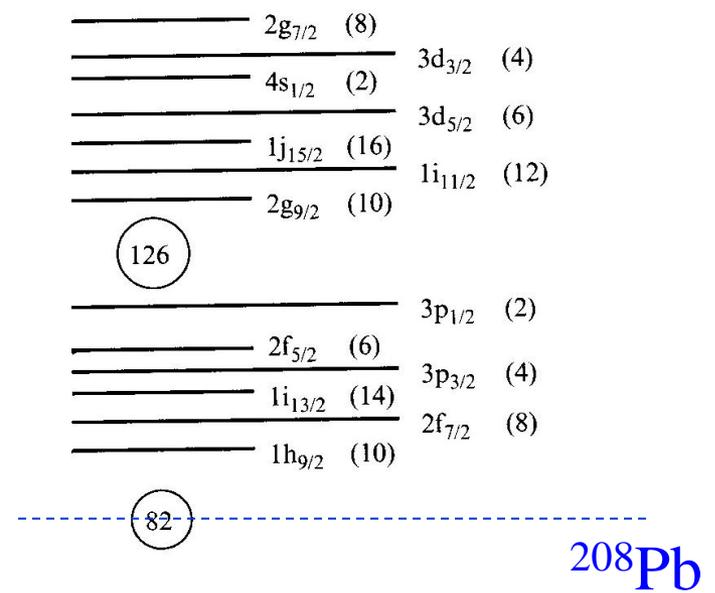
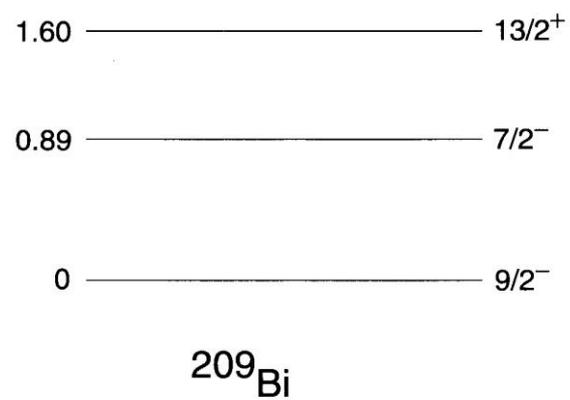


# 対相関

殻模型：閉核+1核子は非常にうまくいく

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



閉核+2核子  
だとどうなる？

$${}^{210}_{84}\text{Po}_{126} = {}^{208}_{82}\text{Pb}_{126} + 2p$$

独立粒子模型から予測される状態:

$$E=0: [h_{9/2} \otimes h_{9/2}]^I \quad (I=0,2,4,6,8)$$

$$E=0.89 \text{ MeV}: [h_{9/2} \otimes f_{7/2}]^I \quad (I=1,2,3,4,5,6,7,8)$$

→ 1 MeV 以下の励起エネルギーに 13 個の状態



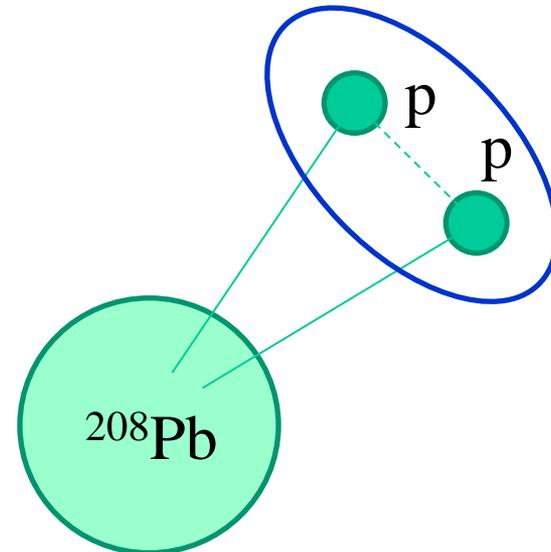
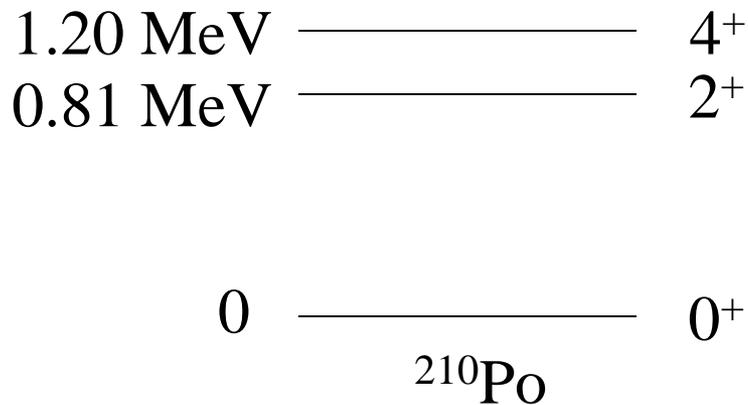
## 独立粒子模型の予測:

$$E=0: [h_{9/2} \otimes h_{9/2}]^I \quad (I=0,2,4,6,8)$$

$$E=0.89 \text{ MeV}: [h_{9/2} \otimes f_{7/2}]^I \quad (I=1,2,3,4,5,6,7,8)$$

→ 1 MeV 以下の励起エネルギーに 13 個の状態

## 実際に観測されたスペクトル:



↔ 残留相互作用の効果

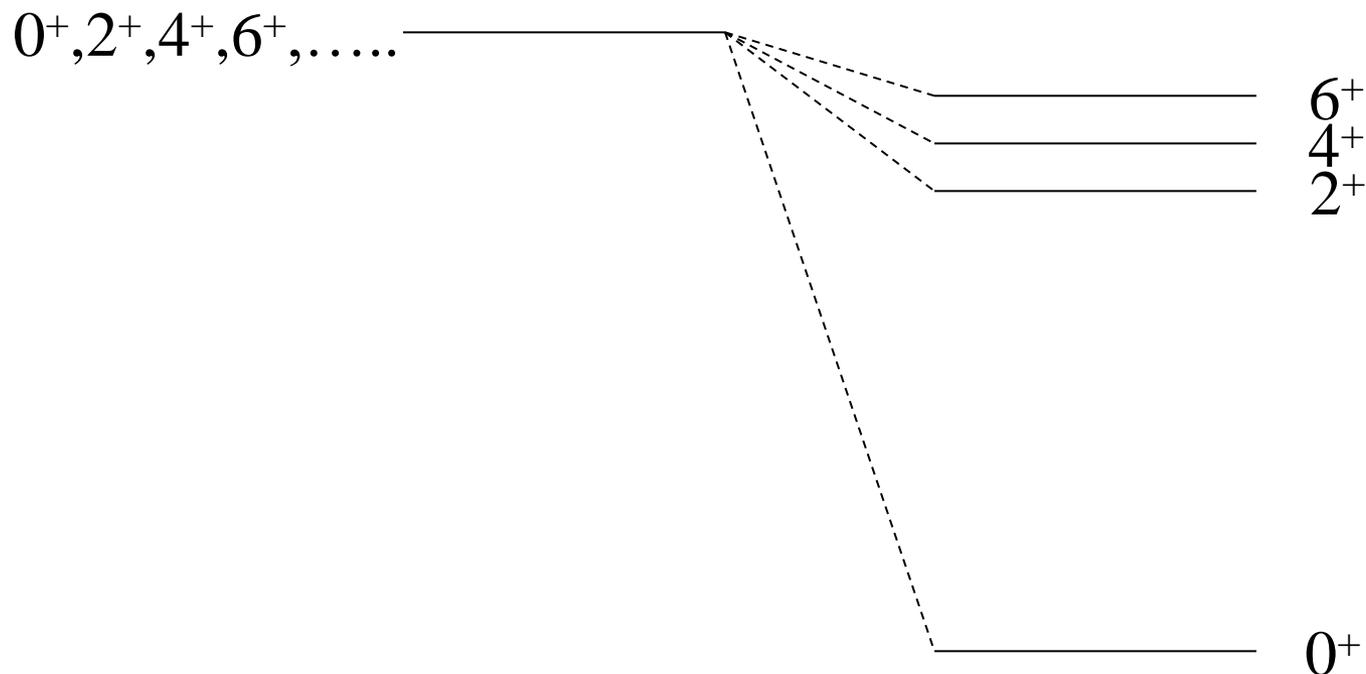
$$H = \sum_{i=1}^A \left( -\frac{\hbar^2}{2m} \nabla_i^2 + V_{\text{HF}}(i) \right) + \frac{1}{2} \sum_{i,j}^A v(\mathbf{r}_i, \mathbf{r}_j) - \sum_i V_{\text{HF}}(i)$$

## 残留相互作用の効果

$$H = \sum_{i=1}^A \left( -\frac{\hbar^2}{2m} \nabla_i^2 + V_{\text{HF}}(i) \right) + \frac{1}{2} \sum_{i,j} v(\mathbf{r}_i, \mathbf{r}_j) - \sum_i V_{\text{HF}}(i)$$

$\sim -g \delta(\mathbf{r} - \mathbf{r}')$  (短距離力を仮定)

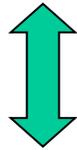
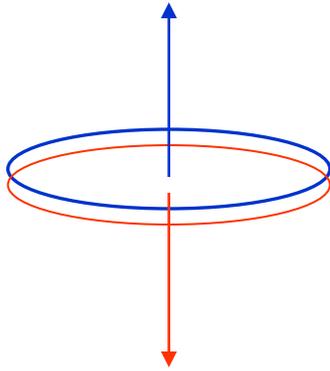
$$\text{摂動論: } \Delta E_I \sim \langle [j \otimes j]^I | -g \delta(\mathbf{r} - \mathbf{r}') | [j \otimes j]^I \rangle$$



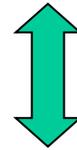
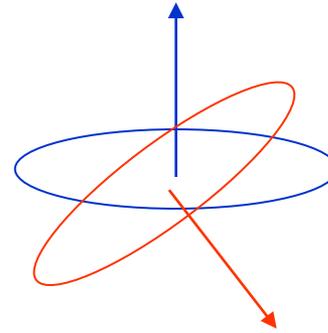
残留相互作用  
なし

残留相互作用  
あり

## 単純な解釈:



$I=0$  対

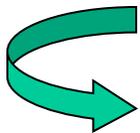
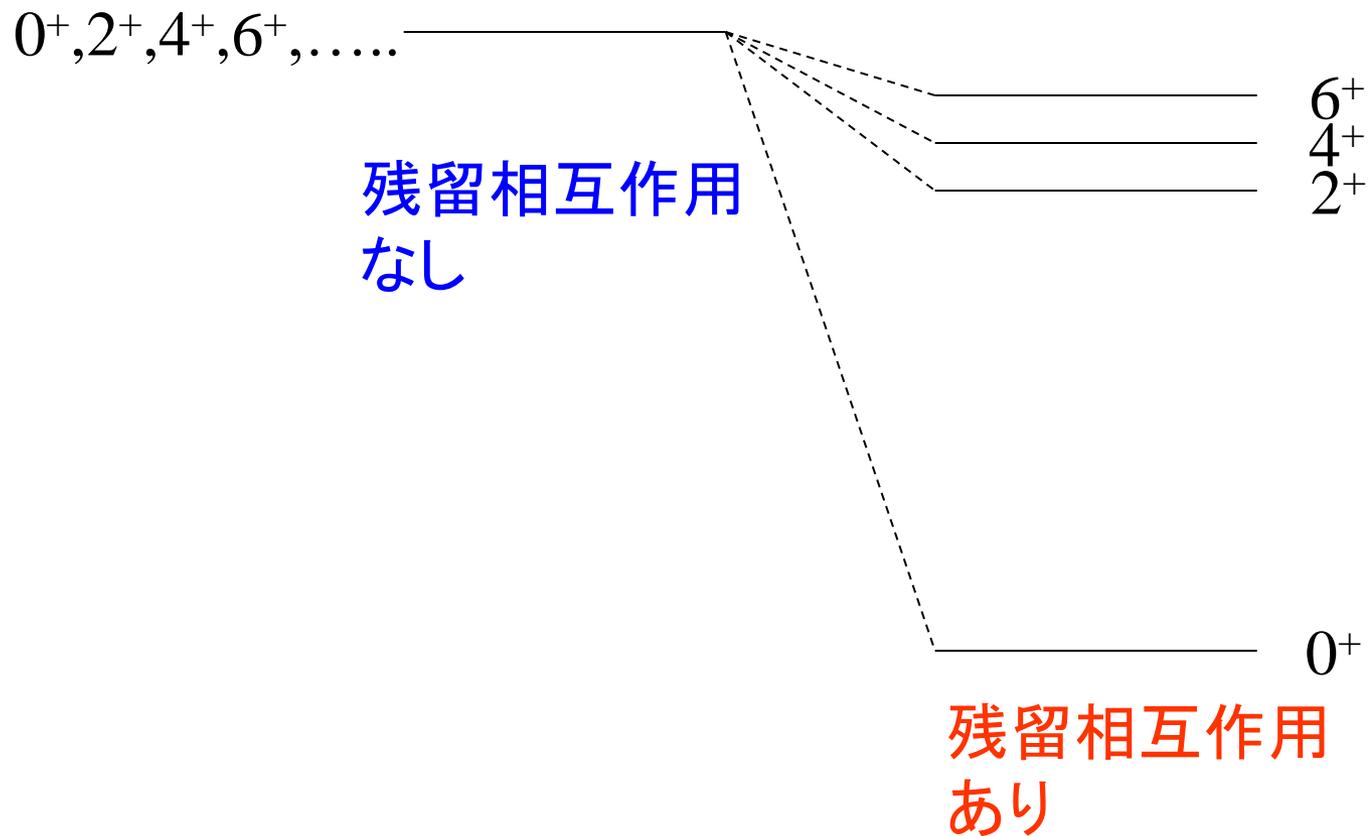


$I \neq 0$  対

$I=0$  のとき空間的な重なりが最大

“対相関”

(note)  $I=2j$  対はパウリ原理に抵触



## 原子核の基底状態のスピ

- 偶偶核:  $0^+$
- 偶奇核: 最外殻粒子のスピ

## 質量公式(偶奇性による質量差)

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)

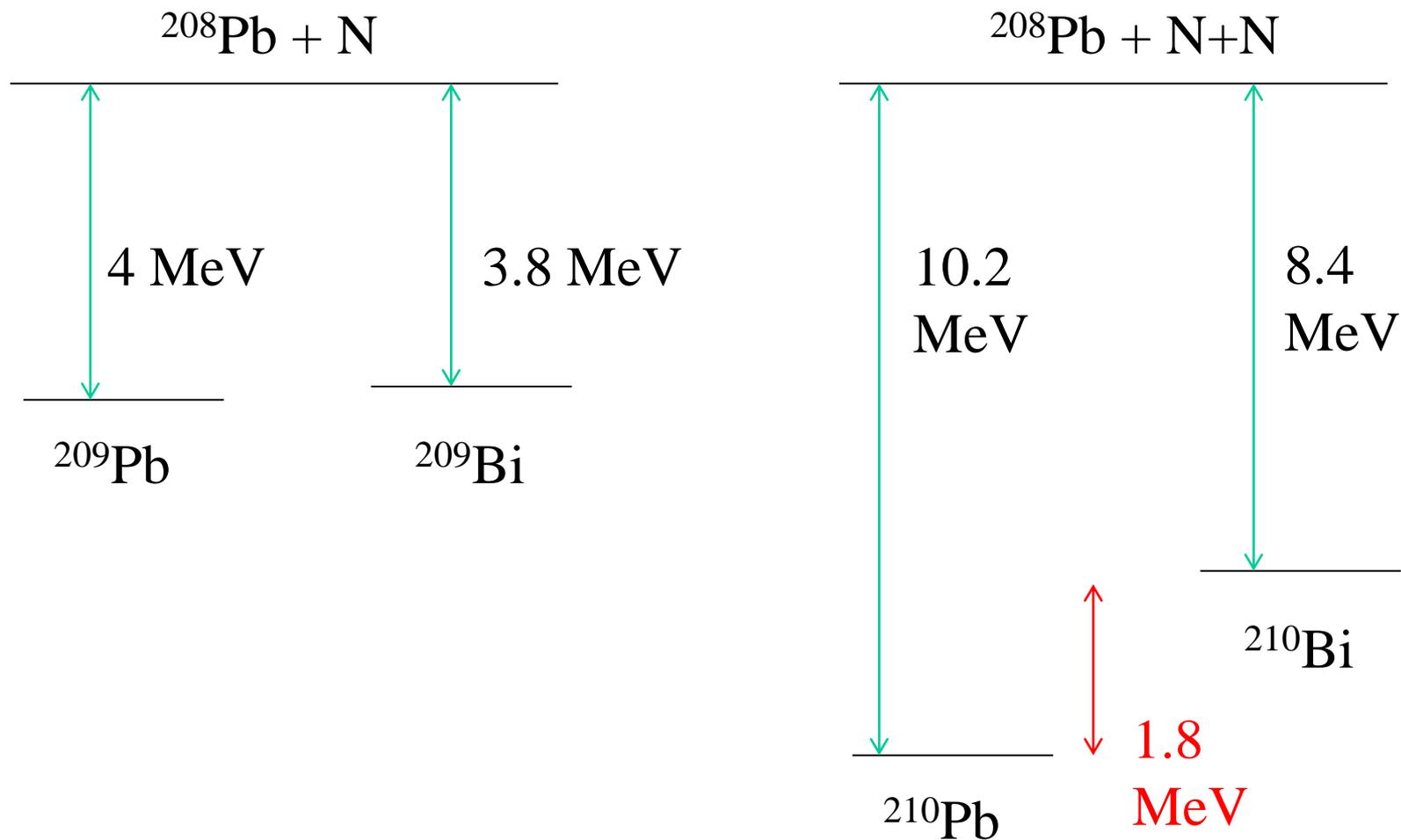
$${}^{210}_{82}\text{Pb}_{128} = {}^{208}_{82}\text{Pb}_{126} + 2n \quad 1646.6$$

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

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

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

$^{208}\text{Pb}$  の束縛エネルギー: 1636.4 MeV



## 質量公式(偶奇性による質量差)

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)

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

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

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

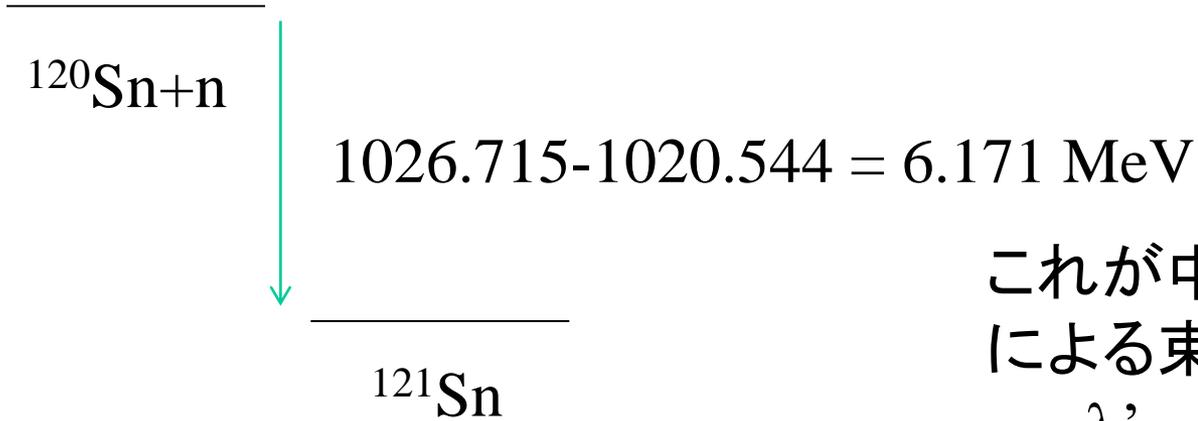
$${}^{209}_{83}\text{Bi}_{126} = {}^{208}_{82}\text{Pb}_{126} + p \quad 1640.2$$

$B_{\text{pair}} = \Delta$	(for even – even)	偶偶
$= 0$	(for even – odd)	偶奇 or 奇偶
$= -\Delta$	(for odd – odd)	奇奇

例)  $^{120}\text{Sn}$  の束縛エネルギー 1020.544 MeV

$^{121}\text{Sn}$  の束縛エネルギー 1026.715 MeV

$^{122}\text{Sn}$  の束縛エネルギー 1035.528 MeV

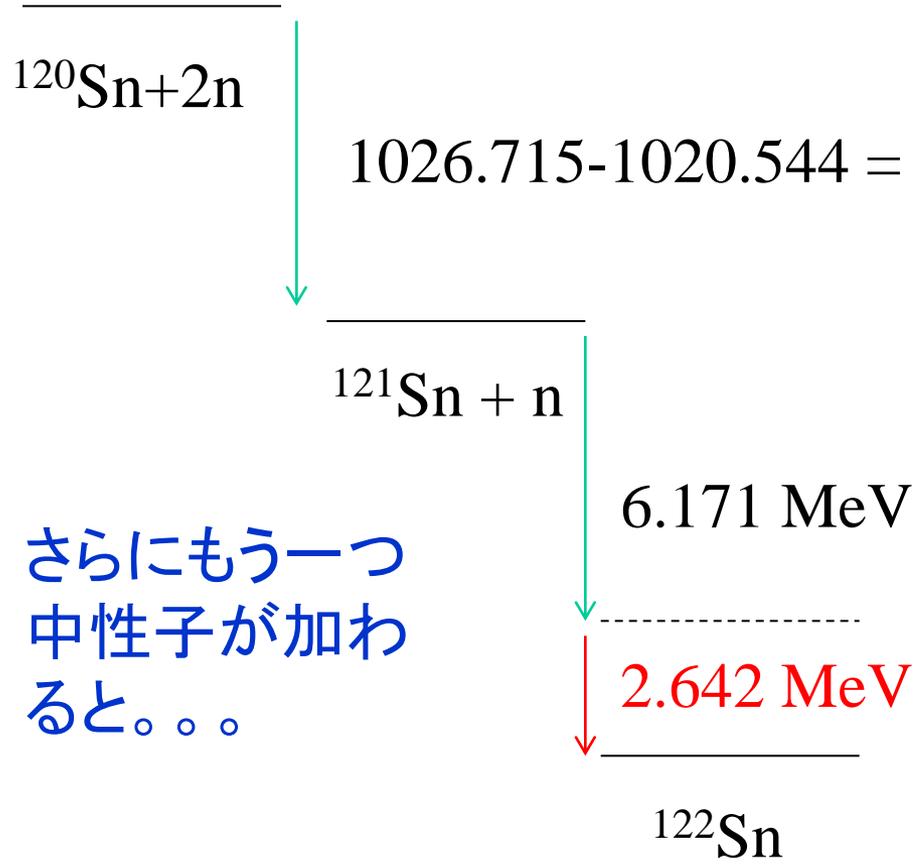


これが中性子1つ増えたこと  
による束縛エネルギーの増分  
 $= -\lambda'_n$

例)  $^{120}\text{Sn}$  の束縛エネルギー 1020.544 MeV

$^{121}\text{Sn}$  の束縛エネルギー 1026.715 MeV

$^{122}\text{Sn}$  の束縛エネルギー 1035.528 MeV



$$1026.715 - 1020.544 = 6.171 \text{ MeV}$$

これが中性子1つ増えたこと  
による束縛エネルギーの増分  
 $= -\lambda'_n$

2中性子間の対相関による  
増分

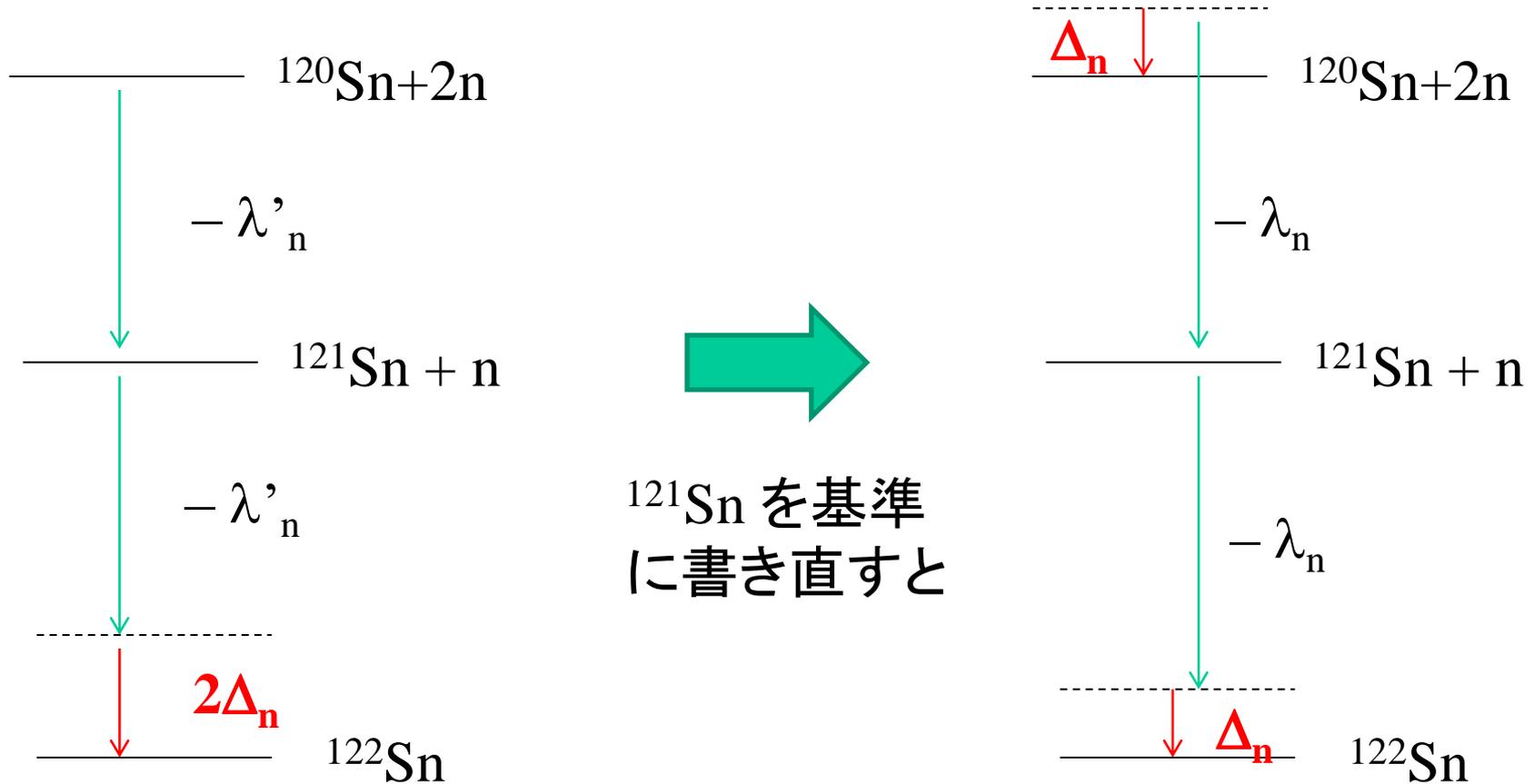
これを  $2\Delta_n$  とおく。

\*  $1035.528 - 1026.715 = 8.813 = 6.171 + 2.642$

例)  $^{120}\text{Sn}$  の束縛エネルギー 1020.544 MeV

$^{121}\text{Sn}$  の束縛エネルギー 1026.715 MeV

$^{122}\text{Sn}$  の束縛エネルギー 1035.528 MeV



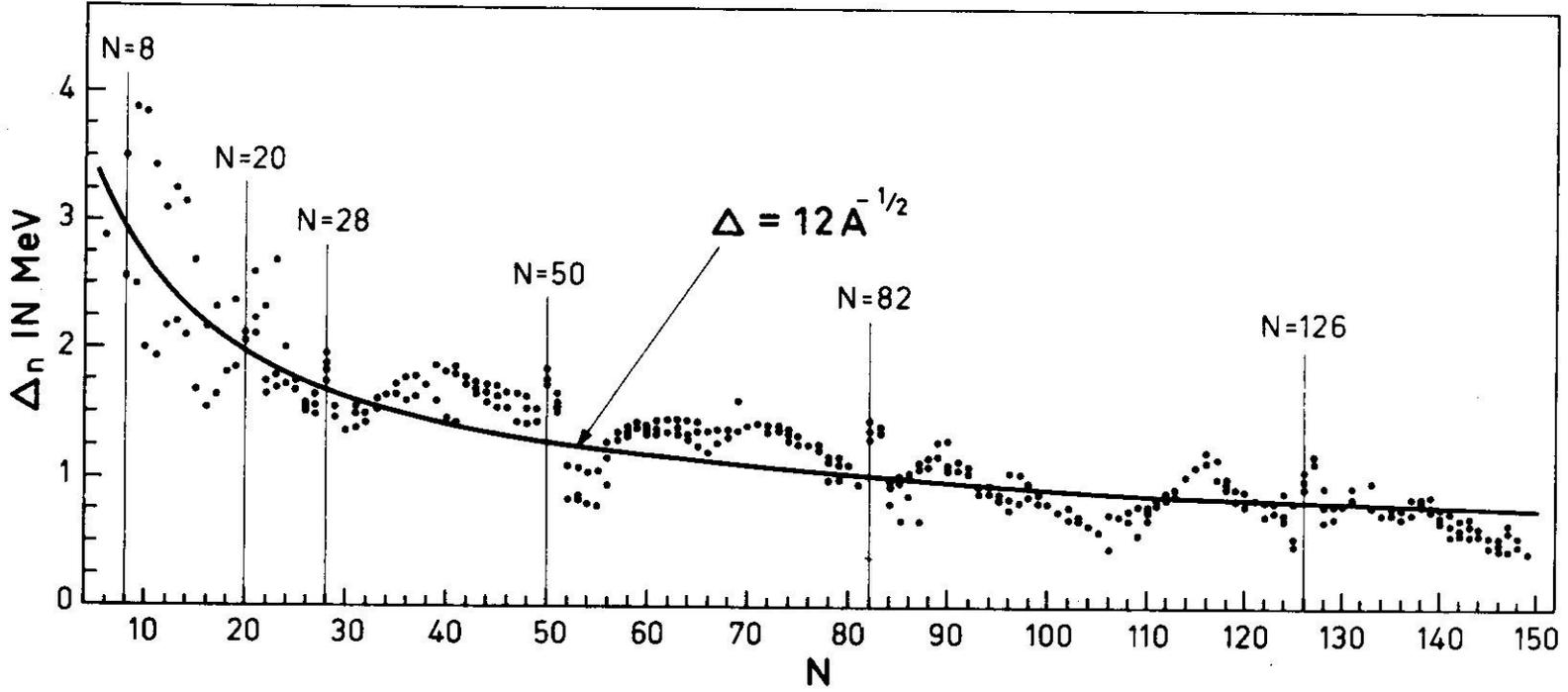
$^{121}\text{Sn}$  を基準  
に書き直すと

偶偶核は束縛エネルギーに  $\Delta$  を足す  
偶奇核・奇偶核は何もしない

$$B(N+1, Z) = B(N, Z) - \lambda'_n$$

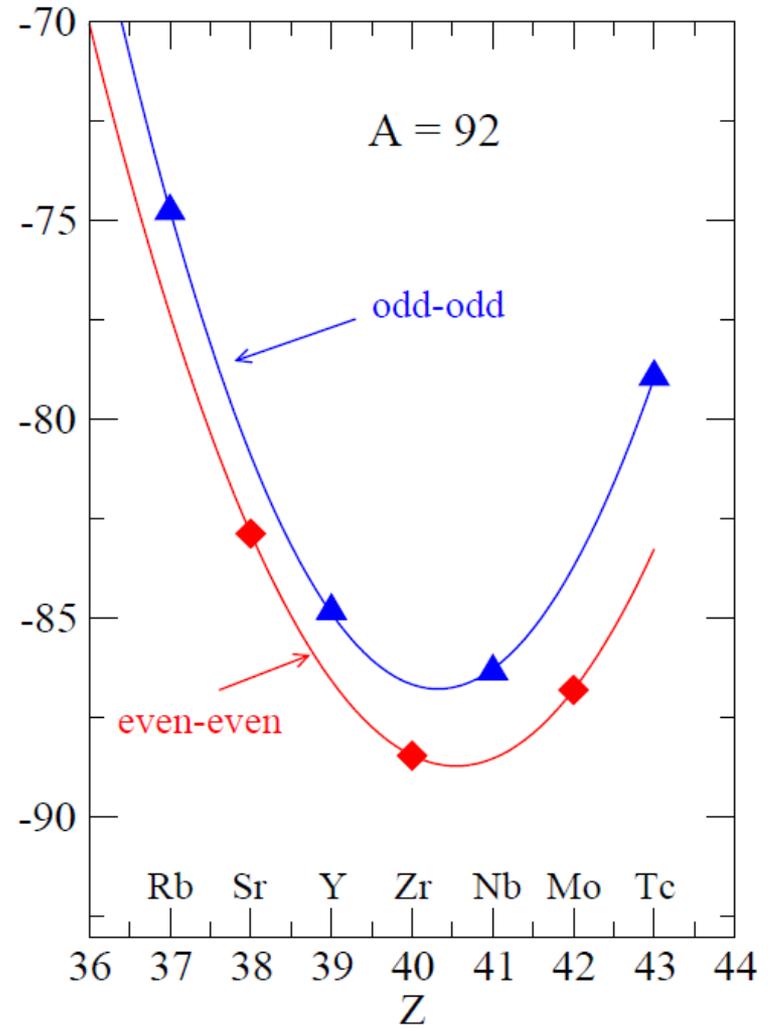
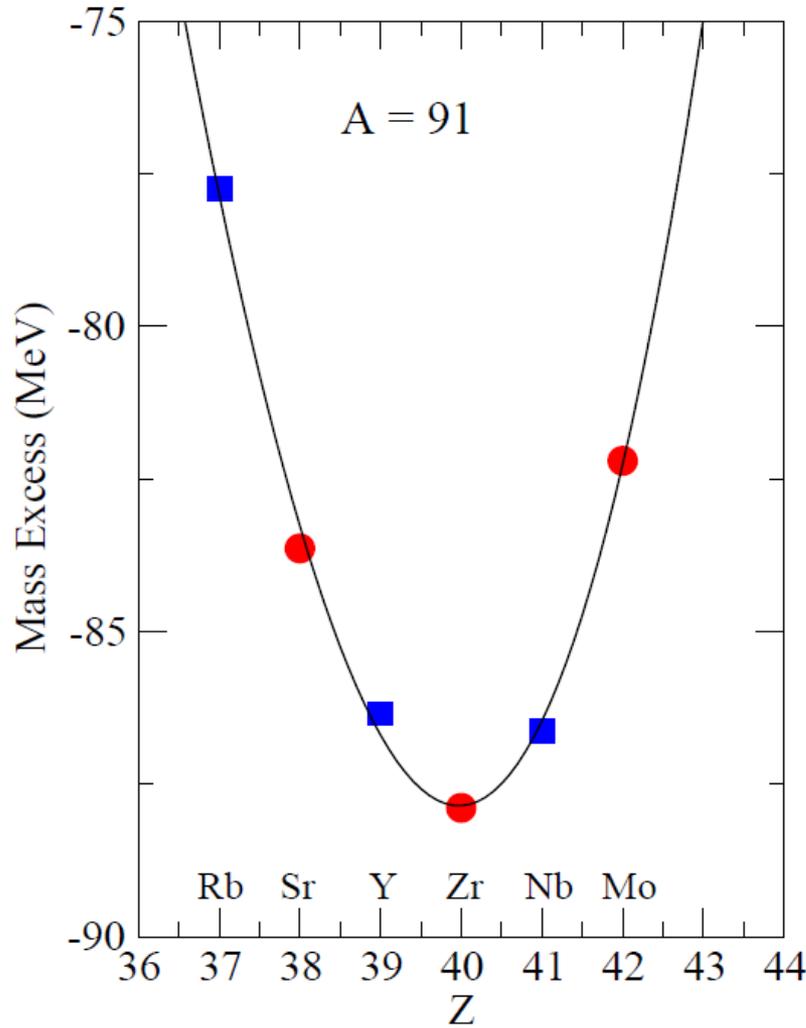
$$B(N+2, Z) = B(N, Z) - 2\lambda'_n + 2\Delta_n$$

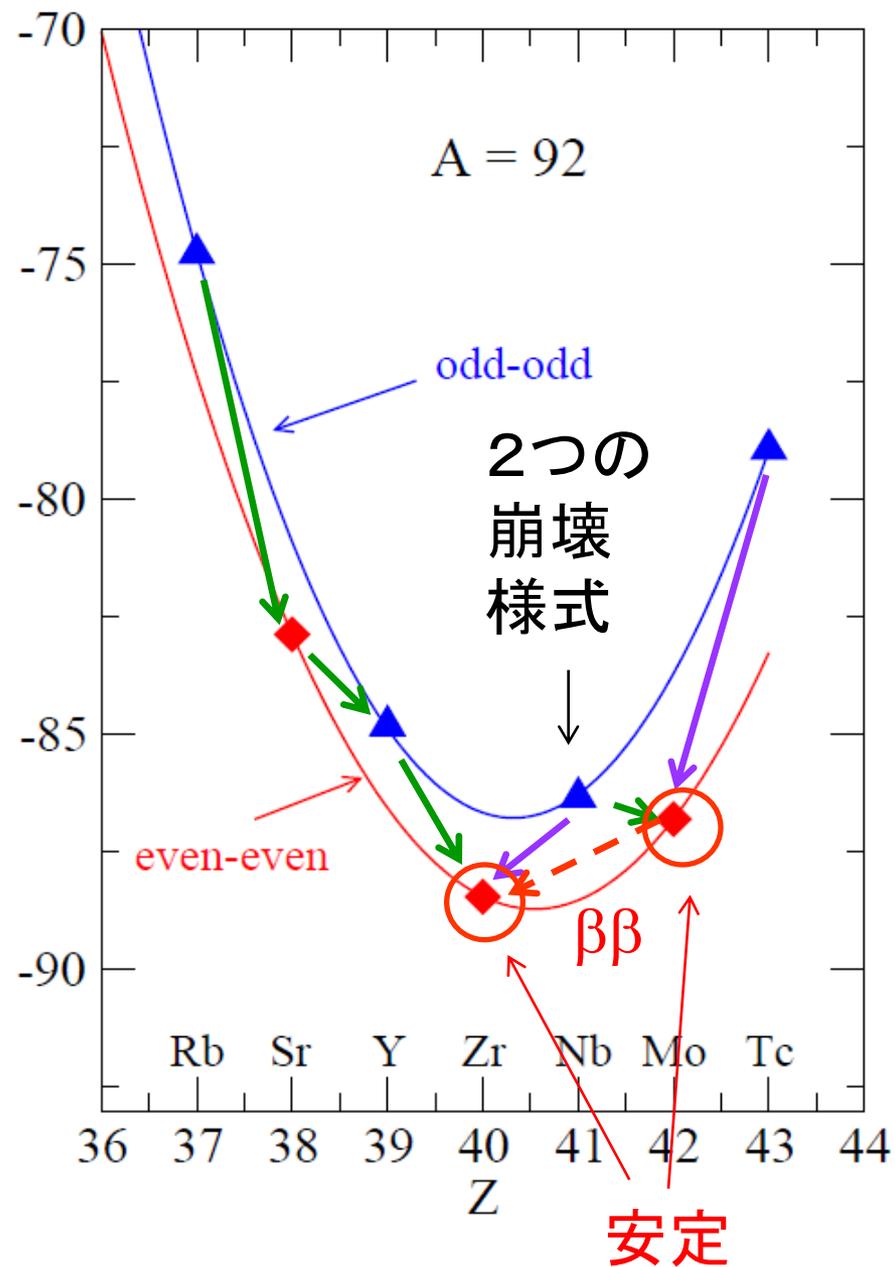
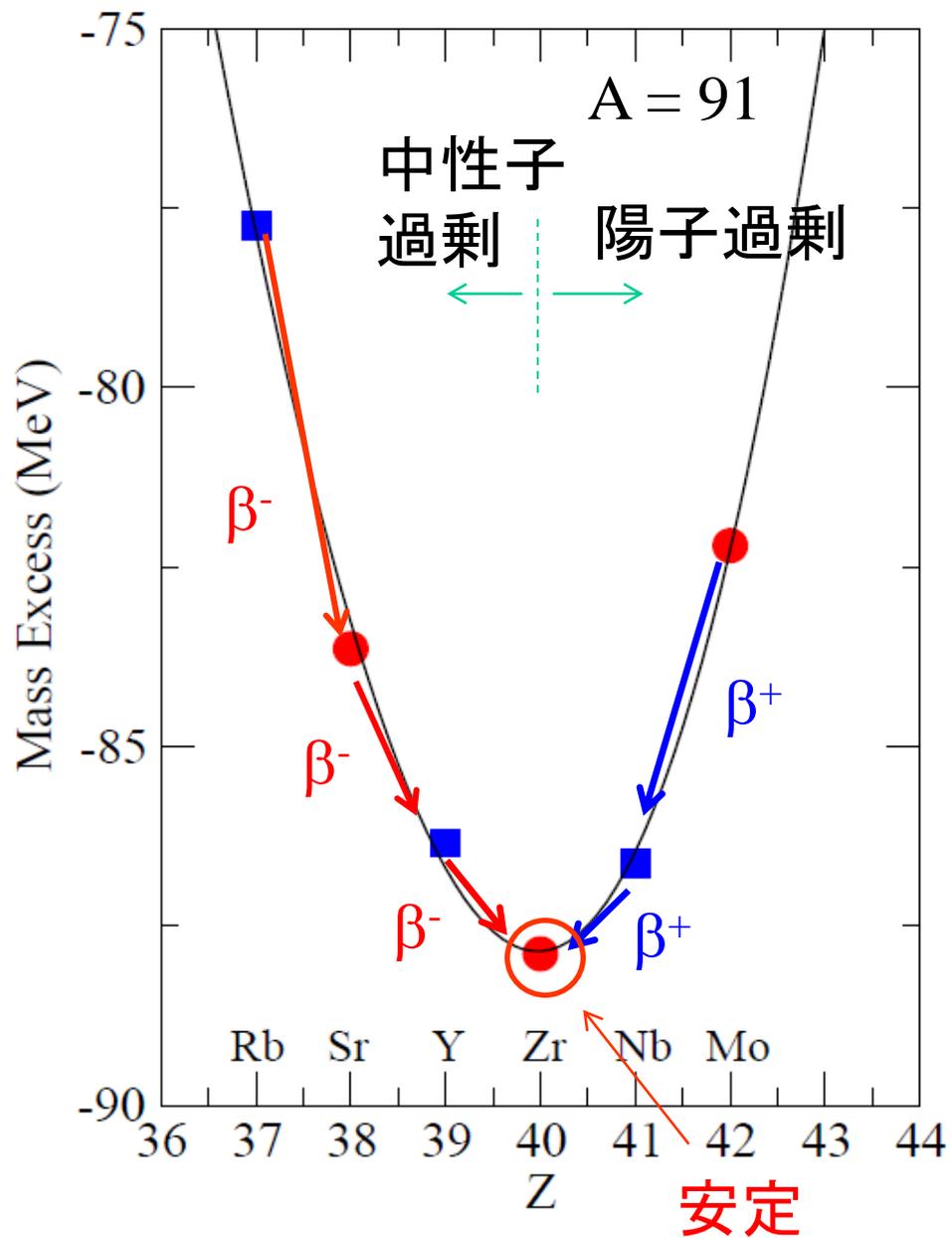
であれば、  $\Delta_n = [B(N+2, Z) - 2B(N+1, Z) + B(N, Z)] / 2$



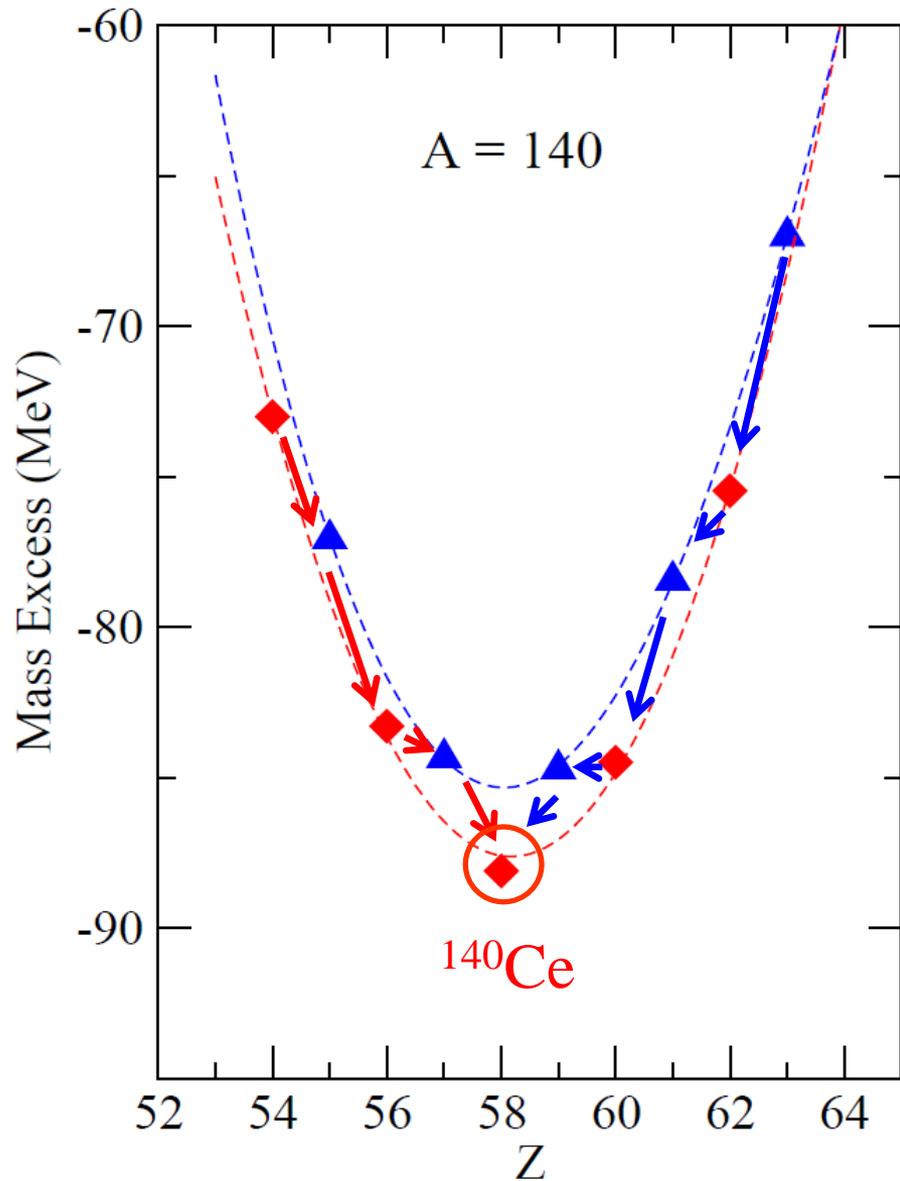
$$\Delta_n \sim \frac{12}{\sqrt{A}} \text{ MeV}$$

$$\begin{aligned}
 B_{\text{pair}} &= \Delta && \text{(for even - even)} \\
 &= 0 && \text{(for even - odd)} \\
 &= -\Delta && \text{(for odd - odd)}
 \end{aligned}$$

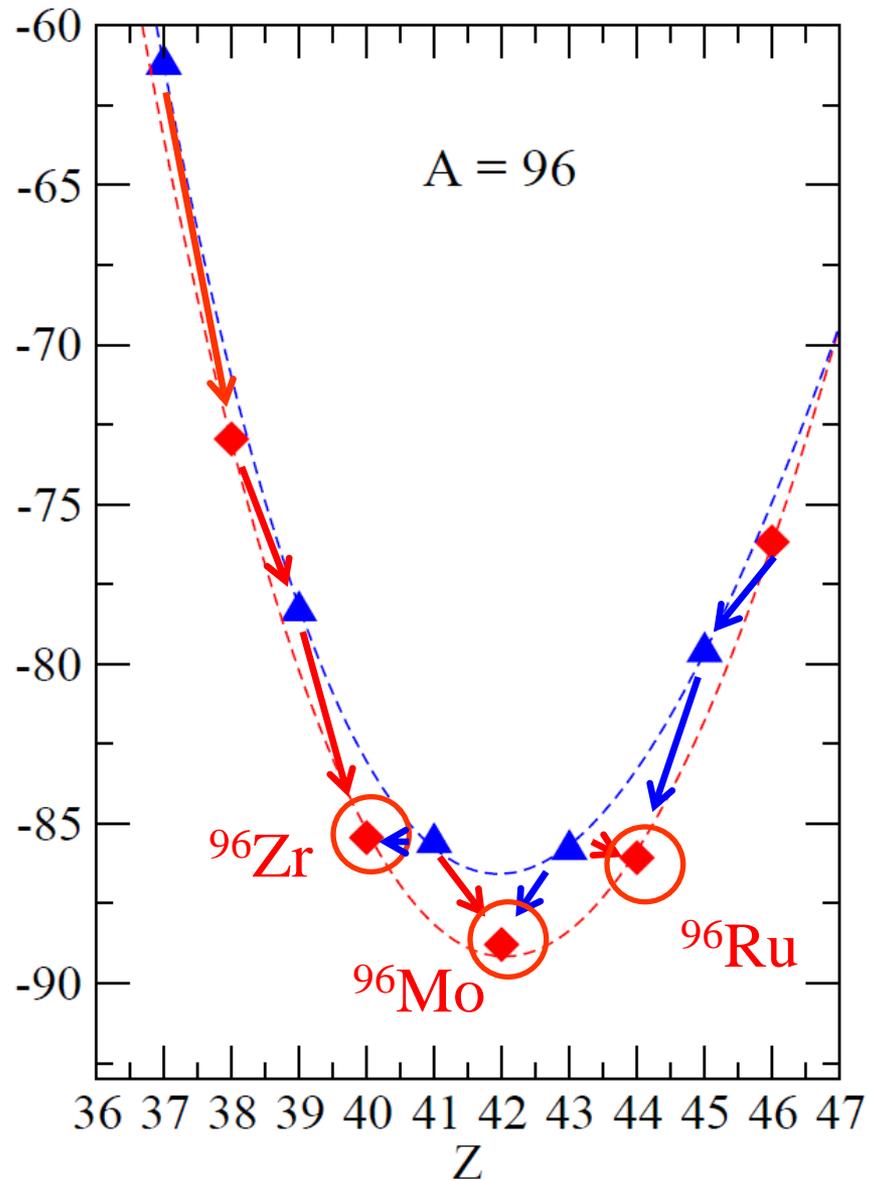




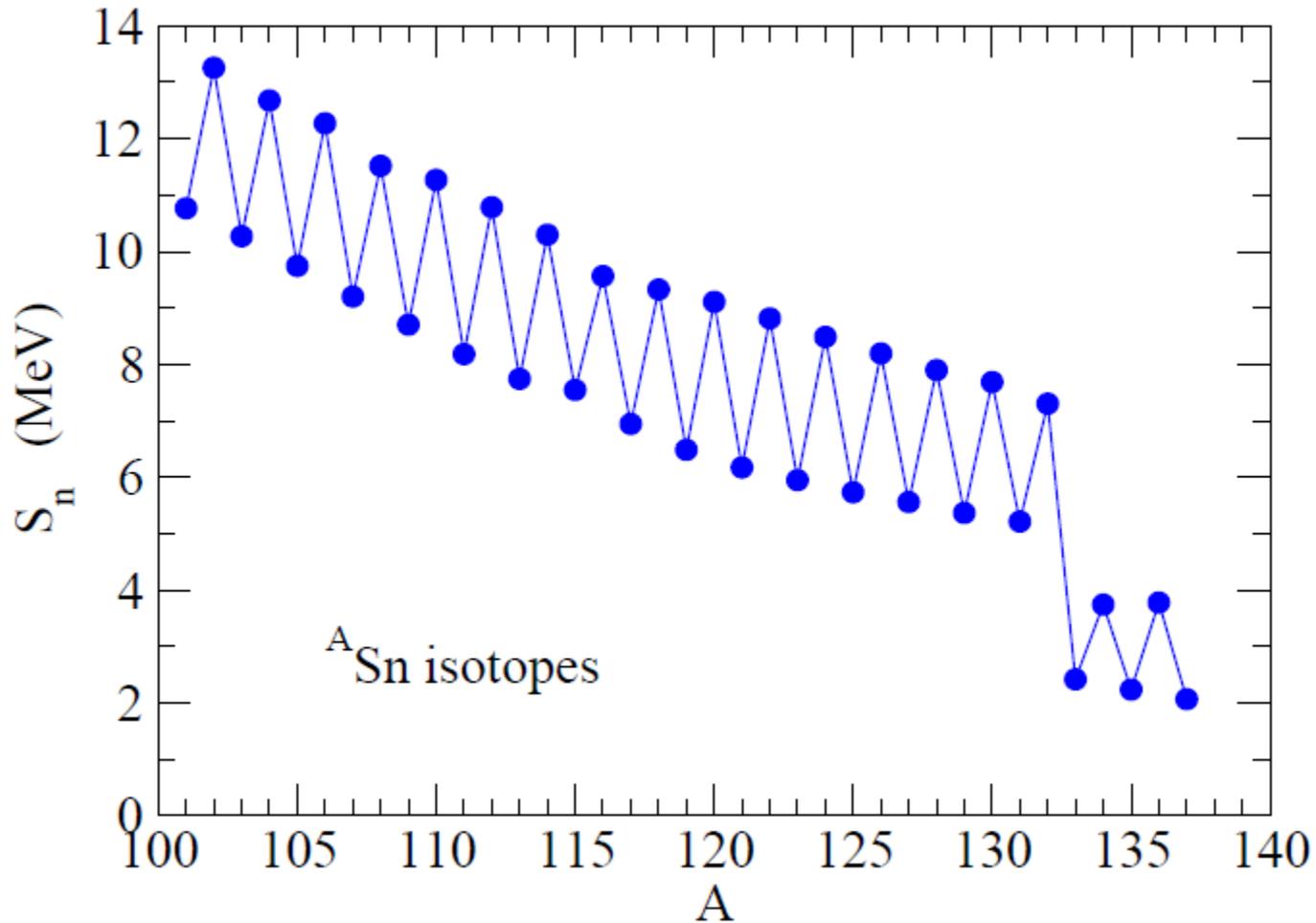
安定核が1つの場合



安定核が3つの場合



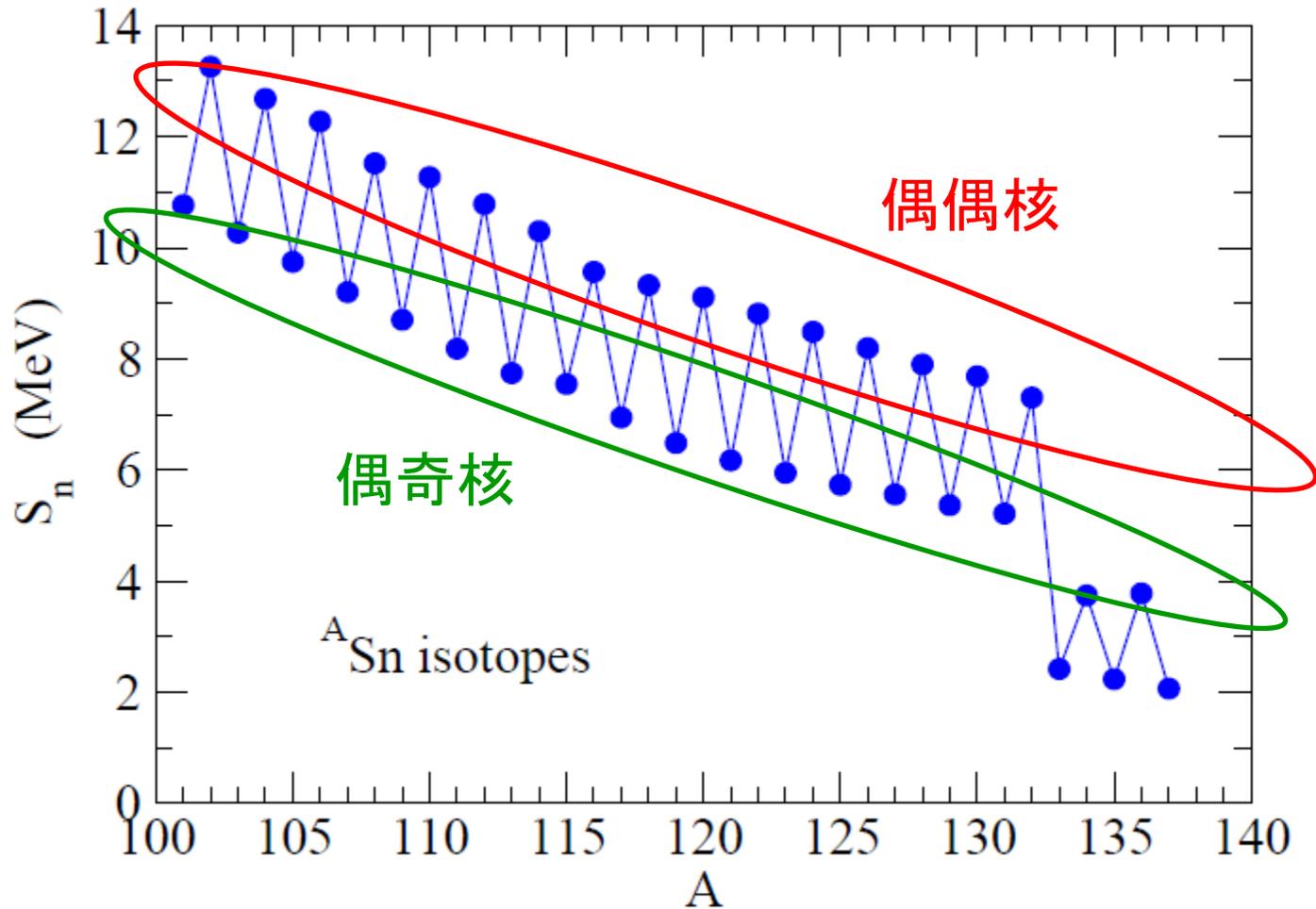
## 分離エネルギーにおける偶奇効果



1n separation energy:  $S_n (A,Z) = B(A,Z) - B(A-1,Z)$

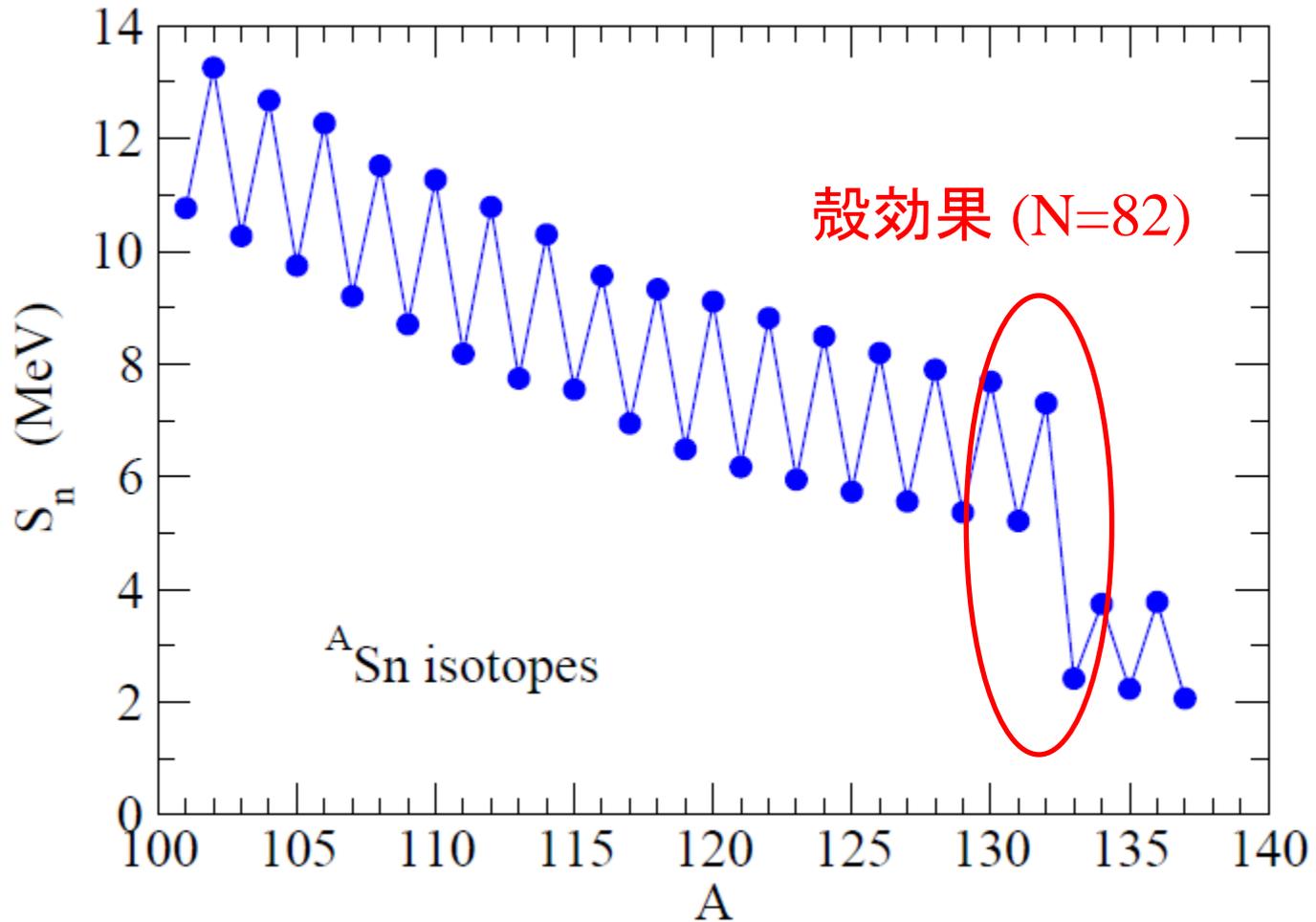
偶数個の中性子から1つ中性子  
を取る方が奇数個から取るより  
大きなエネルギーが必要

even-odd staggering



1n separation energy:  $S_n (A,Z) = B(A,Z) - B(A-1,Z)$

even-odd staggering



1n separation energy:  $S_n (A,Z) = B(A,Z) - B(A-1,Z)$

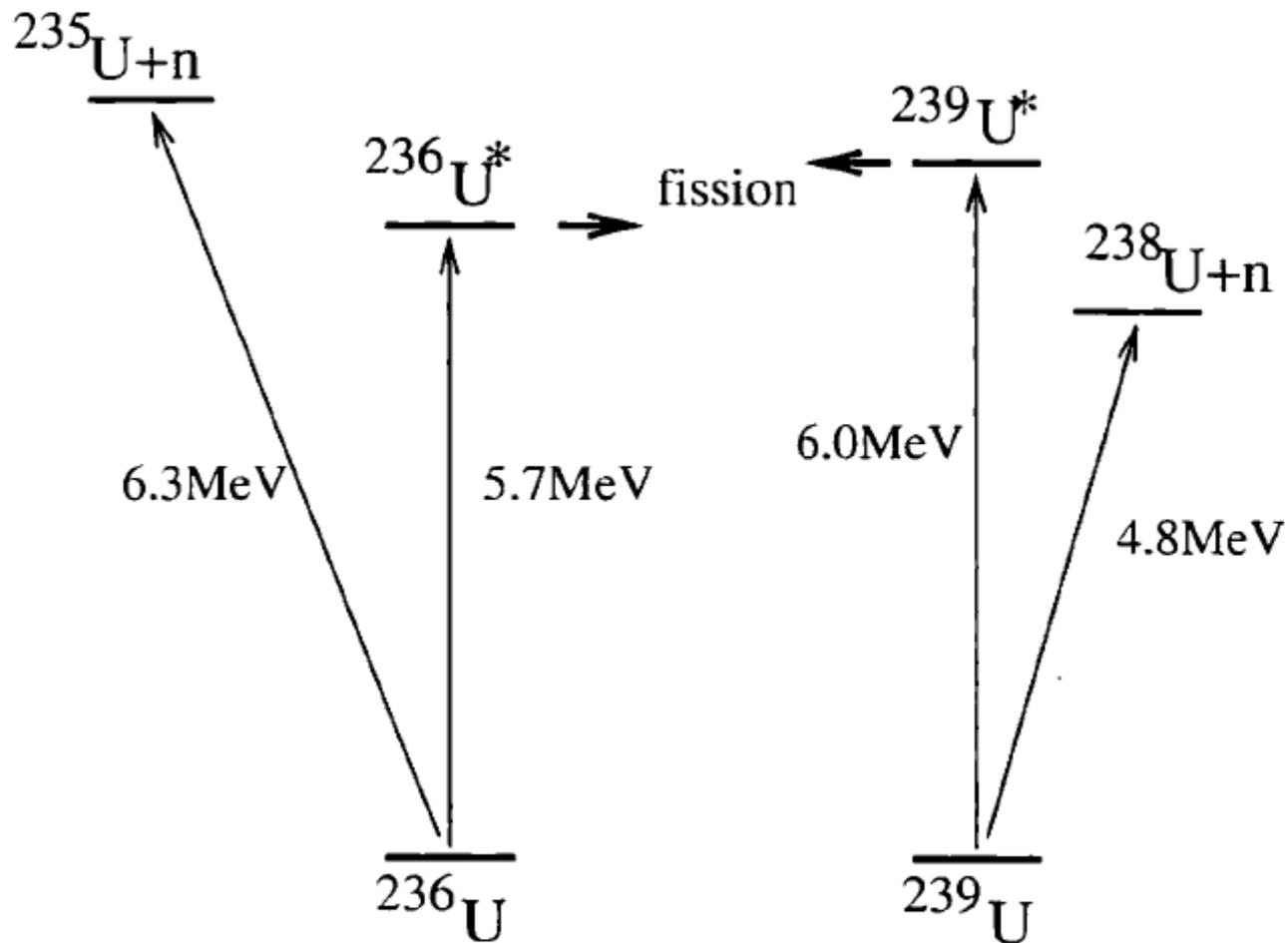


Fig. 6.6. Levels of the systems  $A = 236$  and  $A = 239$  involved in the fission of  $^{236}\text{U}$  and  $^{239}\text{U}$ . The addition of a motionless (or thermal) neutron to  $^{235}\text{U}$  can lead to the fission of  $^{236}\text{U}$ . On the other hand, fission of  $^{239}\text{U}$  requires the addition of a neutron of kinetic energy  $T_n = 6.0 - 4.8 = 1.2 \text{ MeV}$ .

核分裂障壁の高さと1中性子分離エネルギーの関係