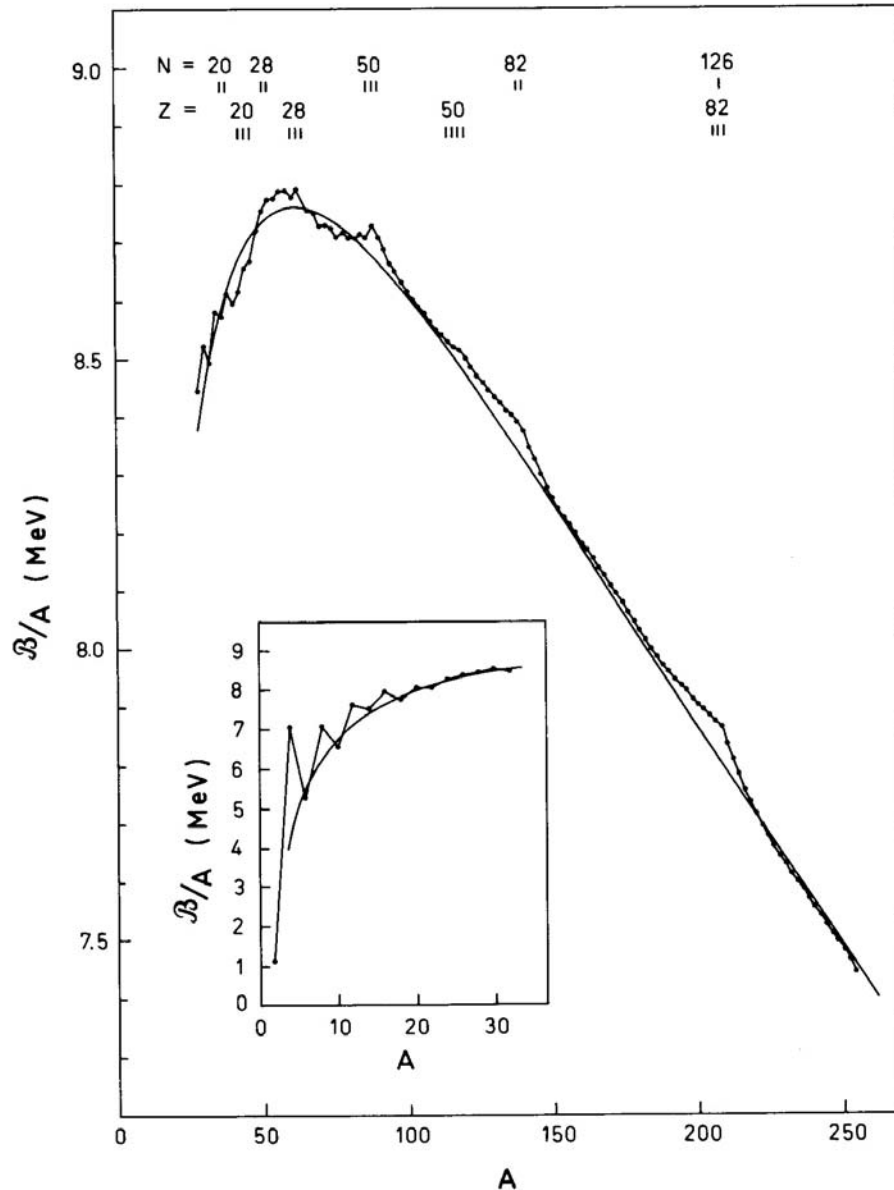


# 殻構造

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



## • 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:

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

# 対相関エネルギー

2つの陽子または2つの中性子がスピン0を組むと束縛が大きくなる

例:

束縛エネルギー (MeV)

$${}^{210}_{82}\text{Pb}_{128} = {}^{208}_{82}\text{Pb}_{126} + 2n \quad 1646.6$$

$${}^{210}_{83}\text{Bi}_{127} = {}^{208}_{82}\text{Pb}_{126} + n + p \quad 1644.8$$

$${}^{209}_{82}\text{Pb}_{127} = {}^{208}_{82}\text{Pb}_{126} + n \quad 1640.4$$

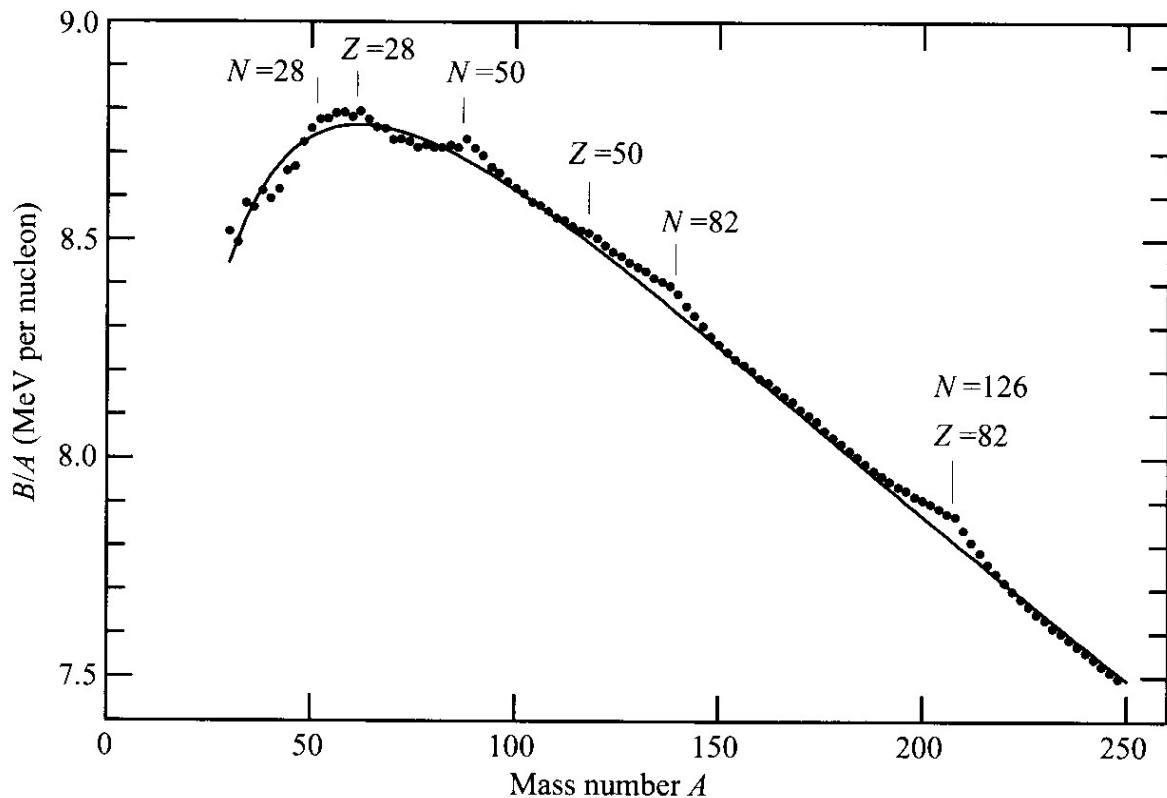
$${}^{209}_{83}\text{Bi}_{126} = {}^{208}_{82}\text{Pb}_{126} + p \quad 1640.2$$

$$B_{\text{pair}} = \Delta \quad (\text{for even} - \text{even})$$

$$= 0 \quad (\text{for even} - \text{odd})$$

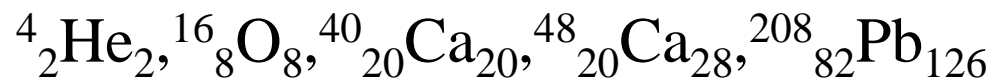
$$= -\Delta \quad (\text{for odd} - \text{odd})$$

# 殻エネルギー

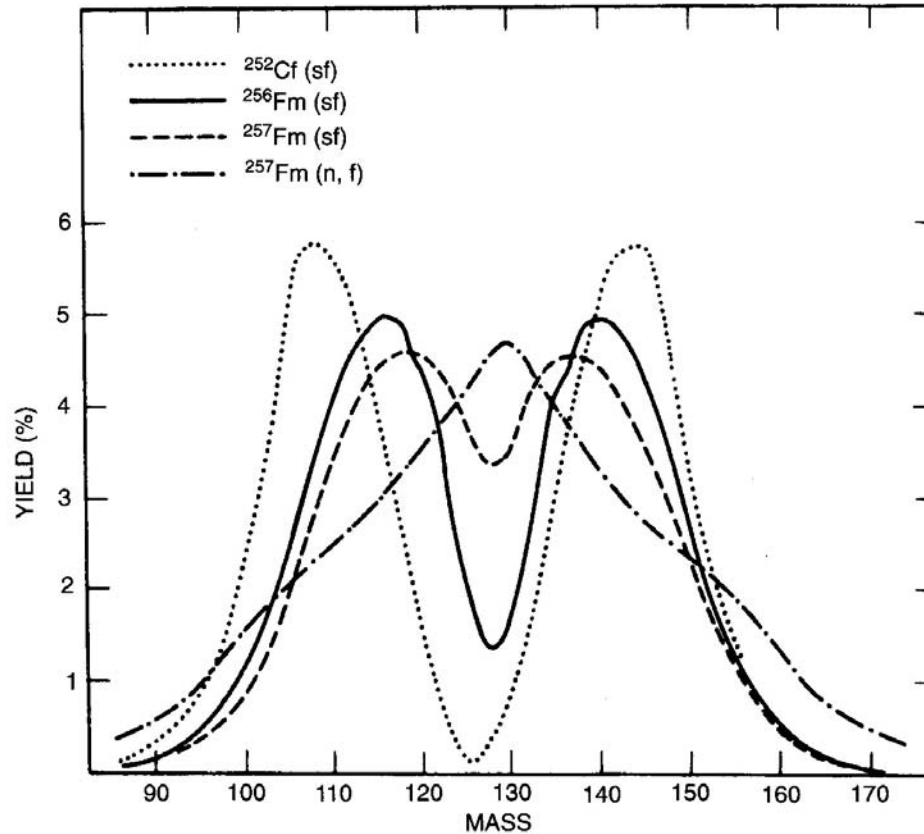


$N, Z = 2, 8, 20, 28, 50, 82, 126$  (魔法数)に対して束縛エネルギー大

⇒ とても安定



# 核分裂片の質量分布

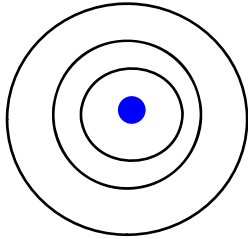


cf.  $^{120}_{50}\text{Sn}$

Fig. 4.1. Mass distributions in terms of the fission fragment masses for spontaneous fission of  $^{252}_{98}\text{Cf}$ ,  $^{256}_{100}\text{Fm}$  and  $^{257}_{100}\text{Fm}$  and for neutron-induced fission of  $^{257}_{100}\text{Fm}$ . Note the trend toward symmetric fission with increasing mass and in addition the larger number of symmetric events for neutron-induced than for spontaneous fission (from R. Vandenbosch and J.R. Huizenga, *Nuclear Fission* (Academic Press, New York and London, 1973)).

## (note) 原子の魔法数 (貴ガス)

He (Z=2), Ne (Z=10), Ar (Z=18), Kr (Z=36), Xe (Z=54), Rn (Z=86)

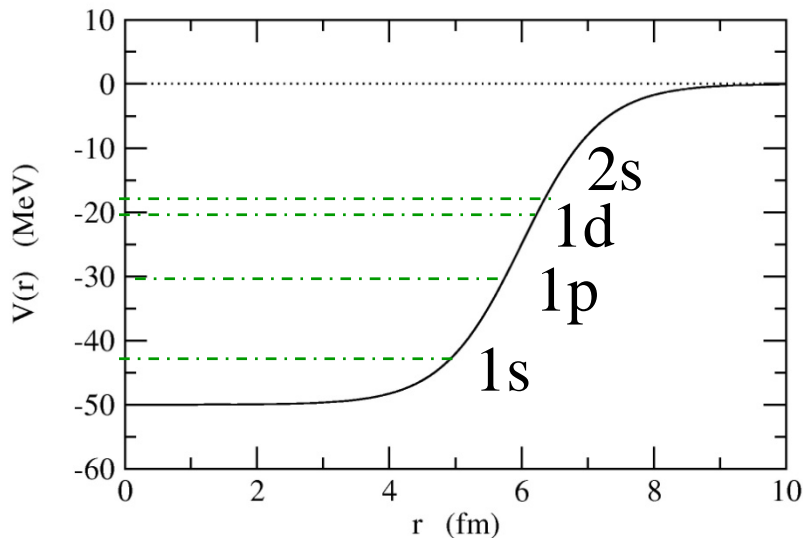


殻構造

原子核物理における似た試み: ポテンシャル中の独立粒子運動

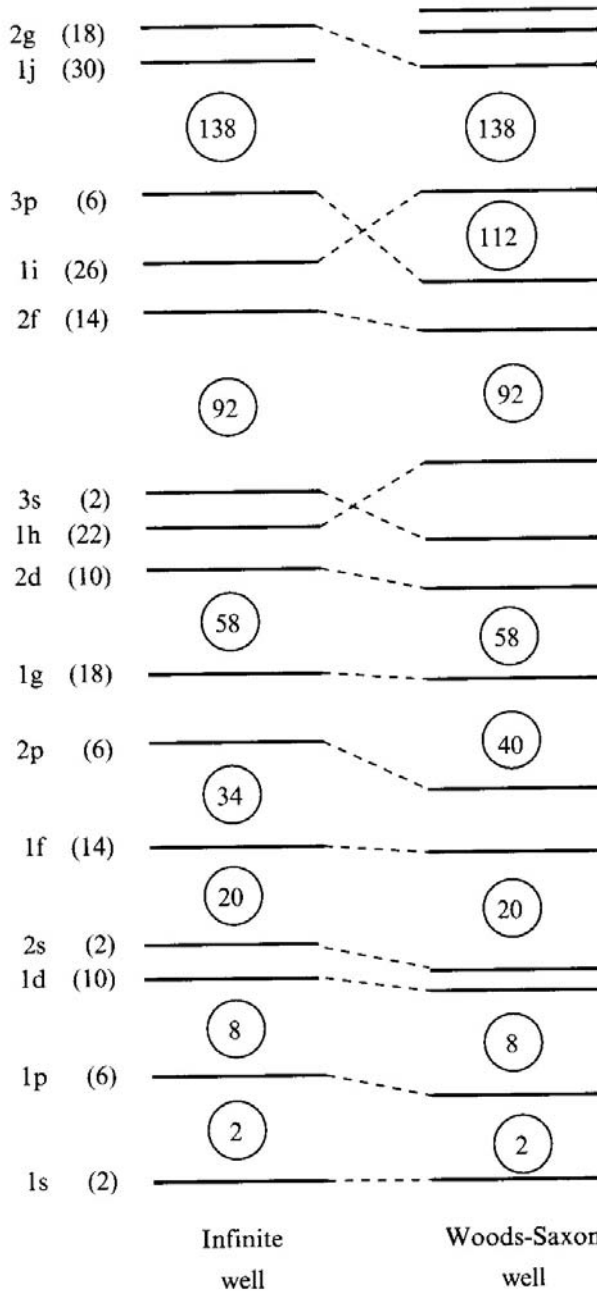
## Woods-Saxon ポテンシャル

$$V(r) = -V_0/[1 + \exp((r - R_0)/a)]$$



$$\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) - \epsilon \right] \psi(\mathbf{r}) = 0$$

$$\psi(\mathbf{r}) = \frac{u_l(r)}{r} Y_{lm}(\hat{\mathbf{r}}) \cdot \chi_{m_s}$$



Woods-Saxon ポテンシャルのみでは  
魔法数 (2,8,20,28,50,82,126)が正しく  
出ない。



Meyer and Jensen (1949):  
強いスピン・軌道力

$$\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) + V_{ls}(r) \mathbf{l} \cdot \mathbf{s} - \epsilon \right] \psi(\mathbf{r}) = 0$$

$$V_{ls}(r) \sim -\lambda \frac{1}{r} \frac{dV}{dr} \quad (\lambda > 0)$$

Infinite  
well

Woods-Saxon  
well

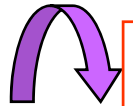
## jj 結合殻模型

$$\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) - \epsilon \right] \psi(\mathbf{r}) = 0 \quad \Longrightarrow \quad \psi_{lm m_s}(\mathbf{r}) = \frac{u_l(r)}{r} Y_{lm}(\hat{\mathbf{r}}) \cdot \chi_{m_s}$$

## スピン・軌道力

$$\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) + V_{ls}(r) \mathbf{l} \cdot \mathbf{s} - \epsilon \right] \psi(\mathbf{r}) = 0$$

$$\text{(note) } \mathbf{j} = \mathbf{l} + \mathbf{s} \quad \Longrightarrow \quad \mathbf{l} \cdot \mathbf{s} = (j^2 - l^2 - s^2)/2$$



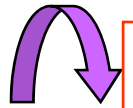
$$\psi_{jlm}(\mathbf{r}) = \frac{u_{jl}(r)}{r} \mathcal{Y}_{jlm}(\hat{\mathbf{r}})$$

$$\mathcal{Y}_{jlm}(\hat{\mathbf{r}}) = \sum_{m_l, m_s} \langle l \ m_l \ 1/2 \ m_s | j \ m \rangle Y_{lm_l}(\hat{\mathbf{r}}) \chi_{m_s}$$

## jj 結合殻模型

$$\left[ -\frac{\hbar^2}{2m} \nabla^2 + V(r) + V_{ls}(r) \mathbf{l} \cdot \mathbf{s} - \epsilon \right] \psi(\mathbf{r}) = 0$$

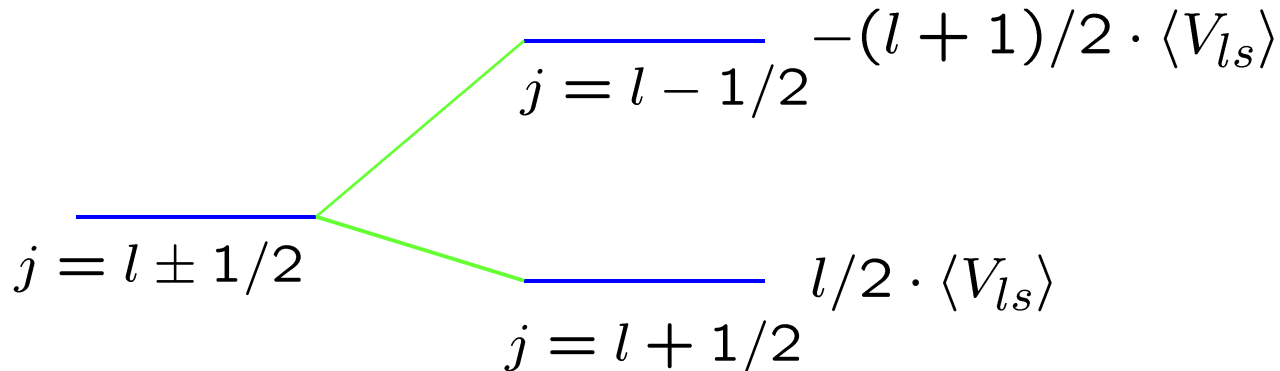
(note)  $j = l + s \implies \mathbf{l} \cdot \mathbf{s} = (j^2 - l^2 - s^2)/2$



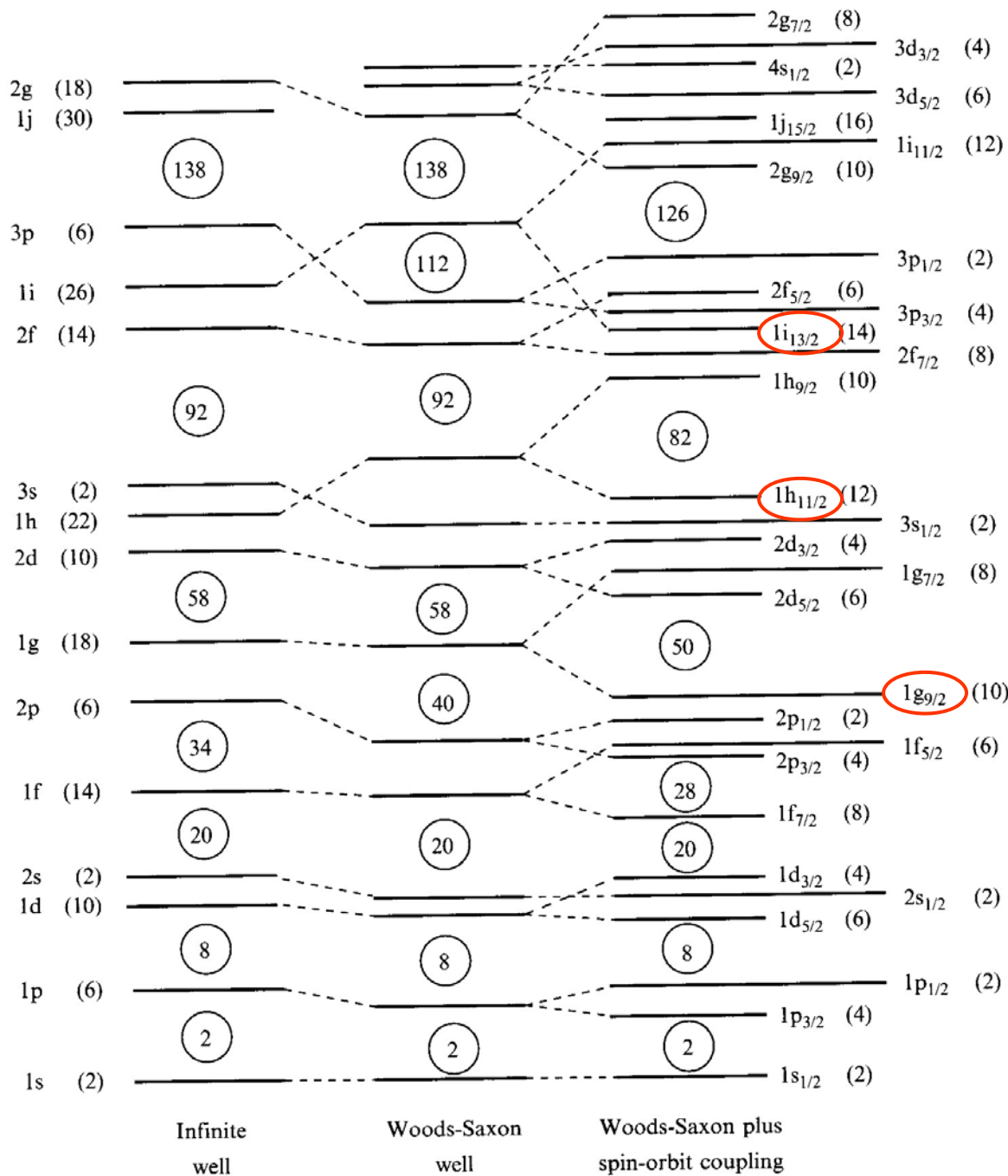
$$\psi_{jlm}(\mathbf{r}) = \frac{u_{jl}(r)}{r} \mathcal{Y}_{jlm}(\hat{\mathbf{r}})$$

$$\mathcal{Y}_{jlm}(\hat{\mathbf{r}}) = \sum_{m_l, m_s} \langle l \ m_l \ 1/2 \ m_s | j \ m \rangle Y_{lm_l}(\hat{\mathbf{r}}) \chi_{m_s}$$

$$\mathbf{l} \cdot \mathbf{s} = l/2 \ (j = l + 1/2), \quad -(l + 1)/2 \ (j = l - 1/2)$$







intruder 状態  
unique parity 状態

# 一粒子準位

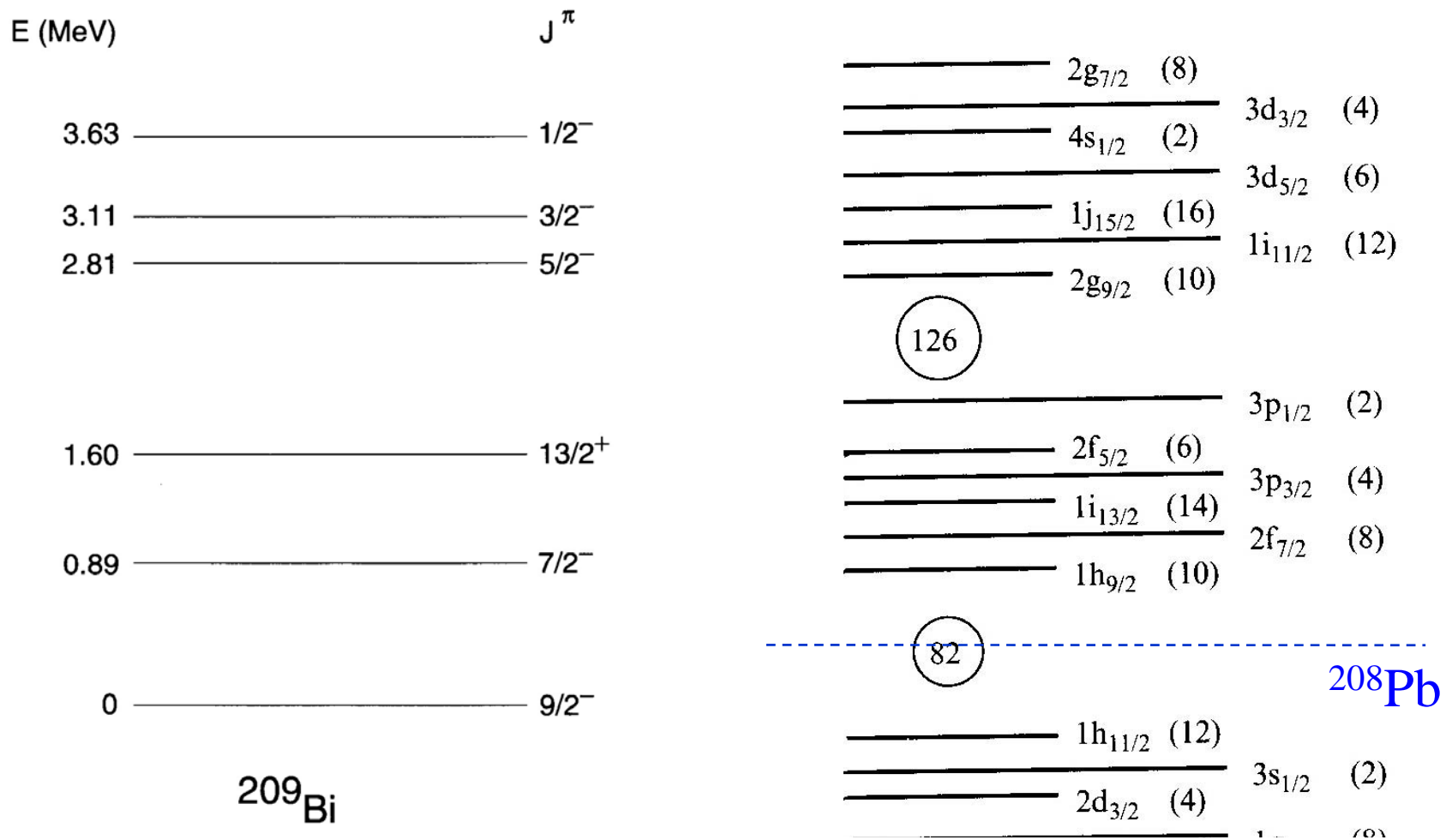


FIG. 3.6. Low-lying single-particle levels of  $^{209}\text{Bi}$ .