

「現代の核構造論」ミニマム

Chapter 1 現代的な核構造論への招待

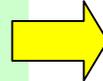
- 1a 間違いだらけの原子核像
- 1b 核構造論の歴史

Chapter 2 平均場近似とは何か

- 2a 真空とその励起モード
- 2b 対称性の自発的破れとその回復

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- 3a 超低温核物理学
高スピフロンティアー
- 3b 回転座標系での準粒子シェルモデル
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- 5a オブレート・プロレート変形共存現象
- 5b パリティ二重項とカイラル二重項

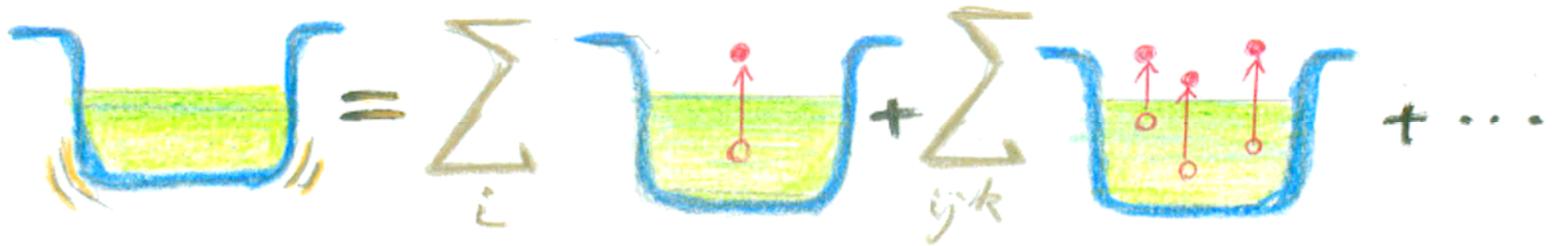
Chapter 6 不安定核の集団励起モード

- 6a 新しい理論的課題
- 6b 期待される新しい集団現象

振動する平均場

集団振動の微視的理論(準粒子RPA)

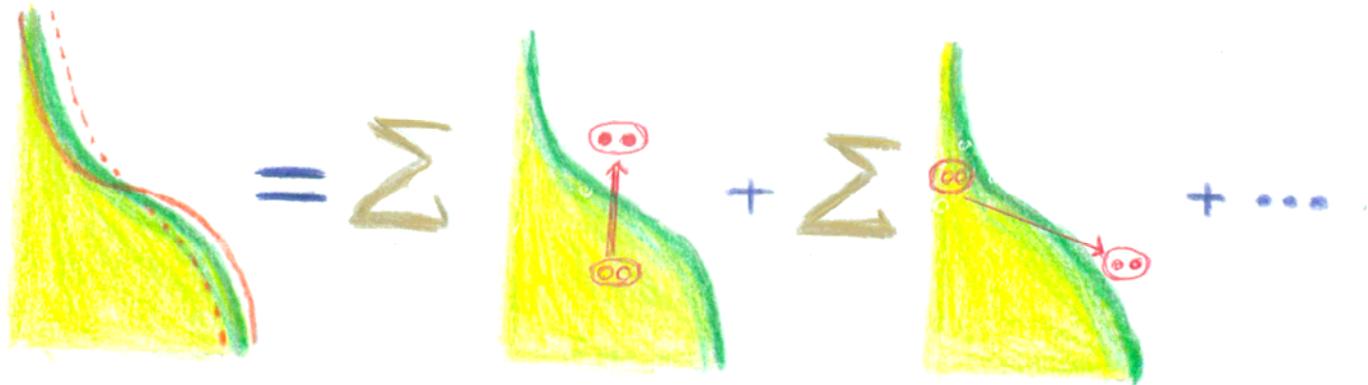
表面の形の振動



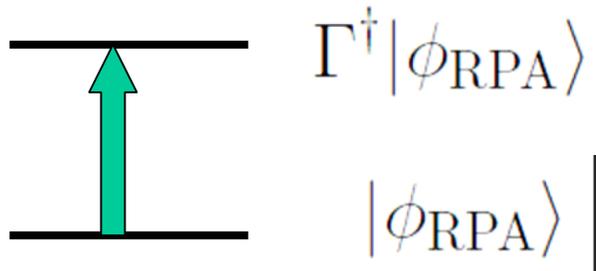
ポテンシャルの振動 ~ 粒子-空孔励起のコヒーレントな重ねあわせ

豊かなシェル構造をもつ平均場は膨大な自由度を内包している

核子ペアーの分布の振動



振動の励起モード



$$\Gamma^\dagger = \sum_{ij} (f_{ij} a_i^\dagger a_j^\dagger - g_{ij} a_j a_i)$$

準粒子RPA方程式

$$\delta \langle \phi_{\text{BCS}} | [H, \Gamma^\dagger] - \hbar\omega \Gamma^\dagger | \phi_{\text{BCS}} \rangle = 0$$

時間依存変分原理

$$\delta \langle \phi(t) | i\hbar \frac{\partial}{\partial t} - H | \phi(t) \rangle = 0$$

$$\begin{aligned} |\phi(t)\rangle &= e^{i\hat{G}(t)} |\phi(t=0)\rangle = e^{i\hat{G}(t)} |\phi_{\text{BCS}}\rangle \\ &\approx (1 + i\hat{G}(t)) |\phi_{\text{BCS}}\rangle \end{aligned}$$

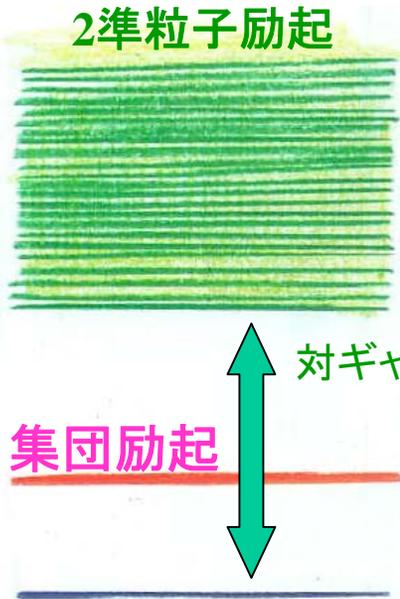
小振幅近似

$$\delta \langle \phi_{\text{BCS}} | [H, i\hat{G}] + \hbar \frac{\partial \hat{G}}{\partial t} | \phi_{\text{BCS}} \rangle = 0$$

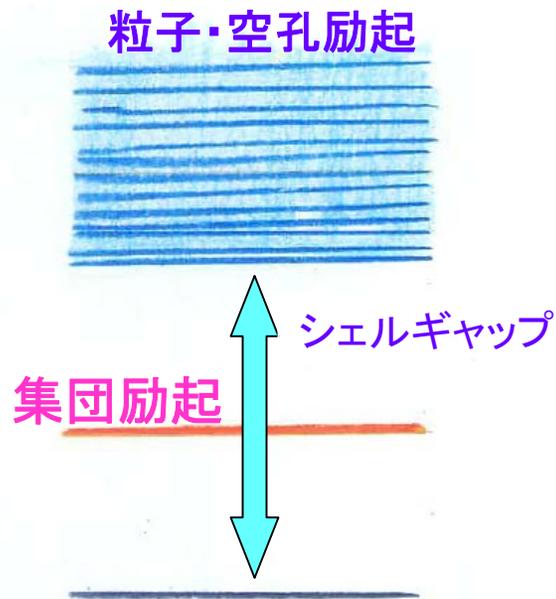
$$\hat{G}(t) = i\eta^* e^{i\omega t} \Gamma^\dagger - i\eta e^{-i\omega t} \Gamma$$

調和振動

集団励起モードの存在条件

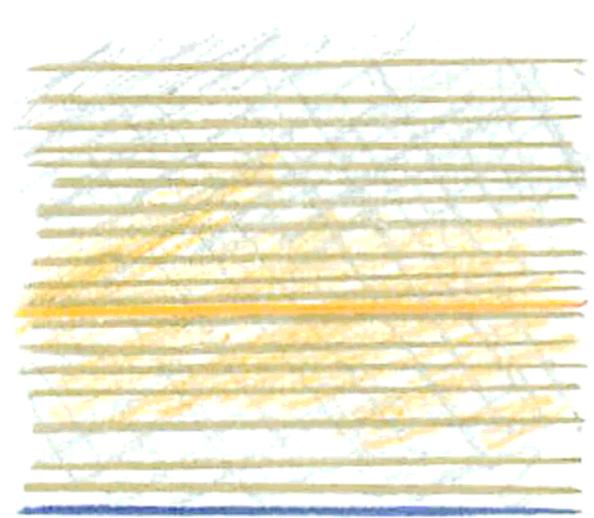


基底状態
(対相関)



基底状態
(閉シェル)

対相関もシェルギャップも
無ければ.....



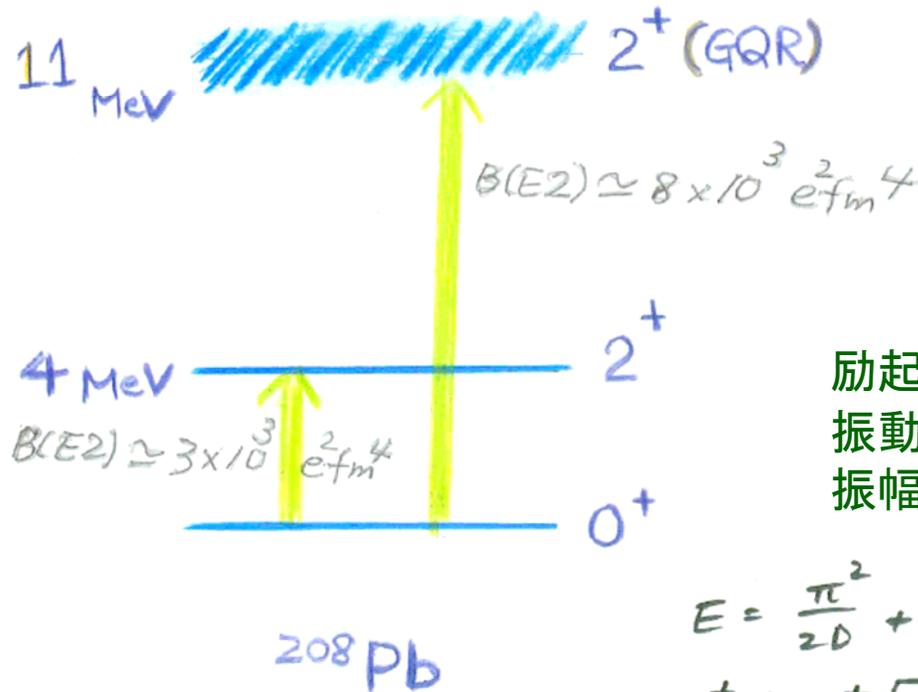
イラスト状態

質問集 (その1)

問2 球形核の第1励起 2^+ 状態に対して液滴モデルの描像を適用することは 妥当(妥当でない)ですか。その理由は何ですか。

問3 アイスカラー四重極巨大共鳴状態に対して液滴モデルの描像を適用することは妥当(妥当でない)ですか。その理由は何ですか。

低励起2+振動と巨大共鳴2+振動



励起エネルギーと遷移強度 $B(E2)$ から振動の質量パラメタ、復元力パラメタ、振幅が計算できる

$$E = \frac{\pi^2}{2D} + \frac{1}{2} C \alpha^2$$

$$\hbar\omega = \hbar\sqrt{C/D}, \quad C = \frac{\frac{5}{2}\hbar\omega \cdot \left(\frac{3}{4\pi}ZeR^2\right)^2}{B(E2: 0^+ \rightarrow 2^+)}$$

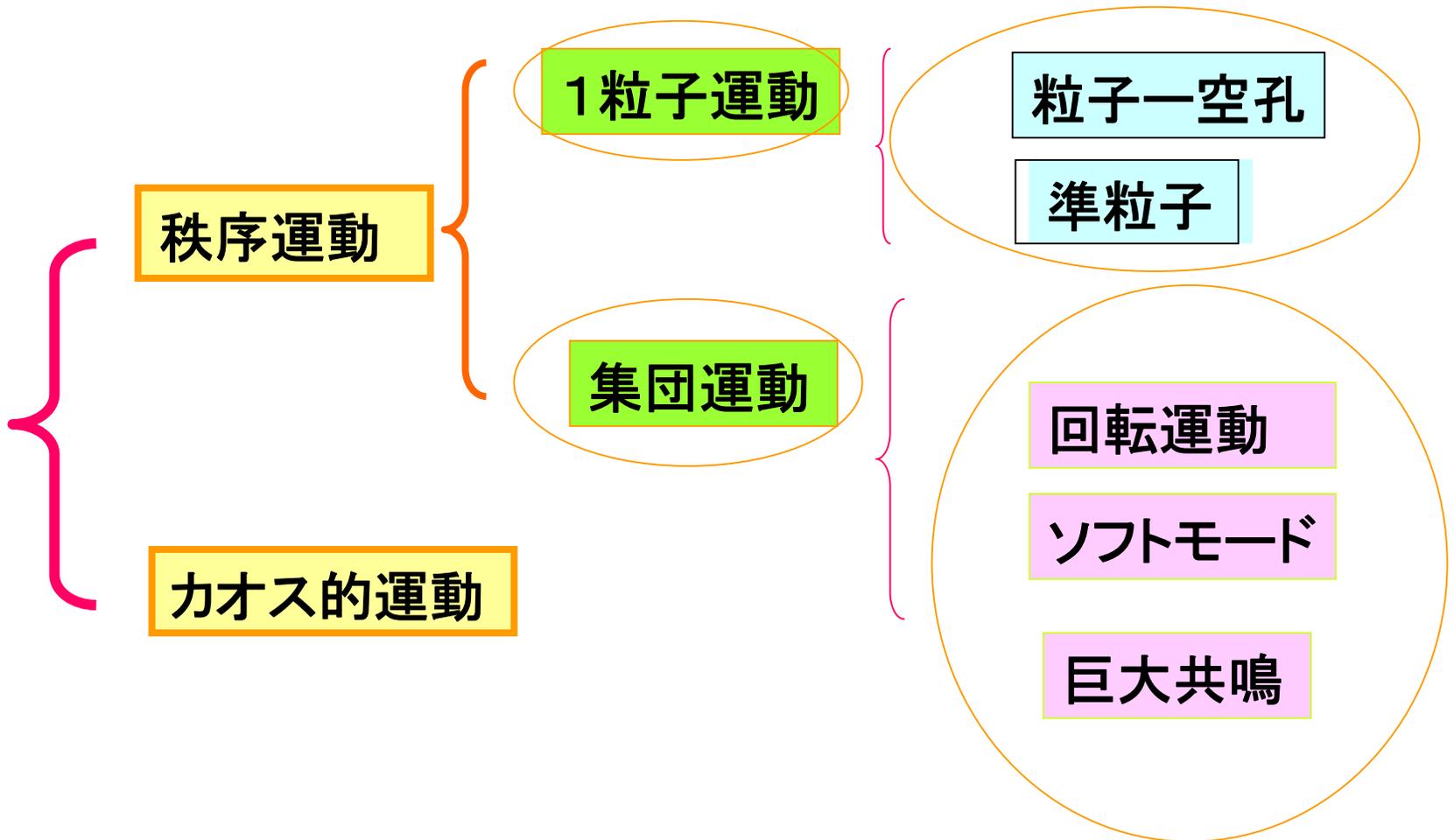
$$\alpha_0 = \sqrt{\hbar\omega/2C}$$

$$\sqrt{\langle\alpha^2\rangle} = \sqrt{5\alpha_0^2} \quad D = (\hbar C/\hbar\omega)^2$$

$$\approx 0.06$$

→ GQRは小振幅の振動である

核構造の大統一理論にむけて



粒子-振動結合ハミルトニアン

$$\begin{aligned} H &= H_{\text{coll}}(\pi, \alpha) + \sum_{i=1}^A \left(\frac{\mathbf{p}^2}{2m} + U(\mathbf{x}, \alpha) \right)_i \\ &= H_{\text{coll}}(\pi, \alpha) + H_{\text{particle}}(\mathbf{p}, \mathbf{x}, \alpha^0) + H_{\text{coupl}}(\mathbf{x}, \alpha) \end{aligned}$$

$$H_{\text{particle}}(\mathbf{p}, \mathbf{x}, \alpha^0) = \sum_{i=1}^A \left(\frac{\mathbf{p}^2}{2m} + U(\mathbf{x}, \alpha^0) \right)_i$$

$$H_{\text{coupl}}(\mathbf{x}, \alpha) = \sum_{i=1}^A (U(\mathbf{x}, \alpha) - U(\mathbf{x}, \alpha^0))_i$$

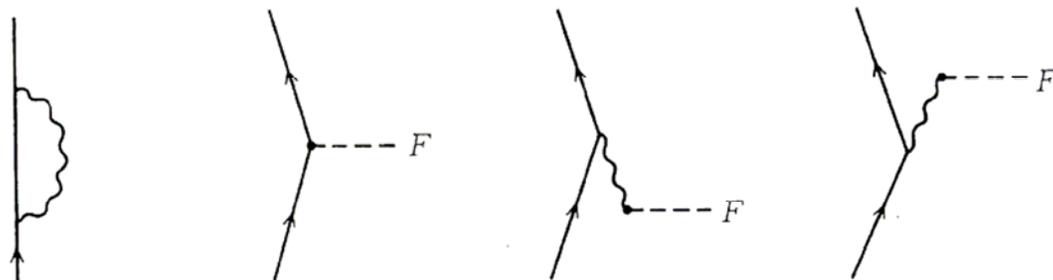
$$U(r, \theta, \varphi, \alpha) = U_0 f \left(r - R_0 \left(1 + \sum_{\lambda\mu} \alpha_{\lambda\mu}^* Y_{\lambda\mu}(\theta, \varphi) \right) \right)$$

$$U(r, \theta, \varphi, \alpha) = U^{(0)}(r) - R_0 \frac{\partial U^{(0)}}{\partial r} \sum_{\lambda\mu} Y_{\lambda\mu}(\theta, \varphi) \alpha_{\lambda\mu}^* + \dots$$

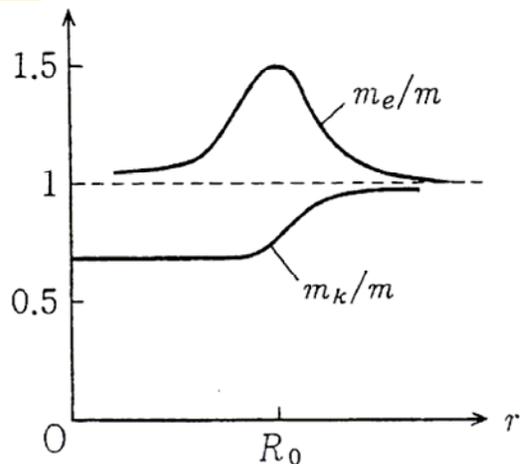
$$H_{\text{coupl}}(\mathbf{x}, \alpha) \cong - \sum_{i=1}^A \sum_{\lambda\mu} (k_\lambda(r) Y_{\lambda\mu}(\theta, \varphi) \alpha_{\lambda\mu}^*)_i$$

$$k_\lambda(r) = R_0 \frac{\partial U^{(0)}}{\partial r}$$

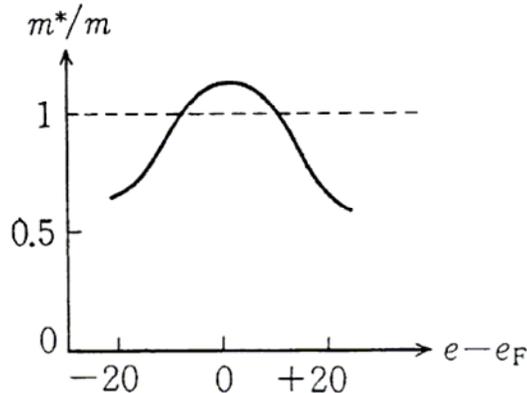
着物を着た1粒子モード



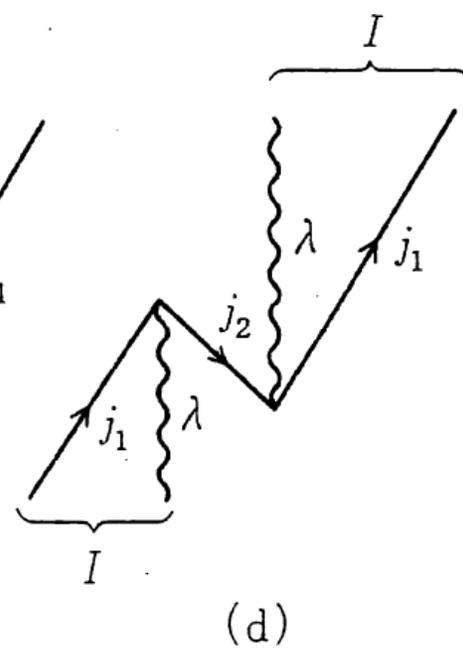
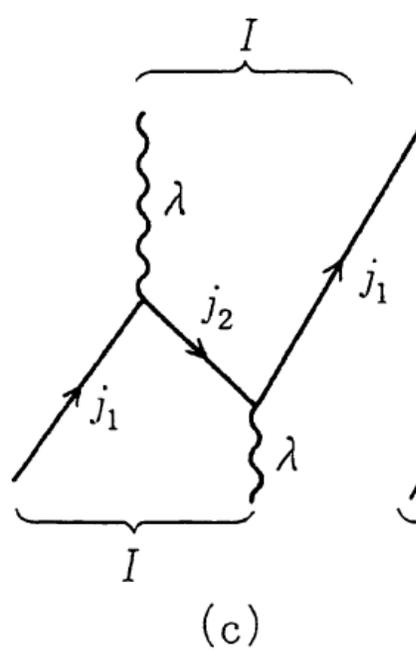
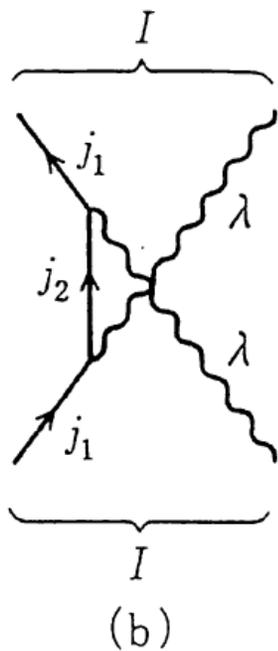
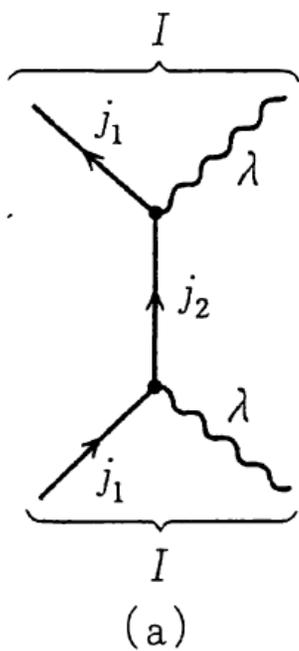
有効質量



有効結合定数

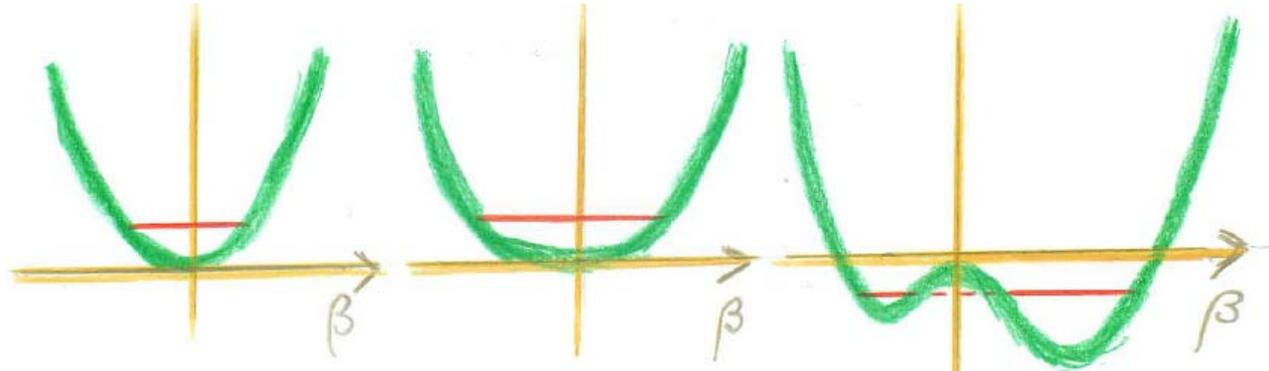


Nuclear Field Theory



粒子-振動結合ダイアグラム

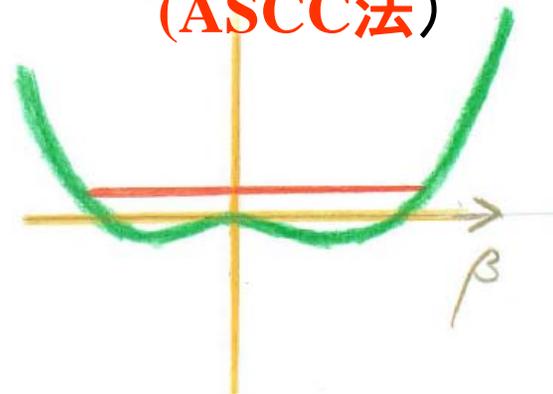
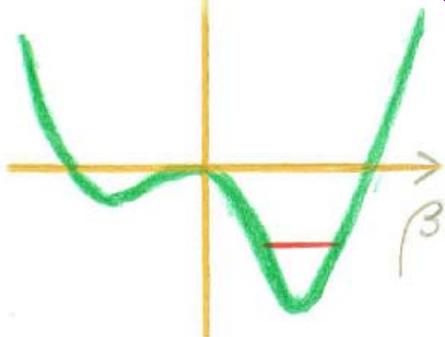
非線形振動



調和振動
(準粒子RPA)

非調和振動
(ボソン展開)
(SCC法)

大振幅振動
(ATDHF)
(ASCC法)

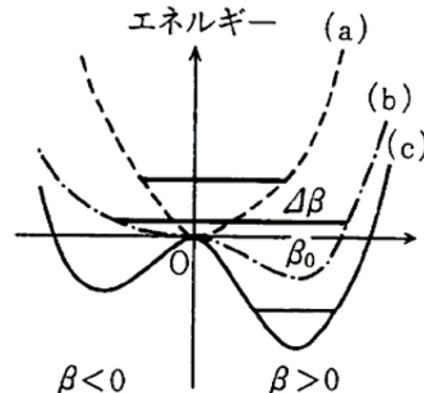


Quantum Phase Transition

ゆるやかな量子相転移(真空の構造変化)

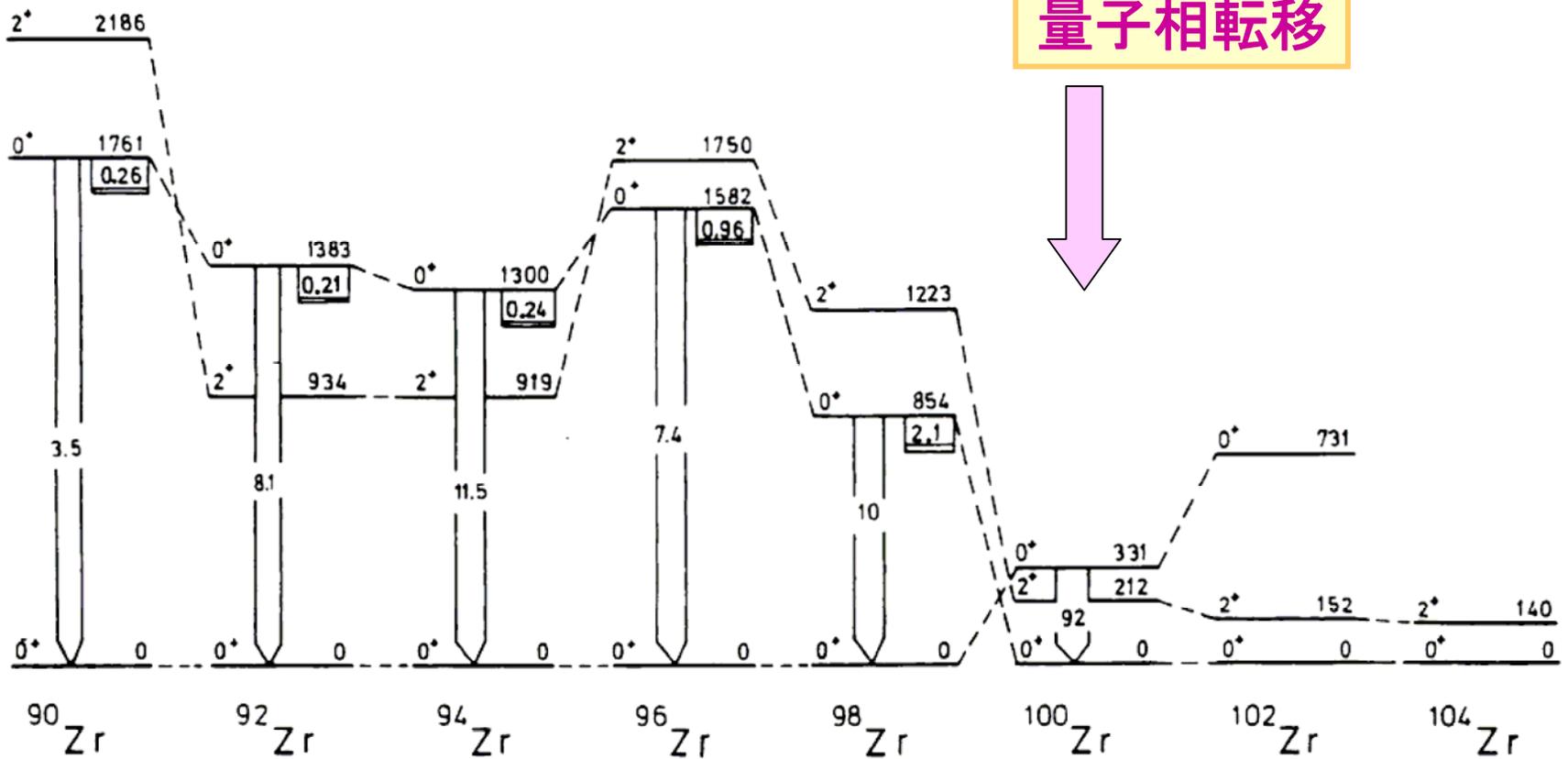
有限系の特徴

温度ゼロ



	2428 4 ⁺	2400 8 ⁺	2438 8 ⁺	2304 10 ⁺	2286 12 ⁺	2613 14 ⁺
		1849 6 ⁺	1945 6 ⁺	1748 8 ⁺	1725 10 ⁺	2049 12 ⁺
	1678 2 ⁺	1458 4 ⁺	1262 4 ⁺	1224 6 ⁺	1216 8 ⁺	1520 10 ⁺
		804 2 ⁺	614 2 ⁺	747 4 ⁺	770 6 ⁺	1040 8 ⁺
				334 2 ⁺	404 4 ⁺	638 6 ⁺
					138 2 ⁺	317 4 ⁺
						99 2 ⁺
	0 ⁺					
	¹⁴⁸ Dy ₈₂	¹⁵⁰ Dy ₈₄	¹⁵² Dy ₈₆	¹⁵⁴ Dy ₈₈	¹⁵⁶ Dy ₉₀	¹⁵⁸ Dy ₉₂
$\frac{E(4^+)}{E(2^+)}$	1.45	1.81	2.06	2.24	2.93	3.20

Zr isotopes の低励起スペクトル



N=50

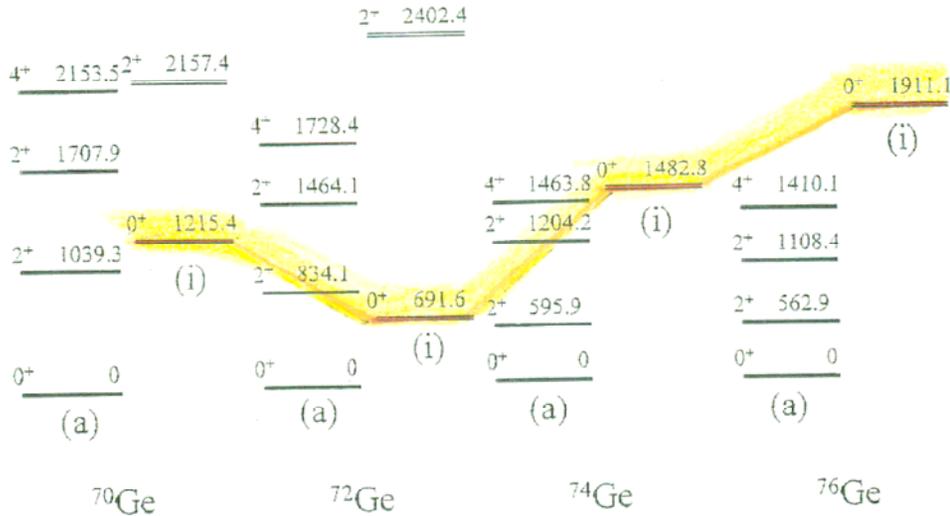
N=60

集団運動の微視的理論の進展

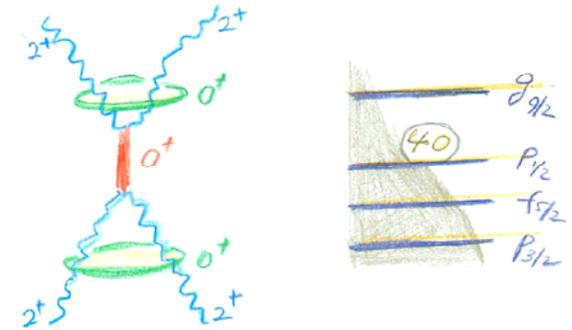
- 1960 準粒子RPA (qRPA) (丸森, Baranger, Arvieu-Veneroni)
- 1962-1964 ボソン展開 (Belyaev-Zelevinsky, 丸森-山村-徳永)
- 1966 生成座標法の具体化 (大西-吉田)
- 1972 Skyrme-Hartree-Fock (Vautherin-Brink)
- 1970-1980年代 TDHF法の発展と広汎な適用 (Bonche-Koonin-Negele, et al.)
ボソン展開法の発展と広汎な適用 (岸本-田村-坂本)
- 1975 連続状態RPA (Shlomo-Bertsch)
- 1977-1983 回転系qRPA
- 1976-1978 大振幅集団運動理論への試み
(Rowe-Basserman, Villars, 丸森, Baranger-Veneroni)
- 1980 SCC法 (丸森-益川-坂田-栗山)
- 1984 座標表示HFB (Dobaczewski-Flocard-Treiner)
- 1985-1987 準粒子SCC法と非調和振動への適用
- 1991 Generalized Valley Theory (Klein-Walet-Dang)
- 2000 断熱的SCC法
- 2001 連続状態qRPA (松尾)
- 2005 吸収境界条件TDHF (矢花-中務)

Mysterious 0^+ states

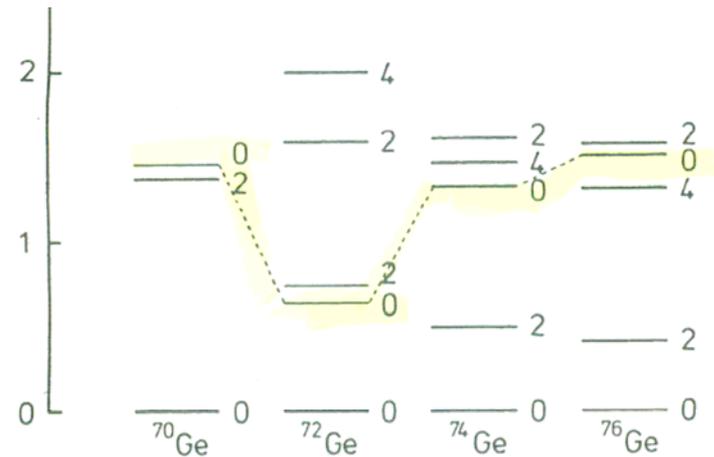
古くて新しい問題



四重極振動と対振動は強く結合する

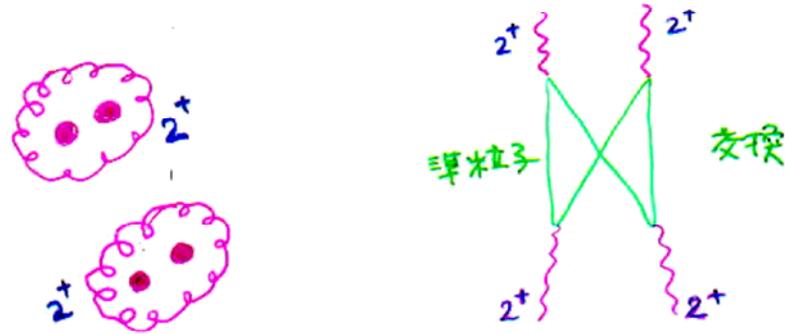


M. Sugawara et al., Eur. Phys. J. A 16 (2003) 409



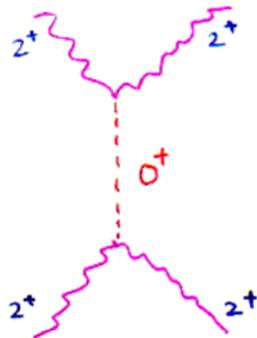
K. Takada and S. Tazaki, Nucl. Phys. A 448 (1986) 56

フォノンは複合粒子..... ボソンの様でボソンでない



非調和効果のなかに隠された規則性を求めて

励起 0^+ 状態の特異性



四重極フォノンと対振動フォノンの動的結合

ペアー演算子の準スピン表現

$$A^\dagger = \frac{1}{\sqrt{\Omega}} \sum_{i>0} c_i^\dagger c_i^\dagger$$

$$\hat{N} = \sum_{i>0} (c_i^\dagger c_i + c_{\bar{i}}^\dagger c_{\bar{i}}) \quad \Omega = j + 1/2 \text{ for a single-}j \text{ shell}$$

$$S_+ = \sqrt{\Omega} A^\dagger \quad [S_+, S_-] = 2S_0$$

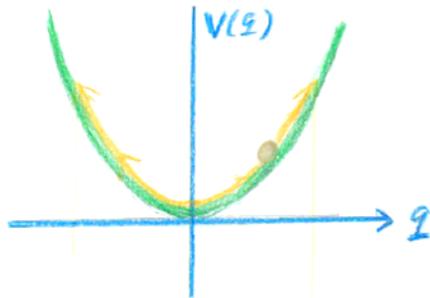
$$S_- = \sqrt{\Omega} A$$

$$S_0 = \frac{1}{2}(\hat{N} - \Omega) \quad [S_0, S_\pm] = \pm S_\pm$$

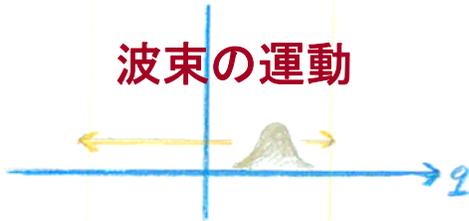
準スピンのボソン表現

$$\begin{aligned}A^\dagger &= \mathbf{P} b^\dagger \sqrt{1 - b^\dagger b / \Omega} \\ &= b^\dagger - (1 - \sqrt{1 - 1/\Omega}) b^\dagger b^\dagger b + \dots \\ A &= \mathbf{P} \sqrt{1 - b^\dagger b / \Omega} b \\ &= b - (1 - \sqrt{1 - 1/\Omega}) b^\dagger b b + \dots \\ \hat{N} &= 2b^\dagger b\end{aligned}$$

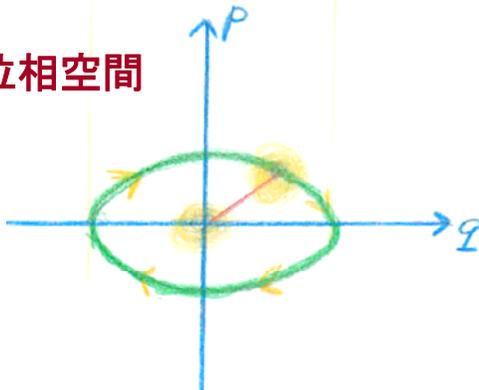
調和振動子



波束の運動



位相空間



振動運動の描像を得るためには
コヒーレント状態を導入する必要がある

$$|z\rangle = e^{za^\dagger - z^*a} |0\rangle = e^{i(p\hat{Q} - q\hat{P})} |0\rangle$$

$$\hat{Q} = \sqrt{\frac{\hbar}{2m\omega}}(a^\dagger + a), \quad \hat{P} = i\sqrt{\frac{m\hbar\omega}{2}}(a^\dagger - a)$$

$$z(t) = z(0)e^{-i\omega t}$$

$$q = \langle z | \hat{Q} | z \rangle = \sqrt{\frac{\hbar}{2m\omega}}(z^* + z),$$

$$p = \langle z | \hat{P} | z \rangle = i\sqrt{\frac{m\hbar\omega}{2}}(z^* - z)$$

主軸系への変換

$$q_{2\mu} = \frac{z}{\sqrt{2}} (\eta_{2\mu}^* + \eta_{2\mu}), \quad p_{2\mu} = \frac{i}{\sqrt{2}z} (\eta_{2\mu}^* - \eta_{2\mu}),$$

$$q'_{2\mu} = \sum_{\nu} D_{\nu\mu}^2(\vartheta_i) q_{2\nu},$$

$$\mathcal{H}(q_{2\mu}, p_{2\mu}) = T(q_{2\mu}, p_{2\mu}) + V(q_{2\mu}),$$

$$p'_{2\mu} = \sum_{\nu} D_{\mu\nu}^{2*}(\vartheta_i) p_{2\nu},$$

$$Q'_{2\mu} = \sum_{\nu} D_{\nu\mu}^2(\vartheta_i) Q_{2\nu}$$

$$Q'_{22} = Q'_{2-2}, \quad Q'_{21} = Q'_{2-1} = 0,$$

K. Yamada,
Prog. Theor. Phys.
89(1993)995

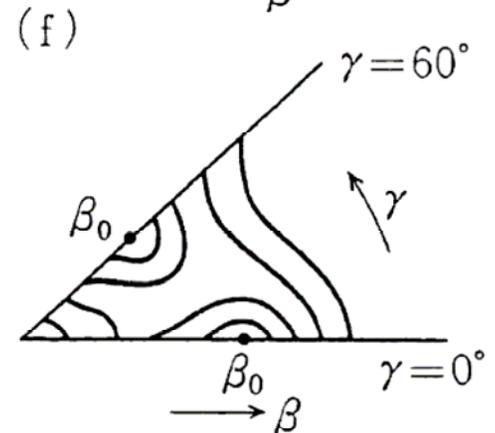
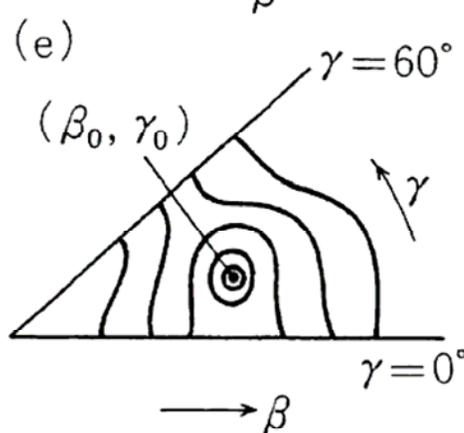
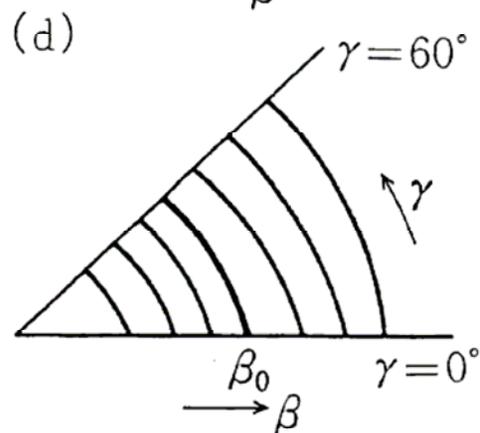
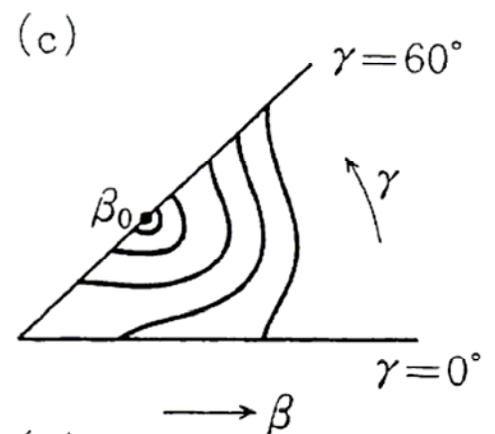
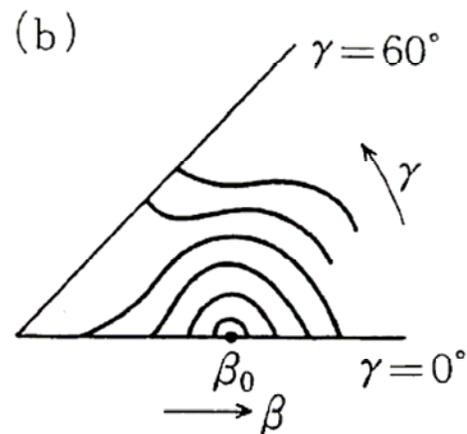
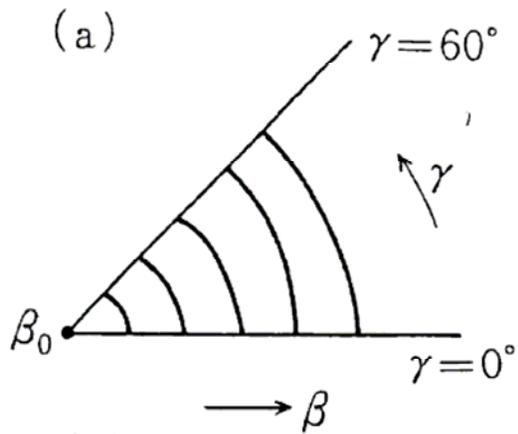
$$\mathcal{H}'(\alpha_{\rho}, \pi_{\rho}, J'_k) = T'(\alpha_{\rho}, \pi_{\rho}, J'_k) + V'(\alpha_{\rho}),$$

$$T'(\alpha_{\rho}, \pi_{\rho}, J'_k) = \frac{1}{2} \mathcal{B}_{00}(\alpha_{\rho}) \pi_0^2 + \frac{1}{2} \mathcal{B}_{22}(\alpha_{\rho}) \pi_2^2 + \mathcal{B}_{02}(\alpha_{\rho}) \pi_0 \pi_2 + \frac{1}{2} \sum_k \frac{J_k'^2}{g_k(\alpha_{\rho})} \\ + B_4 \left(\pi_0^2 + \pi_2^2 + \sum_k \frac{J_k'^2}{g_k^{(0)}(\alpha_{\rho})} \right)^2,$$

$$V'(\alpha_{\rho}) = C_2(\alpha_0^2 + \alpha_2^2) + C_3(\alpha_0^3 - 3\alpha_0\alpha_2^2) + C_4(\alpha_0^4 + 2\alpha_0^2\alpha_2^2 + \alpha_2^4) \\ = C_2\beta^2 + C_3\beta^3 \cos 3\gamma + C_4\beta^4.$$

$$H_{\text{coll}} = \frac{1}{2} B_{\beta\beta}(\beta, \gamma) \dot{\beta}^2 + B_{\beta\gamma}(\beta, \gamma) \dot{\beta} \dot{\gamma} + \frac{1}{2} B_{\gamma\gamma}(\beta, \gamma) \dot{\gamma}^2$$

$$+ \frac{1}{2} \sum_{\kappa=1,2,3} \mathcal{I}_{\kappa}(\beta, \gamma) \omega_{\kappa}^2 + V(\beta, \gamma)$$



ボソン展開法の適用例

H. Sakamoto and T. Kishimoto,
Nucl. Phys. A528 (1988) 73

$$B_I/B_2 \equiv B(E2; I^+ \rightarrow (I-2)^+) / B(E2; 2_1^+ \rightarrow 0_g^+)$$

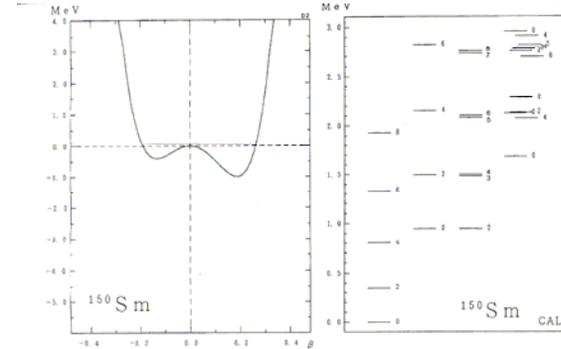
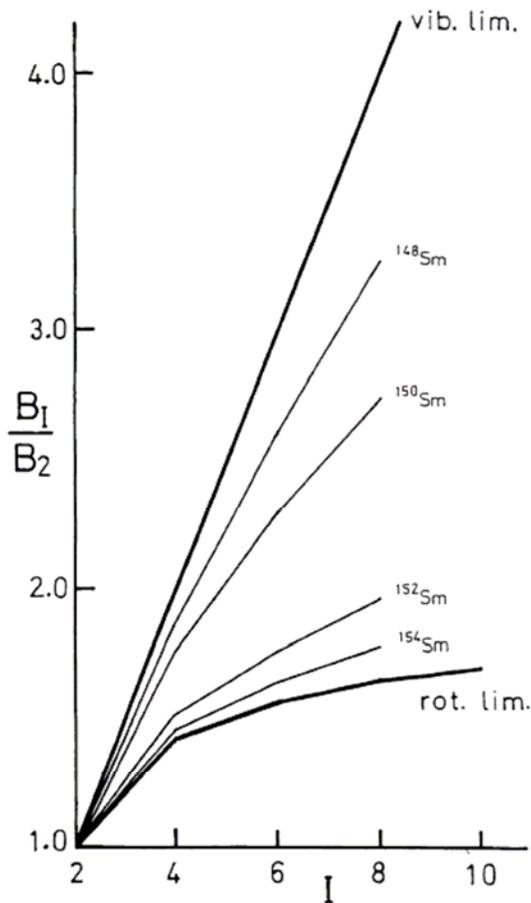


Fig. 5. Calculated potential energy surface and level scheme for ^{150}Sm . The collective coordinate is chosen as the case of TD-3, the non-collective couplings are fully included and the interaction strengths are fixed as $f_1 = f_2 = f_3 = 0.85$ and $g_1 = 0.85$. The spurious number excitation modes are removed. The horizontal line in the figure of the potential surface corresponds to the ground-state energy. In the figure of the level scheme, all the resulting states with $E_x < 3$ MeV and $I \leq 8$ are listed. Especially, the spins in the ground-band, the quasi β -band or the quasi γ -band are separately accumulated.

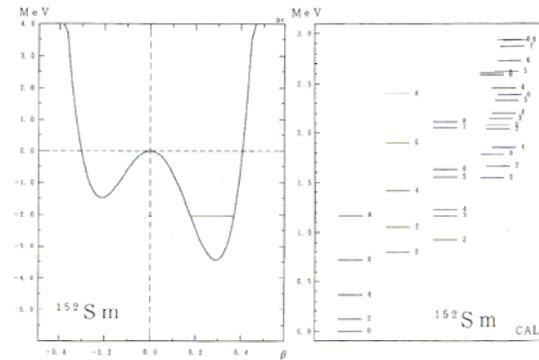


Fig. 34. Same as fig. 33, except that the interaction strengths are fixed as $f_1 = f_2 = f_3 = 0.90$, $g_1 = 0.83$.

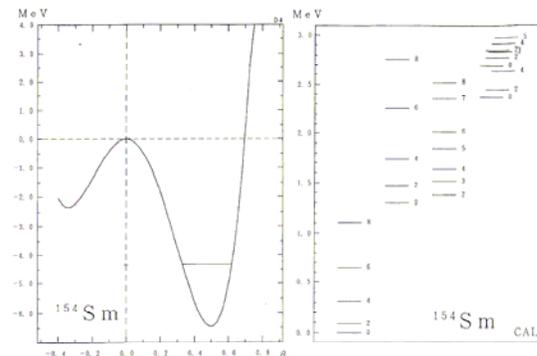
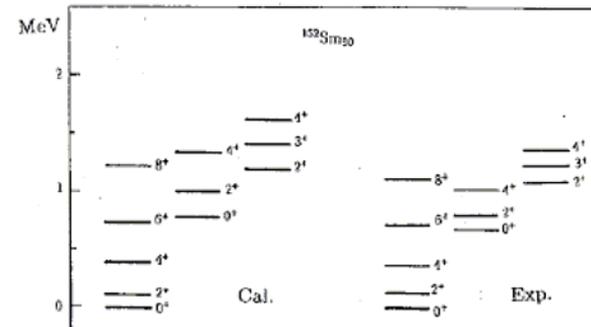
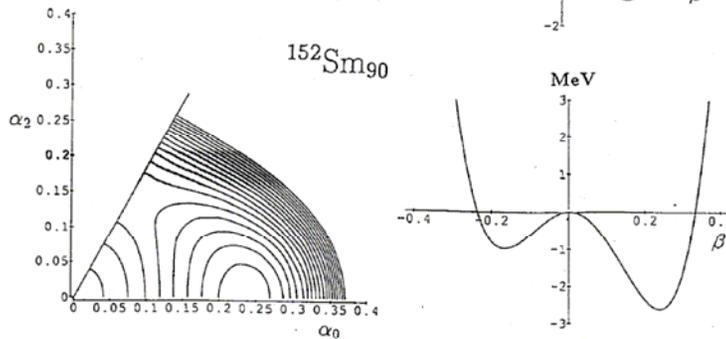
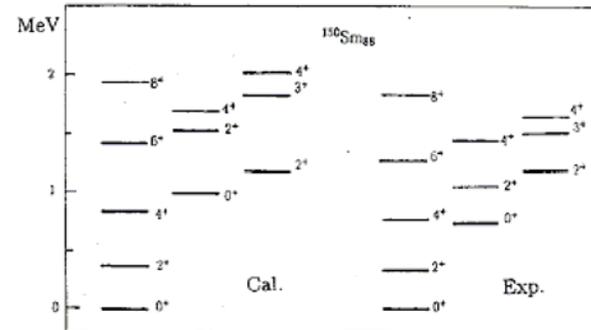
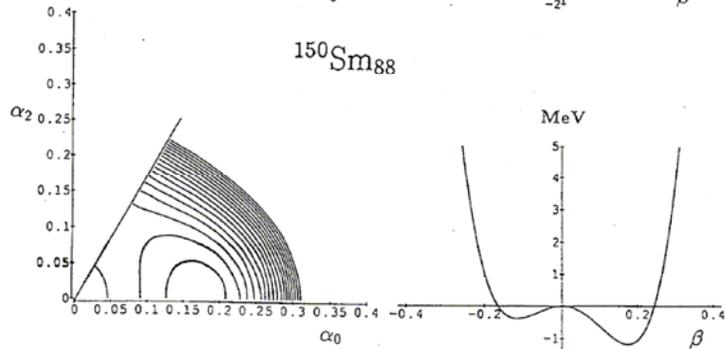
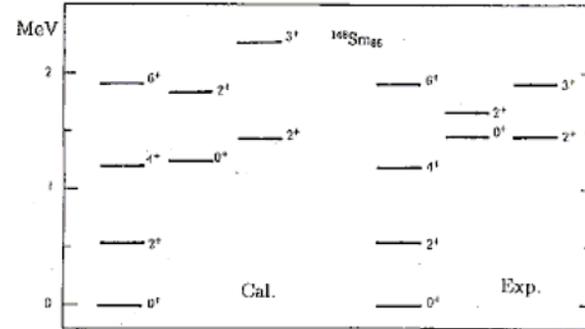
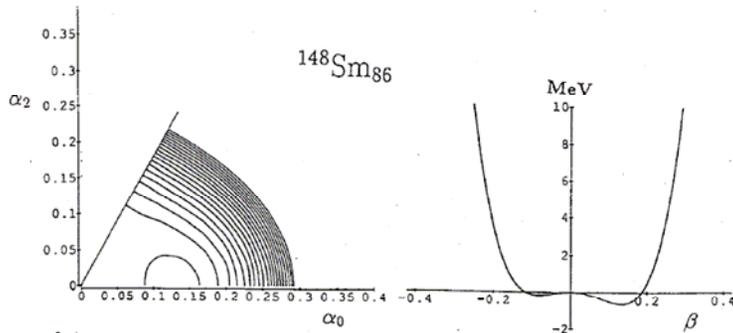
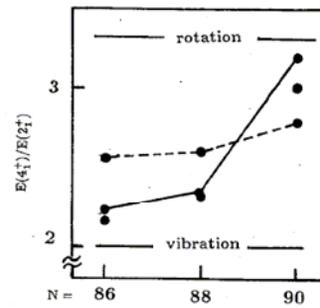


Fig. 37. Same as fig. 36, except that the interaction strengths are fixed as $f_1 = f_2 = f_3 = 0.91$, $g_1 = 0.69$.

SCC法の適用例

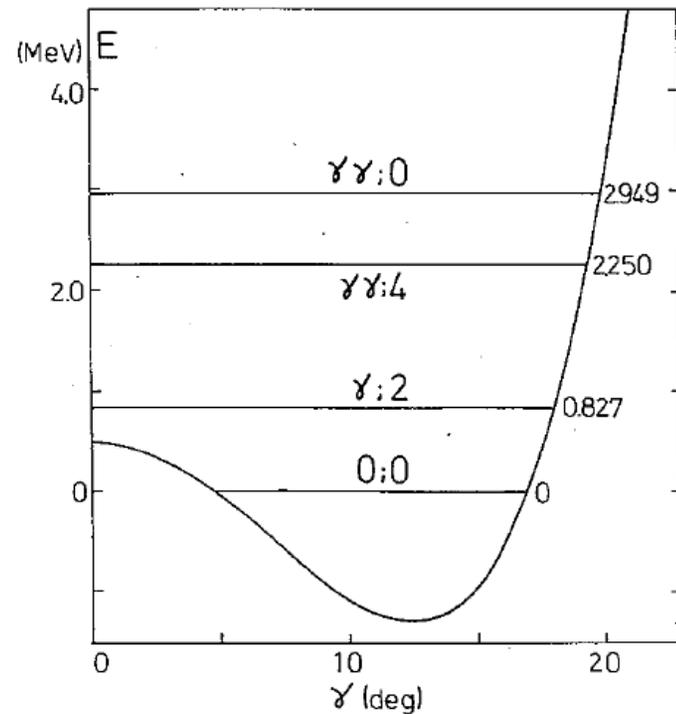
K. Yamada,
Prog. Theor. Phys.
89(1993)995



SCC法を用いて導出した非調和 γ 振動に対するハミルトニアン

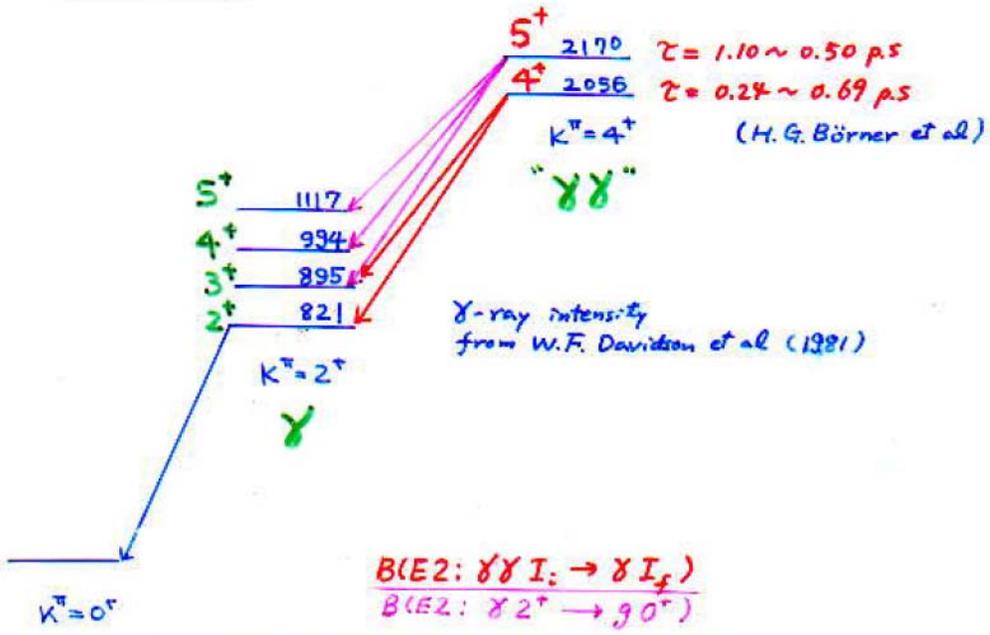
$$H_{\text{coll}} = -\frac{\hbar^2}{2D} \left(\frac{\partial^2}{\partial \gamma^2} + \frac{1}{\gamma} \frac{\partial}{\partial \gamma} + \frac{1}{4\gamma^2} \frac{\partial^2}{\partial \varphi^2} \right) + \epsilon_1 \frac{\hbar^2}{2D} \left(\gamma^2 \frac{\partial^2}{\partial \gamma^2} + 3\gamma \frac{\partial}{\partial \gamma} + 1 \right) + \epsilon_2 \frac{\hbar^2}{2D} \frac{1}{4} \frac{\partial^2}{\partial \varphi^2} \\ + \epsilon_3 \left(\frac{\hbar^2}{2D} \right)^2 \left(\frac{\partial^2}{\partial \gamma^2} + \frac{1}{\gamma} \frac{\partial}{\partial \gamma} + \frac{1}{4\gamma^2} \frac{\partial^2}{\partial \varphi^2} \right)^2 + V_{\text{coll}}(\gamma),$$

$$V_{\text{coll}}(\gamma) = \frac{1}{2} C_2 \gamma^2 + C_4 \gamma^4$$



M.Matsuo and KM,
Prog. Theor. Phys. 74 (1985) 1227

^{168}Er



$$R(4^+) = \frac{B(E2: 4_{\gamma\gamma}^+ \rightarrow 2_{\gamma}^+)}{B(E2: 2_{\gamma}^+ \rightarrow 0_{\gamma}^+)}$$

$$= \frac{25}{18} \frac{|\langle K=4, \gamma\gamma | M(E2) | K=2, \gamma \rangle|^2}{|\langle K=2, \gamma | M(E2) | K=0, g \rangle|^2}$$

intrinsic matrix elements

$$\rightarrow \frac{25}{9} \approx 2.78$$

in the harmonic limit.

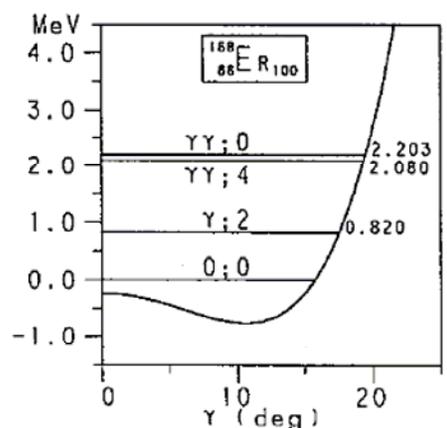
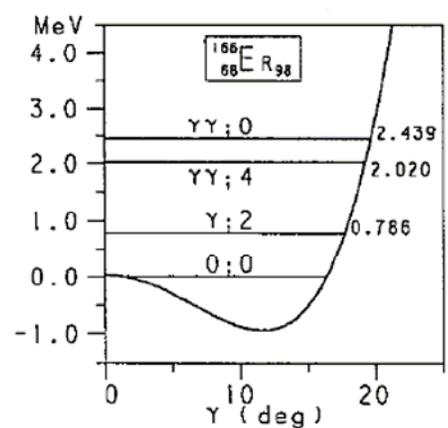
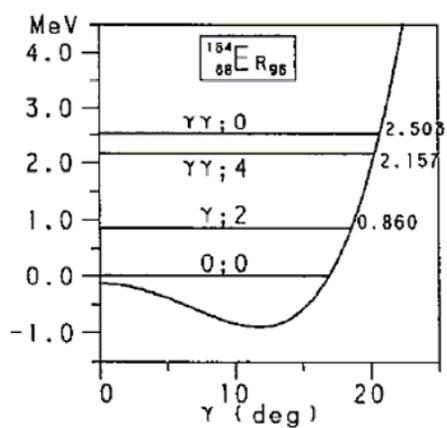
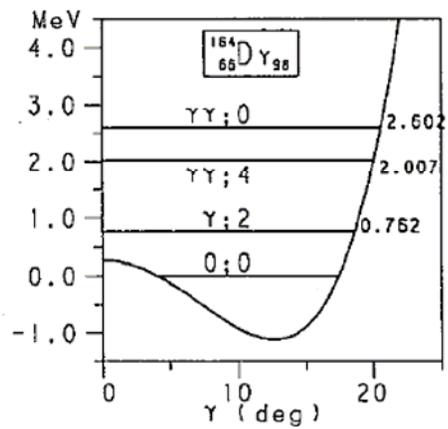
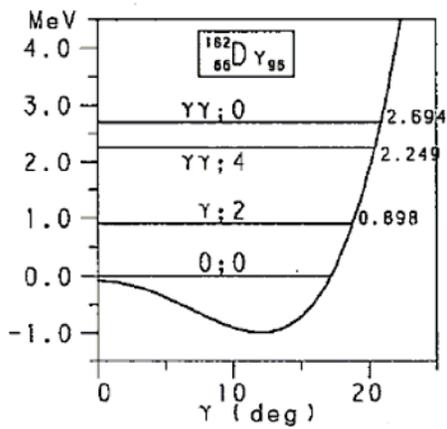
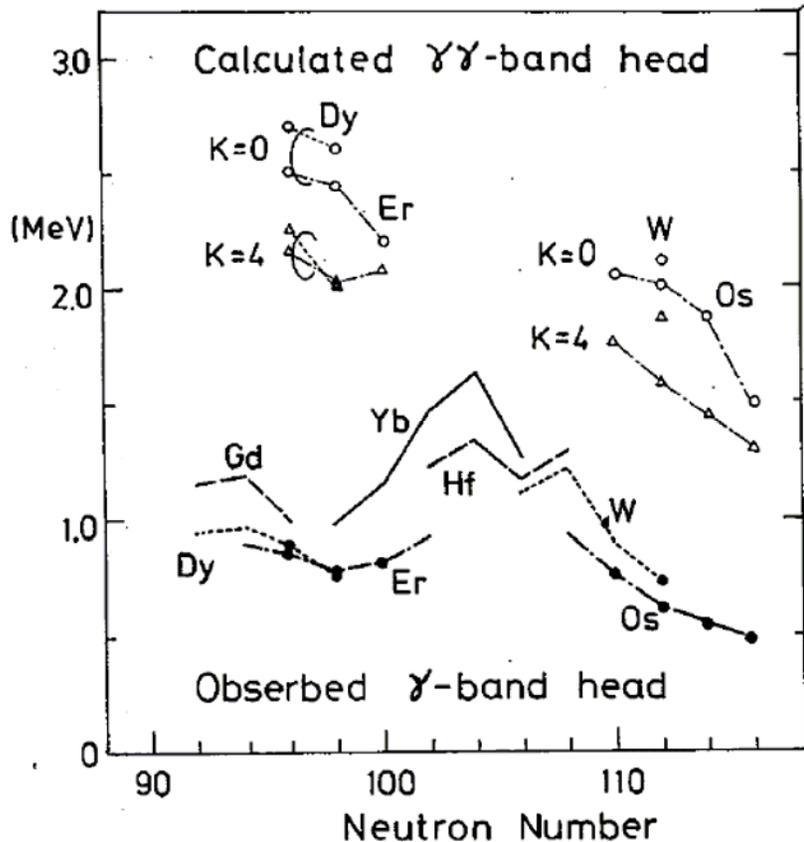
$$\frac{B(E2: 2_{\gamma}^+ \rightarrow 4_{\text{err}}^+)}{B(E2: 0_{\gamma}^+ \rightarrow 2_{\gamma}^+)} = \frac{1}{2} \frac{|\langle K=4, \gamma\gamma | M(E2) | K=2, \gamma \rangle|^2}{|\langle K=2, \gamma | M(E2) | K=0, g \rangle|^2}$$

$$\rightarrow 1 \text{ in the harmonic limit}$$

9

$\gamma\gamma \gamma$ $I_i \rightarrow I_f$	experiment lower limit ~ upper limit	theory SCC method (OWAS)*	harmonic limit
$4^+ \rightarrow 2^+$	0.5 ~ 1.5	1.89	2.78
$\rightarrow 3^+$	0.3 ~ 1.0	0.95	1.11
$5^+ \rightarrow 3^+$	0.6 ~ 3.2	1.30	1.91
$\rightarrow 4^+$	0.5 ~ 2.5	1.30	1.91
$\rightarrow 5^+$	0.4 ~ 2.3	0.63	0.92

ガンマ振動の2フォノン状態に対するSCC法の理論的予測



M.Matsuo and KM,
 Prog. Theor. Phys. 87 (1978) 591

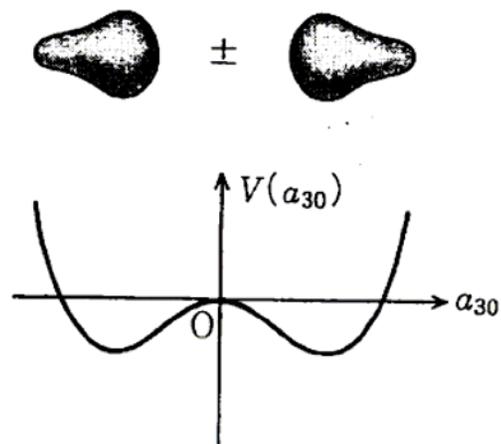
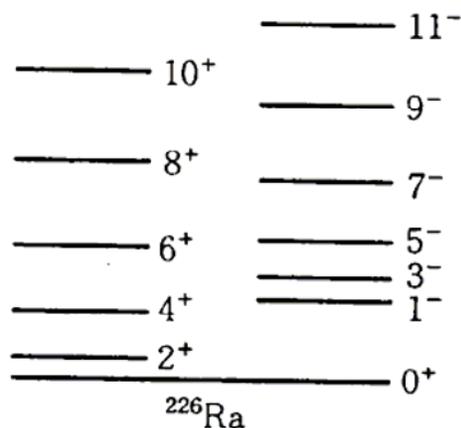
対称性の自発的破れに伴う励起スペクトルの例

♥ 軸対称性の破れ → Wobbling motion

♥ カイラル対称性の破れ → カイラル2重項

巨視的トンネル現象

♥ 空間反転対称性の破れ → パリティ2重項



L.D. Landau and E.M. Lifshitz, Quantum Mechanics

§50

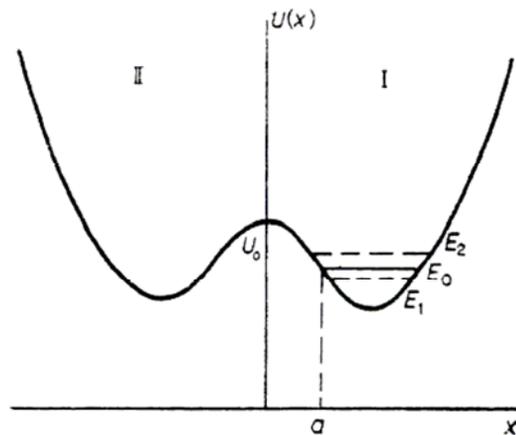
Penetration through a potential barrier

177

the level splits into levels E_1 and E_2 with wave functions which are symmetric and anti-symmetric combinations of $\psi_0(x)$ and $\psi_0(-x)$:

$$\psi_1(x) = (1/\sqrt{2})[\psi_0(x) + \psi_0(-x)], \quad \psi_2(x) = (1/\sqrt{2})[\psi_0(x) - \psi_0(-x)]. \quad (1)$$

The quasi-classical function $\psi_0(x)$ diminishes exponentially outside the well, and in particular



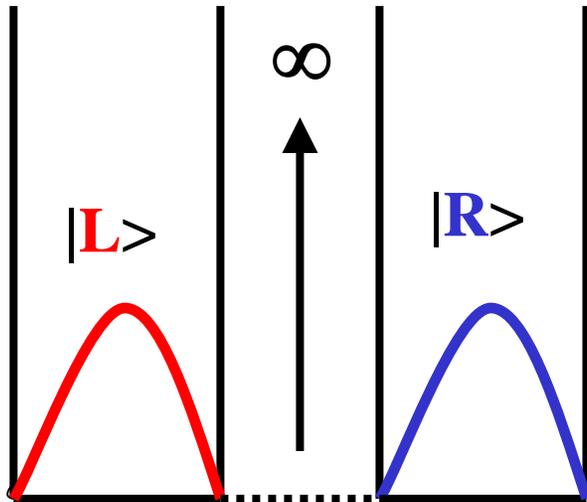
$$\psi_0(0) = \sqrt{\frac{\omega}{2\pi v_0}} \exp\left[-\frac{1}{\hbar} \int_0^a |p| dx\right], \quad \psi_0'(0) = \frac{\mu v_0}{\hbar} \psi_0(0),$$

where $v_0 = \sqrt{2(U_0 - E_0)/\mu}$. Thus

$$E_2 - E_1 = \frac{\omega \hbar}{\pi} \exp\left[-\frac{1}{\hbar} \int_{-a}^a |p| dx\right].$$

Symmetry Breaking and Degeneracy

Symmetrical Double-Well potential with an **infinite** well



$$[\mathbf{H}, \pi] = 0$$

$$\begin{aligned} \pi|\mathbf{L}\rangle &= |\mathbf{R}\rangle \\ \pi|\mathbf{R}\rangle &= |\mathbf{L}\rangle \end{aligned}$$

$$\mathbf{H}|\mathbf{L}\rangle = \varepsilon_{\mathbf{L}}|\mathbf{L}\rangle$$

$$\mathbf{H}|\mathbf{R}\rangle = \varepsilon_{\mathbf{R}}|\mathbf{R}\rangle$$

$$\varepsilon_{\mathbf{L}} = \varepsilon_{\mathbf{R}}$$

$$|\mathbf{S}\rangle = 1/\sqrt{2}(|\mathbf{R}\rangle + |\mathbf{L}\rangle)$$

$$|\mathbf{A}\rangle = 1/\sqrt{2}(|\mathbf{R}\rangle - |\mathbf{L}\rangle)$$

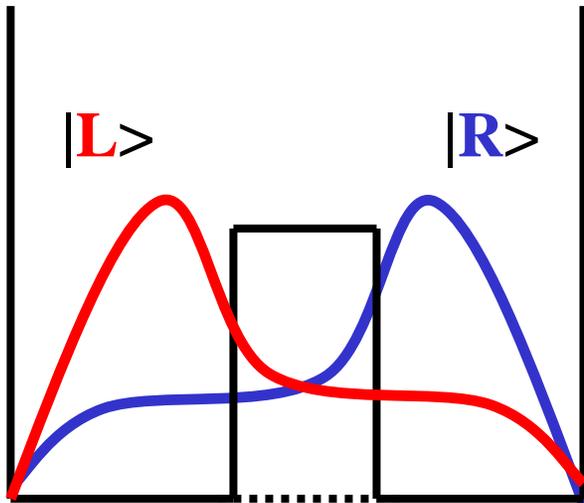
$$\pi|\mathbf{S}\rangle = (1)|\mathbf{S}\rangle$$

$$\pi|\mathbf{A}\rangle = (-1)|\mathbf{A}\rangle$$

From *Modern Quantum Mechanics*
by J.J Sakurai, p.p. 256-259

Weak Symmetry Breaking

Symmetrical Double-Well potential with an **finite** well



$$[\mathbf{H}, \pi]=0$$

$$\pi|\mathbf{L}\rangle = |\mathbf{R}\rangle$$

$$\pi|\mathbf{R}\rangle = |\mathbf{L}\rangle$$

$$\mathbf{H}|\mathbf{L}\rangle \neq \varepsilon_{\mathbf{L}}|\mathbf{L}\rangle$$

$$\mathbf{H}|\mathbf{R}\rangle \neq \varepsilon_{\mathbf{R}}|\mathbf{R}\rangle$$

$$\mathbf{H}|\mathbf{S}\rangle = E_{\mathbf{S}}|\mathbf{S}\rangle$$

$$\mathbf{H}|\mathbf{A}\rangle = E_{\mathbf{A}}|\mathbf{A}\rangle$$

$$\pi|\mathbf{S}\rangle = (\mathbf{1})|\mathbf{S}\rangle$$

$$\pi|\mathbf{A}\rangle = (-\mathbf{1})|\mathbf{A}\rangle$$

$$E_{\mathbf{A}} > E_{\mathbf{S}}$$

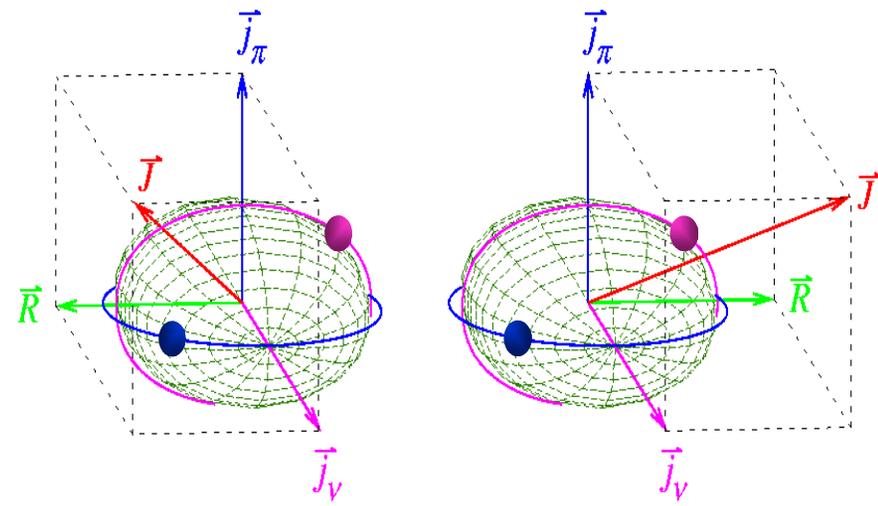
Chirality

$$[O, H] = 0, O = TR_y(\pi)$$

$$H |R\rangle = \varepsilon_R |R\rangle, H |L\rangle = \varepsilon_L |L\rangle,$$

$$|R\rangle = O |L\rangle, |L\rangle = O |R\rangle,$$

$$\varepsilon_R = \varepsilon_L$$



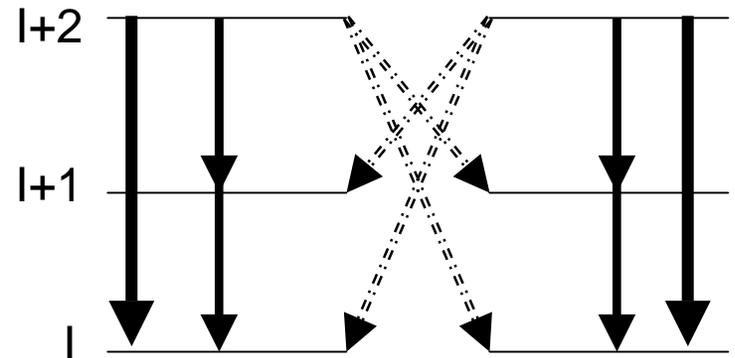
$$|IM +\rangle = \frac{1}{\sqrt{2}} (|R\rangle + |L\rangle),$$

$$|IM -\rangle = \frac{i}{\sqrt{2}} (|R\rangle - |L\rangle),$$

$$H |IM \pm\rangle = \varepsilon_{\pm}^{IM} |IM \pm\rangle,$$

$$O |IM \pm\rangle = |IM \pm\rangle,$$

$$\varepsilon_{+}^{IM} = \varepsilon_{-}^{IM}$$



Different from Parity
T: time reversal operator anti-linear

Which candidates are truly chiral? Experimental confirmation

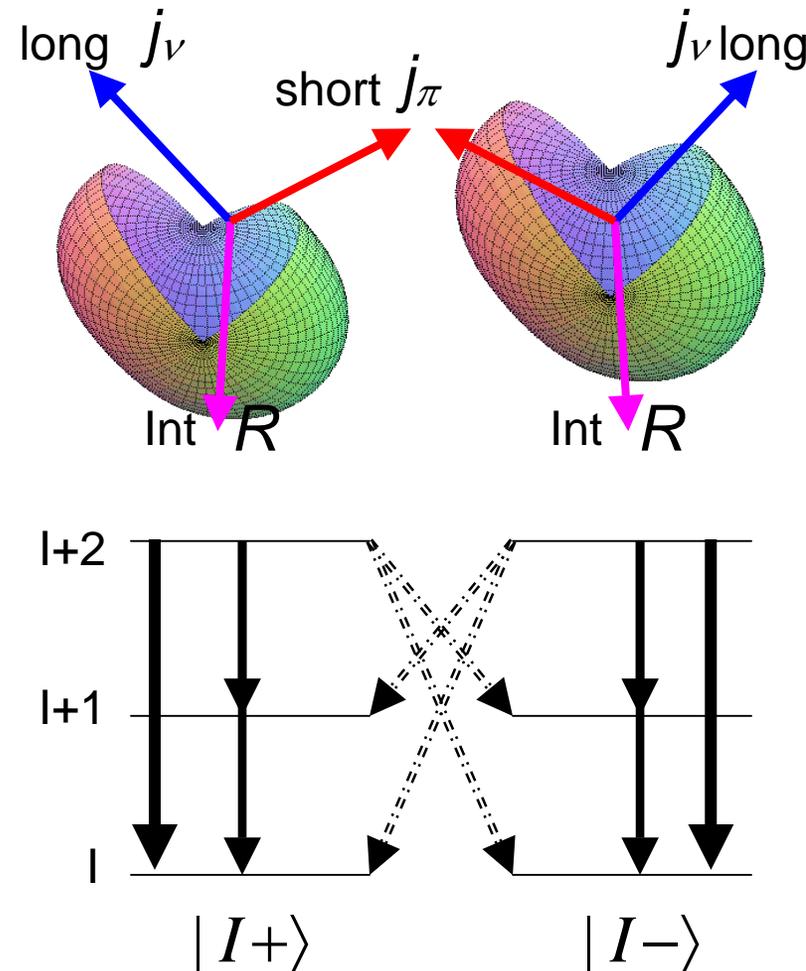
Bottom line:

Ideally identical and practically very similar characters between chiral pairs → **TWINS**

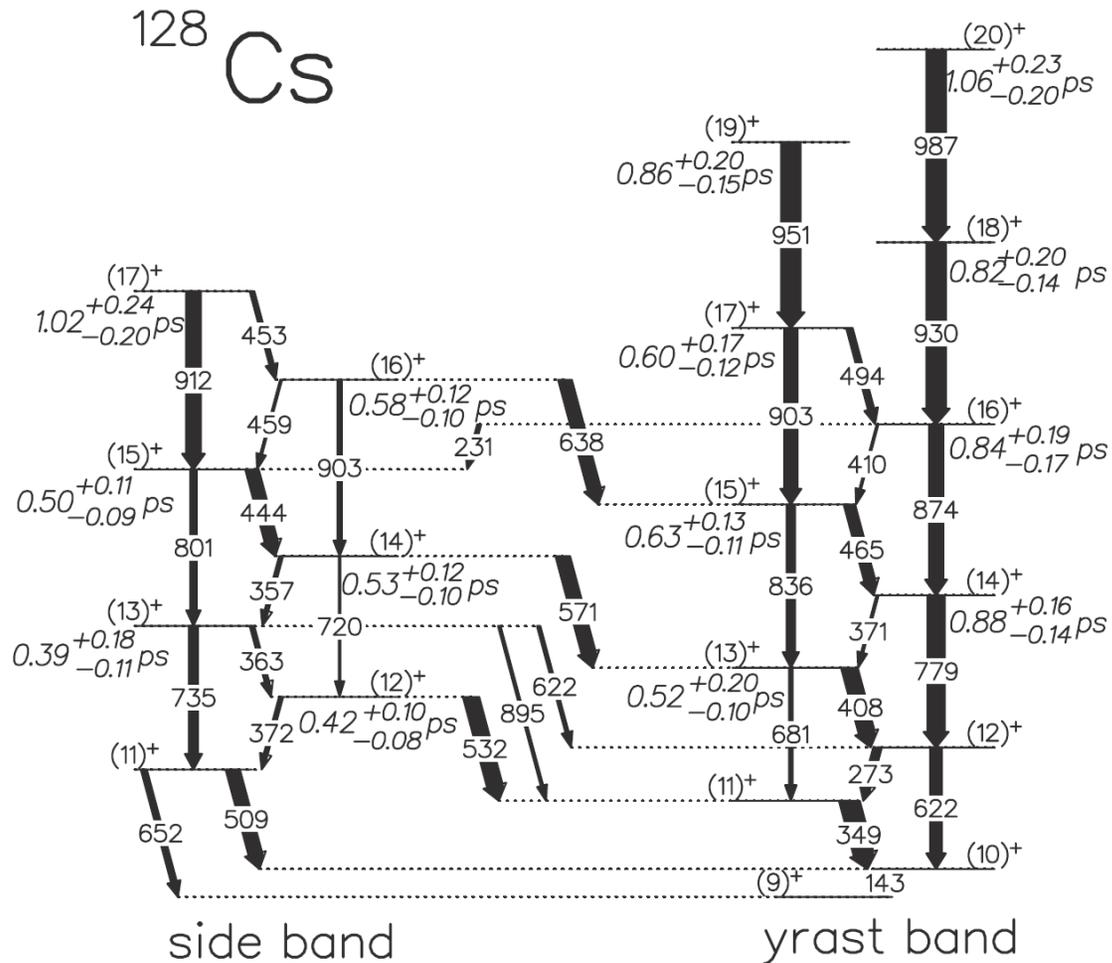
- Degeneracy
- Single particle configuration
 - Unique parity (experimentally pure)
 - q.p alignment
- Collective aspects
 - Moment of inertia
 - Shape/deformation
- Electromagnetic properties (most sensitive to wave functions)

$$B(EM; I_i+ \rightarrow I_f+) \approx B(EM; I_i- \rightarrow I_f-)$$

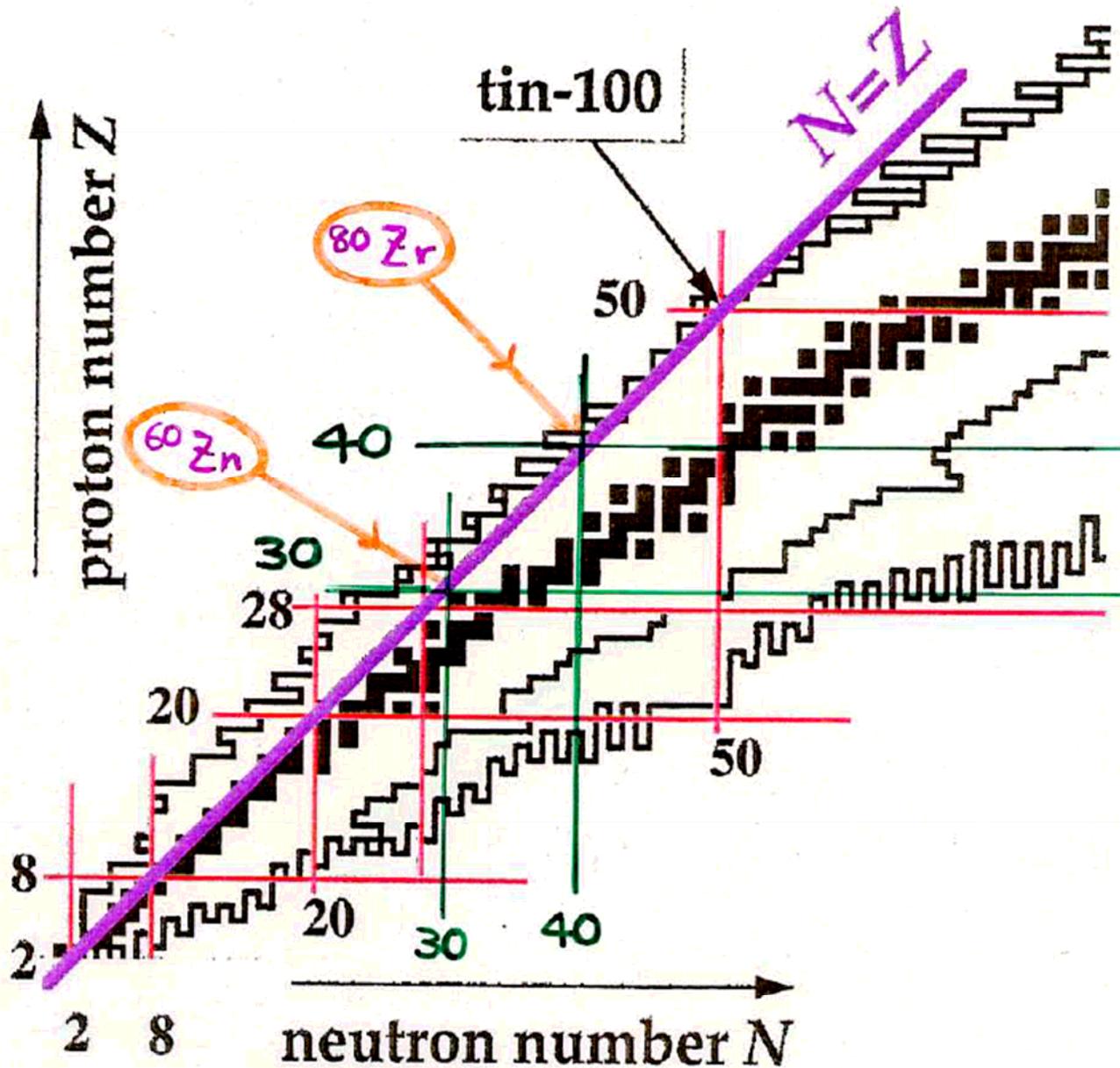
$$B(EM; I_i+ \rightarrow I_f-) \approx B(EM; I_i- \rightarrow I_f+)$$
- Small Coriolis interaction
 - Smooth and identical variation of $S(I)=[E(I)-E(I-1)]/2$



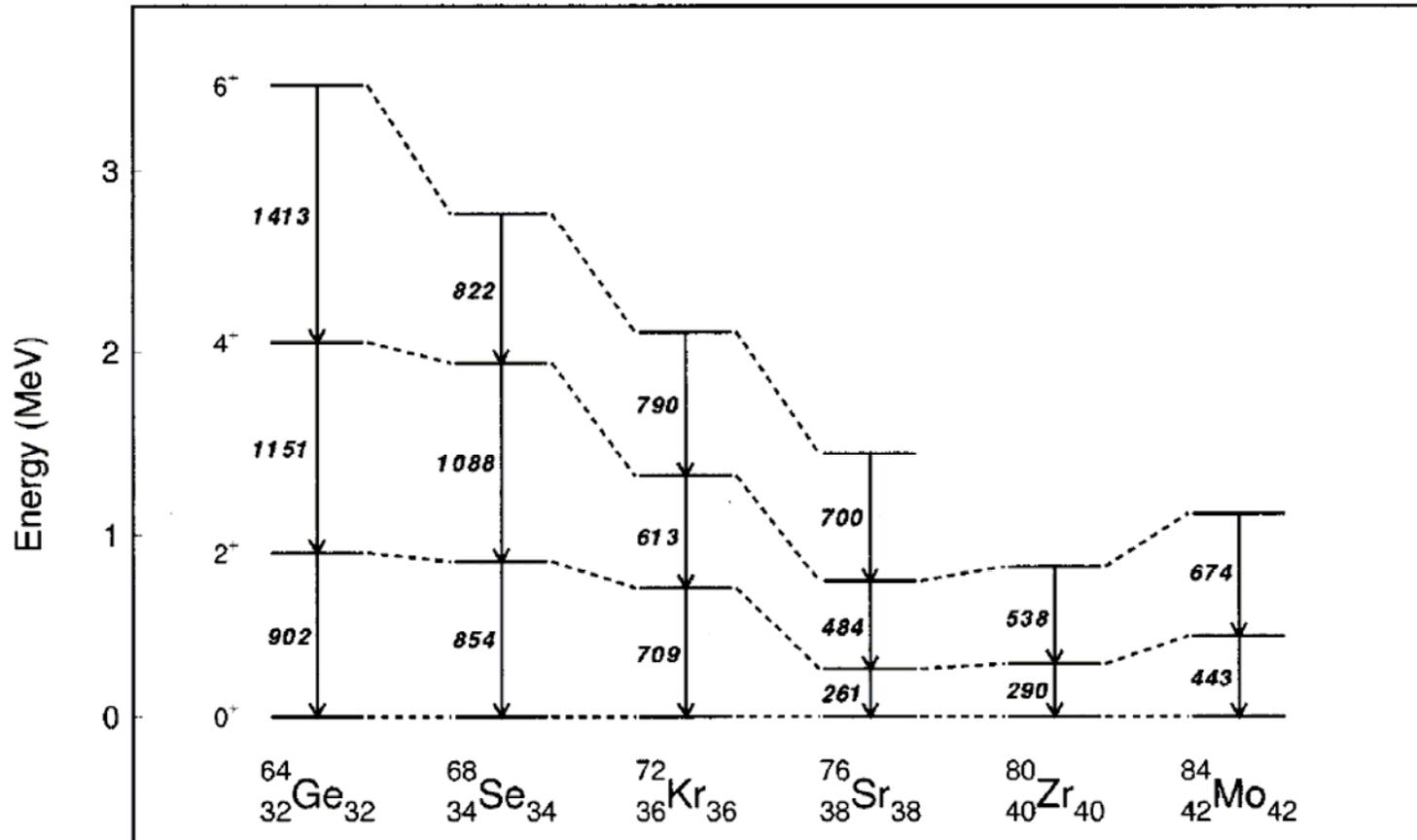
カイラル2重項



N=Zでは陽子と中性子の変形シェル効果がコヒーレントに効くだろう



Zr80 領域の陽子過剰N=Z核の低励起スペクトル



D. Bucurescu et al., Phys. Rev. C 56 (19 97) 2497

^{64}Ge

^{68}Se

^{72}Kr

^{76}Sr

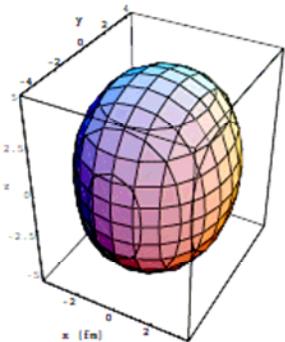
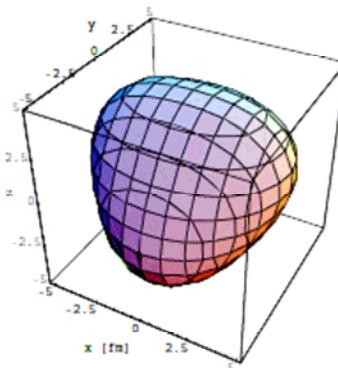
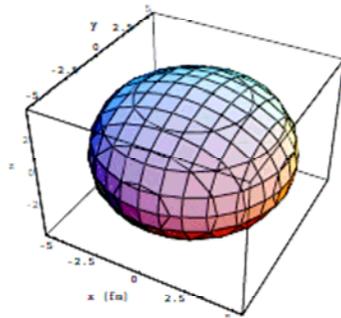
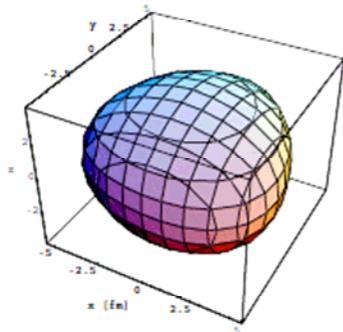
^{80}Zr

triangular (g.s.)

oblate (g.s.)

tetrahedral

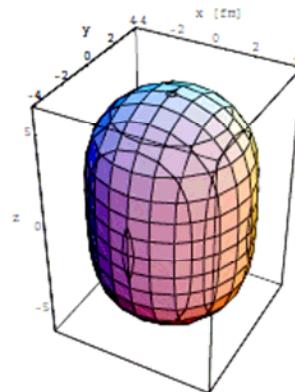
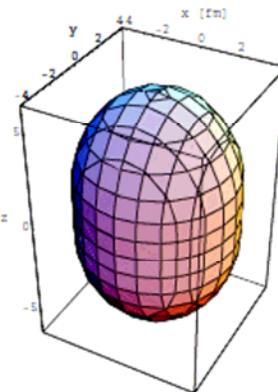
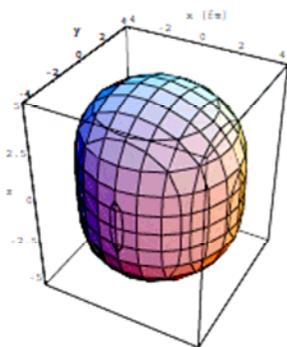
triaxial (g.s.)



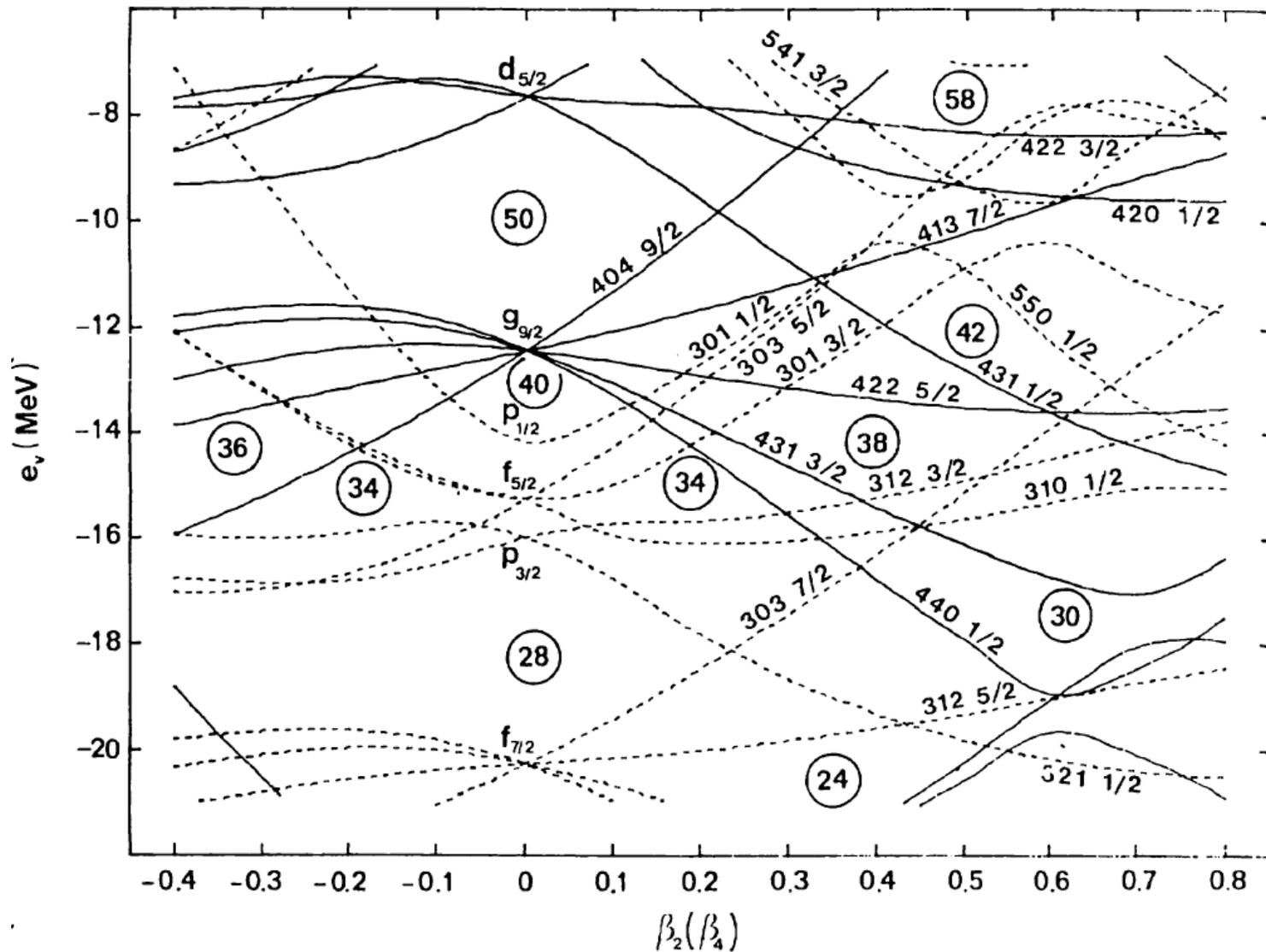
prolate

prolate (g.s.)

prolate (g.s.)

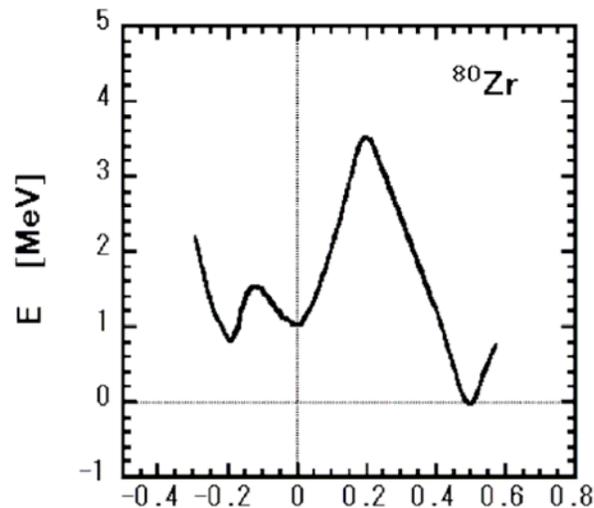
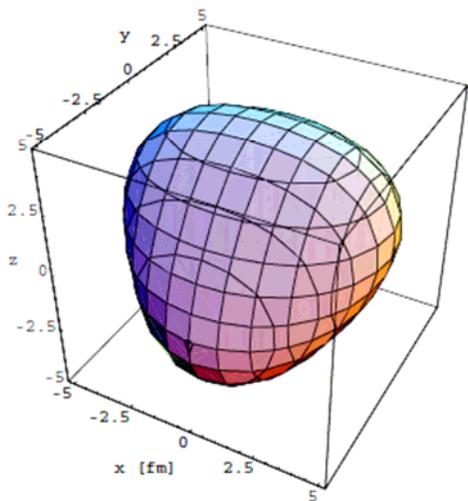


変形魔法数



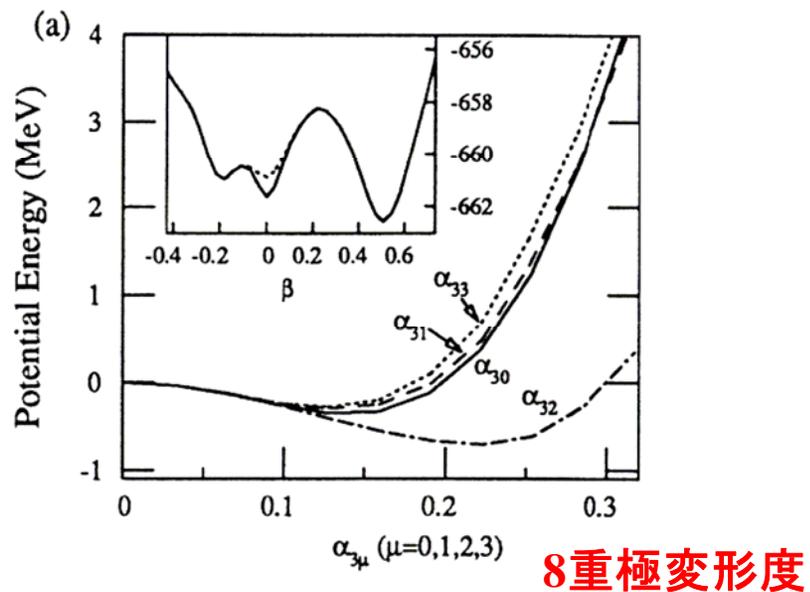
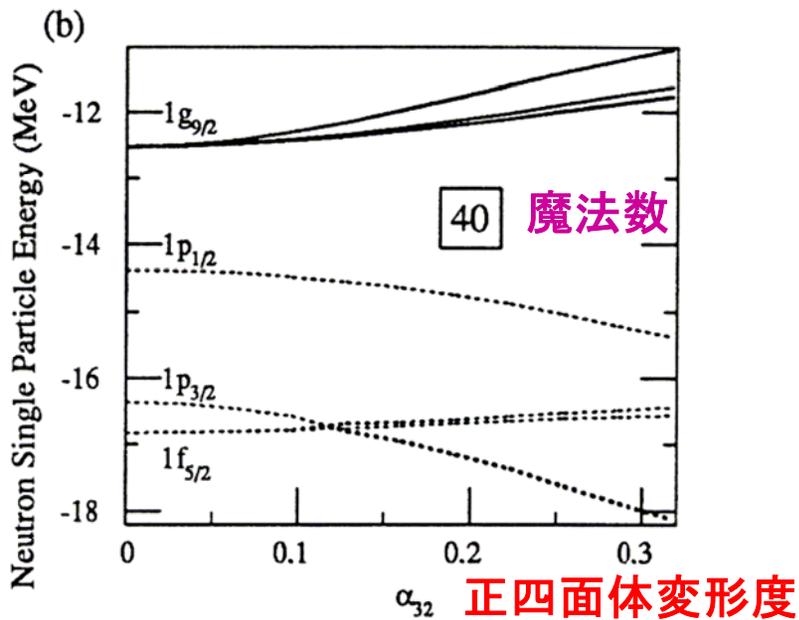
^{80}Zr

正四面体 tetrahedral 变形



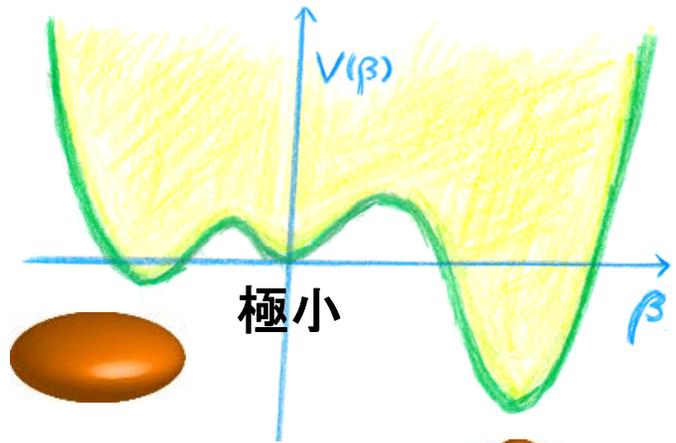
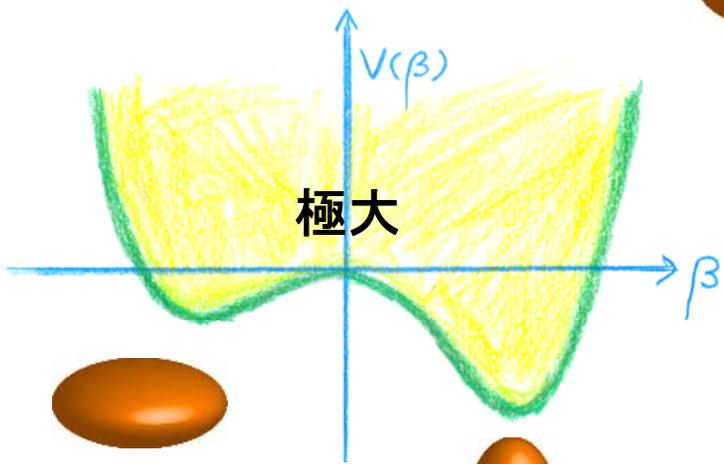
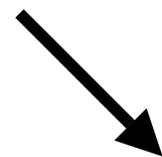
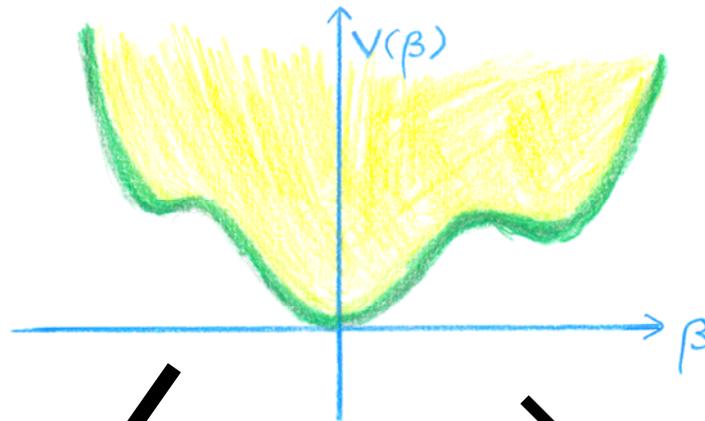
β_2 (Axial Symm.) 4重極变形度

M. Yamagami et al. Nucl. Phys. A 693 (2001) 579



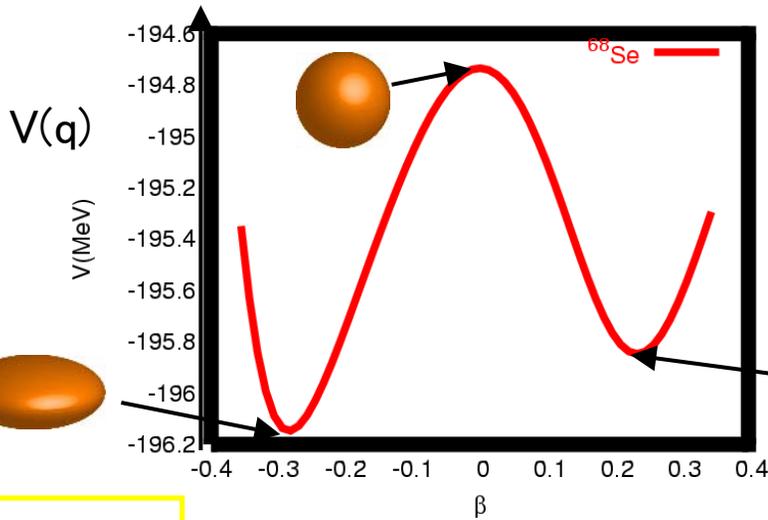
S. Takami et al. Phys. Lett. B 431 (1998) 242

變形共存現象



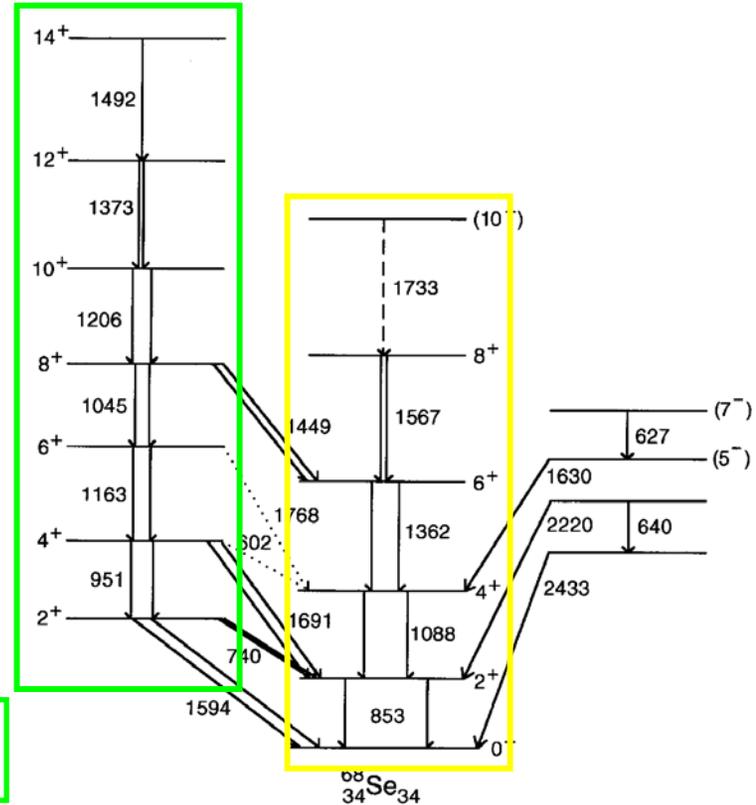
Oblate 変形とProlate変形の共存現象

^{68}Se



oblate

prolate

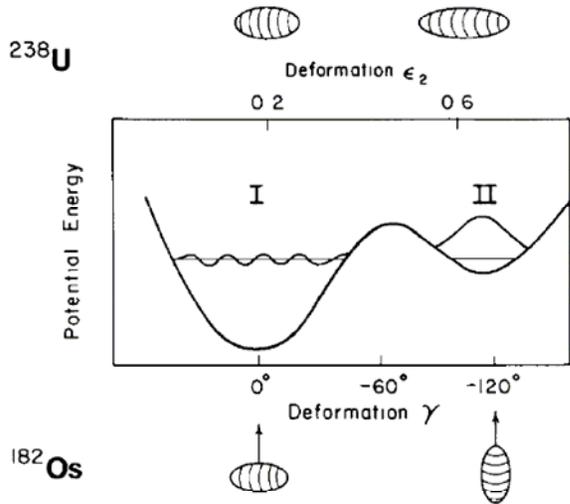


大振幅集団運動の微視的理論

Adiabatic Self-consistent Collective Coordinate (ASCC) Method

High-K バンドからLow-Kバンドへの崩壊

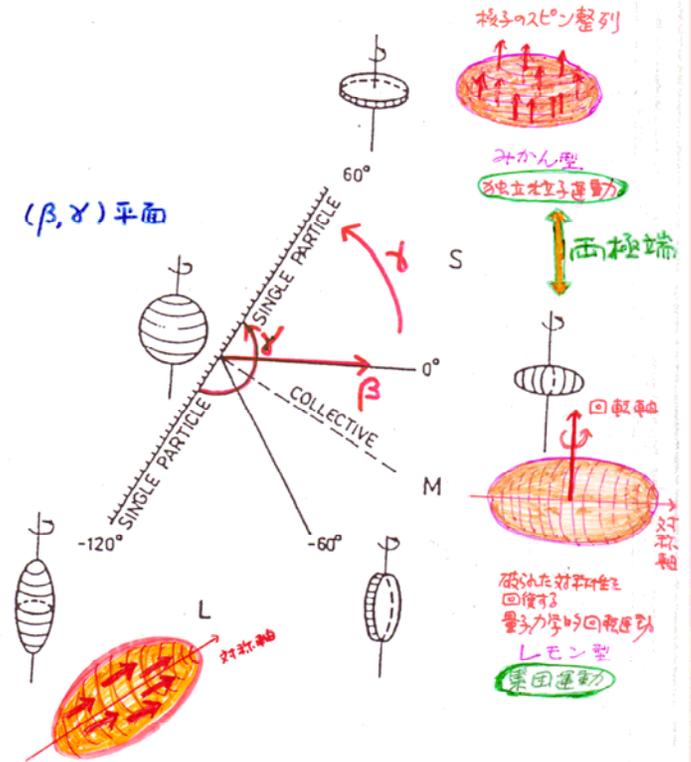
P Chowdhury et al / Decay of high-spin isomers



Schematic representation of the analogy between the γ -decay of prolate shape isomers and the decay of the high-spin isomer in ^{182}Os

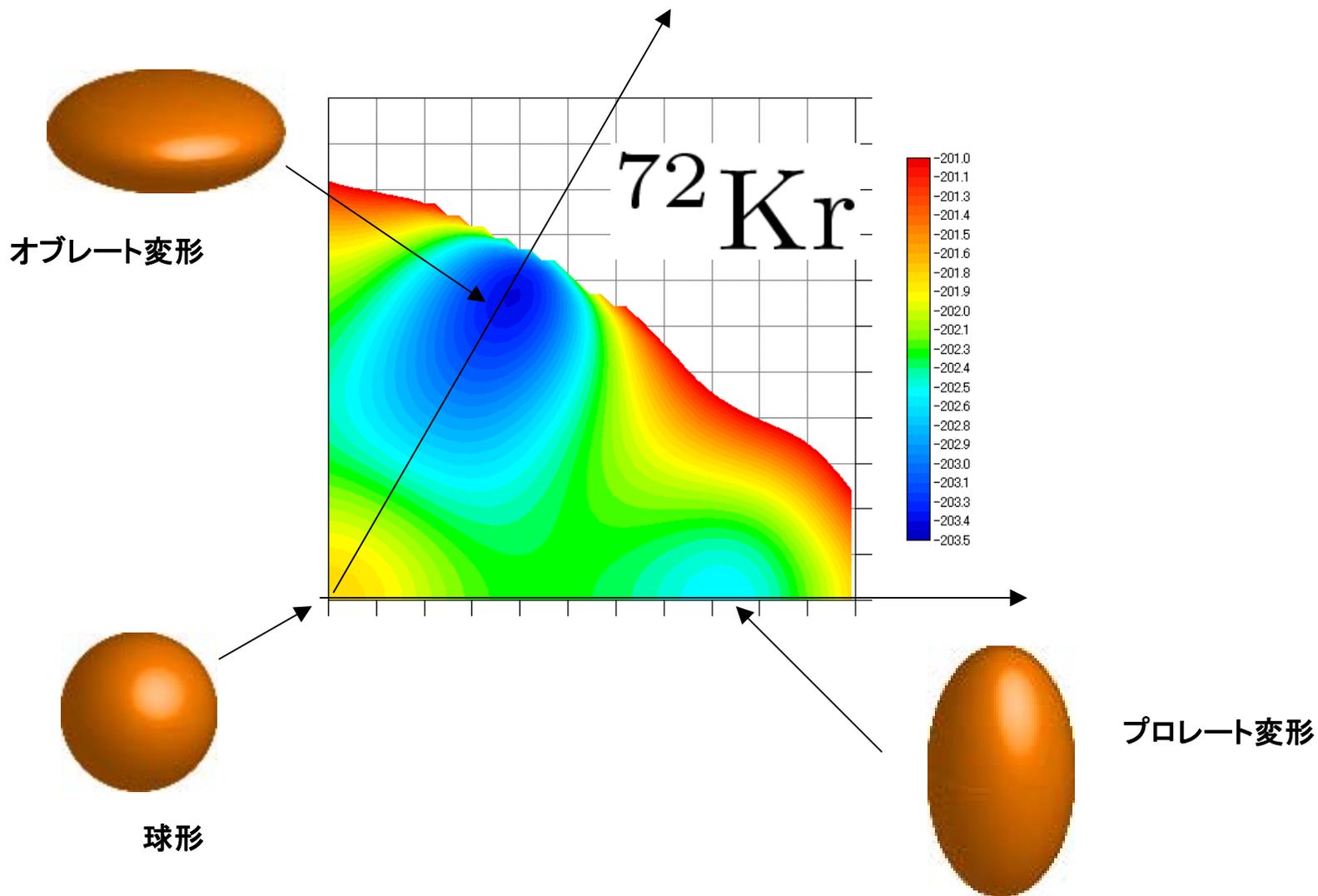
P. Chowdhury et al., Nucl. Phys. A 485 (1988) 136

④ 重極変形パラメータ (β, γ)
による構造の分類
(高速回転する原子核の構造)



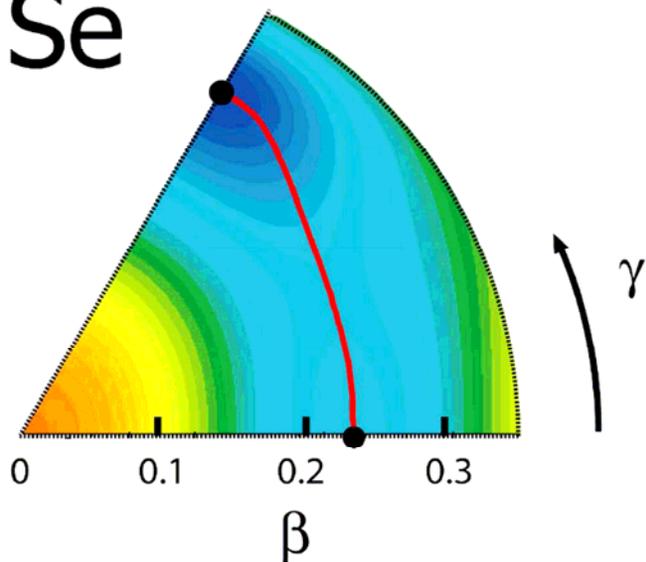
複数の真空(平均場)の間の巨視的トンネル現象

オブレート・プロレート変形共存現象

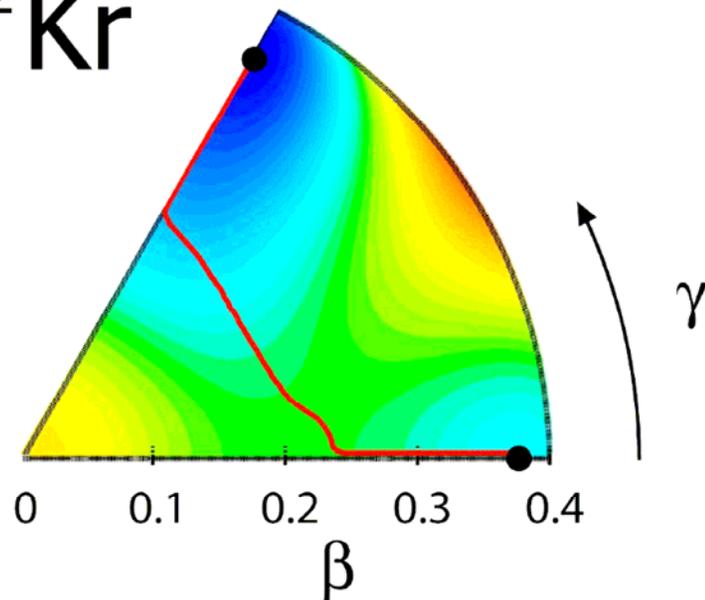


ASCC法で微視的に求めた集団経路

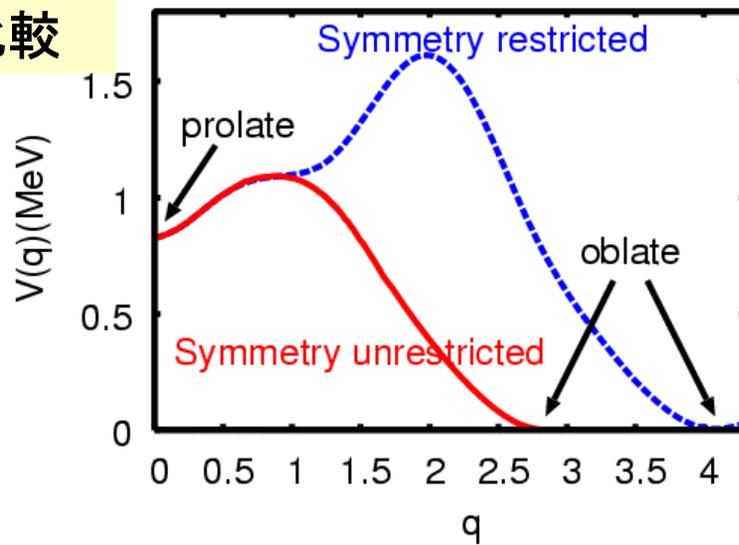
^{68}Se



^{72}Kr



軸対称性を課した場合との比較



時間変化する平均場

時間に依存する変分原理

$$\delta \langle \phi(q, p) | i\hbar \frac{\partial}{\partial t} - H | \phi(q, p) \rangle = 0.$$

Self-Consistent Collective Coordinate (SCC)法

集団座標 q

集団運動量 p

$$\frac{\partial}{\partial t} \Rightarrow \dot{q} \frac{\partial}{\partial q} + \dot{p} \frac{\partial}{\partial p}$$

$$|\phi(q, p)\rangle = e^{ip\hat{Q}(q)} |\phi(q)\rangle$$

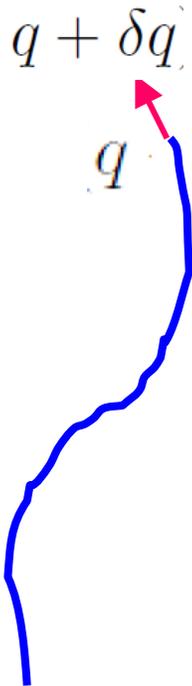
Adiabatic展開

$$\hat{P}(q) |\phi(q)\rangle = i \frac{\partial}{\partial q} |\phi(q)\rangle$$

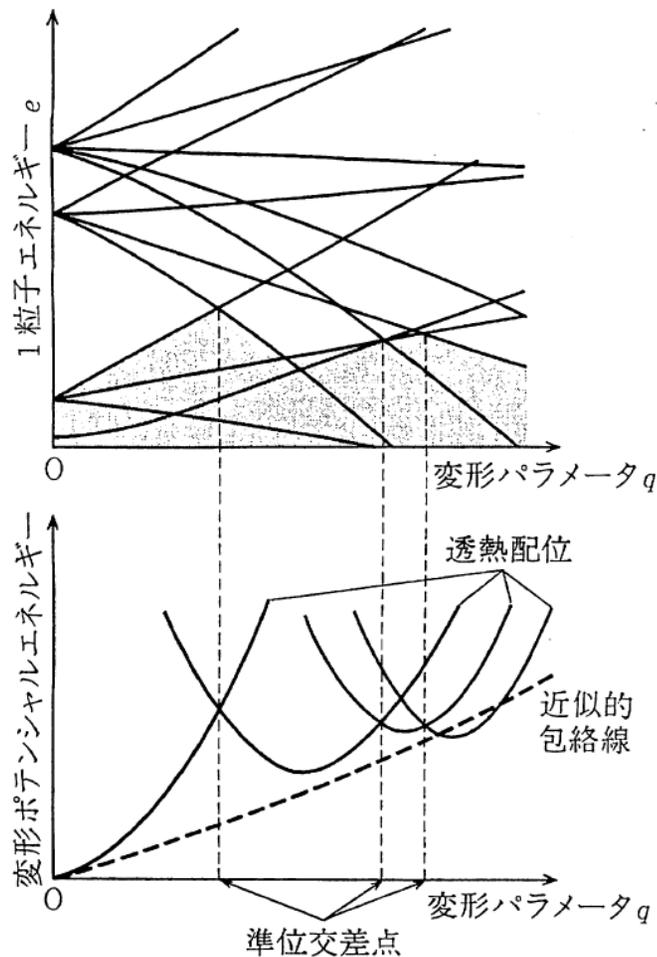
集団座標 q は大きくなる

$$|\phi(q + \delta q)\rangle = (1 - i\delta q \hat{P}(q)) |\phi(q)\rangle$$

各点 q で最適な演算子と方向を見定めながら進む



大振幅集団運動の慣性質量の微視的起源

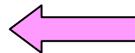


Collective Mass

$$\frac{1}{M(q)} = \langle \phi(q) | [[H, i\hat{Q}(q)], i\hat{Q}(q)] | \phi(q) \rangle$$

運動する平均場の一粒子ポテンシャルは時間反転対称性を破る(time-odd)成分を含む。クランキング質量公式ではこの成分が無視されている

質量は配位替えのし難さ(慣性)を表す



対相関は質量を軽くする

剛性(rigidity)とは

一見矛盾するようだが、
独立粒子運動(平均場)がこの性質をもたらす

弾性(elasticity)とは

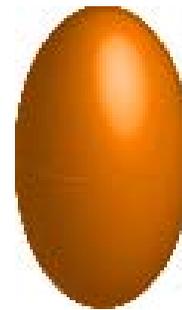
短い時間スケールでの応答 (巨大共鳴)
配位をたもったまま1粒子波動関数に変形する

塑性(plasticity)とは

長い時間スケールでの応答(大振幅集団運動)
配位が不可逆的に変化する

問9 なぜプロレート変形した原子核の方が
オブレート変形した原子核より沢山存在するのですか

オブレート-プロレート非対称性の起源は
まだ良く分かっていません。
シェル構造エネルギーに対するより深い理解が
求められています。



寄せられた質問

「対称性を回復するためのゴールドストーン・モードとしての回転モード」という考え方と

「(同一バンドであっても)回転によって変形が変わってしまう」、
いう第2回の後半の考え方の間に、やや不自然さ、論理のギャップを感じるのですが。 どう考えればよいでしょうか？

ゴールドストーン・モードによって「真空」が変わってしまうとは？

band-crossingの場合はよくわかるのですが、
同一バンド内でも変わるという点が気に掛かります。

合の手

- 有限量子系におけるNambu-Goldstoneモードをどのように定義するか
 - 回転エネルギーは何処から来るか
 - 現実に見える回転スペクトルとどのように関係しているか
- もっと議論したいところです。「ミニマム」の範囲を逸脱してしまいましたが....
相互作用する自己束縛系としての原子核の回転エネルギーの起源は
分子の回転エネルギーの起源と本質的に異なっています。