Mass Formula (Even-odd mass difference)

Extra binding when like nucleons form a spin-zero pair

Example:

	Binding energy (MeV)
${}^{210}_{82}Pb_{128} = {}^{208}_{82}Pb_{126} + 2n$	1646.6
${}^{210}_{83}Bi_{127} = {}^{208}_{82}Pb_{126} + n + p$	1644.8
${}^{209}_{82}Pb_{127} = {}^{208}_{82}Pb_{126} + n$	1640.4
${}^{209}_{83}Bi_{126} = {}^{208}_{82}Pb_{126} + p$	1640.2

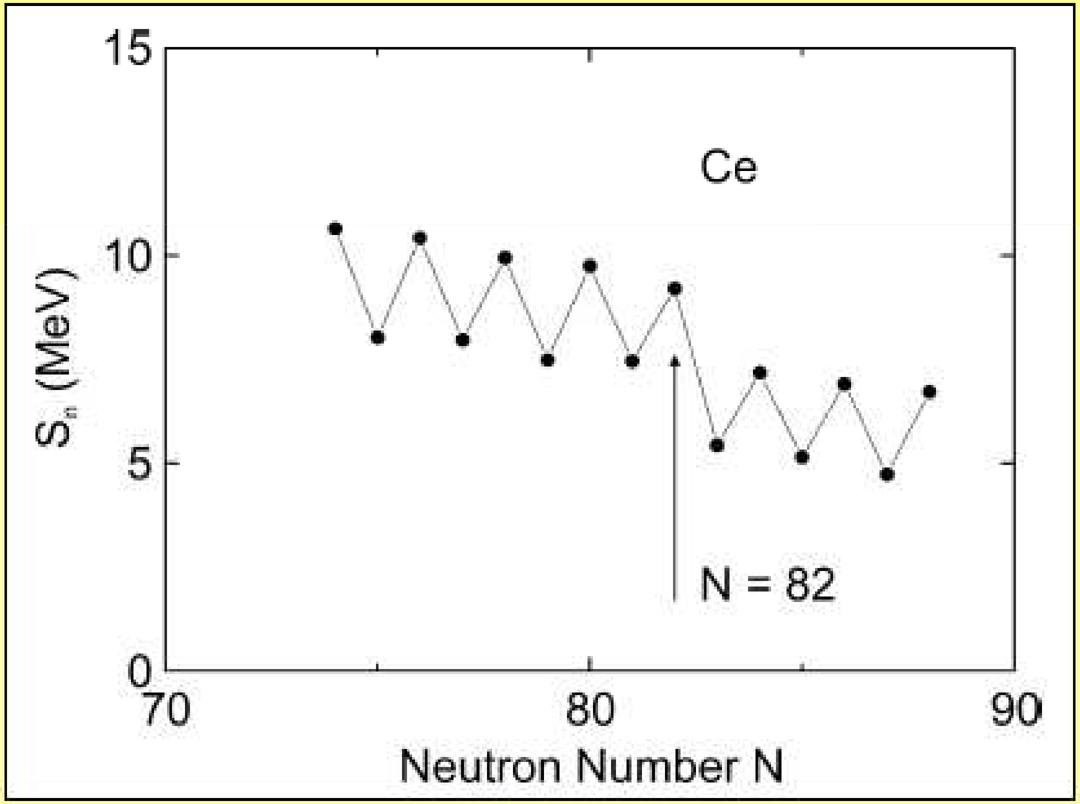
$$\begin{aligned} B_{\text{pair}} &= \Delta && \text{(for even} - \text{even)} \\ &= 0 && \text{(for even} - \text{odd)} \\ &= -\Delta && \text{(for odd} - \text{odd)} \end{aligned}$$

More later

Evidence for Pairing Correlations in Nuclei

(i) Odd-even effect: mass of an odd-even nucleus is larger than the mean of adjacent two even-even nuclear masses → shows up in S_n and S_p for all nuclei.

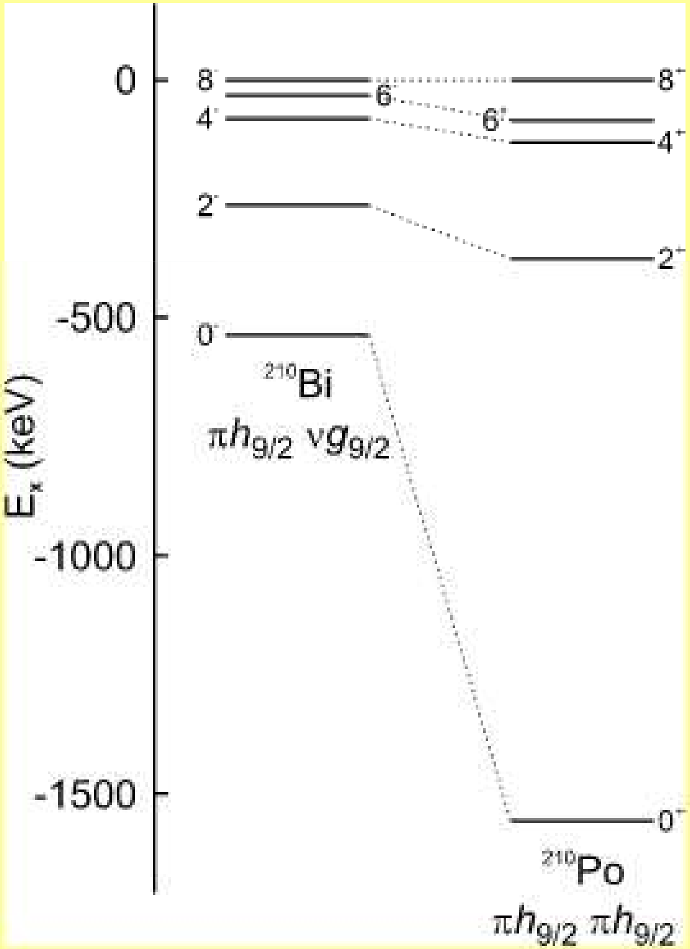
Example: $S_n = BE(A,Z) - BE(A\text{-}1,Z)$ of Ce nuclei



- Behavior points towards pair formation of nucleons.

Evidence for pairing correlations in nuclei

(ii) Energy spectra for nuclei near closed shells (A ± 2, A ± 4) show a clear gap for the 0^+ g.s.



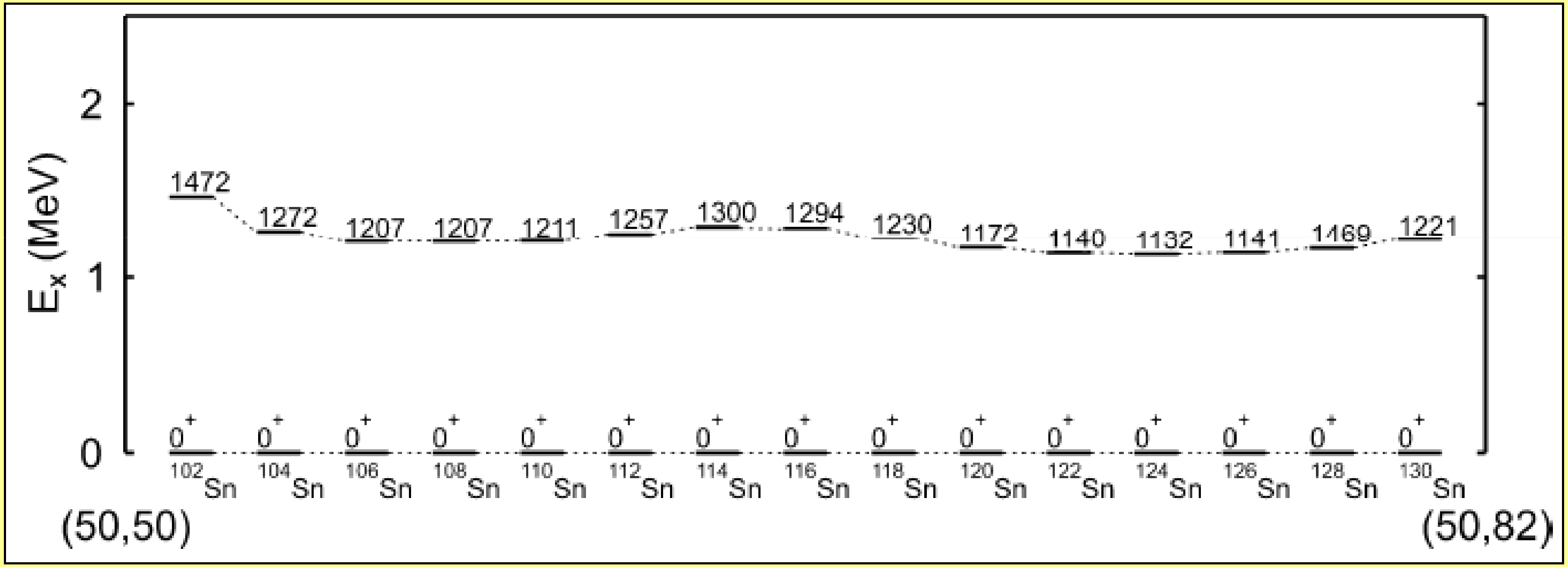
- In ^{210}Po the configuration outside the doubly-closed shell core of ^{208}Pb is $(1h_{9/2})^2$. If there were no interaction between the two π's constituting the pair, i.e. if they behaved like independent particles, the various $(1h_{9/2})^2$ spin couplings, which reflect the orbital alignments, would lead to states degenerate in energy.

  → correlated pair of two π's

- Pairing effect ≈ 2Δ

Evidence for Pairing Correlations in Nuclei

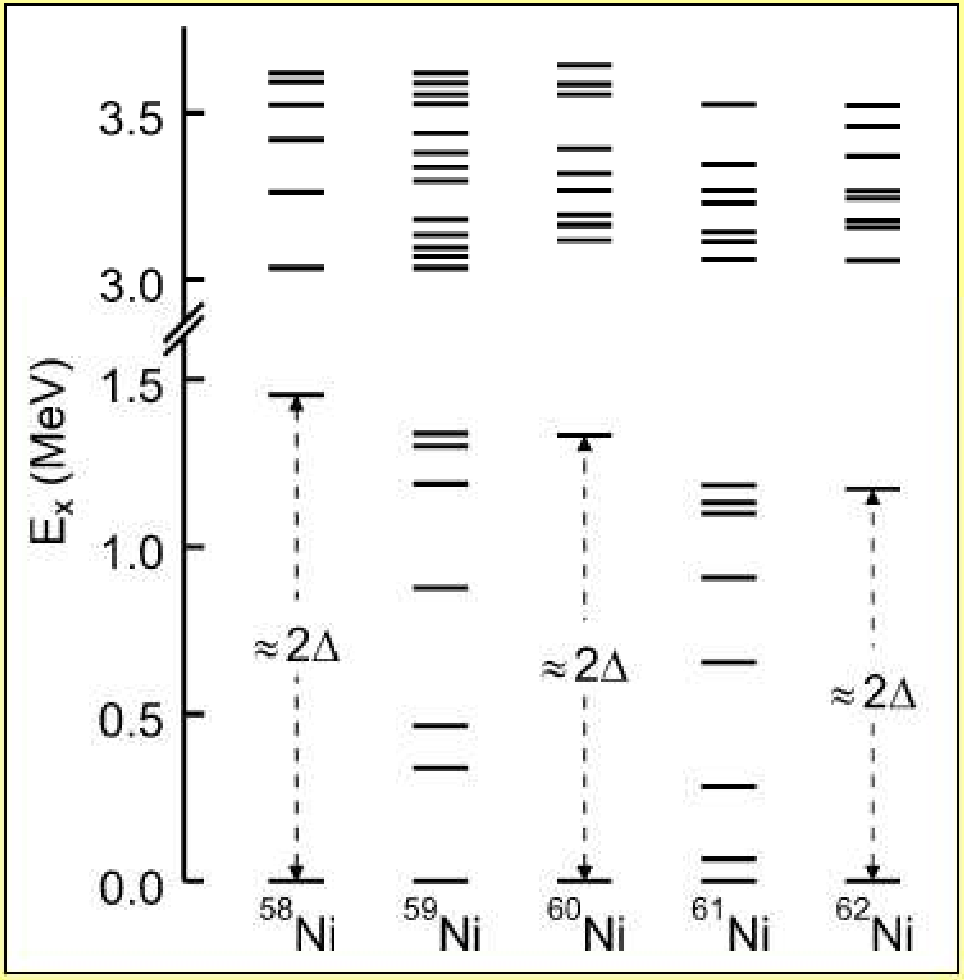
(ii) The excitation energy of the first excited 2^+ state in nuclei remains remarkably constant over large intervals of neutron (proton) numbers.
Example: 2^+_1 excitation energy in Sn nuclei



- These 2^+ states are not rotational states but are connected to a coherent pairing condensate.
- Pair breaking energy: $2\Delta \approx 2$ MeV

Evidence for Pairing Correlations in Nuclei

(iii) Energy gap: odd-even and even-odd nuclei (especially deformed nuclei) have energy spectra different from even-even nuclei.
Example: Ni isotopes



- e-e nuclei: only a few states at most (vibrations, rotations) appear below the pairing gap 2Δ.
- But in o-e and e-o nuclei (where the last nucleon is unpaired) many s.p. and collective states appear.
- Note: above the pair breaking energy 2Δ many excited states are possible → level density $\rho = \rho(\Delta)$
  → **2nd Lecture**

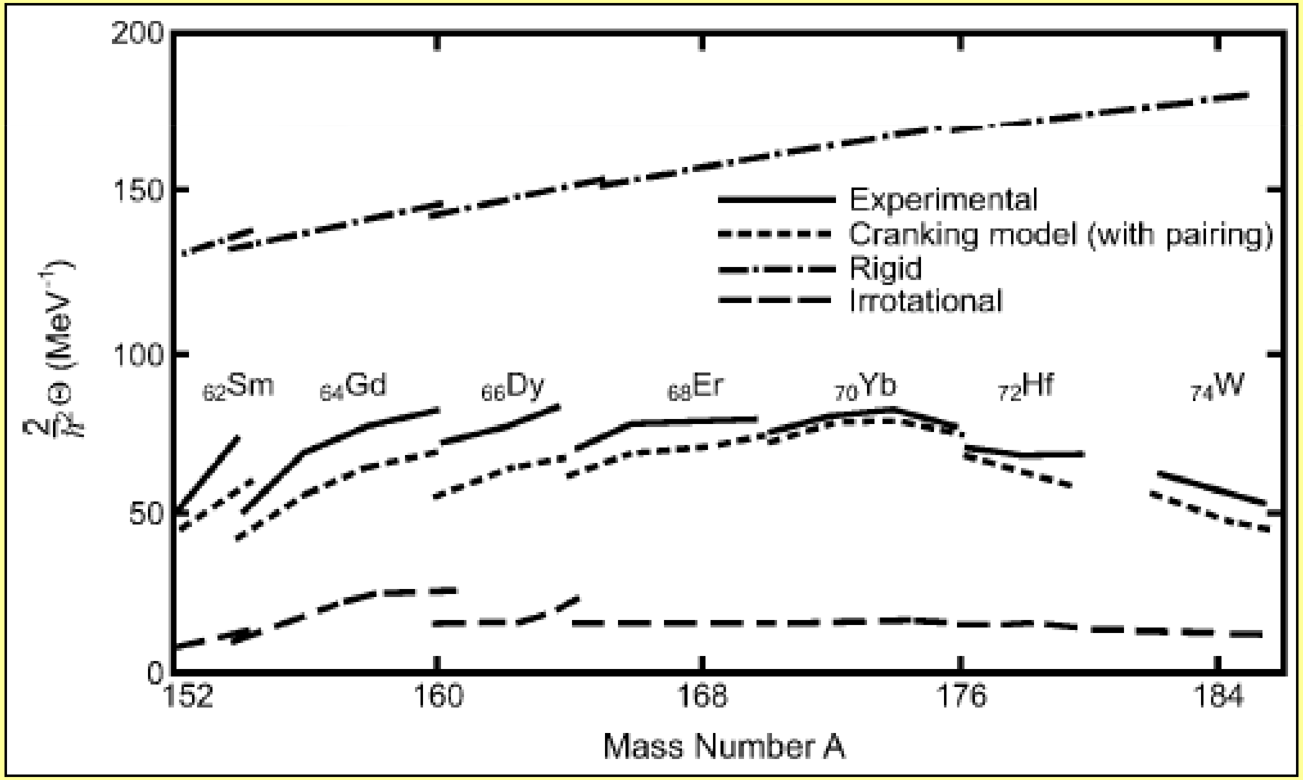
Evidence for Pairing Correlations in Nuclei

(iv) Moment of inertia: extracted from level spacing in rotational bands

$$E = \frac{\hbar^2}{2\Theta} J(J+1)$$

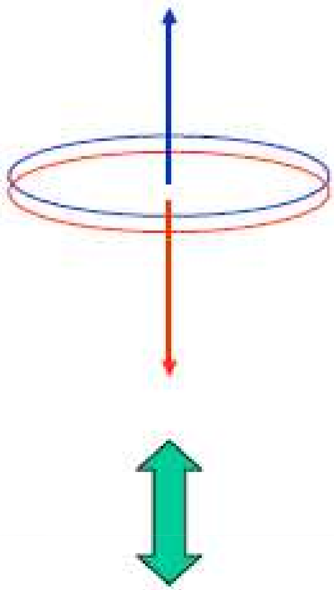
deviates about a factor of two from the rigid rotor values.

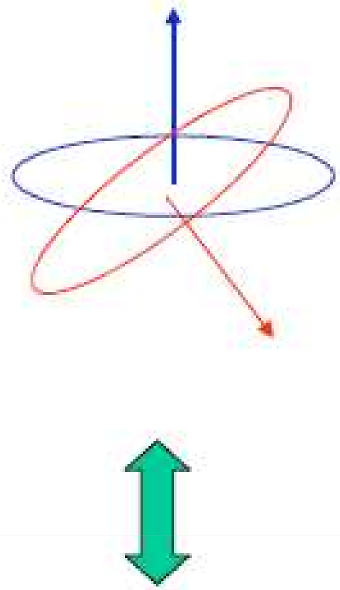
Example: Moments of inertia of even-nuclei in the rare-earth region



- $\Theta_{irrot} < \Theta_{exp} < \Theta_{rigid}$
- Pairing correlations have a dramatic influence on collective modes.

Simple interpretation:





I=0 pair	$I \neq 0$ pair

The spatial overlap is the largest for the I=0 pair.

"Pairing Correlation"

(note) The I=2j pair is unfavoured due to the Pauli principle.

(note)

$$\psi(l^2; L=0) = \sum_{\mu} \langle l\mu l-\mu | L=0,0\rangle\, Y_{l\mu}(\hat{\boldsymbol{r}}_1) Y_{l-\mu}(\hat{\boldsymbol{r}}_2) = Y_{l0}(\theta_{12})/\sqrt{4\pi}$$