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Mixed Symmetry States in Even-Even $^{96-108}$Mo Nuclei*

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Abstract *Excitation energies and electromagnetic transition strengths in even-even $^{96-108}$Mo nuclei have been described systematically by using the proton-neutron interacting boson model (IBM-2). It appears that the properties of low-lying levels in these isotopes, for which the comparison between experiment and theory is possible, can be satisfactorily described by the IBM-2 model, provided proper account is taken of the presence at low energy of states having a mixed-symmetry character. It seems possible to identify, in each isotope, a few states having such a character, the lowest ones being either 2_2^+ or 2_3^+ levels. It is found that these nuclei are in the transition from U(5) to SU(3).*

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1 Introduction

The structure of Mo isotope nuclei has for many years provided a challenge to theoretical interpretations, for instance, the very rapid transition from a vibrational to a rotational-like structure and the unusually low first excited 0^+ state connected by strong $E2$ transitions to the first 2^+ states. The structure of Mo nuclei was studied by applying a variety of models, such as the framework of the Hartree–Fock–Bogoliubov method,[1] algebraic interacting boson model (IBM),[2] and the shell model.[3,4] These studies have concluded several important points. First, this rotational structure gradually develops, as neutrons are added. Second, the behavior of 0_2^+ states is closely related to the proton cross-shell excitations. Recently, an investigation[5,6] of the mixed-symmetry (MS) states of the ^{94}Mo nucleus has been provided within the proton-neutron interacting boson model (IBM-2)[7−11] which distinguish between proton and neutron degrees of freedom. For instance, the staggering problem in the O(6) limit of the IBM1 can be solved by introducing the quadrupole interactions among like-nucleons in the IBM2.[12−15] In particular, the IBM-2 predicts the existence of mixed-symmetry states, i.e. not completely symmetric states with respect to the proton-neutron boson exchange. Signatures of MS state, accessible to spectroscopy, are low excitation energy, weakly collective $E2$ transitions to symmetric states, and strong $M1$ transitions to symmetric states with matrix elements of about $|\langle J^f_{\rm sym}\|M1\|J^i_{\rm ms}\rangle| \approx \mu_N$. The most prominent mixed-symmetry state is the 1^+ state[16] known as the "scissors mode" due to its geometrical picture in rotors.[17] This 1^+ state was discovered by A. Richter *et al.*[18] in electron scattering experiments on well-deformed nuclei. The existence of the MS scissors mode has been systematically investigated by resonant photon scattering in the $100 < A < 200$ mass region.[19] Meanwhile, the excitation energy of these $J = 1^+$ levels provides a way of determining the strength of the Majorana force.[20] It was suggested recently that mixed symmetry states may form isomeric states under certain conditions.[21] Mixed-symmetry 2^+ and 3^+ states have been identified recently in ^{94}Mo[5,6] by measuring additionally the $B(M1)$-strength. Detailed IBM2 calculation of the structure of ^{94}Mo was carried out.[22] It is therefore interesting to carry out a systematic comparison of the experimental data with model calculations in Mo isotopes, in particular the properties of MS states in these nuclei in the light of new experimental data accumulated over the past few years. These MS states in Mo isotopes are absent except in ^{94}Mo. After this short introduction, we describe briefly the model Hamiltonian, the $E2$ and $M1$ transition operators in Sec. 2. In Sec. 3, we give the results and discussions on spectrum, $E2$ and $M1$ transition properties and mixed symmetry states. Finally, in Sec. 4, a summary is given.

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