Coupling of α- and t-cluster Structures in Excited Deformed States of ^{35}Cl
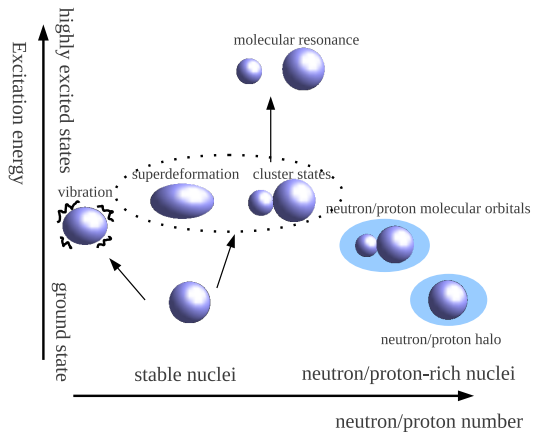
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The 26th International Nuclear Physics Conference (INPC2016),
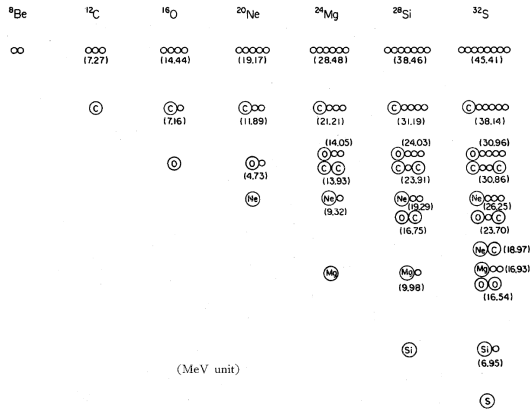Adelaide, Australia,
September 11-16, 2016

Cluster structures coupling to deformed states

- Clustering and deformation are important for nuclear structure changes.
- Cluster components couple to deformed states.

Candidates of mechanism of cluster correlations in deformed states
Threshold energy rule

(MeV unit)

[H. Hriuchi et al, Prog. Theor. Phys. Suppl. 52, 89 (1972)]
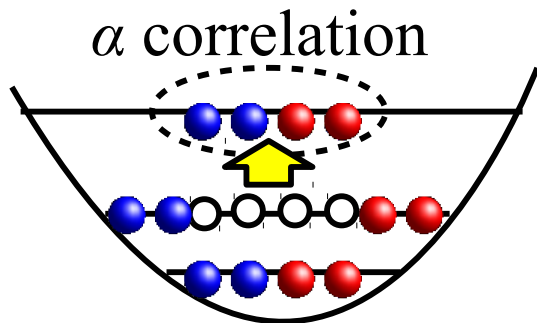
Threshold energy rule

Cluster structures develop in excited states whose excitation energies are similar to threshold energies of the cluster decay.

- It works well to p-shell nuclei.
- It does not work to heavier nuclei.
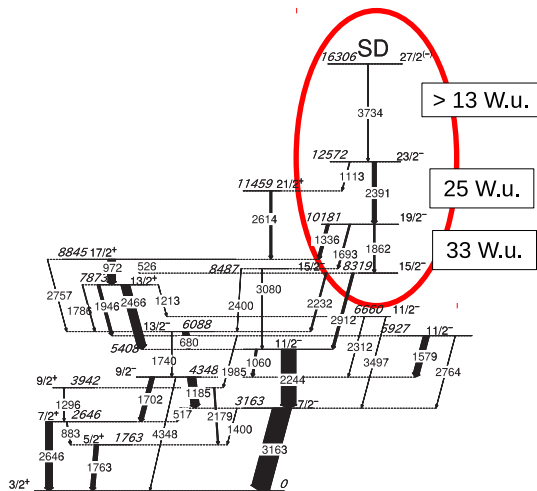
α correlation

Particle-hole (ph) configurations and clustering

Nucleons excited to a higher shell correlate and form a cluster.

- It is an open problem whether this rule works well for various nuclei such as odd nuclei.

Deformed states in ^{35}Cl

[Original: A. Bisoi et al, Phys. Rev. C 88, 034303 (2013)]

- A negative-parity deformed band was observed by a γ-spectroscopy experiment.
- It is predicted that this deformed states have α-^{31}P cluster structure.
- There is no evidence for α-clustering.

Aims

- Structure of the negative-parity deformed band.
- α-^{31}P and t-^{32}S clustering.
- Mechanism of coupling of cluster structure to deformed states.

Wave functions: deformed-basis antisymmetrized molecular dynamics (AMD)

$$|\Phi\rangle = \hat{\mathcal{A}} |\varphi_1, \ \varphi_2, \cdots, \varphi_A\rangle.$$

φ_i: deformed Gaussian wave packet

Energy variational calculation with a constraint potential

$$\delta \left[\left\langle \hat{P}^\pi \Phi \, \middle| \, \hat{H} \, \middle| \, \hat{P}^\pi \Phi \right\rangle + V_{\mathrm{cnst}} \right] = 0$$

effective interaction $\hat{H}$: Gogny D1S

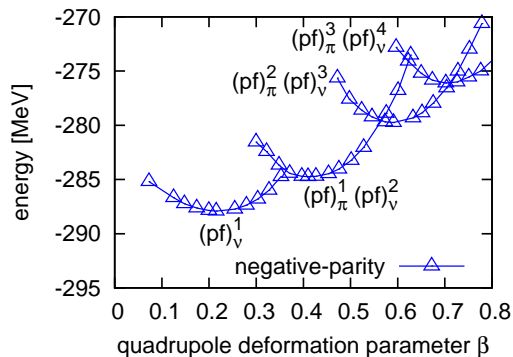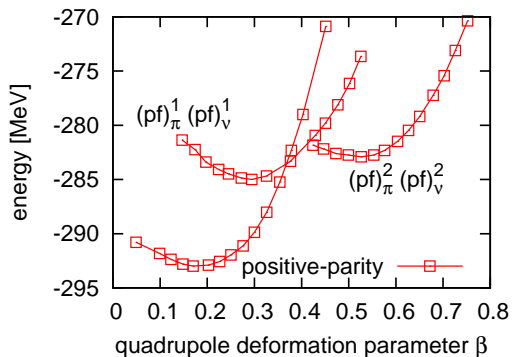V_{cnst}: quadrupole deformation parameter β
   intercluster distance between $\underline{\alpha\text{-}^{31}P}$ and $\underline{t\text{-}^{32}S}$

Conjugate gradient method.

Generator coordinate method (GCM)

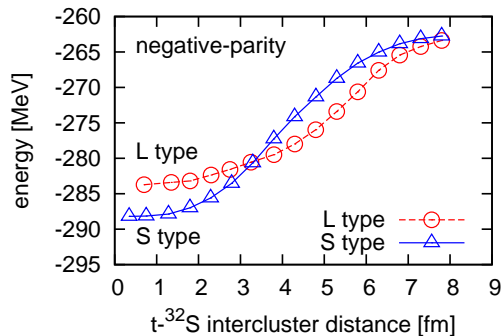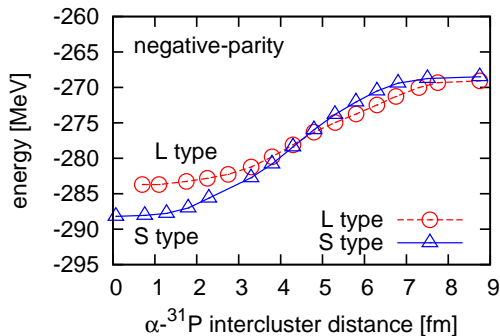$$\left|\Phi_n^{J\pi M}\right\rangle = \sum_i f_{ni} \hat{P}^J_{MK_i} \hat{P}^\pi |\Phi_i\rangle$$
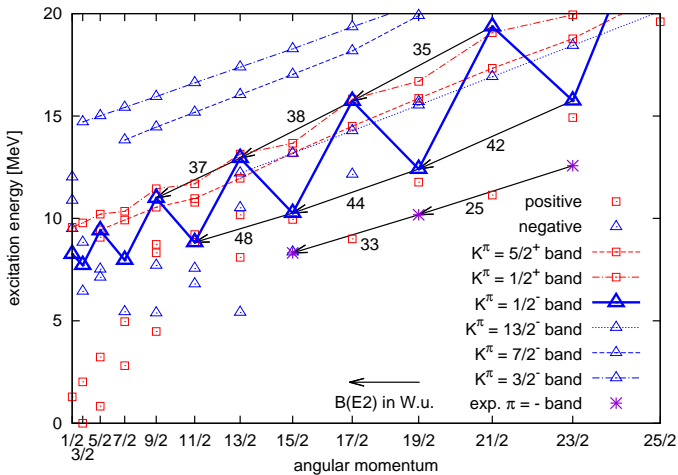
β-energy curves

- In negative-parity states, a local minimum with $3\hbar\omega$ excited configurations exists at $\beta \sim 0.4$.

Negative-parity α-^{31}P and t-^{32}S cluster wave functions

- In the L/S type, a smaller cluster is on the long/short axis of a larger cluster.
- Energies of L type wave functions of α-^{31}P and t-^{32}S cluster structures are similar in small intercluster distance region.
- Energy of L type wave functions with small intercluster distance is similar to that of $3\hbar\omega$ configurations on the β-energy curve.
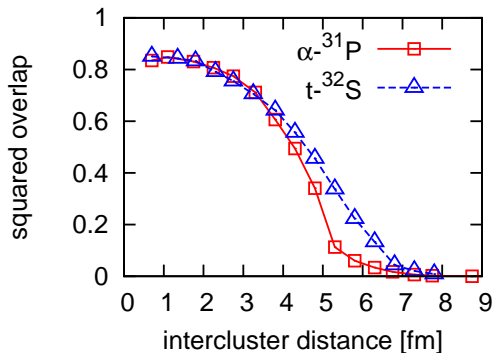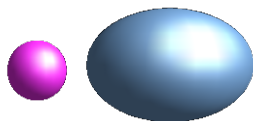
Level scheme of ^{35}Cl

- Various deformed bands such as a $K^\pi = \frac{1}{2}^-$ are obtained.
- Dominant components of the $K^\pi = \frac{1}{2}^-$ band have $3\hbar\omega$ excited configurations on the β-energy curve.
- The $K^\pi = \frac{1}{2}^-$ deformed band corresponds to the observed deformed band.

α- and t-cluster structure components in the $K^{\pi} = \frac{1}{2}^-$ deformed band

$J^{\pi} = \frac{1}{2}^-$ ($K^{\pi} = \frac{1}{2}^-$ band)

- The $K^{\pi} = \frac{1}{2}^-$ deformed states contain similar amounts of L type α-^{31}P and t-^{32}S cluster structure components even in surface region.
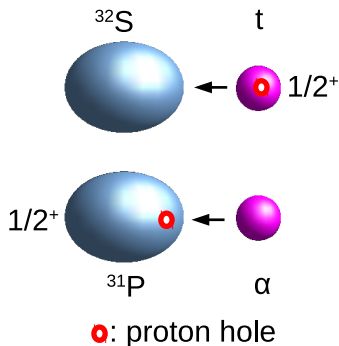

- Threshold energy is not important for coupling to deformed states.

$$E_{\mathrm{th}}(\alpha) = 7 \text{ MeV}$$
$$E_{\mathrm{th}}(t) = 18 \text{ MeV}$$

^{32}S   t

$1/2^+$

$1/2^+$

^{31}P   α

o: proton hole

- L type α- and t-cluster structure become $\underline{3\hbar\omega}$ excited configurations in small intercluster distance.
- sd-shell orbits in a ^{32}S cluster are fully occupied in the direction of the long axis.
- A ^{31}P cluster has a proton hole at a sd-shell orbit in the direction of the long axis.

Mechanism of coupling of cluster structure to deformed states

small distance Similar ph-configurations of cluster structure and deformed states.

large distance Structure of cluster wave functions change gradually with increasing intercluster distance.

Conclusions

- Structure of excited states in ^{35}Cl are investigated by using the AMD and the GCM.
- The observed negative-parity deformed band corresponds to the theoretical $K^\pi = \frac{1}{2}^-$ band.
- The $K^\pi = \frac{1}{2}^-$ band contain large amounts of α-^{31}P and t-^{32}S cluster structure components even in surface region.
- Threshold energy is <u>not</u> important of coupling of cluster structure to deformed states.
- Particle-hole configurations of cluster structures with small intercluster distance are important for coupling to low-lying deformed states.