

COHERENT STATE DESCRIPTION OF THE α -EMISSION SPECTRUM*

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We review the main aspects concerning the calculation of α -decay intensities to excited states in even-even nuclei using a Coherent State Model (CSM) for the description of the daughter nucleus. The analysis of the α -emission process is based on an α -daughter interaction having a monopole component and a quadrupole-quadrupole (QQ) interaction. The decaying states are calculated through the coupled channels method. The decay intensities to 2^+ states are reproduced by means of the QQ strength. This interaction strength can be fitted with a linear dependence on the deformation parameter, as predicted by the CSM. Predicted decay-intensities to higher excited states are in reasonable agreement with available experimental data.

Key words: coherent states, α -decay fine structure, coupled channels method.

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1. INTRODUCTION

Nuclear structure details are not very relevant for the study of α -transitions between ground states, because the α -particle formation amplitude is a coherent superposition of many single-particle configurations [1]. In the case of transitions to excited states (the so called α -decay fine structure), only the single-particle levels around the Fermi surface are involved and the corresponding decay widths are much more sensitive to the structure of the daughter nucleus [2]. A central problem in this field is the study of the α -daughter interaction. One of the most popular approaches is the double folding procedure [3]. This procedure has been used together with the coupled channels method and a repulsive core simulating the Pauli principle in order to study the α -decay fine structure in transitional and rotational even-even nuclei [4]. For a broader overview of the subject and a thorough study of the structure and

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α -emission spectrum in vibrational, transitional and rotational even-even nuclei see Ref. [12]. In this proceeding we shall only summarize the main results concerning the emission spectrum.

2. SUMMARY OF THE COHERENT STATE MODEL

The CSM was developed [5, 6] as a tool able to describe the spectra of vibrational, transitional and rotational nuclei in a unified framework. In this model, the surface vibrations of a deformed nucleus are treated by means of a coherent superposition of boson operators [7, 8]. The model was later extensively developed [9, 10] for the description of low-lying as well as high spin states in nuclei, including isospin degrees of freedom.

In the intrinsic system of coordinates, the wave function of an axially deformed even-even nucleus is given by a coherent superposition of quadrupole boson operators $b_{2\mu}$ with $\mu = 0$ acting on the vacuum state

$$|\psi_g\rangle = e^{d(b_{20}^\dagger - b_{20})} |0\rangle, \quad (1)$$

in terms of the deformation parameter proportional to the static quadrupole deformation [9]. Physical states which define the ground band are obtained by projecting out components of given angular momentum

$$|\varphi_J^{(g)}\rangle = \mathcal{N}_J^{(g)} \hat{P}_{M0}^J |\psi_g\rangle. \quad (2)$$

3. THE COUPLED CHANNELS METHOD FOR α -EMISSION

The α -decay process under study connects the ground state of the parent nucleus to an excited level of the daughter

$$P \rightarrow D(J) + \alpha, \quad (3)$$

where J denotes the spin of the excited level in the even-even axially deformed daughter nucleus. The wave function of the α -daughter system has the total spin of the ground state (*i.e.* zero)

$$\begin{aligned} \Psi(b_2, \mathbf{R}) &= \sum_J \frac{f_J(R)}{R} \mathcal{Z}_J(b_2, \Omega) \\ \mathcal{Z}_J(b_2, \Omega) &\equiv \left[\varphi_J^{(g)}(b_2) \otimes Y_J(\Omega) \right]_0, \end{aligned} \quad (4)$$

where $\mathbf{R} \equiv (R, \Omega)$ denotes the distance between the centers of the two fragments. We describe the α -daughter dynamics by applying the stationary Schrödinger equation,

i.e.

$$\left(-\frac{\hbar^2}{2\mu} \nabla_R^2 + H_D(b_2) + V(b_2, \mathbf{R}) \right) \Psi(b_2, \mathbf{R}) = Q_\alpha \Psi(b_2, \mathbf{R}), \quad (5)$$

where Q_α is the Q-value of the decay process. Using an α -core interaction

$$V(b_2, \mathbf{R}) = V_0(R) + V_2(b_2, \mathbf{R}), \quad (6)$$

the experimental Q-Value and total half-life can be fixed by a proper parametrisation of the monopole plus repulsive core term $V_0(R)$. In order to study the fine structure of the emission spectrum, one needs the quadrupole-quadrupole (QQ) interaction $V_2(b_2, \mathbf{R})$. Using the orthonormality of the angular functions entering the superposition (4), one obtains in a standard way the coupled system of differential equations for radial components [11]

$$\frac{d^2 f_J(R)}{d\rho_J^2} = \sum_{J'} A_{JJ'}(R) f_{J'}(R). \quad (7)$$

The coupling matrix is given explicitly in Ref. [12], where it is shown that various channels are coupled through the matrix elements of the QQ interaction. In the same reference it is shown that the matrix elements of the QQ interaction are related to those of the standard quadrupole transition operator with harmonic and anharmonic terms, having as adjustable parameter the effective coupling strength

$$C = C_0 \left(1 - \sqrt{\frac{2}{7}} a_\alpha d \right), \quad (8)$$

where a_α is the anharmonic strength. By properly applying the boundary conditions of this system, one can use the effective coupling strength C to reproduce α transitions to 2^+ states, *i.e.* the intensities

$$I_J = \frac{\Gamma_0}{\Gamma_J}, \quad (9)$$

for $J = 2$. In general, Γ_J is the partial decay width to the channel with angular momentum $J = 0, 2, 4, 6$. Using the dependence $C(d)$ which results from this fit, transitions to higher excited states can be predicted.

4. RESULTS CONCERNING DECAY INTENSITIES

In Fig.1 we show the value of C which reproduces the experimental intensity I_2 versus the deformation parameter d of each nucleus, separately for nuclei with the number of neutrons $N < 126$ (white circles) and $N \geq 126$ (dark circles). One can see that the prediction of Eq. (8) is fulfilled for each region, with the added comment that for nuclei in the $N < 126$ region we have an additional separation between a straight

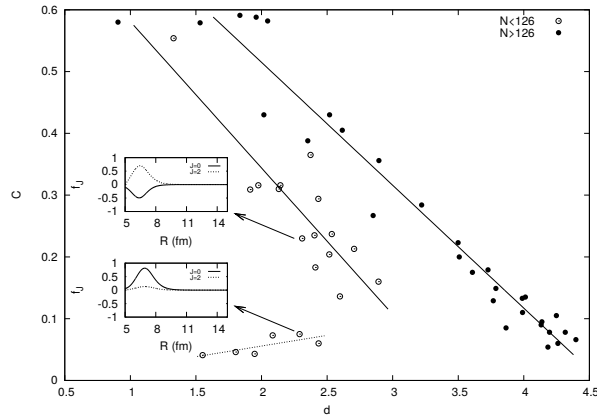


Fig. 1 – Effective coupling strength *versus* deformation parameter around $N=126$ neutrons.

line with a negative slope for nuclei having the phases of the $J = 0, 2$ wave functions in opposition and a straight line with a positive slope for the nuclei having the wave functions in phase.

In Fig.2 we show experimental (white circles) and predicted (dark circles) intensities for $J = 2, 4, 6$ states *versus* an index number for isotopes in the Th-Cf region. The predictions are made based on the linear dependences with negative slope seen in Fig. 1. One notices a reasonable agreement with experimental data until around $n = 20$ which lies in the Pu region. The peak at I_4 observed there cannot be reproduced in an approach based on a collective model.

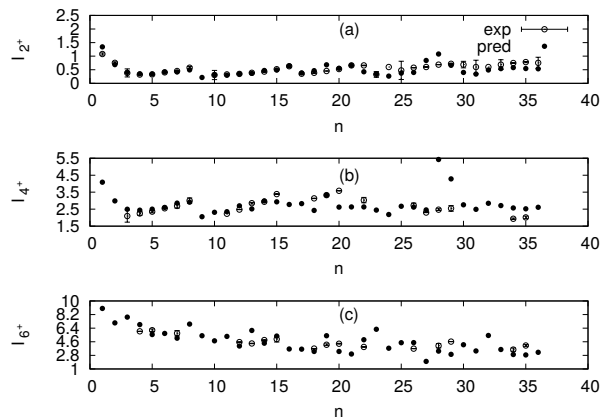


Fig. 2 – Experimental and predicted intensities *versus* index number. Panel (a) shows the $J=2$ states, panel (b) shows the $J=4$ states and panel (c) shows the $J=6$ states.

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