β DECAY AS A NEW PROBE FOR THE LOW-ENERGY E1 STRENGTH*

M. Scheck[a,b], S. Mishev[c,d], V.Yu. Ponomarev[e], O. Agar[f]
T. Beck[e], A. Blanc[g], R. Chapman[a,b], U. Gayer[e]
L.P. Gaffney[a,b], E.T. Gregor[a,b], J. Keatings[a,b], P. Koseoglou[e]
U. Köster[g], K.R. Mashtakov[a,b], D. O'Donnell[a,b], H. Pai[e,h]
N. Pietralla[e], D. Savran[i,j], J.F. Smith[a,b], P. Spagnoletti[a,b]
G.S. Simpson[k], M. Thürauf[e], V. Werner[e]

[a]School of Engineering and Computing, University of the West of Scotland Paisley, UK
[b]SUPA, Scottish University Physics Alliance, Glasgow, UK
[c]JINR, Joint Institute for Nuclear Research, Dubna, Russia
[d]Institute for Advanced Physical Studies, New Bulgarian University Sofia, Bulgaria
[e]Institut für Kernphysik, Technische Universität Darmstadt Darmstadt, Germany
[f]Fizik Bölümü, Karamanoğlu Mehmetbey Üniversitesi, Karaman, Turkey
[g]Institut Laue–Langevin, Grenoble, France
[h]Saha Institute of Nuclear Physics, Kolkatta, India
[i]ExtreMe Matter Institute and Research Division, GSI, Darmstadt, Germany
[j]FIAS, Frankfurt Institute of Advanced Studies, Frankfurt am Main, Germany
[k]LPSC, Laboratoire de Physique Subatomique et de Cosmologie de Grenoble Grenoble, France

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In this contribution, it is evaluated whether high Q-value β decays from mothers with low ground-state spin are suitable to probe the structure of 1^- levels associated with the pygmy dipole response. A comparison of data from the exemplary $^{136}\mathrm{I} \rightarrow ^{136}\mathrm{Xe}$ β decay and the $^{136}\mathrm{Xe}(\gamma,\gamma')$ reaction reveals that some 1^- levels are populated in both reactions but with a different pattern. An investigation within the microscopic quasiparticle phonon model shows that the pattern is related to the population of different parts of the wave functions of these 1^- levels establishing β decay as a novel probe.

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1. Introduction

Since the nucleus contains only protons as charged particles, an electric dipole moment must be generated by a separation of centre of charge (proton body) and the centre of mass (proton and neutron bodies). This demixing of proton and neutron bodies implies a link towards the symmetry energy, which enters the nuclear equation of state. The dominant structure associated with the nuclear dipole response, the Giant Dipole Resonance (GDR) [1], is often visualised as an out-of-phase motion of the proton and neutron liquids. The GDR exhausts 100% or even more of the electric dipole (E1) strength predicted by the Thomas–Reiche–Kuhn sum rule (TRK) and is found near 15 MeV excitation energy. In the last three decades, experiments have revealed a weaker excited structure on the low-energy tail of the GDR. This structure exhausts typically a few percent or even less of the E1 strength predicted by the TRK. This resonance-like accumulation of 1^- levels between 5 and 9 MeV excitation energy is denoted as Pygmy Dipole Resonance (PDR) [2]. In a geometric picture, the PDR is visualised as an oscillation of excess neutrons against a nearly isospin saturated $N \approx Z$ core. Yet this picture is quite controversial and it is under debate to which degree shell effects [3, 4] or other collective patterns such as toroidal modes contribute to this low-lying E1 strength [5].

Equally controversial is the experimental picture, especially for the (γ, γ') method of resonant photon scattering, the so-called nuclear resonance fluorescence (NRF) [6]. The latter is the work horse for the investigation of the PDR in stable nuclei. Due to the vanishing rest mass of the photon, the angular momentum transfer in NRF is almost entirely given by the photons $1\,\hbar$ intrinsic angular momentum. Therefore, NRF represents a spin-selective probe perfectly suited for the investigation of dipole excited levels. However, the total cross section for scattering off the atom outweighs the cross section for the intended scattering off the nucleus and the recorded spectra suffer from a huge background, which is exponentially growing towards lower-energies. In most cases, this background prevents the observation of weak decay branches from strongly excited levels or even strong decay branches from weakly excited levels. Consequently, the extracted excitation strength is underestimated. The use of quasi-mononchromatic photon beams as, for example, provided by the High Intensity γ-ray Source at TUNL (Durham, NC, USA) allows the observation of the depopulation of fed low-lying states to correct for the missing branches and extract the total excitation strength [7–9]. However, in terms of a state-by-state spectroscopy, the situation remains unsatisfactory.

2. *β* decay as probe for 1⁻ levels

An approach to measure these in NRF inaccessible decay branches on a state-by-state basis has been indicated when Total Absorbtion γ-ray Spectrosocpy (TAGS) demonstrated for β decays with high Q values from mothers with low ground-state spin a significant population of high-lying levels [13, 14]. This led to the suggestion that these β decays are capable of populating the 1^- levels of interest [12]. Advantageous is that γ-ray spectroscopy following β decay does not suffer from the atomic background and offers the opportunity to perform coincidence measurements. Consequently, this tool represents an alternative approach for decay branches from off-yrast low-spin states to lower-lying excited levels, as it has been proven for weak decay branches from 1^+ levels [15, 16].

An evaluation of data from the ^{136}Xe(γ,γ') reaction [10] and the ^{136}I $[J_0^\pi = (1^-)] \rightarrow ^{136}$Xe β decay [11] ($Q_\beta = 6.93(5)$ MeV) [17] (see Fig. 1) exhibits that several levels are populated in both reactions. However, there are several levels, which are populated solely in one of the two reactions. Therefore, the branching problem will not be fully solved by this complementary approach but at least improved.

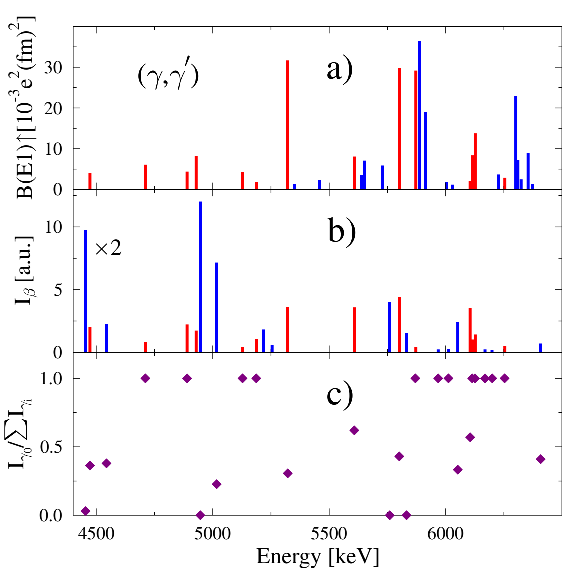

Fig. 1. Comparison of levels belonging to ^{136}Xe observed (a) in the (γ,γ') reaction [10] and (b) β decay of the ^{136}I $J^\pi = (1^-)$ ground state [11]. Part (c) shows the branching ratios as measured in β decay. The E1 excitation strength extracted from (γ,γ') is not corrected for the branching ratios from β decay. Figure is taken from Ref. [12].

In order to evaluate the different population patterns in the two reactions, calculations within the microscopic quasiparticle phonon model (QPM) [18] were performed. In the QPM, the 1^- levels have a complex structure with several components. The major components are two-quasiparticle excitations, which in the shell model correspond to a one-particle one-hole excitation (1p1h) across a major shell gap, multi-phonon excitations and $2n$–quasiparticle excitations ($n > 1$). The latter two components are expected to decay to lower-lying excited states. A more detailed description can be found in Ref. [19]. As shown in Fig. 2, the calculations demonstrate that inelastic scattering experiments such as (γ, γ') populate almost exclusively 1p1h parts of the wave function. In contrast, β decay populates only selected 1p1h configurations, which are related to the ground state of the mother, but mostly 2p2h configurations. Hence, β decay represents a novel and independent probe for these levels. By comparing the level population patterns from the two reactions and considering the information content of the branching behaviour of these levels, conclusions about the amplitudes of the various components in their wave function can be drawn and compared to model calculations.

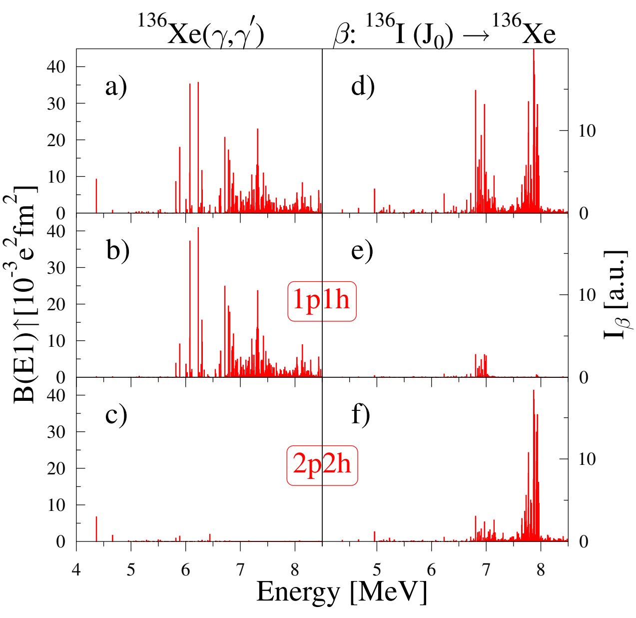

Fig. 2. 1^- level population probabilities in the ^{136}Xe(γ, γ') reaction (a) and in ^{136}I β decay (d) as calculated in the quasiparticle phonon model. Additionally, the calculated population of 1p1h [(b) and (e)] and 2p2h [(c) and (f)] components in the wave function of the final states are shown. For a discussion, see the text. Figure is taken from Ref. [12].

3. Recent experimental work

Yet, when the comparison of the data sets is made, it becomes obvious that the β decay data published in 1977 suffers from the small volume of the used germanium detectors and, therefore, low γ-ray detection efficiency, especially for the high γ-ray energies of the ground-state transitions. Consequently, some interesting cases like the above-mentioned ^{136}I decay and the ^{96}Y ($J_0^\pi = 0^-$) $\rightarrow^{96}$Zr (Q_β = 7096(23) keV) were recently investigated at the LOHENGRIN fission-fragment recoil separator (Institute Laue–Langevin (ILL), Grenoble) employing a setup of Clover and other large-volume High-Purity Germanium detectors. For the ^{96}Y decay, an additional silicon β-particle detector was employed. Preliminary spectra recorded for the ^{96}Y decay are shown in Fig. 3. For the upper spectrum, a coincidence towards β particles has been applied, in order to clean the spectrum from background γ rays. The lower spectrum has been gated on electrons associated with the E0 transition from the first excited level ($J^\pi = 0^+$) and shifted to the energy of the emitting level. Additionally, the positioning of 1^- levels as known from $(\vec{\gamma}, \gamma')$ experiments [20] is indicated by arrows.

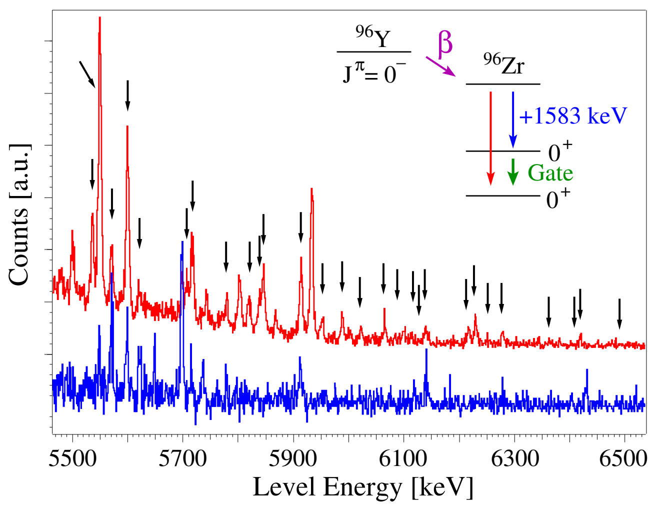

Fig. 3. Spectra recently recorded at LOHENGRIN (ILL) following the β decay of ^{96}Y. For the upper spectrum, a coincidence with β particles was demanded. The lower spectrum, which is gated on the E0: $0_2^+ \rightarrow 0_{\rm gs}^+$ transition, has been shifted by the energy of this transition. The arrows correspond to the energy of known 1^- levels [20]. For several 1^- levels branching γ-ray transitions are obvious.

4. Summary

The comparison of data for 1^- levels associated with the PDR recorded following β decay and the (γ,γ') reaction demonstrates that additional spectroscopic information for several but not all 1^- levels can be obtained. A study within the QPM revealed the sensitivity of β decay towards components in the wave functions that are only weakly, if at all, populated in inelastic scattering experiments. From a comparison of (γ,γ') and β decay, conclusions about the microscopic structure of the observed 1^- can be drawn. Promising is that β decay is perfectly suited to investigate neutron-rich nuclei, in which the PDR is expected to be more pronounced.

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