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THE MICROSCOPIC QUASIPARTICLE–PHONON MODEL*

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The Microscopic Quasiparticle–Phonon Model (MQPM) is shortly presented. The energies of excited states of odd $N = 82$ isotones calculated using MQPM are compared to results obtained by making large-scale shell-model calculations with microscopic effective interaction. Comparison to experimental spectra shows that MQPM can reproduce the experimental spectra better than shell-model when the number of valence nucleons is large.

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1. Introduction

The Quasiparticle–Phonon Models (QPM) describe states of odd nuclei using basis states built by adding quasiparticles to the excited states of nearby double-even nucleus (core nucleus). In microscopic QPM (MQPM) the quasiparticle-vibration interaction is derived from a realistic microscopic Hamiltonian. The excited states of the core nucleus are calculated using quasiparticle random-phase approximation (QRPA) [1] based on BCS quasiparticle vacuum. In MQPM the excited states of an odd nucleus look like

$$|i;jm\rangle = \left[\sum_a C_i^1(a) a^\dagger_{ajm} + \sum_{a\omega} C_i^3(a\omega)[a^\dagger_a Q^\dagger_\omega]_{jm}\right]|0^+_{\rm g.s.}\rangle\,,$$

where $Q^\dagger_\omega$ are QRPA phonon creation operators and $a^\dagger_a$ quasiparticle creation operators. The MQPM equations for one- and three-quasiparticle amplitudes can be derived using the Equations-of-motion technique presented

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in Refs [2–3]. The result is a generalised hermitian eigenvalue problem

$$\begin{pmatrix} A & B \\ B^T & A' \end{pmatrix} \begin{pmatrix} C_i^1 \\ C_i^3 \end{pmatrix} = \hbar\Omega_i \begin{pmatrix} 1 & 0 \\ 0 & S \end{pmatrix} \begin{pmatrix} C_i^1 \\ C_i^3 \end{pmatrix} .$$

Expressions for the Hamiltonian and overlap matrix elements of this equation calculated in the quasi-boson approximation and complete explanation of the MQPM model can be found from Ref. [4].

2. Application to $N = 82$ isotones

To demonstrate the usefulness of MQPM model we have applied it to semi-magic $N = 82$ isotones which have 3–13 valence protons. In the MQPM calculations major shells $3\hbar\omega$ and $4\hbar\omega$ were used both for protons and neutrons. Experimental single-particle energies were used for the $4\hbar\omega$ valence major shell and Woods–Saxon single-particle energies for the other, mainly occupied, major shell (see Ref. [4] for more details).

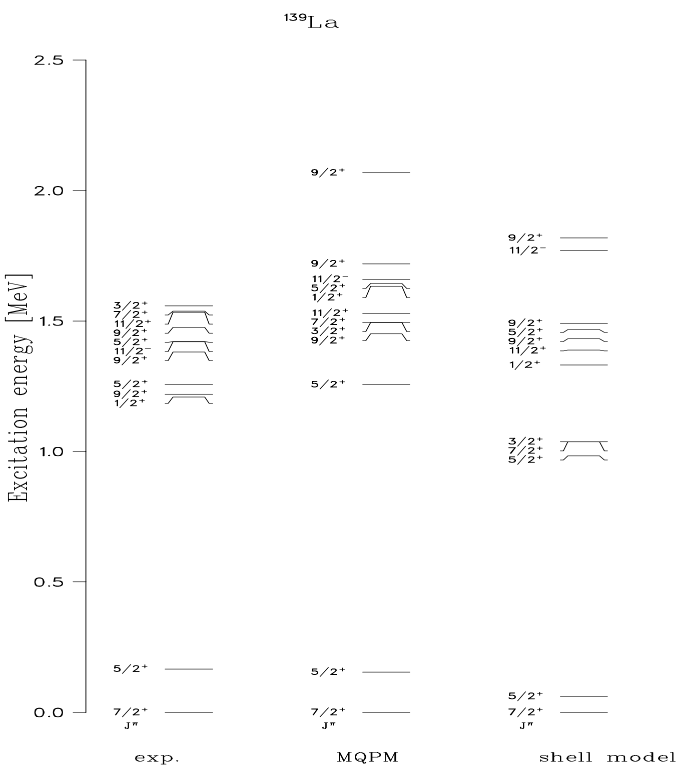

Fig. 1. Excitation spectra for ^{139}La.

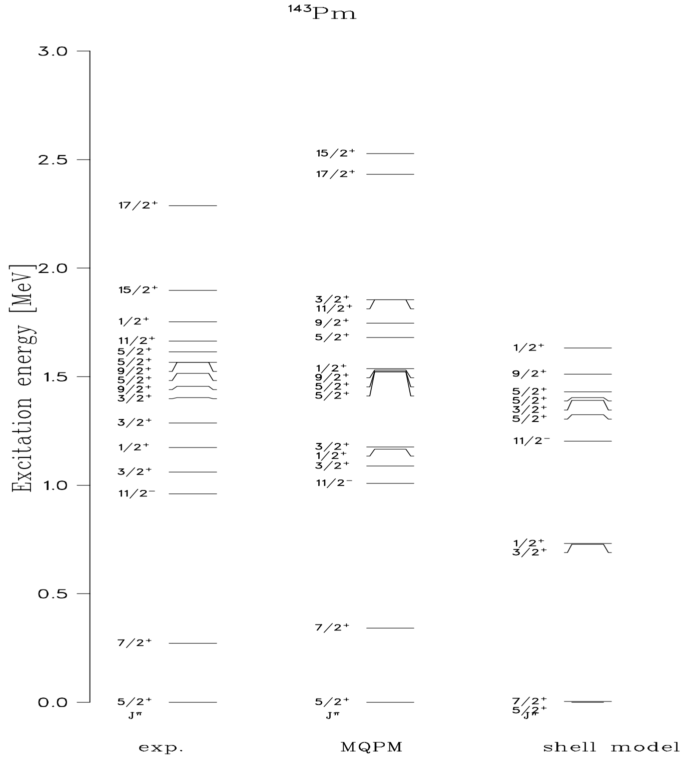

Fig. 2. Excitation spectra for ^{143}Pm.

The nucleon–nucleon interaction used in the MQPM calculations was bare G-matrix of the Oslo group [5] derived from Bonn meson-exchange potential. In the shell-model calculations only the $4\hbar\omega$ major shell was used and the same experimental single-particle energies were used as in the MQPM calculations. To take into account the missing degrees of freedom an effective interaction based on the bare G-matrix was calculated.

The MQPM and shell-model calculations were completely parameter-free — theoretical level energies were not fixed to experimental ones by altering the G-matrix interaction matrix elements from their bare values. Figures 1 and 2 show energy spectra for nuclei ^{139}La and ^{143}Pm. The first nucleus belongs to the light end of the isotones (seven valence protons) and second to the heavy end (eleven valence protons). Energy spectra for the other isotones can be found from Ref. [4].

As could be expected, shell-model describes the experimental spectra somewhat better in the light end of the isotones where the nuclei have only a few valence particles. For the case of ^{139}La shell-model describes individual states, except the lowest-lying ones, better than MQPM but the overall centroids of various multiplets are described equally well by MQPM model.

In the heavy end where shell-model dimensions are very high (for ^{143}Pm the shell-model dimension is 3609550) MQPM performs in general better than shell-model. This is mainly due to the fact that quasiparticle representation gets better when the number of valence protons is far away from the magic value $Z = 50$. As can be seen from figure 2 shell-model cannot reproduce the energies of the lowest $7/2^+$ and $5/2^+$ one-particle states as well as MQPM. The reason for this is that the $4\hbar\omega$ major shell alone is not enough to reproduce single-particle states whereas the BCS+MQPM calculation is able to reproduce them because of the additional $3\hbar\omega$ major shell.

As a conclusion the MQPM calculations can reproduce the overall centroid energies of excited states reasonably accurately for all isotones. Shell-model works best in the light end of the isotones where it can describe most states satisfactorily, but is in trouble in the heavy end where it can not describe the energies of one particle states and does not reproduce the centroid energies of $2p-1h$ states as well as MQPM.

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