COLLECTIVE QUADRUPOLE EXCITED STATES IN ACTINIDE AND TRANSURANIC NUCLEI* **

K. Zając, L. Próchniak, K. Pomorski

Institut of Physics, Maria Curie-Skłodowska University
Pl. M. Curie-Skłodowskiej 1, 20-031 Lublin, Poland

S.G. Rohoziński and J. Srebrny

Institut of Physics, Warsaw University
Hoża 69, 00-681 Warsaw, Poland

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The quadrupole excitations of transuranic nuclei are described dynamically in the frame of the microscopic collective Bohr Hamiltonian modified by adding the coupling with the pairing vibrations. The ground-state bands in No and Fm even–even isotopes are reproduced within the model containing no adjustable parameters.

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The recent progress of experimental techniques has significantly enriched the evidence of excited states of transuranic, or even transfermium $Z > 100$ nuclei which are especially interesting with regard for their closeness to the super-heavy mass region. For instance, the refined spectroscopic measurements performed for ^{252}No and ^{254}No [1,2] gave us an insight into the structure of $Z = 102$ isotopes. These nuclei are axially deformed and they have almost perfect rotational ground state bands what was also confirmed by the HFB calculations [3]. However, in order to get the dynamical description of an excited heavy nucleus, one should take into account at least the coupling of the rotational motion with the quadrupole shape vibrations. Also the influence of the pairing correlations could be estimated through the corresponding collective mode [4].

Recently we have developed [5] a microscopic approach to the low-lying nuclear excitations. This model bases on the "quadrupole plus pairing" collective Hamiltonian. Our approach was successfully applied in the wide

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range of transitional nuclei from neutron-rich Ru isotopes up to rare earth nuclei [6–8]. The aim of the present study is to test if our calculations can be reliable when unstable and heavy or maybe super-heavy isotopes are considered.

Following the idea of the generalized Bohr Hamiltonian we would like to describe the motion of a given even–even nucleus in a collective space spanned by the intrinsic Bohr variables β and γ parameterizing the nuclear shape and three Euler angles (Ω) giving the orientation of the main axis of nucleus in space. Independently of these quadrupole degrees of freedom we add to our collective space the pairing gap parameters Δ^p and Δ^n which describe the proton and neutron pairing vibrations, respectively.

The total collective nuclear Hamiltonian

$$\hat{\mathcal{H}}_{\rm CQP} = \hat{\mathcal{H}}_{\rm CQ}(\beta,\gamma,\Omega;\Delta^p,\Delta^n) + \hat{\mathcal{H}}_{\rm CP}(\Delta^p,\Delta^n;\beta,\gamma) + \hat{\mathcal{H}}_{\rm int} \tag{1}$$

contains two known terms responsible for the quadrupole and pairing collective movements and the mixing operator $\hat{\mathcal{H}}_{\rm int}$ which will be omitted in further calculations. The first term in (1) is simply the generalized Bohr Hamiltonian [5, 9] and it depends on the set of microscopically determined inertial functions of β, γ, Δ^p and Δ^n. Assuming a nucleus as a system of nucleons moving in the mean-field potential and interacting through monopole pairing forces we determine all inertial functions (at each point of the collective space) using the cranking method. The collective potential is evaluated within the Strutinsky macroscopic–microscopic method. The pairing term $\hat{\mathcal{H}}_{\rm CP}$ describes the collective pairing vibrations of protons and neutrons [4]. Solving the eigenproblem of $\hat{\mathcal{H}}_{\rm CP}$ we obtain the collective pairing ground-state energy $\mathcal{E}'_{\rm CP}$ and the corresponding ground-state wave function. The maximum of this function is usually shifted from the equilibrium point (determined by the BCS equations) towards smaller values of the proton and neutron gap parameters [5]. As far as the low-lying excitations are considered we can assume that in fact only the ground state of the collective pairing hamiltonian $\hat{\mathcal{H}}_{\rm CP}$ is involved and that the main effect of the coupling of the quadrupole and pairing vibrations comes into account by the modification of the inertial functions determining the collective Hamiltonian. Thus we derive the collective quadrupole states by solving the eigenproblem of the Hamiltonian

$$\hat{\mathcal{H}}_{\rm CQP} = \hat{\mathcal{H}}_{\rm CP}(\beta,\gamma;\Delta^p_{\rm vib},\Delta^n_{\rm vib}) + \mathcal{E}'_{\rm CP}\ . \tag{2}$$

The inertial functions appearing in (2) as well as the collective potential are calculated at each (β,γ) deformation point using the most probable values of the proton and neutron gap parameters $\Delta^p_{\rm vib}, \Delta^n_{\rm vib}$. The procedure sketched above significantly [6] improves the predictive power of the generalized Bohr Hamiltonian and, to advantage, introduces no additional parameters into the description.

In applying our model to fermium and nobelium isotopes we have used the standard set of parameters of the Nilsson single-particle potential and the pairing strength value adjusted to the mass differences of actinide nuclei. The results presented here are rather preliminary but nevertheless, the theoretical energies of the ground-state bands for Fm and No isotopes (Fig. 1)

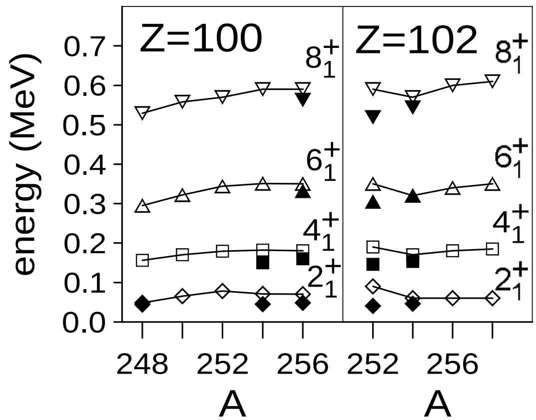

Fig. 1. The comparison of the experimental [1, 2, 10, 11] and theoretical (open symbols) energies of the ground state band of even–even Fm and No isotopes.

are close to the experimental data. As it is exemplified in the left hand side part of Fig. 2 the quadrupole collective modes are well separated. It is in consistency with the shape of the collective potential for ^{254}No which has a deep minimum at $\beta \approx 0.265\,\gamma \approx 0^o$. The 2_2^+ and 0_2^+ bands of ^{254}No are situated of about 1.5 to 2 MeV above the ground band energies and they seem to correspond to so called "γ" and "β" excitations.

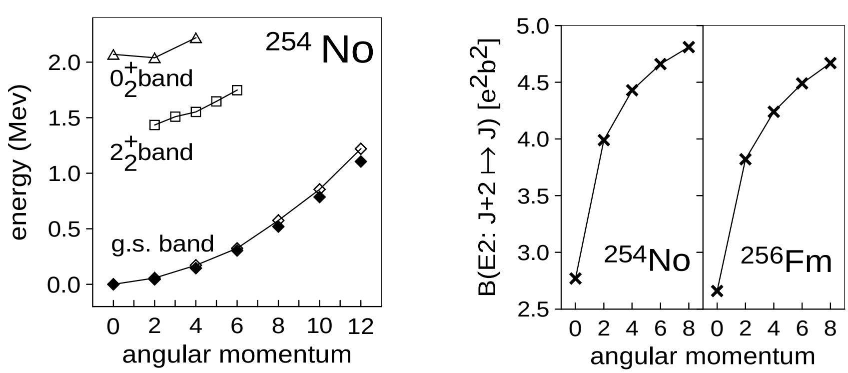

Fig. 2. The low-lying excited levels of ^{254}No (l.h.s. part of the figure), the experimental data [1, 2] are marked with black points. The theoretical reduced probabilities of the E2 transitions within the ground-state band of ^{254}No and ^{256}Fm are plotted in the r.h.s. part of the figure.

We have obtained in fact a very similar dynamical structure for Fm and No isotopes what could be visible in the right hand side part of Fig. 2, where the calculated probabilities of E2 transitions between neighboring members of ^{254}No and ^{256}Fm ground-state bands are drawn.

Summarizing we would like to point out that the rotational character of the ground-state bands in Fm and No isotopes was manifested in our model. In spite of some simplicity of the Nilsson single-particle potential our approximation works good in this rather extreme mass region and a reasonable agreement with the experimental data, obtained without any adjustment of the parameters, confirms that our model takes into account the main features of the collective nuclear excitations of the transuranic nuclei. Moreover, we have shown that the coupling between quadrupole and pairing collective degrees of freedom plays also a non-negligible role in this mass region.

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