

# Isoscalar pairing and pairs in nuclei

P. Van Isacker, GANIL, France

Properties of isoscalar-pair condensates

Pair vibrations and pair rotations

$T=1$  pair vibrations

$T=0$  pair vibrations?

Aligned neutron-proton pairs?

# Pairing and other interactions

Pairing refers to the interaction between nucleons in 'time-reversed orbits':

- *isovector (or singlet) pairing:*  $J=0$  &  $T=1$
- *isoscalar (or triplet) pairing:*  $J=1$  &  $T=0$

Aligned np interaction:  $J=2j$  &  $T=0$

# Neutron-proton pairing hamiltonian

Pairing hamiltonian in  $LS$  coupling:

$$\hat{V}_{LS}(g, x) = -xg\hat{V}_{L=0, S=0, T=1} - (1-x)g\hat{V}_{L=0, S=1, T=0}$$

Properties (for a single- $l$  shell):

$SO(8)$  algebraic structure;

solvable for  $x=0$ ,  $x=1/2$  &  $x=1$ ;

reasonable ansatz in nuclei:  $x=1/2$ .

# Neutron-proton pairing hamiltonian

Pairing hamiltonian in  $jj$  coupling:

$$\hat{V}_{jj}(g, x) = -x g \hat{V}_{J=0, T=1} - (1-x) g \hat{V}_{J=1, T=0}$$

Properties (for a single- $j$  shell):

*solvable for  $x=1$  based on  $Sp(2j+1)$ ;*

*$x=1$  solution based on quasi-spin algebra  $SO(5)$ ;*

*solution for  $x=0$ ?*

# Isoscalar-pair condensate

Augusto Macchiavelli: The lowest eigenstate of an isoscalar pairing hamiltonian in a single- $j$  shell is found to be spin-aligned (e.g.,  $2^+$  for  $2n+2p$ ).

How to understand this result?

*Map onto p-boson hamiltonian;*

*For an attractive isoscalar pairing interaction the boson-boson matrix elements are repulsive;*

*The  $\lambda=2$  interaction is less repulsive than  $\lambda=0$ .*

=> The spin-aligned state is favoured over the paired state due to Pauli (finite-shell) effects.

# Pair vibrations & rotations

Pairing hamiltonian for several shells. For two shells and identical nucleons:

$$\hat{H}(\Delta\varepsilon, g) = \Delta\varepsilon(\hat{n}_+ - \hat{n}_-) - g\hat{V}_{J=0,T=1}$$

Phase transition occurs as a function of  $g/\Delta\varepsilon$ :

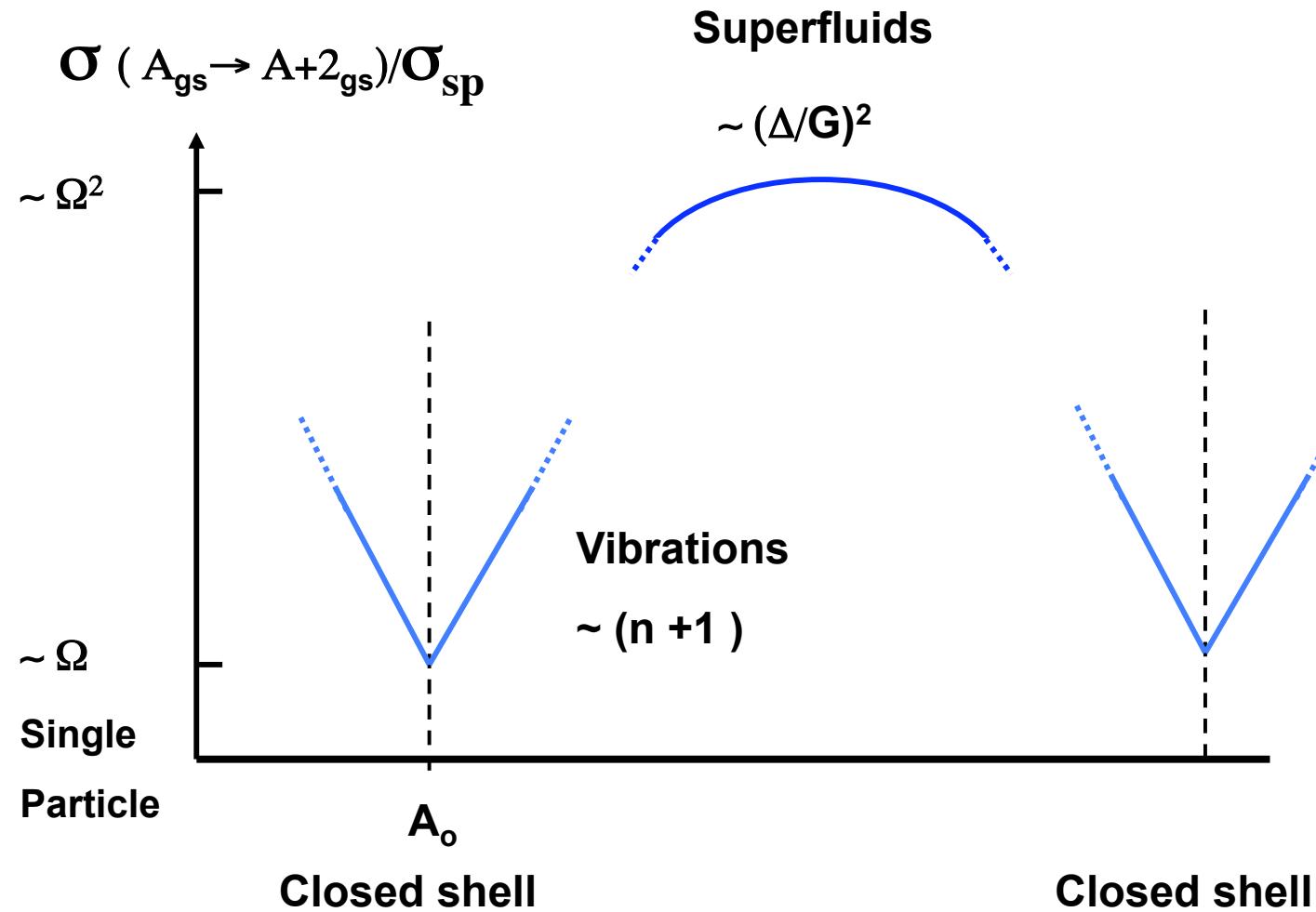
For  $g < g_{\text{crit}}$ : pair vibrations (ex: Pb isotopes)

For  $g > g_{\text{crit}}$ : pair rotations (ex: Sn isotopes)

Two different coupling schemes:

$$SU_+(2) \times SU_-(2) \supset \begin{pmatrix} U_+(1) \times U_-(1) \\ SU(2) \end{pmatrix} \supset U(1)$$

# Pair vibrations and rotations



# Neutron-proton correlations

The question is **not** whether  $T=0$  interactions between nucleons exist or whether they are important. They do and they are.

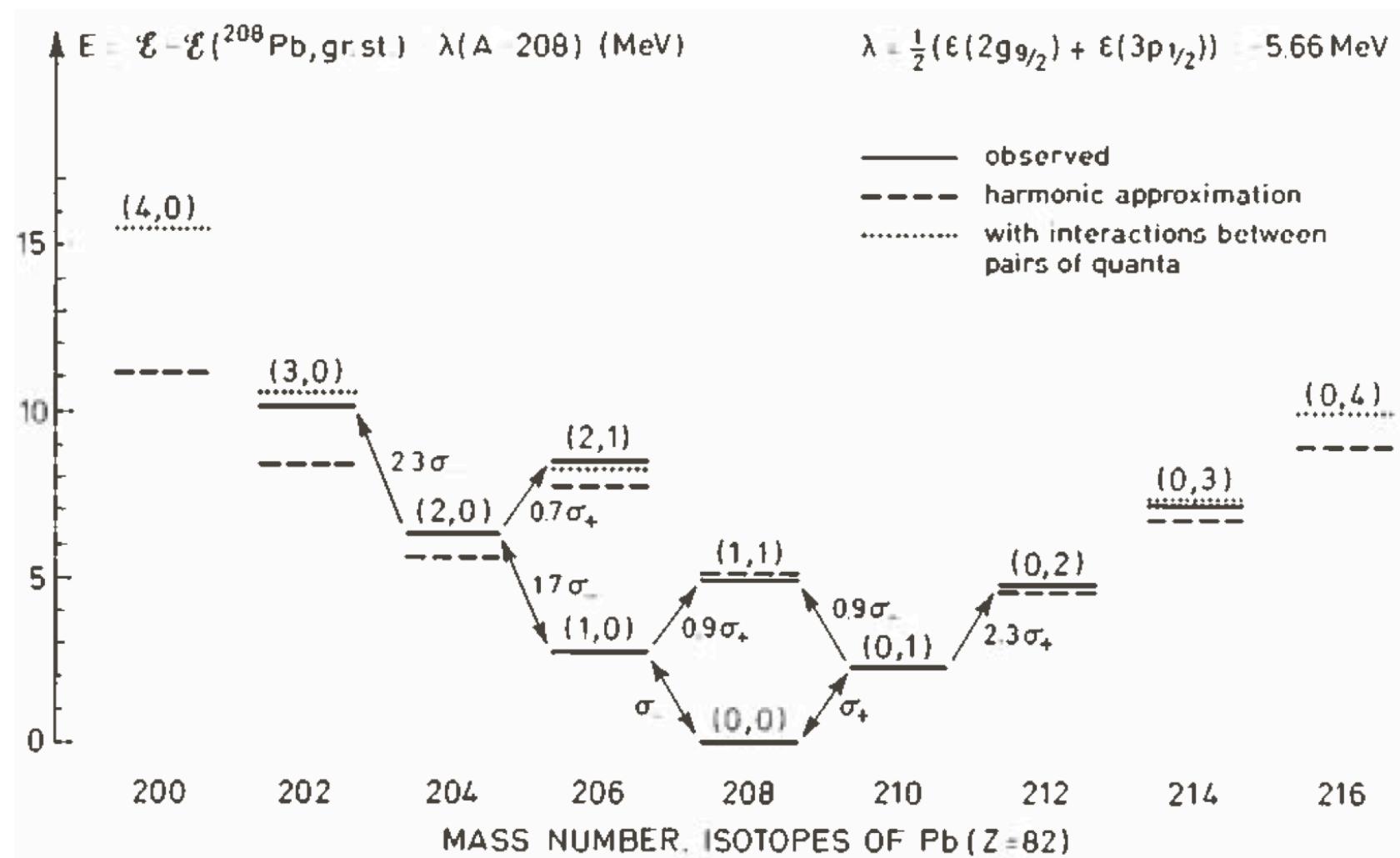
The question is whether

- $T=0$  pairing correlations exist?
- aligned  $T=0$  pairs are dominantly important?
- quartet correlations exist?

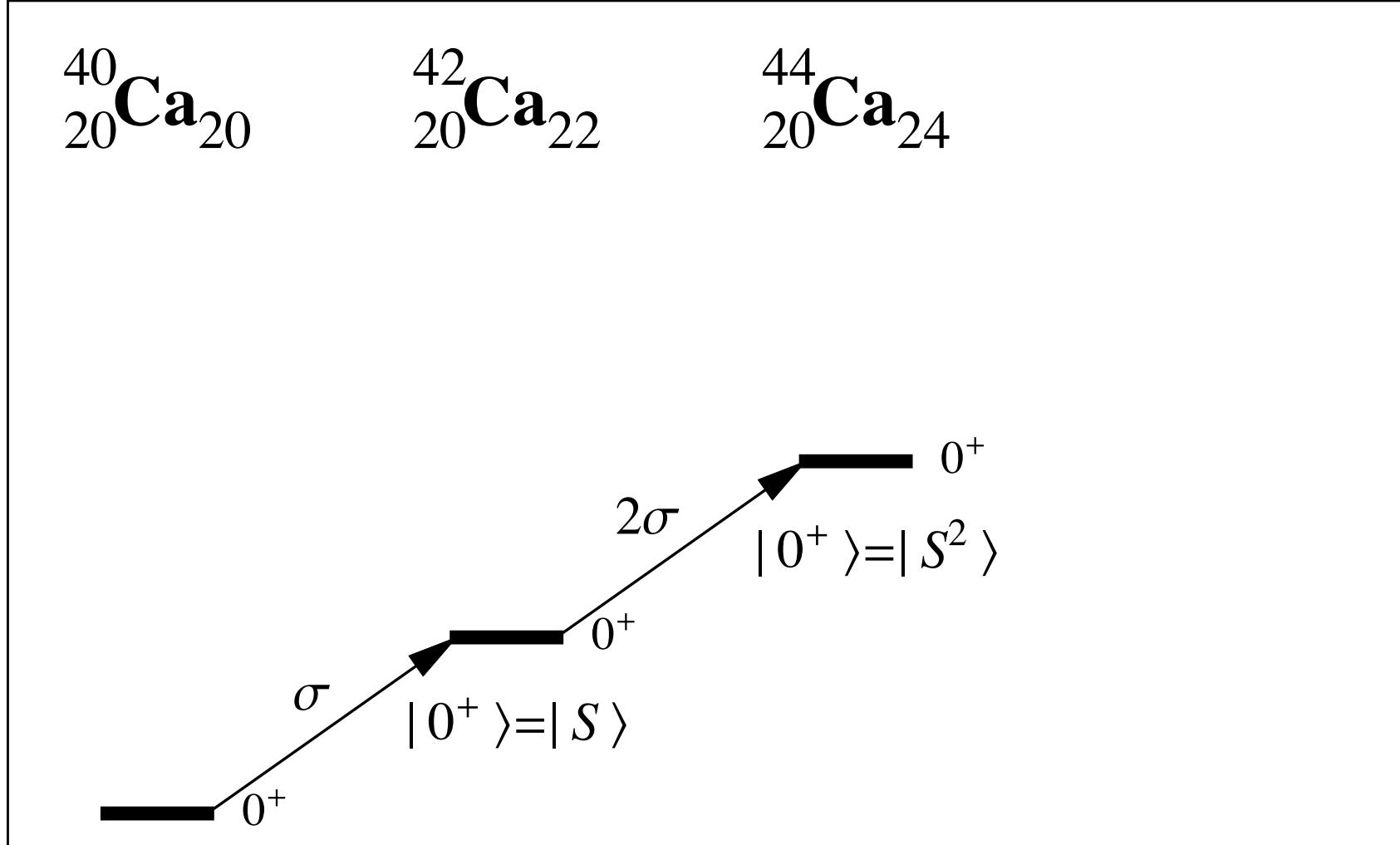
→ “Study of np pairing through two-nucleon transfer reactions” by M. Assié *et al.*

Here: an analysis in terms of pair vibrations.

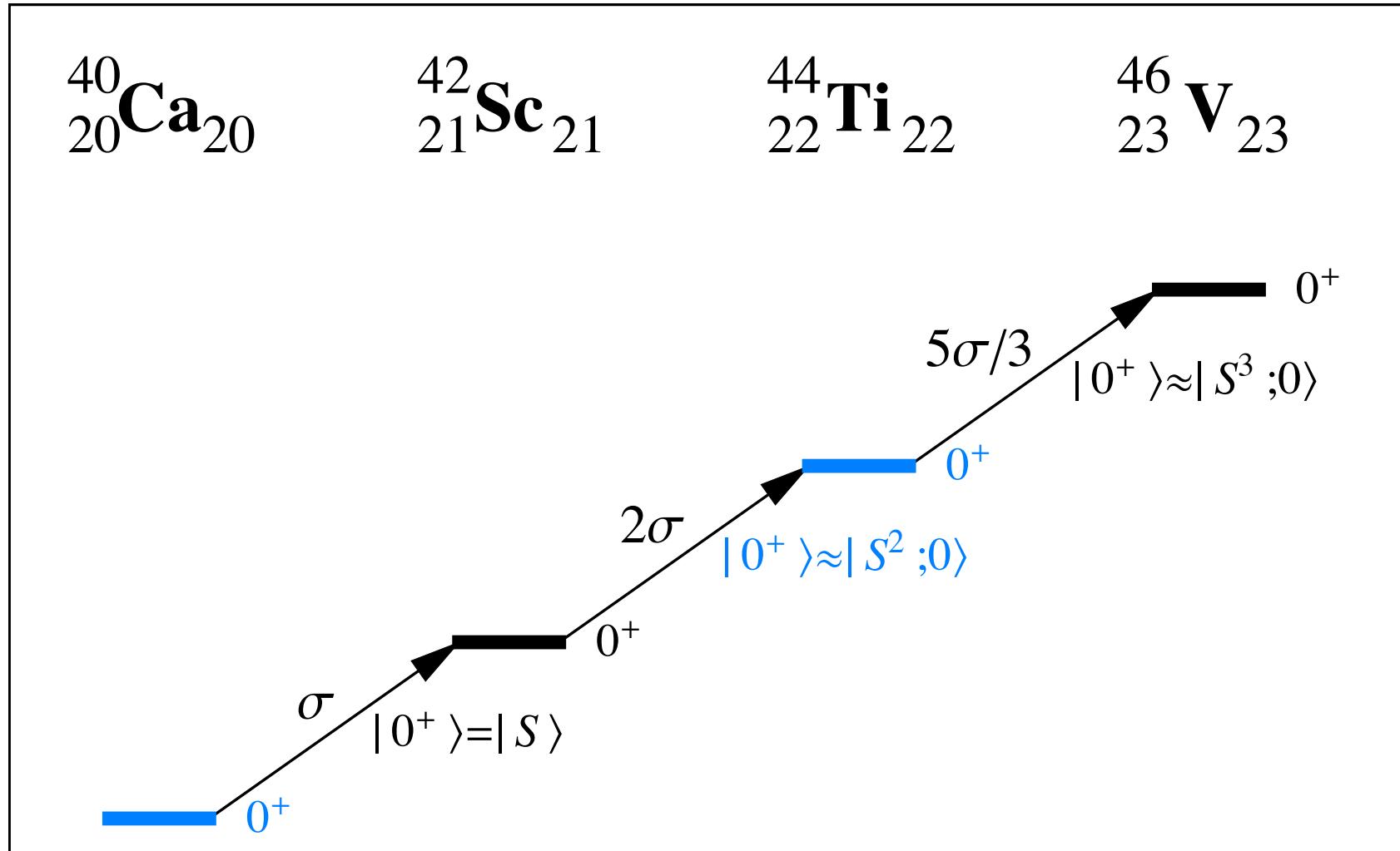
# $T=1$ pair vibrations in Pb



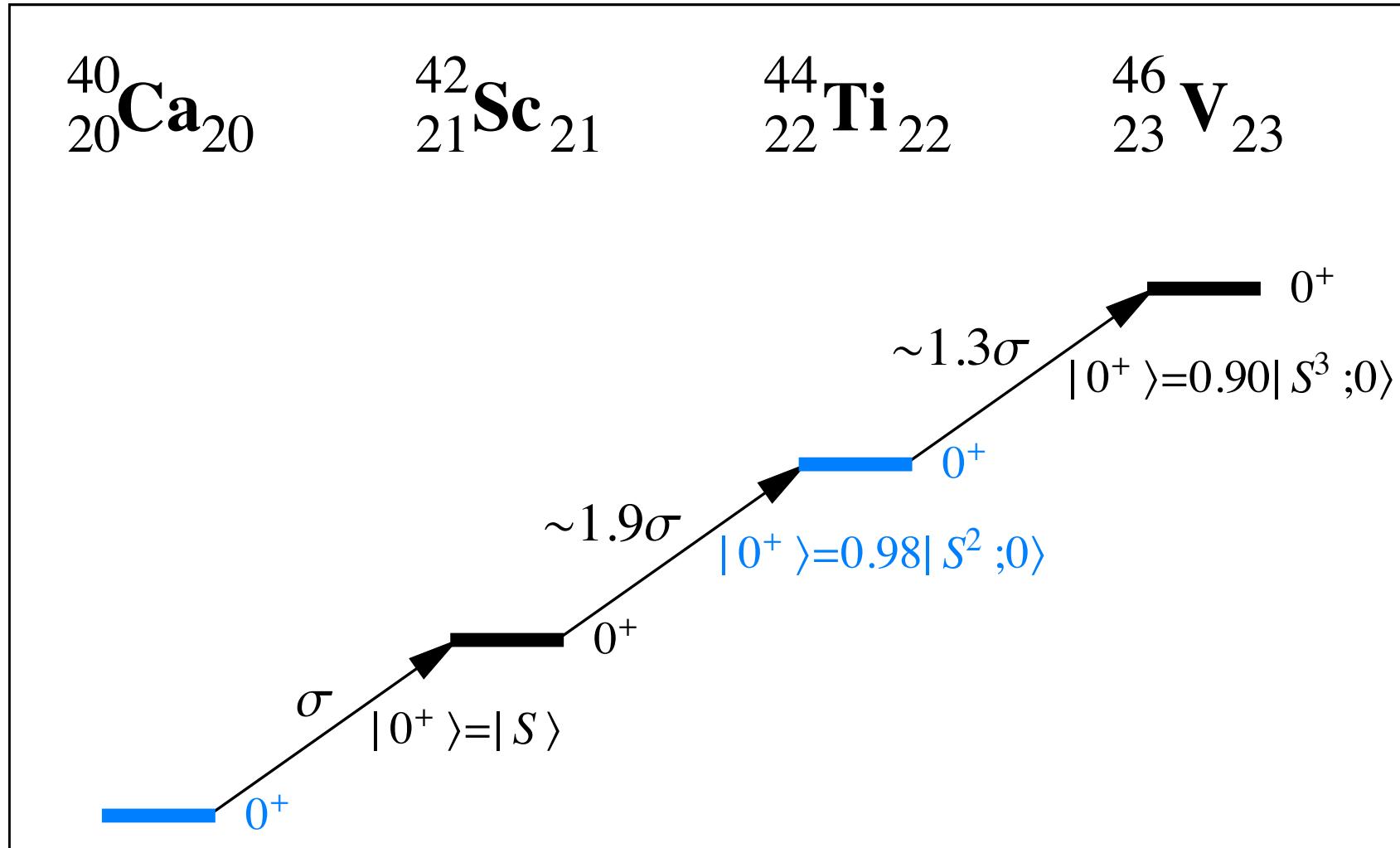
# $T=1$ pair vibrations in Ca



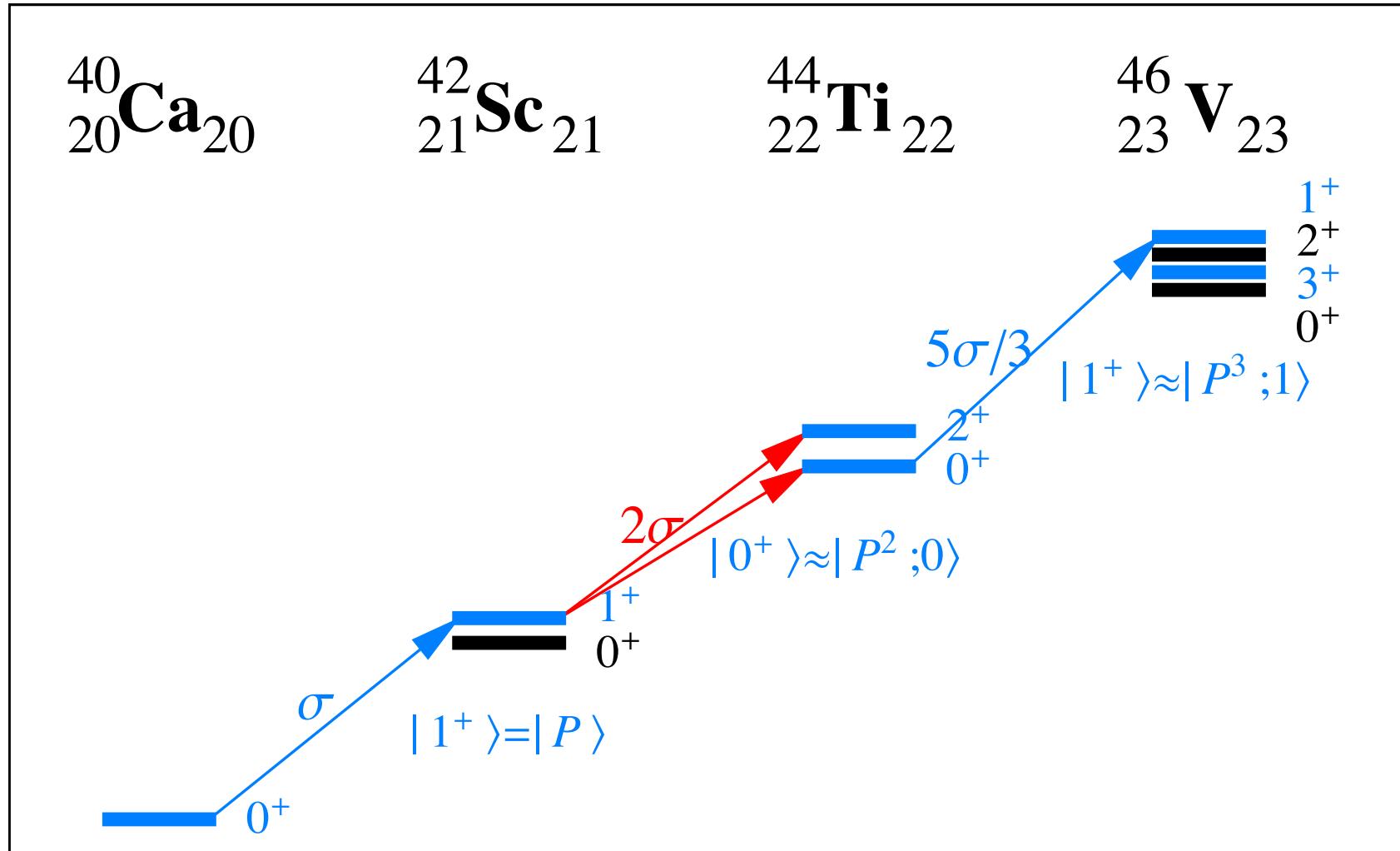
# $T=1$ pair vibrations in Ca-Sc-Ti-V?



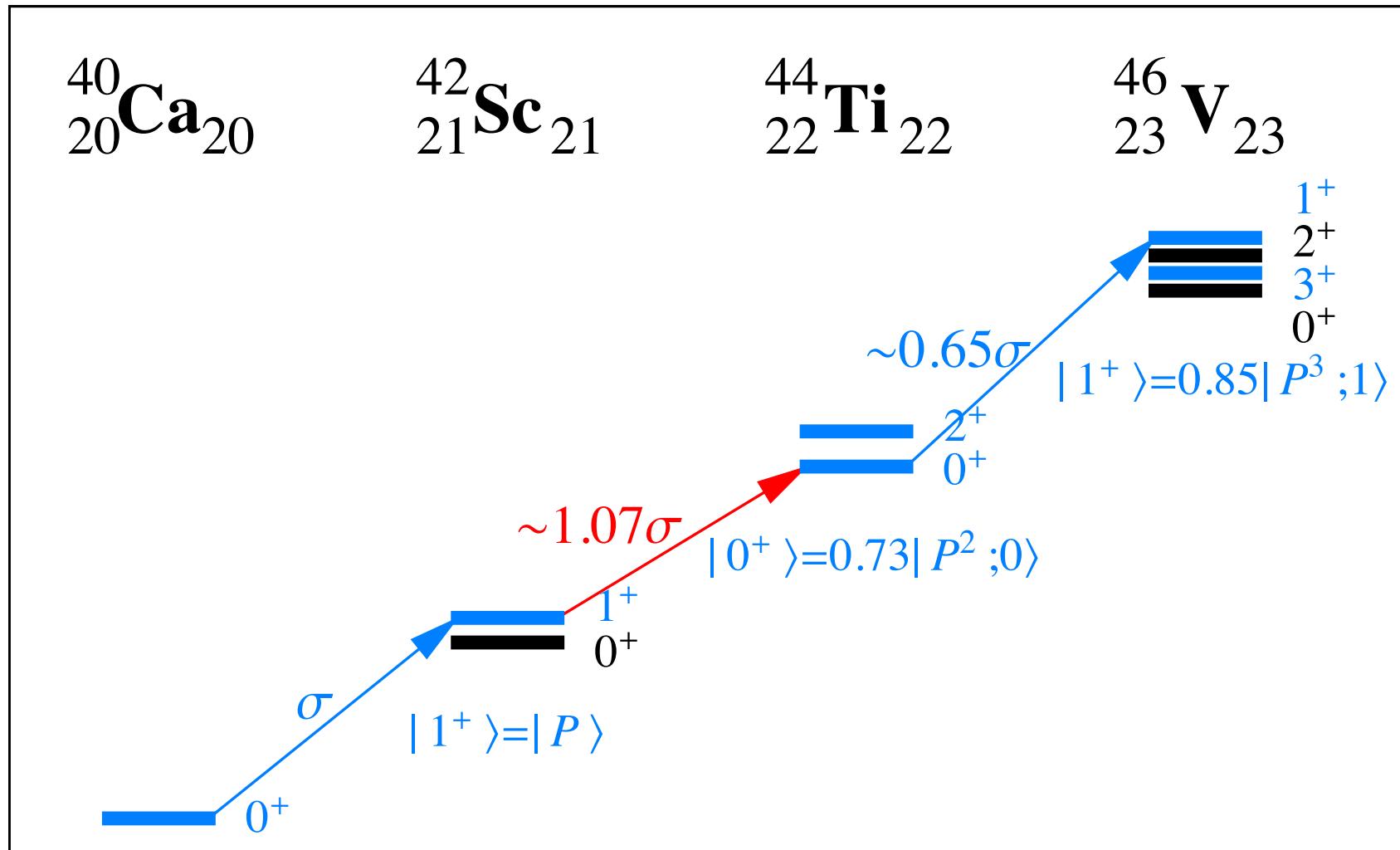
# $T=1$ pair vibrations in Ca-Sc-Ti-V?



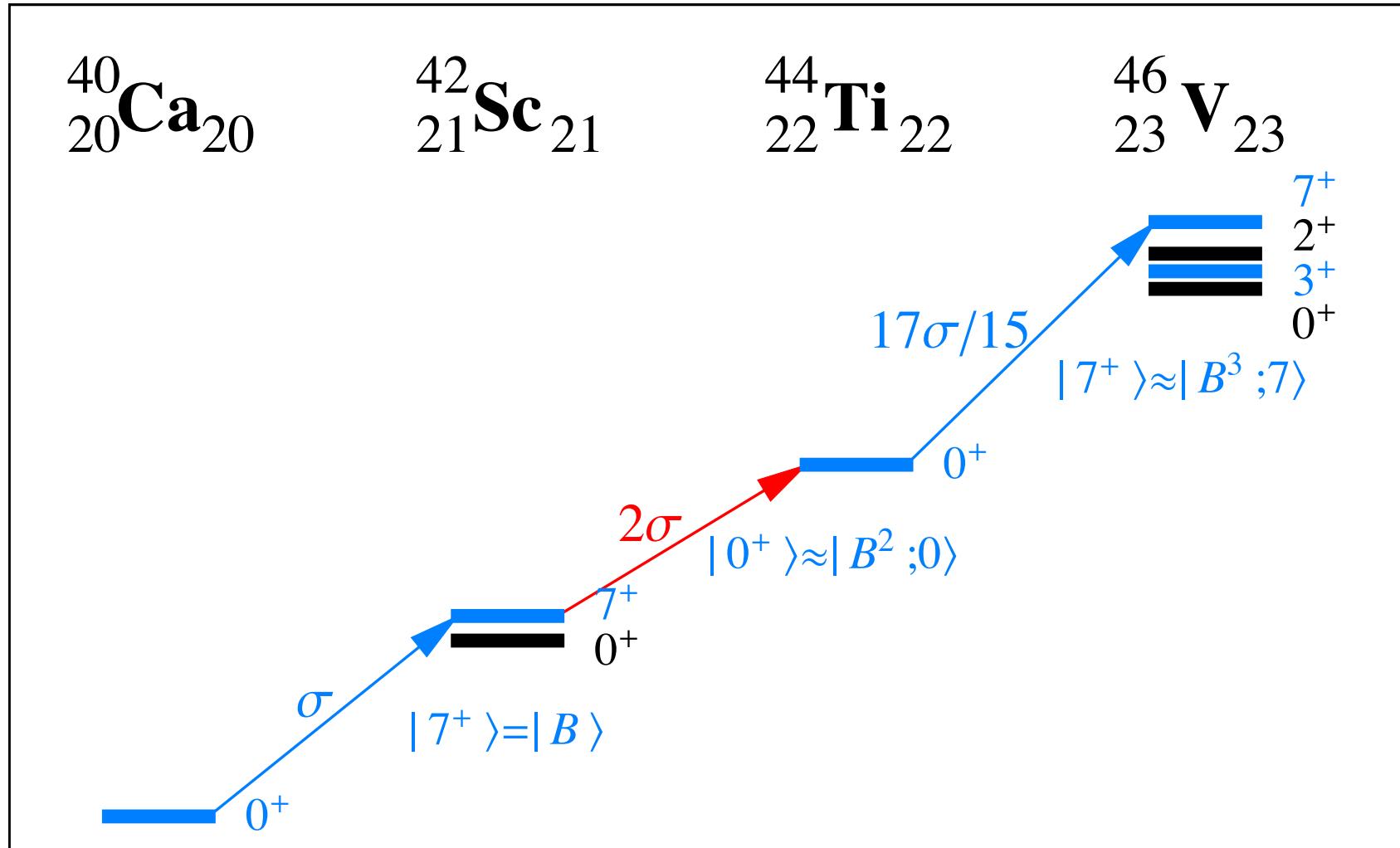
# $T=0$ pair vibrations in Ca-Sc-Ti-V?



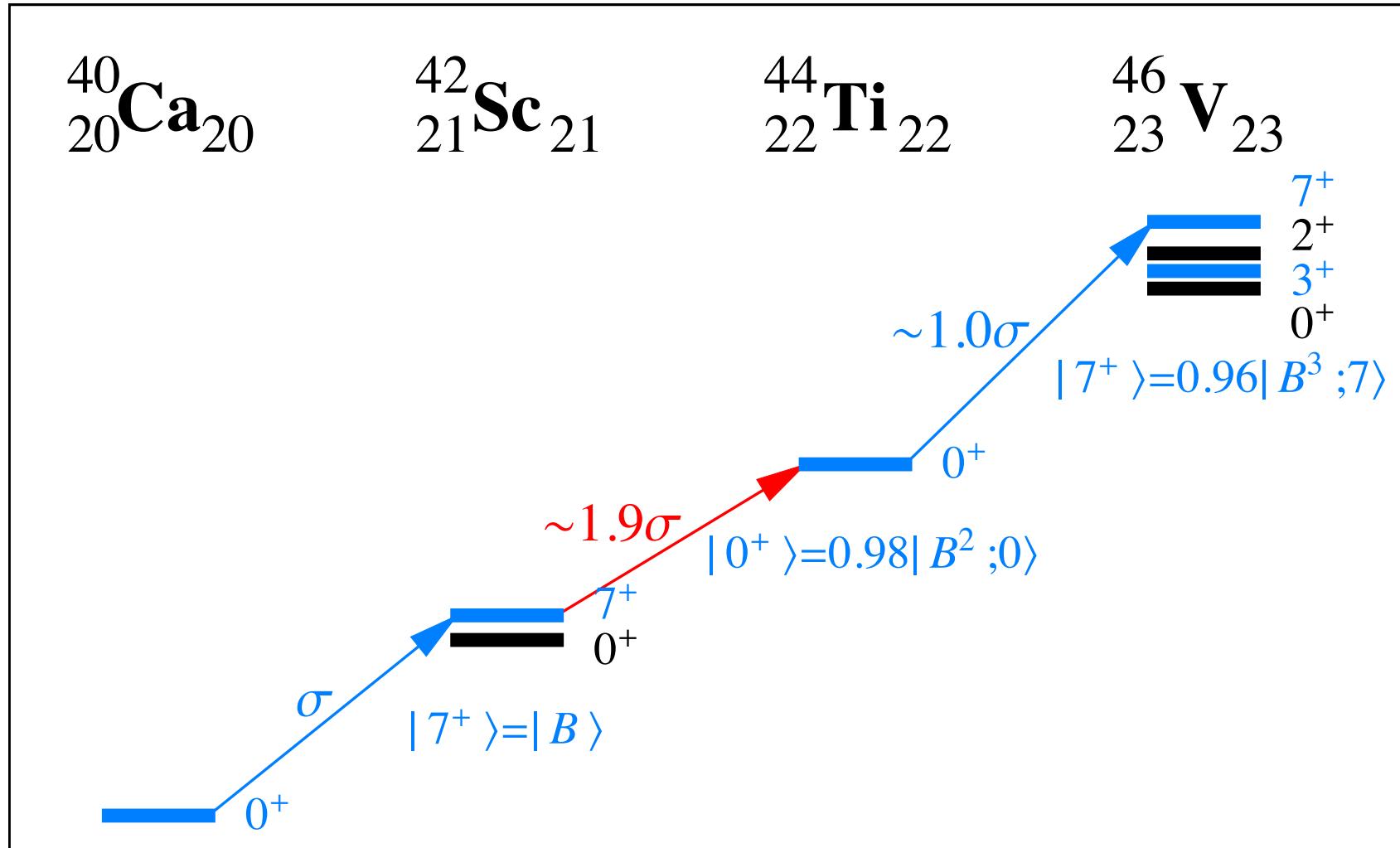
# $T=0$ pair vibrations in Ca-Sc-Ti-V?



# $T=0$ aligned pairs in Ca-Sc-Ti-V?



# $T=0$ aligned pairs in Ca-Sc-Ti-V?



# Conclusions

A systematic picture of  $T=0$  and  $T=1$  deuteron transfer can be obtained in terms of pair vibrations.

Is it valid in  $1f_{7/2}$ -shell nuclei? This also requires the careful consideration of the reaction mechanism.

Heavier  $N=Z$  nuclei? E.g.  $^{58}\text{Cu}$ ?