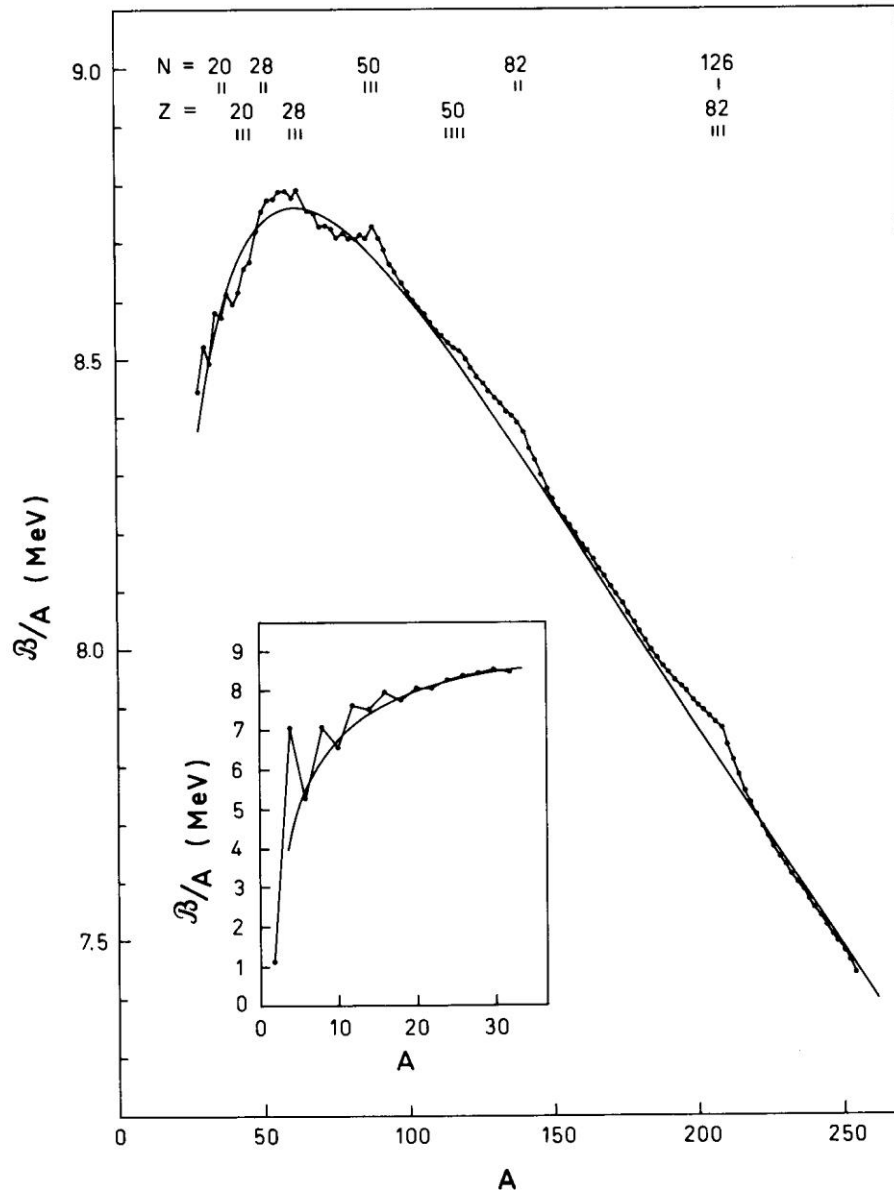


殻構造

$$B(N, Z) = B_{\text{macro}}(N, Z) + B_{\text{micro}}(N, Z)$$



• スムーズな関数

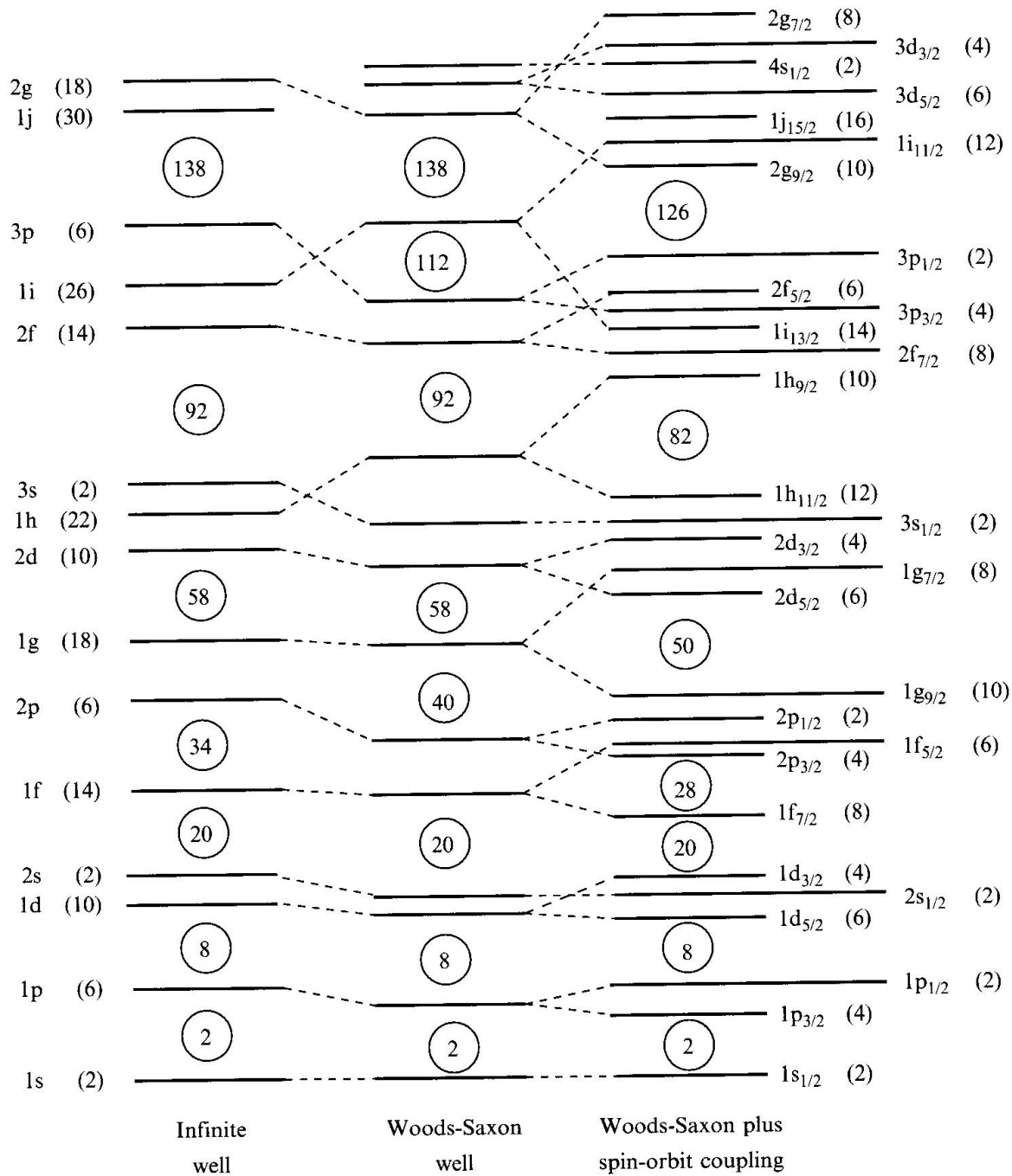
$$B_{\text{macro}}(N, Z) = a_v A - a_s A^{2/3} - a_C \frac{Z^2}{A^{1/3}} - a_{\text{sym}} \frac{(N - Z)^2}{A}$$

• ゆらぎ

$$B_{\text{micro}} = B_{\text{pair}} + B_{\text{shell}}$$

液滴模型:

$$B_{\text{LDM}} = B_{\text{macro}} + B_{\text{pair}}$$

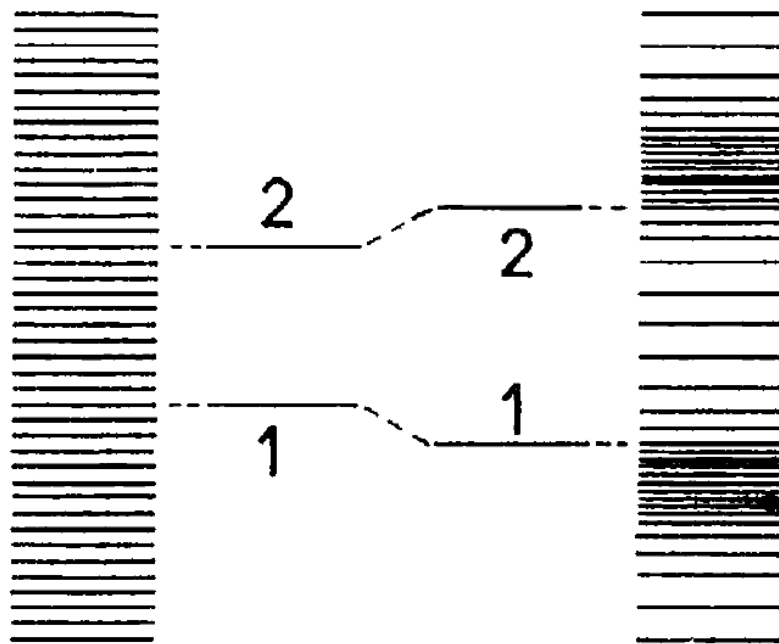


Infinite well

Woods-Saxon well

Woods-Saxon plus spin-orbit coupling

準位密度



(a)

(b)

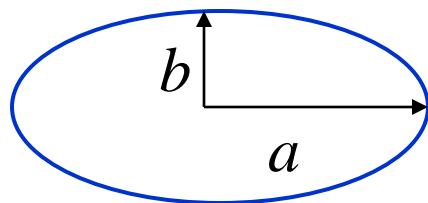
均一の場合

濃淡がある場合

液滴模型による原子核の変形

$$B(N, Z) = a_v A - a_s A^{2/3} - a_C \frac{Z^2}{A^{1/3}} - a_{\text{sym}} \frac{(N - Z)^2}{A}$$

回転楕円体

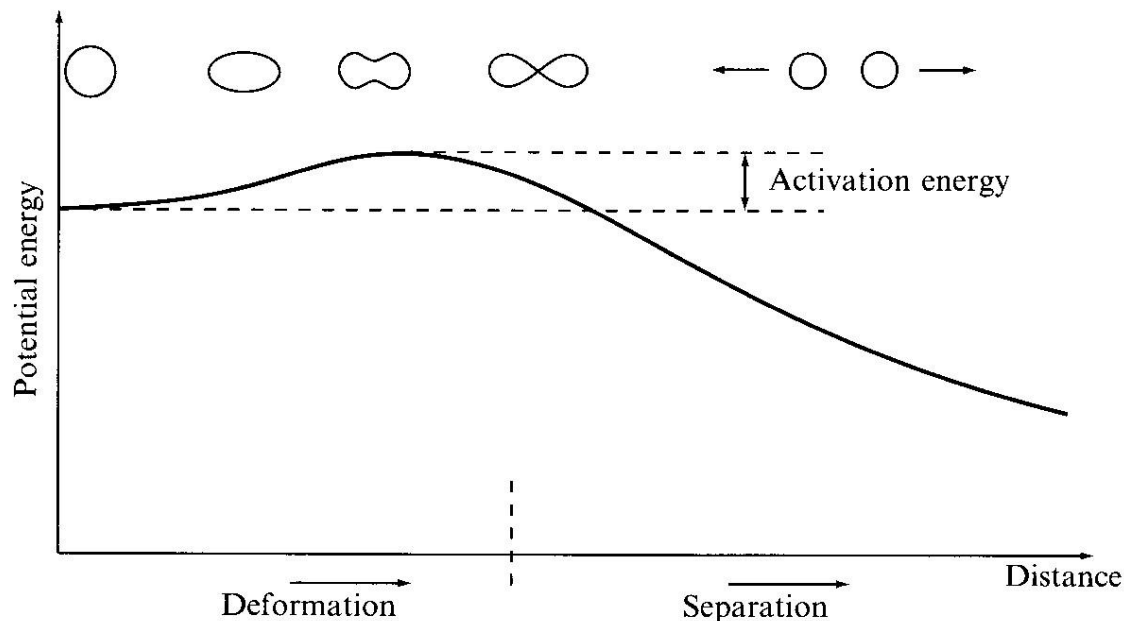


$$a = R \cdot (1 + \epsilon)$$

$$b = R \cdot (1 + \epsilon)^{-1/2}$$

$$E_{\text{surf}} = E_{\text{surf}}^{(0)} (1 + 2\epsilon^2/5 + \dots)$$

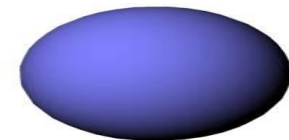
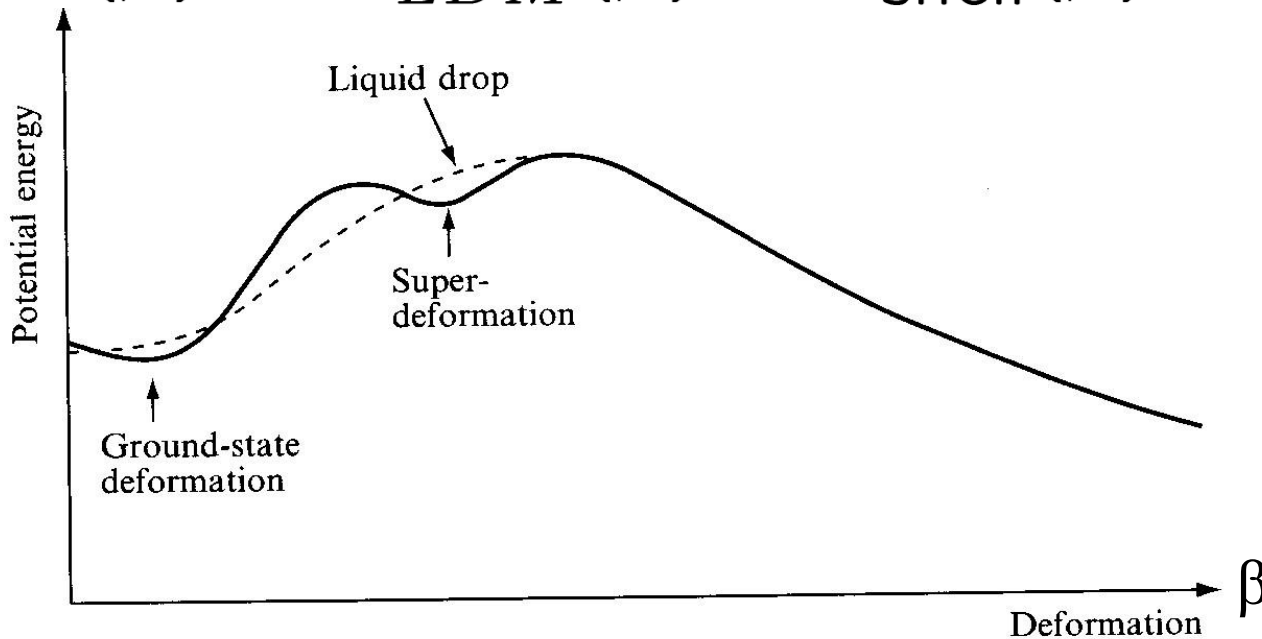
$$E_C = E_C^{(0)} (1 - \epsilon^2/5 + \dots)$$



原子核の変形

原子核の変形に伴うエネルギーの変化

$$E(\beta) = E_{LDM}(\beta) + E_{shell}(\beta)$$



液滴模型
殻補正



必ず球形

変形状態が基底状態になる場合あり

* 対称性の自発的破れ

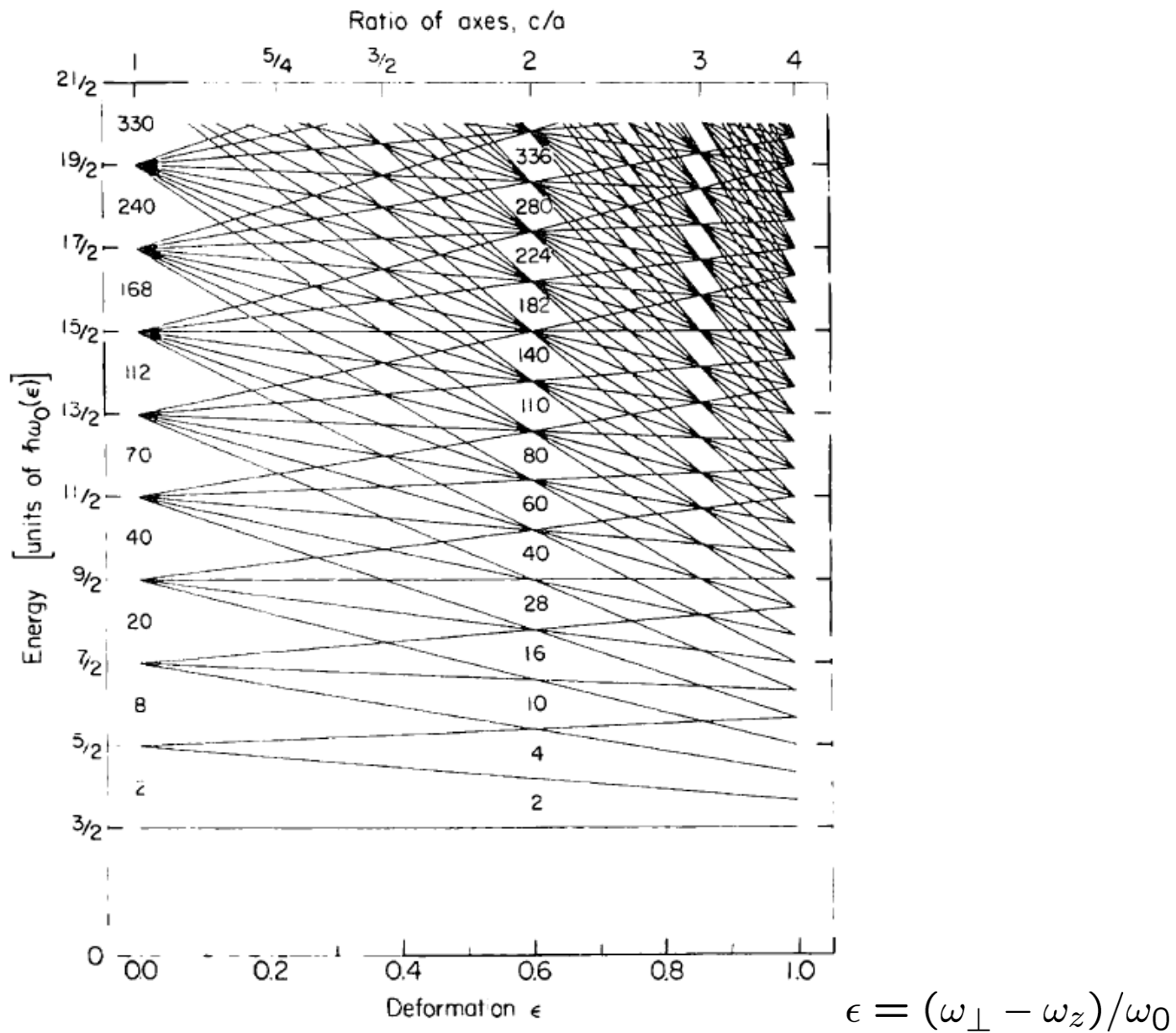
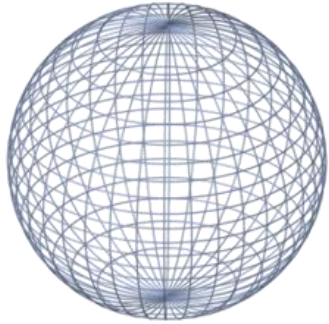
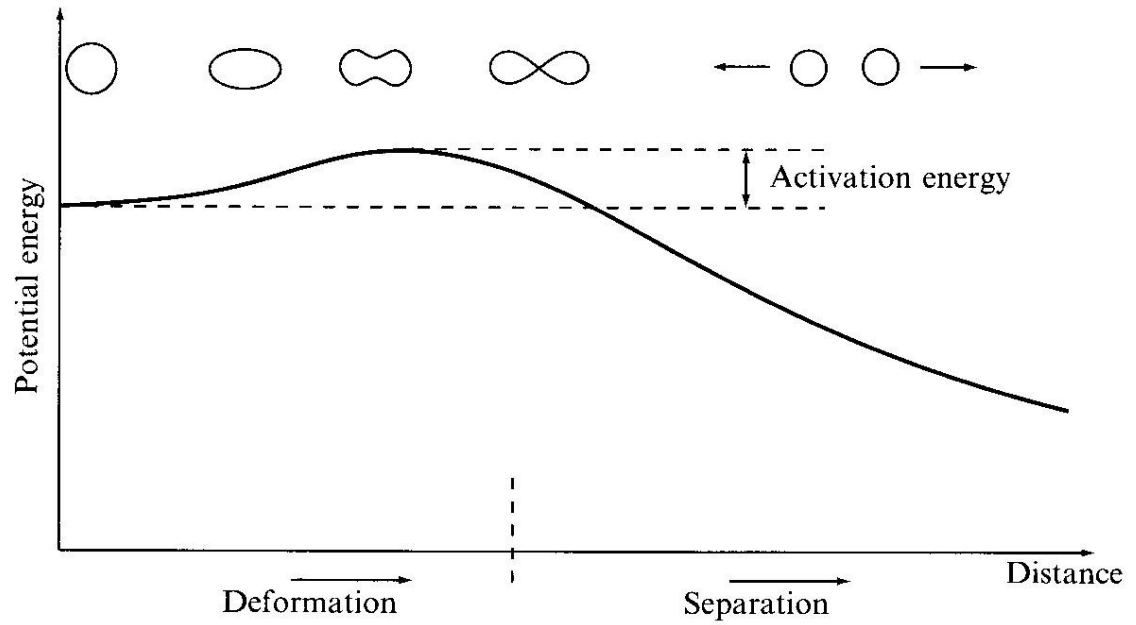


Figure 2.25. Energy levels of an harmonic-oscillator potential for prolate spheroidal deformations ϵ . (From [MN 73].)

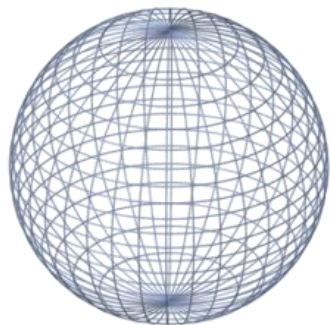
原子核の変形



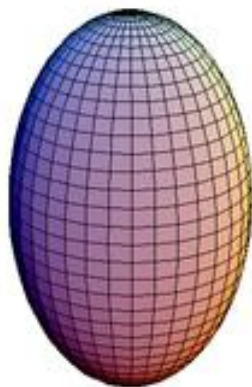
球形



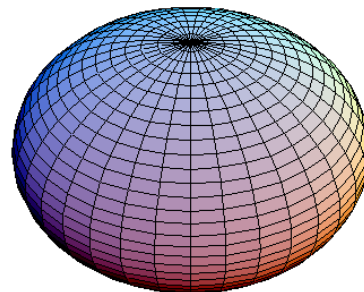
回転楕円体



球形

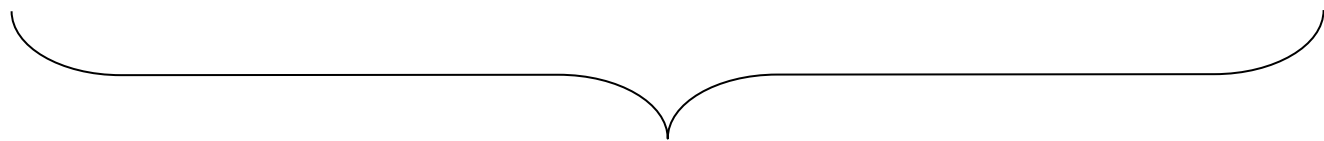


プロレート



オブレート

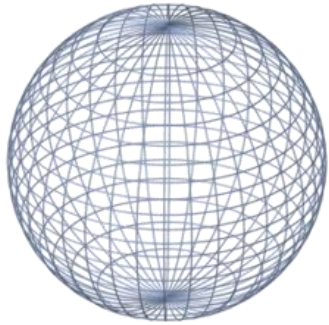
三軸非対称



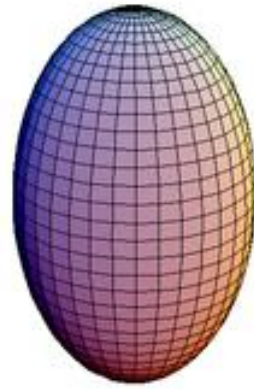
殻効果

$$B_{\text{micro}} = B_{\text{pair}} + B_{\text{shell}}$$

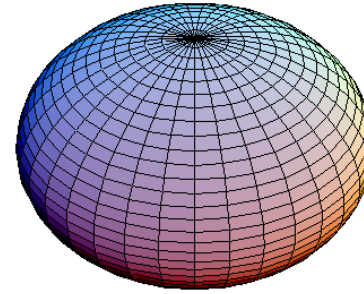
回転楕円体



球形

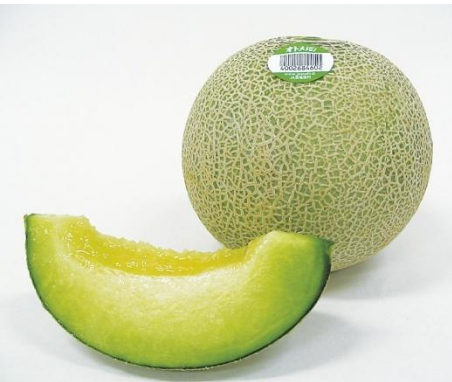


プロレート

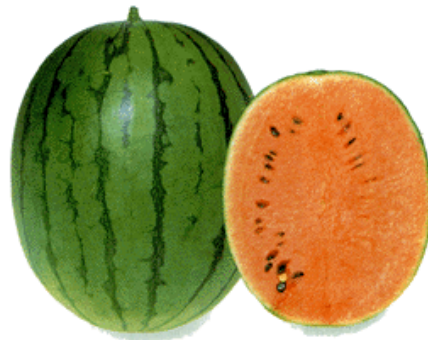


オブレート

三軸非対称



$$\beta = 0$$



$$\beta > 0$$

$$\gamma = 0$$



$$\beta < 0$$

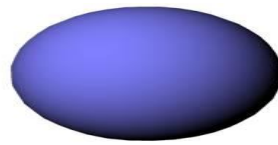
$$\gamma = 0$$



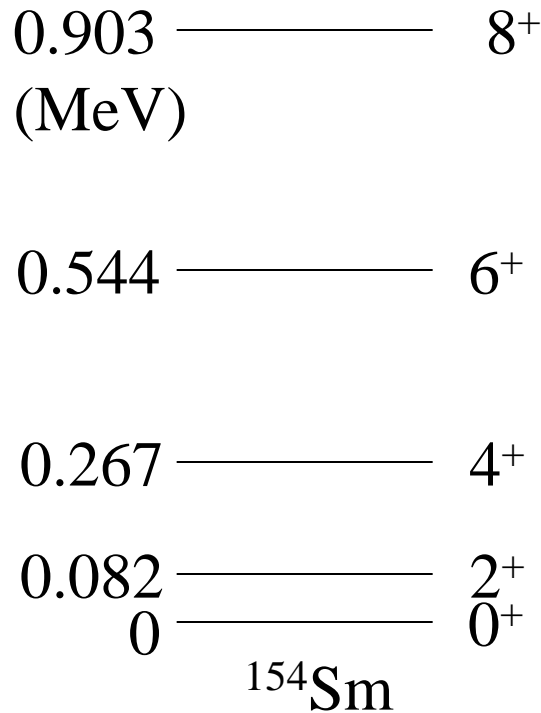
$$\beta > 0$$

$$0 < \gamma < \pi/3$$

原子核の変形



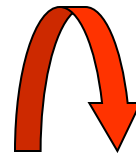
^{154}Sm の励起スペクトル



Cf. 剛体の回転エネルギー(古典力学)

$$E = \frac{1}{2} \mathcal{J} \omega^2 = \frac{I^2}{2\mathcal{J}}$$

$$(I = \mathcal{J} \omega, \omega = \dot{\theta})$$



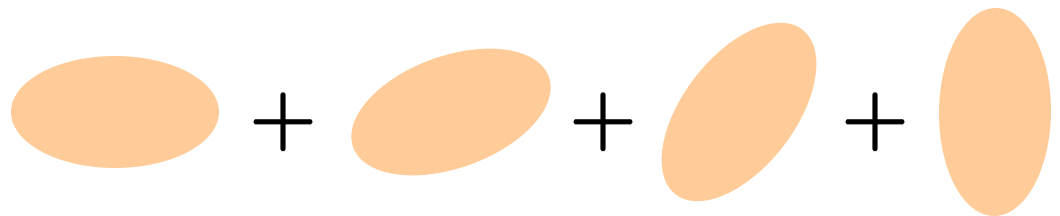
^{154}Sm は変形している

(note) 0^+ 状態とは(量子力学)?

0^+ : 空間の異方性がない

→ 色々な向きが等確率で混ざっている

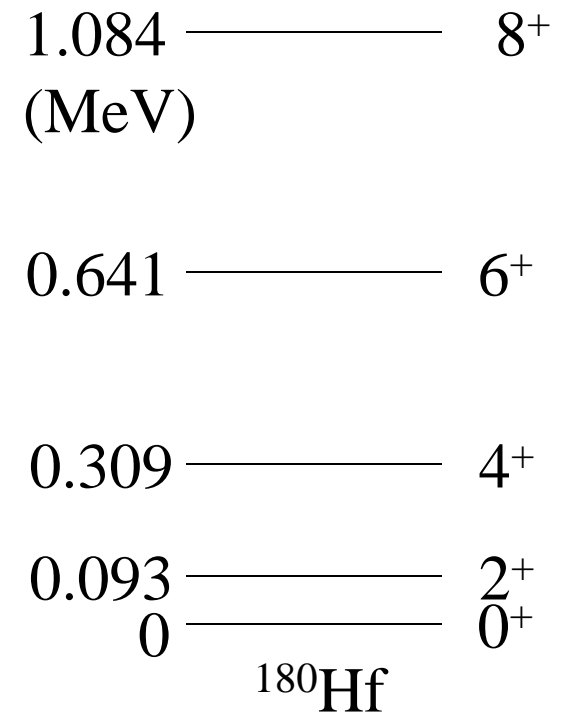
$$E_I \sim \frac{I(I+1)\hbar^2}{2\mathcal{J}}$$



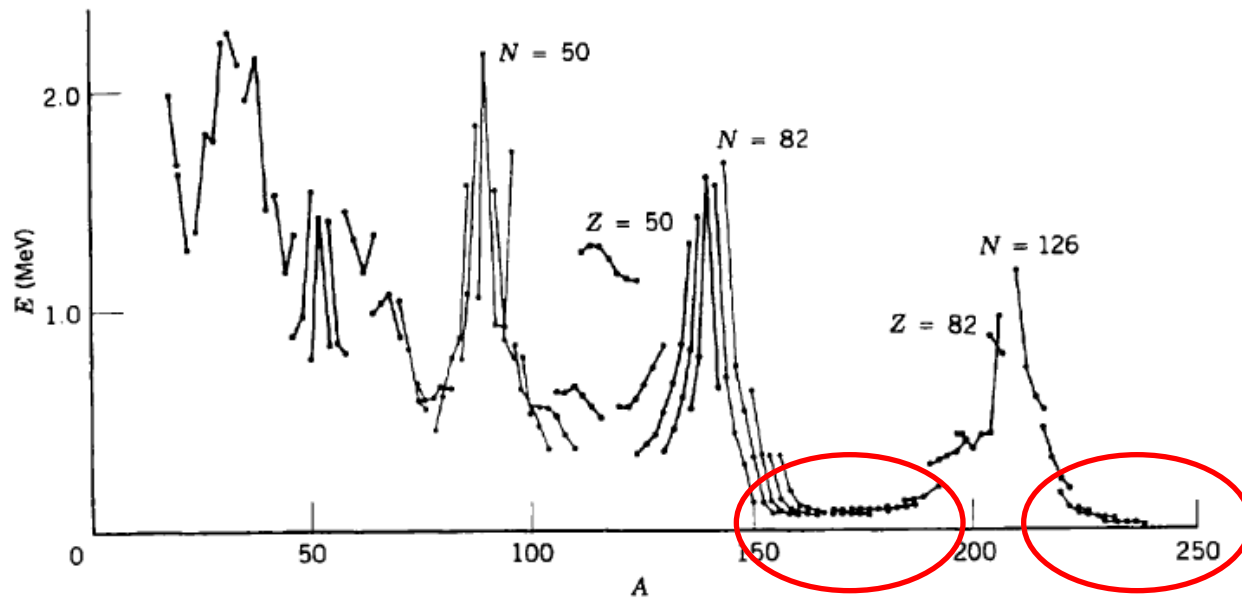
原子核が変形している証拠

- 回転バンドの存在

$$E_I = \frac{I(I + 1)\hbar^2}{2\mathcal{J}}$$



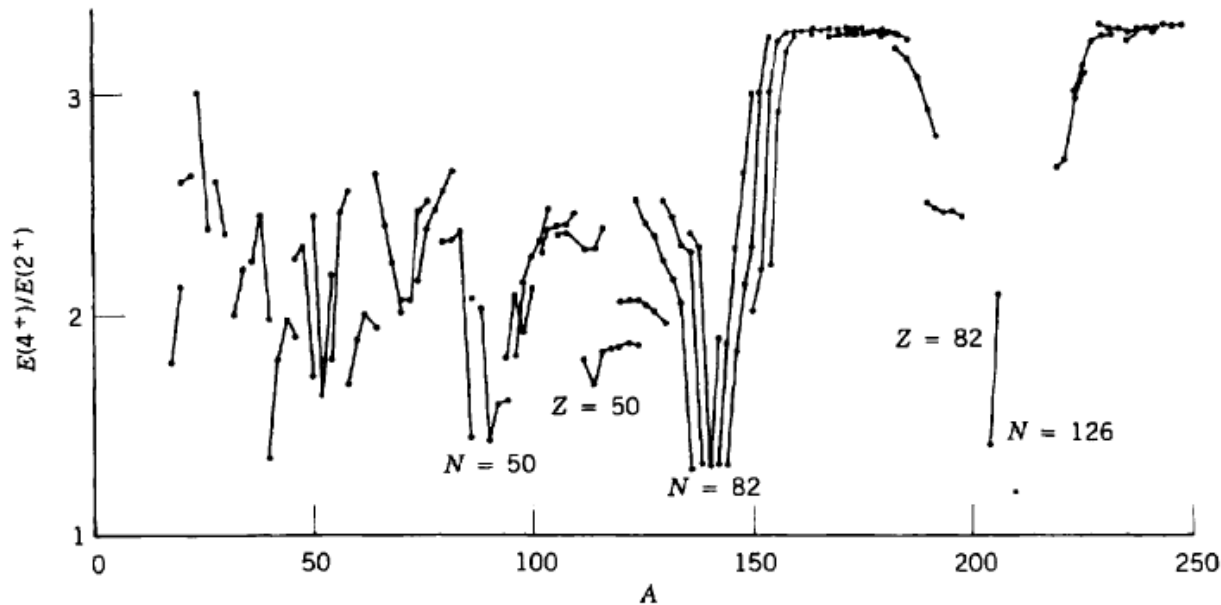
偶偶核の 2^+ 状態のエネルギー



変形核

K.S. Krane, "Introductory Nuclear Physics"

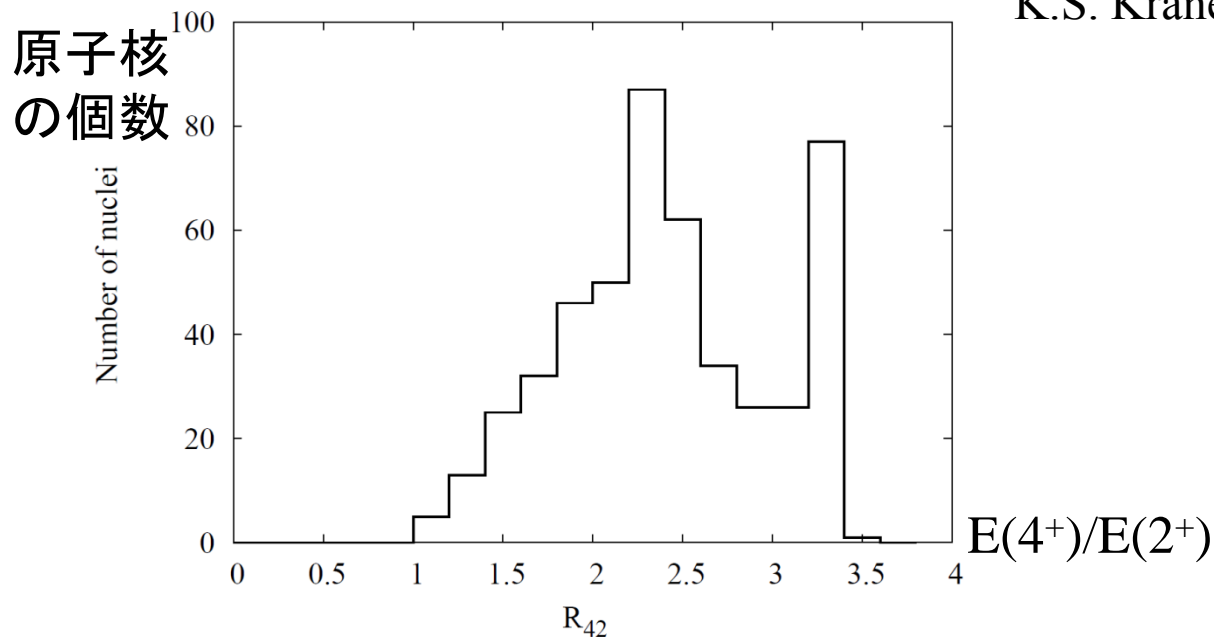
偶偶核における $E(4^+)/E(2^+)$



変形核なら
 $E(4^+)/E(2^+) \sim 3.3$

球形核なら
 $E(4^+)/E(2^+) \sim 2$

K.S. Krane, "Introductory Nuclear Physics"



G.F. Bertsch,
 arXiv:1203.5529

原子核が変形している証拠

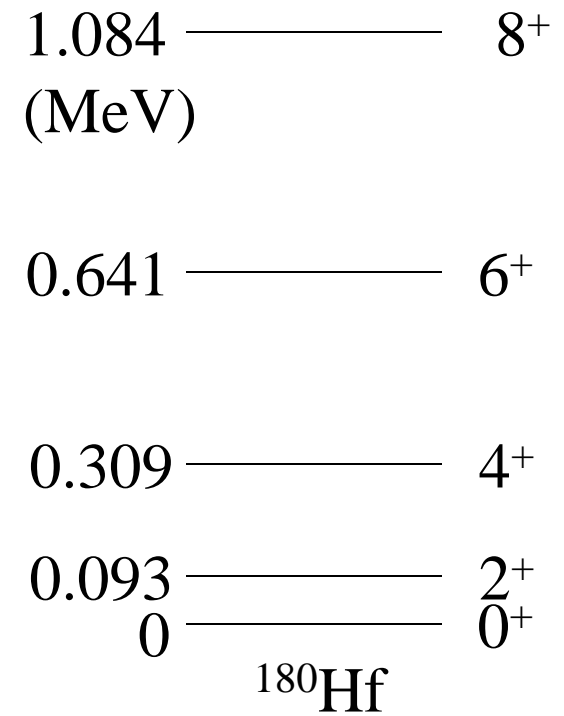
- 回転バンドの存在

$$E_I = \frac{I(I+1)\hbar^2}{2\mathcal{J}}$$

- 非常に大きな四重極モーメント
(奇数個の核子を持つ原子核や励起状態)

$$Q = e\sqrt{\frac{16\pi}{5}}\langle\Psi_{II}|r^2Y_{20}|\Psi_{II}\rangle$$

- 四重極遷移確率の増大



偶偶核の 2^+ 状態の四重極モーメント

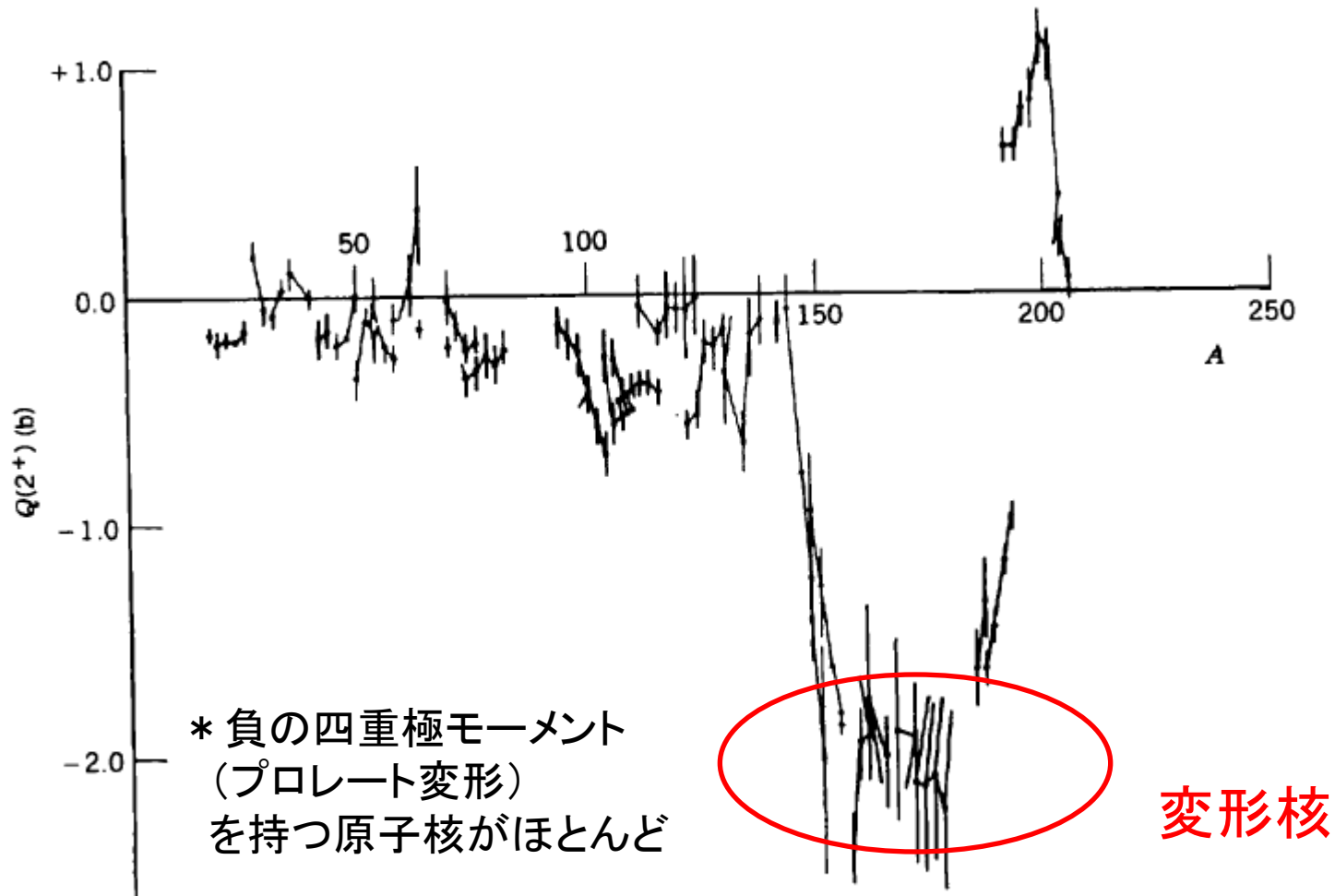


Figure 5.16b Electric quadrupole moments of lowest 2^+ states of even- Z , even- N nuclei. The lines connect sequences of isotopes.

原子核が変形している証拠

- 回転バンドの存在

$$E_I = \frac{I(I+1)\hbar^2}{2\mathcal{J}}$$

- 非常に大きな四重極モーメント
(奇数個の核子を持つ原子核や励起状態)

$$Q = e\sqrt{\frac{16\pi}{5}} \langle \Psi_{II} | r^2 Y_{20} | \Psi_{II} \rangle$$

- 四重極遷移確率の増大
- 一粒子スペクトル

1.084 ————— 8⁺
(MeV)

0.641 ————— 6⁺

0.309 ————— 4⁺

0.093 ————— 2⁺
0 ————— 0⁺

¹⁸⁰Hf

変形核の一粒子準位 (ニルソン・レベル)

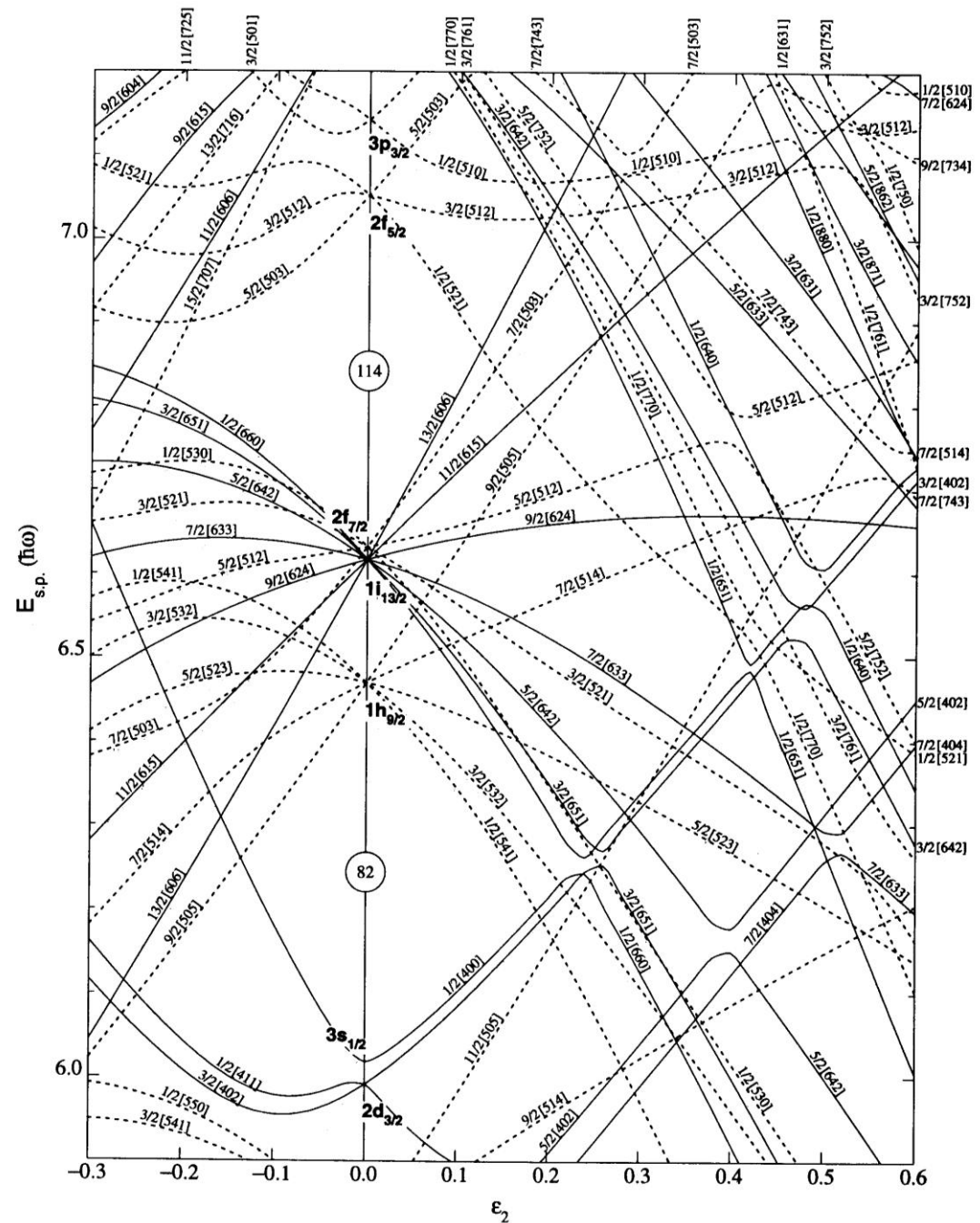
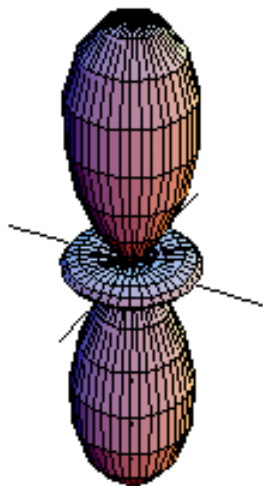
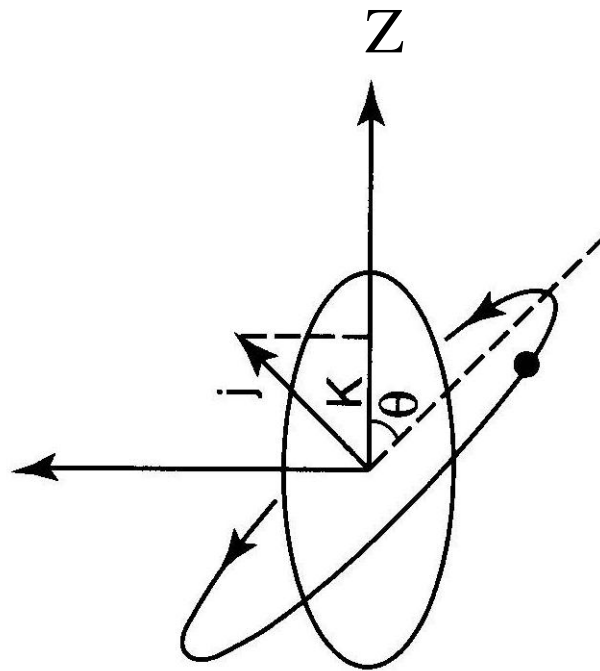
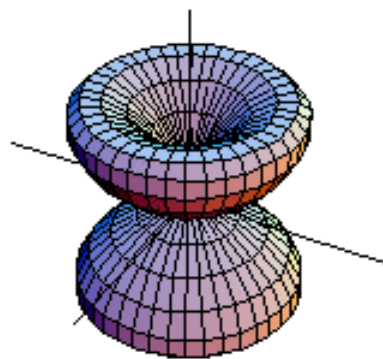


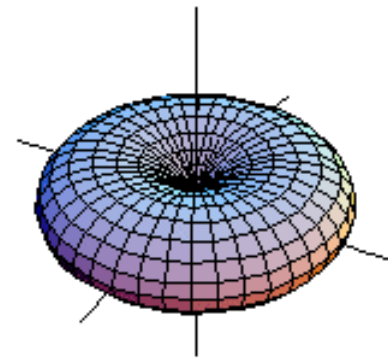
Figure 13. Nilsson diagram for protons, $Z \geq 82$ ($\epsilon_4 = \epsilon_2^2/6$).



$r = Y_{20}$
($K=0$)

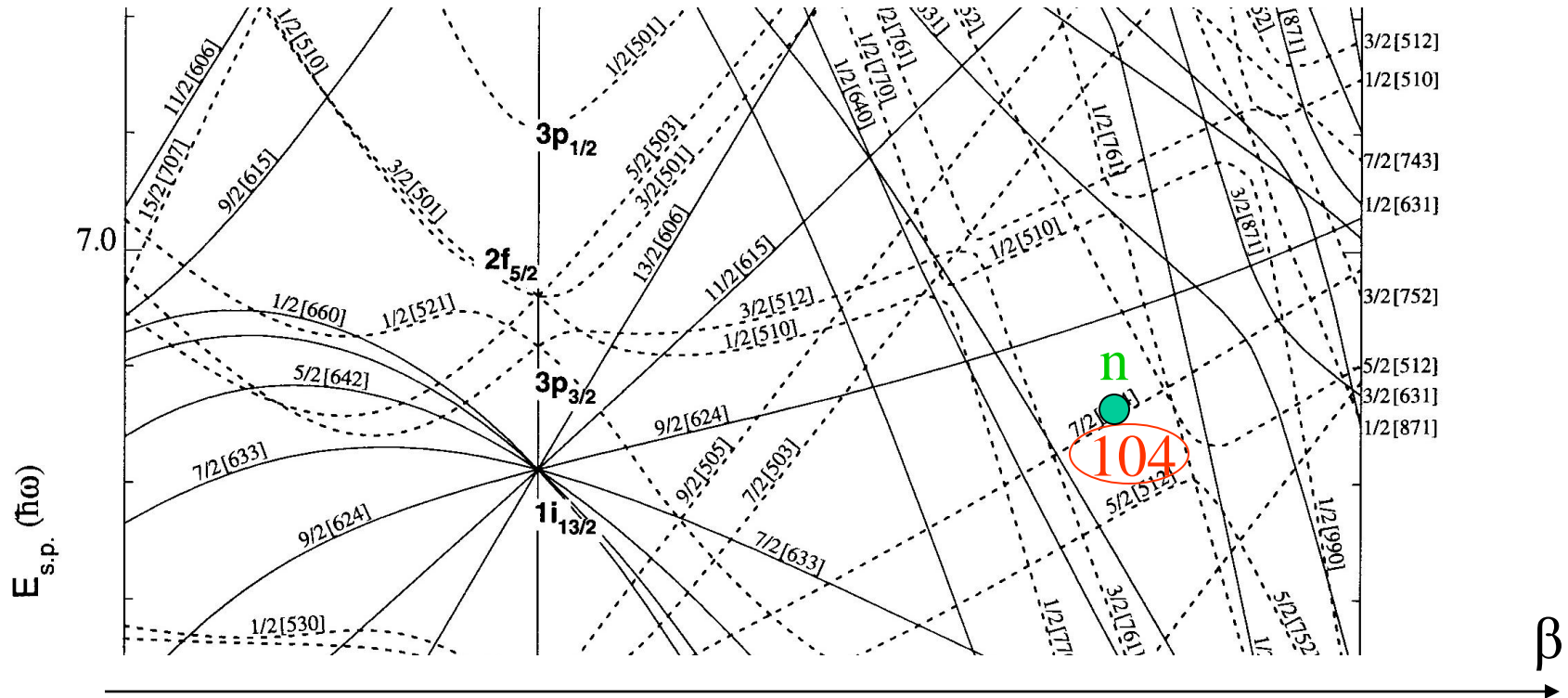


$r = Y_{21}$
($K=1$)



$r = Y_{22}$
($K=2$)

変形核の一粒準位



$5/2^-$ ————— 0.508

$9/2^+$ ————— 0.321 $^{177}_{72}\text{Hf}_{105}$

$7/2^-$ —————