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Nuclear Physics A 906 (2013) 94–107

NUCLEAR PHYSICS A

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Study of the pygmy dipole resonance in ^{94}Mo using the $(\alpha, \alpha'\gamma)$ coincidence technique

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Received 5 December 2012; received in revised form 14 February 2013; accepted 18 February 2013

Available online 1 March 2013

Abstract

The $(\alpha, \alpha'\gamma)$ reaction at $E_\alpha = 136$ MeV was used to study the electric dipole response in the open-shell vibrational nucleus ^{94}Mo below the neutron-separation threshold. The coincidence experiment has been performed at the Kernfysisch Versneller Instituut in Groningen, The Netherlands, exploiting the Big-Bite Spectrometer and an array of large volume High-Purity Germanium (HPGe) detectors. Due to the excellent energy resolution and high selectivity to transitions stemming from the pygmy dipole resonance, singles α-scattering cross sections could be determined for individual electric dipole excitations between 4 and 8 MeV. For three of the excited low-lying $J^\pi = 1^-$ states in ^{94}Mo a γ-decay branch into the $J^\pi = 2_1^+$ state could be observed.

The experiment extends the systematic studies of the pygmy dipole resonance by real-photon scattering (γ, γ') experiments and $(\alpha, \alpha'\gamma)$ experiments. Recently, a (γ, γ') experiment on ^{94}Mo was performed at the Darmstadt High-Intensity Photon Setup at the S-DALINAC in Darmstadt, Germany, permitting the comparison of $B(\text{E1})\uparrow$ strength distribution and α-scattering cross sections.

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0375-9474/$ – see front matter
http://dx.doi.org/10.1016/j.nuclphysa.2013.02.018

Keywords: NUCLEAR REACTIONS ^{94}Mo($\alpha, \alpha'\gamma$), $E_\alpha = 136$ MeV; measured E_α using Big-Bite Spectrometer, E_γ using HPGe, $\alpha\gamma$-coin; deduced levels, J, π, decay branching for discrete levels, pygmy dipole resonance, dipole, quadrupole excitations, B(E1), B(E2)

1. Introduction

In spherical atomic nuclei, the electric dipole strength is mainly exhausted by the well-known isovector giant dipole resonance (IVGDR) [1]. An additional concentration of low-lying E1 strength has been observed below and, partly, above the particle threshold in neutron-rich nuclei and is usually denoted as electric pygmy dipole resonance (PDR) [2,3]. Collectivity and structure of this complex excitation mode are topic of ongoing discussions stimulating experimental as well as theoretical investigations. Microscopic calculations partly support the macroscopic picture of excess neutrons oscillating against a proton-neutron core, see Ref. [4] and references therein. Different theoretical approaches which predict, e.g., E1 strength distributions, transition densities, and integrated characteristics have to be tested directly or indirectly through further experiments [5–11]. The investigation of the PDR in unstable nuclei with a large number of excess neutrons became feasible in radioactive-beam experiments, for example in the vicinity of ^{132}Sn, and in ^{68}Ni [12–14]. Besides the motivation with respect to nuclear structure physics, an investigation of the PDR has also relevance in nuclear astrophysics. It has been shown that reaction rates which are important for nucleosynthesis processes can be significantly affected by the additional electric dipole strength [7,8,15]. Furthermore, the PDR strength is correlated with the neutron-skin thickness, which in turn may be connected to neutron-star properties [16] and to the equation of state of neutron-rich matter [17].

During the last years the PDR has been studied by different experimental methods. Real-photon scattering, (γ, γ'), provides a high selectivity to low multipolarities and, therefore, is an established method to study dipole excitations in stable nuclei [3,18–22], and was applied to stable even-mass Mo isotopes as well [23]. On the other hand, α particles could be used as a complementary isoscalar probe that mainly interacts with the nucleus through the strong interaction exciting different multipolarities depending on the α-particle energy and kinematics. However, the ($\alpha, \alpha'\gamma$) reaction mainly selects electric dipole transitions and to a lesser extent quadrupole ones and recently was used systematically in ^{140}Ce, ^{138}Ba, and ^{124}Sn in order to gain knowledge about the structure of the PDR [24–28].

The systematic study with the two complementary probes revealed a difference in the isospin character of the E1 strength below the neutron threshold, which may enable to distinguish the PDR from excitations belonging to the tail of the IVGDR. The states at lower energies up to about 6 MeV were excited in both kinds of experiments, while the majority of the states at higher energies up to the neutron-separation energy were excited by photons only. This seems to be a general feature of the low-lying E1 strength for nuclei in this mass region. Theoretical calculations in the framework of the Hartree–Fock–Bogoliubov (HFB) model and multiphonon quasiparticle–phonon model (QPM) [29], the relativistic quasiparticle time-blocking approximation (RQTBA) [26], the relativistic quasiparticle random-phase approximation (RQRPA) [30], and the nuclear energy density functionals plus QRPA [10] show that this energy splitting separates states with more isovector character that belong to the low-energy tail of the IVGDR from dipole excitations with more isoscalar character belonging to the PDR located at lower energy. These findings emphasize that the usage of multiple probes and excitation mechanisms is mandatory for a comprehensive understanding and identification of characteristic features of the PDR.