{ll} = 0.125$

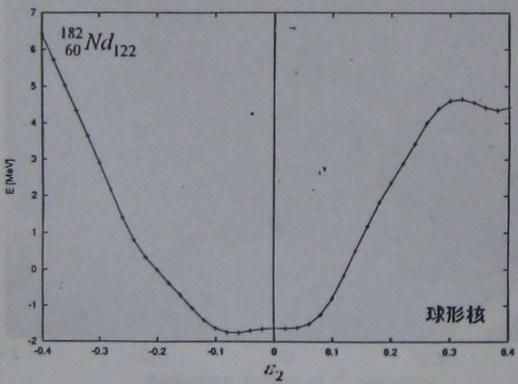
$1834 \times 17 \times 17 \times 3 = 1.6 \times 10^5$ nucl pes

1 cpu @ 400 MHz × 1 month

$\varepsilon_4 = 0$ case, $\tilde{\Delta} \times 0.7$ case

g-oblp102





解の偏長・偏平の自動識別

$$R_p = \frac{\text{偏長解が基底状態である核の数}}{\text{偏長解と偏平解の両方を持つ核の数}}$$

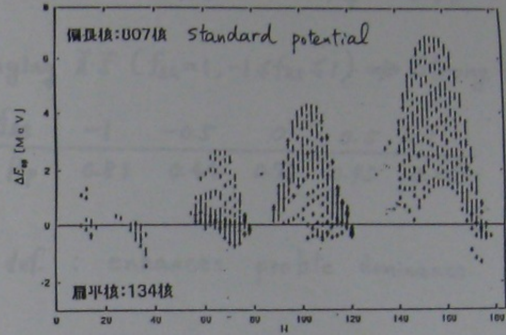


図 5.4: $f_{ls} = f_{ll} = 1$ としたとき、それぞれの核の ΔE_{op}

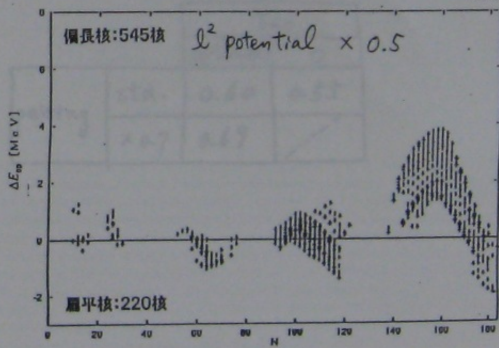


図 5.5: $f_{ls} = 1, f_{ll} = 0.5$ としたとき、それぞれの核の ΔE_{op}

Summary of the Results

- Standard $\vec{l}^2$ and $\vec{l}\cdot\vec{s}$ $\Rightarrow$ $R_p = 0.86$

- Changing $\vec{l}\cdot\vec{s}$ ($f_{ll}=1, -1 \leq f_{ls} \leq 1$) $\Rightarrow$ Strong interference

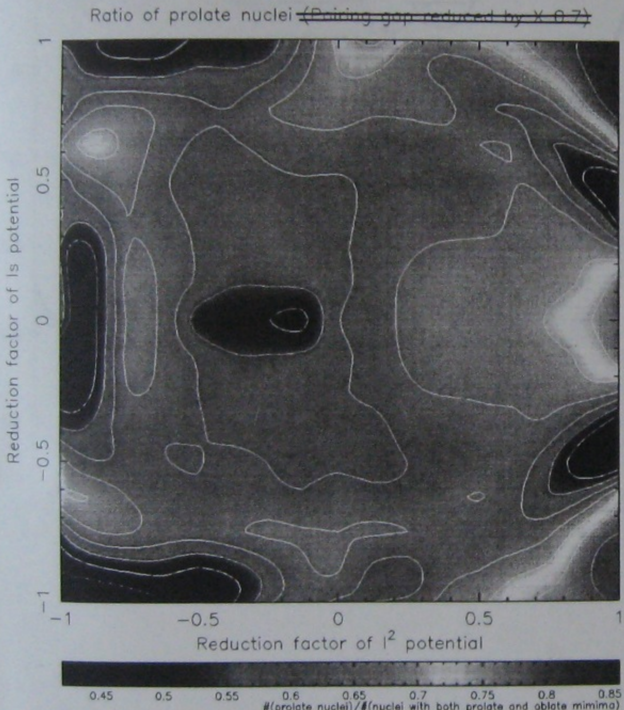
f_{ls}	-1	-0.5	0	0.5	1
R_p	0.81	0.44	0.78	0.45	0.86

- Y_{40} def. : enhances prolate dominance

- pairing : hindering 〃

- R_p average over (f_{ls}, f_{ll}) values:

		Y_{40}	
		optimize	0
pairing	std.	0.60	0.55
	×0.7	0.69	



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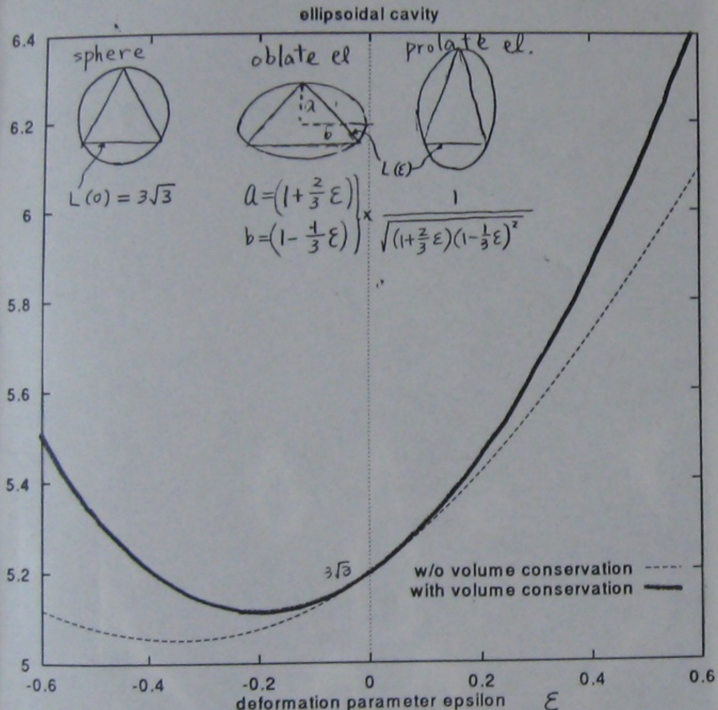

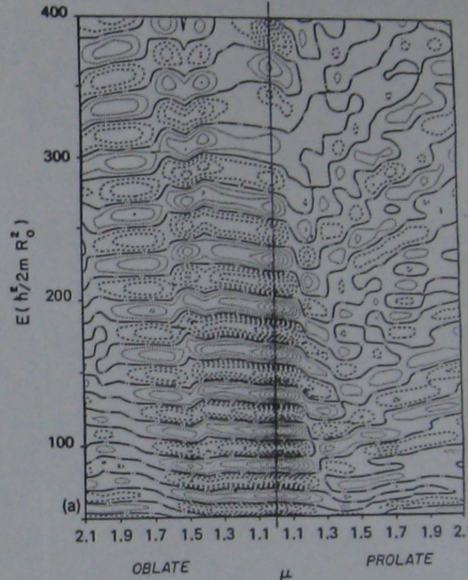

Fig. 4. In (a) the oscillating part of the smoothed semi-classical level density is displayed as function of energy and deformation. For comparison the corresponding quantum-mechanical quantity is shown in (b). Since the smoothing is large, $k_l = 0.6 R_0^{-1}$, only the 10–15 shortest orbits for each deformation have been included and repeated five times except for some orbits in the equatorial plane, which have been repeated fewer times to avoid tedious corrections. The β-values are 0 for the orbits in the prolate cavity, 1 for the sphere and 2 or 0 in the oblate cavity if the planar periodic orbit has elliptic or hyperbolic caustic, respectively. The $(\alpha_\zeta, \alpha_\phi, \alpha_z)$ vector is (2, 0, 3) in the prolate system and (0, 0, 2), for positive parity, or (0, 0, 0), for negative parity, in the oblate system. For the sphere $(\alpha_r, \alpha_\phi) = (3, 2)$. The degeneracy factor ϵ is equal to 1 for $l_z = 0$ orbits and 2 for the other orbits in the ellipsoidal cavity while it is $2I_\phi/\hbar$ fo: the orbits in the sphere. The dotted contours have positive values of $\rho_\gamma(E, \mu) - \rho_{TF}(E, \mu)$, dashed contours correspond to negative values while the thick chain dotted contour indicates the zero level. The distance between the contours is 0.008 $(\hbar^2/2mR_0^2)^{-1}$, which is about 0.6% of the total level density at $E = 225\hbar^2/2mR_0^2$. If spin is included the chosen energy range corresponds roughly to particle numbers between 30 and 950. The energy unit is ~0.35 MeV for a heavy nucleus and therefore the nuclear physics limit is $135\hbar^2/2mR_0^2$. The richer spectrum of important periodic orbits in the prolate cavity gives rise to a much more complex structure for prolate shapes than for oblate shapes. The down slop:ng valleys and ridges for small prolate deformations are due to the increase of the lengths for the triangle and square orbits. The upsloping structure on the prolate side is caused by the decrease of the lengths for the equatorial orbits.