MICROSCOPIC STUDY OF THE MOLECULAR-DIPOLE DEGREE OF FREEDOM IN NUCLEI

H.J.Assenbaum, K.Langanke and A.Weiguny
Institut für Theoretische Physik I
Universität Münster, D-4400 Münster

Recent theoretical[1,2] and experimental[3] studies give strong evidence for molecular-dipole modes to be present in nuclei; this is indicated by the existence of rotational bands of mixed parity with selective intraband E1-transitions, which are enhanced on a molecular scale[2,3]. In this contribution the idea of molecular-dipole modes is tested on a microscopic level for α-cluster configurations in ^{18}O and $^{46,52}Ti$.

The many-body wave function of the two-cluster system is taken as the antisymmetrized product of the internal wave functions of the clusters and their relative motion wave function,

$$\Psi_\ell = \mathcal{A}\{\phi_\alpha\ \phi_A\ \sum_n \frac{1}{\sqrt{\mu_{n\ell}}}\ \langle u_{n\ell}|g_\ell\rangle\ u_{n\ell}(\vec{r})\ \} \qquad (1)$$

where $\phi_A = \phi_{^{14}C}$, $\phi_{^{42}Ca}$, $\phi_{^{48}Ca}$ resp.

The internal wave functions describe the ground states of the nuclei in the harmonic oscillator shell model with the same b-value for both clusters. The relative motion of the two clusters can be determined from a Schrödinger-like equation[4]

$$\Lambda_\ell\ \{-\frac{\hbar^2}{2\mu}\Delta_{\vec{r}} + V_\ell(r) - E\ \}\ g_\ell(\vec{r}) = 0\ . \qquad (2)$$

$u_{n\ell}(\vec{r})$ are the spherical harmonic oscillator wave functions and the normalization constants are

$$\mu_{n\ell} = \langle\phi_\alpha\ \phi_A\ u_{n\ell}|\mathcal{A}|\phi_\alpha\ \phi_A\ u_{n\ell}\rangle\ . \qquad (3)$$

In eq. (2) the projector Λ_ℓ eliminates redundant states of relative motion. The ℓ-dependent potentials $V_\ell(r)$ are local approximations to the true non-local potential of the orthogonalized resonating group method[4]. The E1-transitions between molecular-dipole states are governed by matrix elements of the electric dipole operator between states of the form (1). This many-body matrix element reduces to simple matrix elements of the relative motion dipole operator, if conservation of angular momentum and energy is taken into account.

For ^{18}O eq. (2) gives rise to a rotational 0^+, 1^-, 2^+, 3^-, 4^+ band of molecular dipole type in addition to the 0^+, 2^+, 4^+ ground state band. Changing the strength parameters of $V_\ell(r)$ of ref. 4 by some percent it is possible to obtain a perfect fit to the experimental energies[3] of the $0^+_2, 1^-, 2^+_3, 3^-_3$ and 4^+_3-states of ^{18}O. The results for the B(E1)-values are listed in table I together with the experimental data[3] and the B(E1)-values obtained from

the simple rotator model, normalized to the 1→0 transition. The calculated B(E1)-values are enhanced on a molecular scale[3] and allow for an interpretation of the respective states in terms of a molecular-dipole rotational band. The deviations from the ideal rotator rule can be understood by examining the mean cluster distance d, which grows considerably with ℓ. Compared to the experimental data[3] the calculated B(E1)-values are too large, due to the fact that the cluster wave functions of type (1) turn out more collective than the experimental ones.

Table I B(E1,$\ell\to\ell'$)-values (in standard Weißkopf units) for ^{18}O

$\ell\to\ell'$	experimental	present calc.	ideal rotator
1→0	0.028	0.084	0.084
2→0	0.009	0.107	0.101
3→2	0.022	0.140	0.108
4→3		0.218	0.112

Solving eq.(2) for ^{46}Ti(^{52}Ti) with the potentials $V_\ell(r)$ of ref.4 we obtain rotational bands starting at E^*=11.4 MeV(8.3 MeV) with a rotational constant of 98 keV(94 keV) and with a parity splitting of ≈0.8 MeV. The calculated B(E1)-values (table II) are of the same order of magnitude for ^{52}Ti as for ^{18}O, whereas for ^{46}Ti they are suppressed because the difference of the ratios of charge and mass of the clusters is smaller.

Table II B(E1,$\ell\to\ell'$)-values (in standard Weißkopf units) for $^{46,52}Ti$.

$\ell\to\ell'$	^{46}Ti	$\ell\to\ell'$	^{52}Ti
1→0	0.022	1→0	0.19
1→2	0.043	1→2	0.38
3→2	0.028	3→2	0.24
4→3	0.028	3→4	0.30
5→4	0.029	5→4	0.24

1. F. Iachello, Phys.Rev. C23 (1981) 2778; F. Iachello, A.D. Jackson, Phys.Lett. 108B (1982) 151.

2. Y. Alhassid, M. Gai, G.F. Bertsch, Phys.Rev.Lett. 49 (1982) 1482.

3. M. Gai et al., Phys.Rev.Lett. 50 (1983) 239.

4. D. Wintgen, H. Friedrich, K. Langanke, Nucl.Phys. A408 (1983) 239.