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Excitation and Decay Properties of the $|3_1^- \otimes 3_1^- \,;\, 2^+\rangle$ State in ^{208}Pb*

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Abstract

A nuclear resonance fluorescence experiment using Euroball Cluster detectors is proposed with the aim to identify the long-sought two-octupole-phonon vibration in ^{208}Pb. Based on quasiparticle-phonon model calculations and countrate estimates from previous measurements the experiment seems feasible.

In the low-energy spectra of spherical nuclei one finds collective, natural parity states which can be interpreted as surface vibrations (or phonons) [1]. Due to the coupling of two or even three of these elementary modes multi-phonon states occur. Within a harmonic picture the possible states should be degenerate and have excitation energies according to the sum of the individual phonon excitations, but anharmonicities and residual interactions between the phonons lead to a splitting of the multiplets. Whereas the coupling of two-quadrupole excitations $|2_1^+ \otimes 2_1^+; 0^+, 2^+, 4^+\rangle$ is well established in spherical nuclei, and the coupling of quadrupole and octupole phonon $|2_1^+ \otimes 3_1^-; 1^- \ldots 5^-\rangle$ has been a topic of recent research efforts, the information available on octupole-octupole coupling to a multiplet of states with spin and parity 0^+, 2^+, 4^+, 6^+ is rather sparse.

The doubly-magic nucleus ^{208}Pb represents an outstanding test case for the study of two-octupole-phonon excitations because of its first excited, strongly collective state — the octupole phonon — at an excitation energy of 2.615 MeV, whereas the quadrupole phonon is at a much higher energy (4.086 MeV) and less collective. Therefore, many attempts have been undertaken to identify such excitations in this nucleus (see e.g. [2] for references). On the one hand, e.g. a two-step Coulomb excitation experiment was performed at the GSI some years ago, focusing the interest on the high-spin members of the multiplet [3]. The transition oberved, which was assigned to the decay of the 6^+ member of the quadruplet, was subsequently shown to belong to ^{207}Pb. On the other hand, non-selective probes like (p,p′γ) and (n,n′γ) have been used. Here the attention was mainly focused on the 0^+ member of the multiplet. As it was shown recently, the 0^+ state at $E_x = 5.241$ MeV exhibits a strong two-phonon component, which has been indentified in inelastic neutron scattering by the observation an E3 transition to the one-phonon state [4].

We propose to look for the 2^+ member of the quadruplet using the nuclear resonance fluorescence (NRF) technique [5]. Recent experiments using highly efficient composite high-purity germanium detectors like the Euroball Cluster module [6] show a striking increase in the detection sensitivity compared with the equipment available some years ago, so that even rather weak E2 excitations in nuclei are now accessible in photon scattering experiments.

The signature of the 2^+ member of the two-octupole-phonon multiplet will be a sizable decay branch to the single-phonon state. Whereas the ground-state transition occurs at the full energy (which is close to the endpoint energy and therefore the nonresonant background is small), the branch to the first 3^- state has to be measured at fairly low photon energies, and here the background is large. In order to judge whether a NRF experiment could be successful or not, we did a quasiparticle-phonon model (QPM) calculation and estimated the experimental feasibility on the basis of results from a series of (γ, γ') measurements performed with a Euroball Cluster at the S-DALINAC. For a concise summary of the experimental setup as well as the results see e.g. [7–9].

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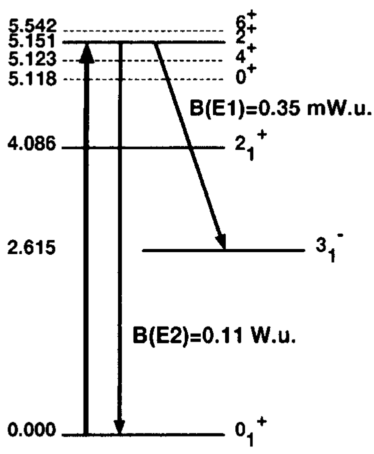

Fig. 1: Energies and transition strengths for the decay of the two-phonon 2^+ state in ^{208}Pb as obtained in the quasiparticle-phonon model calculation.

The QPM calculations — which are presented in detail in [2] — can be summarized as follows: The residual interaction has been chosen to reproduce the energies and excitation strengths of the basic surface vibrations, and admixture with other 2^+ states has been taken into account. With the same ansatz similar calculations have been performed for the two-phonon multiplets in the nuclei ^{96}Zr and ^{144}Sm showing reasonable agreement with experimental data. For ^{208}Pb one finds for the ground state transition $B(\mathrm{E2}; [3_1^- \otimes 3_1^-]\, 2^+ \to 0_1^+) = 0.11$ W. u., which is quite small but still observable within a few days. While a very collective E3 transition to the one-phonon level is predicted by the calculations, the partial decay width is rather small because of the high multipolarity, and E1 decay is found to dominate. The transition strength of $B(\mathrm{E1}; [3_1^- \otimes 3_1^-]\, 2^+ \to 3_1^-) = 0.35 \times 10^{-3}$ W. u. (as shown in Fig. 1) is rather large, but far more difficult to observe compared to the ground-state transition because of the strongly increasing background towards lower photon energies. Other decay branches (e. g. to the 2_1^+ state) can be neglected.

We compared the nonresonant background of spherical nuclei observed in (γ, γ') experiments at the Darmstadt measurement site to a simple Monte Carlo simulated [10] background to estimate the peak-to-background ratio for the transition in ^{208}Pb. For reasonable parameters of the experiment — 3 g target mass, electron beam currents of about 35 μA and 8 days of beam time — the signal of the transition to the single-phonon state should be clearly visible above the background. Thus, the method of NRF, well established as a selective probe of dipole excitations, presents itself now as a new tool for the investigation of excitation and decay properties of even weak E2 transitions due to the recent progress in the development of composite Germanium detectors.

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