

Onset of oblate deformation in Pb isotopes Janne Pakarinen University of Jyväskylä SSNET 2024, Orsay, France

Conversion electron spectroscopy and its role in identifying shape coexisting structures nuc

Denartment of Physics and Astronomy, Louisiana Sta

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Abstract

We present, from a historical perspective, the evolution of instruments and techniques developed by our group, in conjunction with other collaborators, to establish a program in conversion electron spectroscopy that could be routinely implemented in radioactive decay studies. We focus here mainly on the investigations that bear upon the study of nuclear shape coexistence and its relation to electric monopole (E0) transitions. We show that many $I^{\pi} \rightarrow I^{\pi}$ $(I \neq 0)$ transitions in both even and odd nuclei with mixed shape-coexisting configurations have large E0 components accompanying their M1 + E2strength (in some cases nearly pure E0), and that this E0 enhancement is a clear 'signature' for nuclear shape coexistence

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Keywords: nuclear physics, nuclear structure, nuclear shape coexistence

(Some figures may appear in colour only in the online journal)

Introduction

Shape coexistence in atomic nuclei has been a feature in nuclear structure for over 50 years. It has evolved from an exotic rarity (e.g., 16O), to a phenomenon specific to certain regions (e.g., $Z \sim 38$, $Z \sim 80$, to the current understanding that it occurs in almost all nuclei [1]. This paper describes a program to utilize the conversion electron process to elucidate features of the decays between coexisting structures, leading to the development of a 'signature' for shape coexistence: that of an enhancement of electron monopole (E0) transition strength (i.e., of $F0 \perp M1 \perp F2$ multinoles) in $I^{\pm} \rightarrow I^{\pm} (I \neq 0)$ transitions. Electric monopole strength is s. Pure E0 states. We

Journal of Physics G: Nuclear and Particle Physics

Unique and complementary information on shape coexistence in the neutron-deficient Pb region derived from Coulomb excitation

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E-mail: wrosek@ski.uw.edu.nl and Liam Gaffrey@uws.ac.uk Received 11 September 2015, revised 3 November 2015

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Neutron-difficute integes of Ph-Hg-Ph-Ph-Ra are the classic region in the overlaption of shape constinuer in unions tands. A large groupment of energiation eff about the state of the sta Neutron-deficient isotopes of Pt-Hg-Pb-Po-Rn are the classic region in the recently obtained results. Furthermore, we present some new interpretations that arise from this data and show testing comparisons to state-of-the-art

Keywords: Coulomb excitation, shape coexistence, B(E2), mean-field models, deformation nuclear shape quadrupole sum rul

(Some figures may appear in colour only in the online journal)

1. Introductio

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Atomic Data and Nuclear Data Tables 98 (2012) 149-300 Contents lists available at SciVerse ScienceDirect Atomic Data and Nuclear Data Tables

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Nuclear shape isomers

P. Möller^{a,*}, A.J. Sierk^a, R. Bengtsson^b, H. Sagawa^c, T. Ichikawa^d orerical Division, Los Alarnos National Laboratory, Los Alarnos, NM 87545, United States nariment of Mathematical Physics, Lund Institute of Technology, P.O. Bast 118, SE-22100 Lund ter for Mathematical Sciences, University of Alar, Alar, Wakamatsu, Fakashima 865-80, Jopa man Institute for Temarettor (Phases): Parter Definition, Natis AER-ARD 20 Jopa

ARTICLE INFO ABSTRACT

review article Shape coexistence and triaxiality in the superheavy nuclei

S. Ćwiok¹*, P.-H. Heenen² & W. Nazarewicz^{1,4} shape coexisting in a particular production of the shape of the shape

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Z. Phys. A - Atomic Nuclei 134, 269-276 (1989)

COEXISTENCE IN EVEN-MASS NUCLEI

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PHYSICAL REVIEW C. VOLUME 60, 014316

Shape coexistence and the effective nucleon-nucleon interaction

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The phenomenon of shape coexistence is discussed within the self-consistent Hartree-Fock method and the nuclear shell model. The occurrence of the coexisting configurations with different intrinsic shapes is traced back to the properties of the effective Hamiltonian. [S0555-4213(99)(90)3008.3]

The phenomeno of nuclear coexistence manifests issi The phenomeno of nuclear coexistence manifests issi the resence of closs-lving nuclear states with very diffe-tions of the particle-vibration coupling responsible for the strength of the particle-vibration coupling responsible for the

the relative positions of many-particle many-hole intruder

Join Instaine for Harry Ion Research, Oak Ridge National Laboratory, P.D. Bar 2008, Oak Ridge, Tomosan Funchia for Protectischer Profil, Characteria Elegand, Statularez T. D 20185 Elegand, Correary "Dynamics of Physica and Astronomy, University of Tensuses, Rossilli, Tenseres 2709, Oak Physica, Correspondence, Cor

P.O. Box 2008, Oak Ridger, TN 37831, USA and Institute of Theoretical Physics, Warsaw University, ul. Hoza 69, PL-00-681 Warsaw, Poland

PACS number(s): 21.30 Fe. 21.10 Ky. 21.60 Cs. 21.60 Jz

I. INTRODUCTION

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PACS: 21.60 Cr: 27.80 + m 1. Introductio

Shape Coexistence in the Neutron Deficient Pb Isotones

R. Bengtsson¹ and W. Nazarewicz²

and the Configuration-Constrained Shell Correction Approach

Received November 2, 1988; revised version May 29, 1985

Recently observed [1–3] collective structures in the structures in the Strutinsky shell-correction precodure [5] neutron deficient Pb isotopes are a very interesting proved to be a very useful tool for determining and state properties of adomic neutric (masse, usually been interpreted (see e.g. [1]) as proto structures the constrained flartners-Fock λ_{p-2} Avcentition accoss the cloud z = 2.8 zhell. The structure is the str collective rotational bands built on top of excited isomeric states suggest the presence of sizeable nucleo-teraction [6]. One should thus expect that with a deformations In a previous paper [4] the question of shape existence primomena in the even-even P1 and the area of the prime prime prime prime prime prime the prime prime prime prime prime prime short range residual (pairing) interaction the re-tar area of the prime prime prime prime area of the prime prime prime prime short range residual (pairing) interaction the re-tar area of the prime prima prime prima prime prime ar deformations sotones w

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coexistence and collectivity in the

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Multifaceted character of shape coexistence phenomena in atomic nuclei

S Leonish* B Fornals A Braccosh Y Tsunodad T Otsukasi

ARTICLE INFO ABSTRACT

— ment cares the targe is not indicated, due to the mixing between difference configurations. While they prediction based on various models are also presented, none of which able light on the microscopic irrativator of the considered states and the entry of the observations of the states of t

1. Introduction

Review

In many body quantum systems, the phenomenon of coexistence of different arrangements of constituents, within the name object, is present as different avails. In chemistry, for example, malecides or polysionaic ions with identical absochast formation that is, same mather of atoms of each densement — bud districtly different arrangements of atoms in proc, were originally termed ionsens. In the so-called "stereoisoncitum" (or "spatial isometium"), for example, the bonds are the same but the relative positions of the atoms different discovers can be created by by trainistical solution (spatial bonds).

Studi di Milano, Milan 20133, Italy

COEXISTENCE IN ODD-MASS NUCLEI

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REVIEWS OF MODERN PHYSICS, VOLUME 83. OCTOBER-DECEMBER 2011

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Invited Comment

Nuclear shapes: from earli multiple shape coexisting

K Heyde¹ and J L Wood² Department of Physics and Astronomy, Ghent University Proefluinstraat, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332-

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Received 4 February 2016, revised 27 April 2016 Accepted for publication 15 June 2016 Published 21 July 2016

The concept of the atomic nucleus being characterized by an intrinsic pro The concept of the atomic nucleon boing characterized by un intrinsic process are as a real of the high previous hyperbran tasks in the field of atomic internal phases and the previous hyperbran and the strength of the st starting point.

Keywords: nuclear structure, shape coexistence, experimental and theoreti (Some figures may appear in colour only in the online journal)

In the

1. Introduction

In the field of nuclear physics, Nobel prizes were awarded to sion hyper Eugene Wigner, Maria Goeppert-Mayer, and Hans Jensen for any sugge their isdass concerning symmetry and shell structure in the in order to atomic nucleus (Nobel prize in 1963), and to Auge Bohr, Ben between : Montehon, and Langes Rajasource for survoice the state are Mottelson, and James Rainwater for proposing the deep appearance connection between collective motion and independent-par-Harah ticle motion in the atomic nucleus (Nobel prize in 1975). It defor tale motion in the atomic nucleus (Nobel prize in 1975). It deform turns out that there two major realizations, with the original closed papers dating from 1973, 1949, and 1950–1953, respectively. Laking the prize the matter on the later work and evolution of our defore understanding of atomic nuclei over the last 60 years with, as makin and/or them, triging to reconcile collective modes with icular, individual nucleon motion within a mean field, incorporating beams residual interactions.

ell mechanism for the phe-

e in nuclei within the Elliott

ie in nuclei within the Elliott symmetry is proposed for all d, that shape coexistence is e-quadrupole interaction and ong the spin-orbit (SO) like s 6-14, 14–28, 28–50, 50–82.

being described by the proxy

monic oscillator (HO) shells

8-20, 20-40, 40-70, 70-112,

ymmetry. The outcome is, that

certain islands on the nuclear

ism predicts without any free roton number (Z) or neutron 7-20, 34-40, 59-70, 96-112,

ites for shape coexistence. In flip from the HO shell to the

Shape coexistence in atomic nuclei Kris Hevde*

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CONTENTS

(published 30 November 2011; publisher error corrected 6 December 2011) Share coexistence in nuclei appears to be unique in the realm of finite many-body quantum Shape constrained in matter appears to be unaque as the real of time many-body quantum system; It differs from the various generatical arrangements that scientismes court in a molecule in that in a molecule the various arrangements are of the widely separated atomic model. In match it is "arrangements" on inclucions involve (used so) energy caparatists with different detrict quadruppear properties such as moments and transition rates, and different distributions of proton pairs and neutron pairs with respect to their Forms in energies. Somethicments to such affractures will "involv" as an entropy pairs and transition rates.

neutron pairs with nepect to their fermit energies. Sometimes two such arranges with nepect to their fermit energies. Sometimes two such arranges are the properties in snighboring intropents and instores. In the first part of this review the thorntical status of occusiones in models descriptions, are emphasized. The second part of this review presents summit and the other energies of data status and the second part of this review presents summarized. In the status part of this review presents summarized in the other and odd same status (Levies and the status status) status) status (Levies and the status status) status (Levies and the status status) status) status) status (Levies and the status status) status) status) status (Levies and the status status) status) status) status) status) status) status) status) status status) stat major advances in reaching to extremes of proton-neutron number, and the anticipated new "rare isotope beam" facilities, guidelines for search and discovery are discussed.

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3. Clustering in nucle

PHYSICAL REVIEW C 106, 044323 (2022)

Islands of shape coexistence from single-particle spectra in covariant density functional theory

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⁴Department of Physics, National and Kapodistrian University of Athens, Zografou Campus, GR-15784 Athens, Greece ⁵Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, 72 Tzarigrad Road, 1784 Sofia, Bulgaria (Received 12 June 2022: accented 30 Sentember 2022: published 21 October 2022)

Using covariant density functional theory with the DDMP2 functional and labeling single-narticle energy Using covariant density functional theory with the DDME2 functional and labeling single-particle energy orbitals by Nisson quantum numbers, a nearch for particl-hose ($p \rightarrow bacchaince concerted to the appearance$ of shape coexistence is performed for <math>Z = 38 to 84. Mands of shape coexistence are found near the margic numbers Z = 82 and Z = 50, restricted in regions around the relevant neatmon middlell N = 104 and N = 66, expectively, in accordance with the well-accepted p h interpretation of shape coexistence in these regions, which e call neutron-induced share coexistence, since the neutrons act as elevators creating holes in the protoorbitals. Similar but smaller islands of shape coexistence are found near N = 90 and N = 60, restricted in regions around the relevant proton midshells Z = 66 and Z = 39, respectively, related to p-h excitations across the three-dimensional isotropic harmonic-oscillator magic numbers N = 112 and N = 70, which correspond to the beginning of the participation of the opposite parity orbitals $1i_{13/2}$ and $1k_{11/2}$, respectively, to the onset of deformation. We call this case proton-induced shape coexistence, since the protons act as elevators creating holes in the neutron orbitals, thus offering a possible microscopic mechanism for the appearance of shape coaxistence in these regions. In the region around N = 40, Z = 40, an island is located on which both neutron p-h excitations

and proton p-h excitations are present DOI: 10.1103/PhysRevC.106.044323

gated along the Z axis in the regions of N = 90, Z = 64 and N = 60, Z = 40, as well as a region around N = 40, Z = 34. In addition, in lighter nuclei an elongated region along the diagonal is seen for N = Z nuclei, along with a few other L INTRODUCTION Shane coexistence [1-4] in atomic nuclei is receiving resnape coexistence [1→1] in atomic nuclei is receiving re-cently intense experimental and theoretical attention, since it is a suble effect depending on the details of nuclear structure, as shaped up by specific features of the nucleon-nucleon inregions. Over the years the suspicion has been growing that as shaped up by specific features of the nucleon nucleon in-tractions [15]. Shapes constitutence is all of cocer in a nucleon site the ground state hand is accompanied by another similar hand possissing the same angular momenta at similar neargies, but examples with one of them being spherical and the other one deformed. First proposed in 1955 by Morinaga in "O (6), it has tole numerous investigations, reviewed in Ref. [1] for odd nuclei and Berk[1-2-1] for exa-even nuclei. The availability of radioactivi-ion beams in several laboratories for them coversions covered in restore 10 Ref. [14]. In each to them coversions covered in restore 10 Ref. [15] for the theory is the several several several in Ref. [16] for the Ref. [16] for the theory coversions covered in restored 10 Ref. [16] for the theory coversions covered in restored 10 Ref. [16] for the theory coversions covered in restored 10 Ref. [16] for the theory coversions covered in restored 10 Ref. [16] for the theory coversions coversion restored in Ref. [16] for the top laboratories for the coversions coversion restored in Restored 10 Ref. [16] for the theory coversions coversion restored in Restored 10 Ref. [16] for the top laboratories in the Ref. [16] for the top laboratories for the restored in Ref. [16] for the restored in Restored [16] for the restored [16] for the restored [16] for the restored [16] for the restore shape coexistence is an effect which can appear anywhere o the nuclear chart. the nuclear chart. An oppositiv view has been presented in Ref. [7], in which a mechanism for shape coexistence based on the Elliott [8–10] and proxy-SU(3) [11,12] models has been presented. Using algebraic arguments, it has been found that shape coexistence algebraic arguments, it has been found that shape coexistence can only occur within certain horizontial and wertical stripes of the nuclear chart, bordered by 7–8, 17–20, 34–40, 59–70, 96–112, 146–184 neutrons or protons. The predicted stripes of shape coexistence contain all regions shown in Fig. 8 of Ref. [3], described above, but they are considerably wider. for shape coexistence, recently reviewed in Ref. [4], in which the experimental fingerprints of shape coexistence are also discussed in detail. Therefore being within the limits of these stripes appears to be a necessary condition for shape coexistence, but not a suf-ficient one. It would be desirable to find additional arguments The regions in which shape coexistence had been observed narrowing down these stripes into specific regions, in order to provide more specific guidance to the experimental effort. Concerning the microscopic mechanism underlying the aperimentally in even-even nuclei up to that time (2011) e been schematically summarized in Fig. 8 of Ref. [3], z ben schemischily summarized in Fig. 8 of Ref. 1). Gronzening the micro-regime mechanism underlying to any schemischild axis. In Medium-mass and heavy nuclei they are regimes obligation in the N articolar and the major abers Z = 82 and Z = 50, shorter regions slightly clon-

9-9985/2022/106(4)/044323(19) ©2022 American Physical Society 044323-



Journal of Physics G: Nuclear and Particle Physic Phys. G: Nucl. Part. Phys. 43 (2016) 024002 (18oc

Coulomb excitation studies of shape coexistence in atomic nuclei

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Low-energy Coulomb excitation provides a well-understood means o exciting atomic nuclei and allows measuring electromagnetic moments that can be directly related to the nuclear shape. The availability of radioactive ion beams (RIBs) at energies near the Coulomb barrier has made it possible to study shape coexistence in a variety of short-lived exotic nuclei. This eview presents a short overview of the methods related to multi-step



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In-beam spectroscopic studies of shape neutron-deficient Z ≈ 82 nuclei

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Calculations of shape-issentic states in neutron deficient lead isotopes have been j formed using the configuration-constrained shell correction method with a Woods-Sa average potential and a mosopole pairing interaction. This approach enables us decompose the ground state potential energy surface in separate parts characteri uniquely by the number of occupied intructor orbitals. The calculations reproduce positions of the excelled 0⁻ intructor states. The isotope "arby is discussed in detail." 2. Shell Correction Calculations and the Interpretation of Potential Energy Surfaces

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Calculations of shape-isomeric states in neutron deficient lead isotopes have been

PRL 103, 212501 (2009)

PHYSICAL REVIEW LETTERS

Global Calculation of Nuclear Shape Isomers

Peter Möller,1,8 Arnold J. Sierk,1 Ragnar Bengtsson,2 Hiroyuki Sagawa,3 and Takatoshi Ichikawa4

c) MOIREL – FUTORED J. STELL, FARGUM DEGESSION, 1100/YHAL SIGAWA, and Fakadovini Felinkawa "Pheroretical Division, Los Adamos National Laboratory: Los Alamos, New Mexico 87545, USA partment of Mathematical Physics, Lund Institute of Technology. P. O. Box 118, SE-22100 Lund, Sweden "Center for Mathematical Sciences, University of Aixa Aixa" Makawatru, Fukukubina 965-80, Agana

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The nuclear potential energy, calculated as a function of shape parameters may have several local minima. The order" approximation; it shows which nuclei fulfill anc-lowest minimum is associated with the mass and shape super-seven nuclear manifestida asceration of states, see dibatter models bear a calculation of local-sing leavest super-seven nuclear as calculations of local-sing leavest super-seven nuclear as a super-seven seven se

even-leven naccia are manifesto za sectito vi stato, see canoritare indones stose z castistante o nov-jegin zeros (485, 11-3). Nocieda status estato previously been estados bean experimentally and theoretically (4.3), beyond the mean field by constructing wave functions in the been applied study of states isomers model simplicity, we obtain a good overlap between calcu-nis a theoretical model with demonstrated predictive power model simplicity, we obtain a good overlap between calcu-teristics and free of parameters specifically.

which is universal and free of parameters specifically intel regions of miniple minima and regions of experi-alization in haple-isometaria. Its ranges for experison, instances and the otherwork datase constraints. A complete using the mneroscopic-microscopic approach is in [6], A we remain carbo for a straint of the straints of the straints of the straints of the straints afford the straints of the straints of the straints of the straints of the straints afford the straints of the straints of the straints of the straints of the straints afford the straints of the straints of the straints of the straints of the straints afford the straints of the straints of the straints of the straints of the straints afford the straints of the straints afford the straints of the strain

torce used [1]. Many studes have been performed without in a future-dimensional grind in terms of three dorbumous considering statial approximately, however, the student state is a strategiment of the state of th

example [8], that most "shape isomers" obtained in such restricted calculations become unstable with respect to additional details specific to the calculation of these sur-axial asymmetry when this constraint is removed.

In our study we consider axial asymmetry and pre

for the first time a global calculation of the occurrent shape isomers in a model that describes nuclei from light (normally ¹⁶O) to the heaviest nuclei with a consi set of parameters for all studied properties and all m The metantical memory conference one calculated in

The potential-energy surfaces are calculated i

macroscopic-microscopic finite-range liquid-drop m (FRLDM) with the recent 2002 parameter set [9]. It been very extensively benchmarked and been show

Zeitschrift für Physik A Atomic Nuc

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0031-9007/09/103(21)/212501(4)

To determine which nuclei may exhibit shape isomerism, we use a well-benchmarked ma

Global phenomenon in atomic nuclei

Kris Heyde and John L Wood Nuclear shapes: from earliest ideas to multiple shape coexisting structures, Physica Scripta 91, 083008 (2016)

"While shape coexistence has, to date, only been established or inferred in a few hundred nuclei, there are compelling reasons to believe that it is a universal feature of (almost) all nuclei.

It is now understood that it is even the feature of nuclear structure that is 'responsible for us all being here': the Hoyle State is the result of ¹²C possessing shape coexistence."

Level energy systematics prior to this work



¹⁸⁶Pb



Recoil-decay tagging technique



SAGE at JYFL recoil separators



Experiments in a nutshell

	¹⁸⁶ Pb	¹⁸⁸ Pb	¹⁹⁰ Pb		
Instrumentation	SAGE+RITU+GREAT	SAGE+RITU+GREAT	SAGE+MARA+MARA_FP	APPA+RITU+RITU_FP	
Channel selection	Recoil-decay tagging	Recoil gating	Recoil gating	Recoil gating	
Reaction	¹⁰⁶ Pd(⁸³ Kr,3n) ¹⁸⁶ Pb	¹⁶⁰ Dy(³² S,4n) ¹⁸⁸ Pb	¹⁵⁹ Tb(³⁵ Cl,4n) ¹⁹⁰ Pb	¹⁰⁸ Pd(⁸⁶ Kr,4n) ¹⁹⁰ Pb	
Beam energy	365 MeV	165 MeV	164 MeV	378 MeV	
Beam intensity	~5 pnA	~13 pnA	~10 pnA	~2 pnA	
Beam on target	108 h	129 h	320 h	~250 h	
Target thickness	1 mg/cm ²	500 μg/cm²	350 μg/cm²	0.95 mg/cm2	
Production cross section	75µb	1100µb	~10mb	~10mb	

Additional complementary in-beam experiments:

JR4: A recoil-gated plunger lifetime measurement of ¹⁸⁸Pb with JUROGAM and the RITU separator JR33: A recoil-decay tagged plunger lifetime measurement for the yrast levels of ¹⁸⁶Pb

Unique case - ¹⁸⁶Pb nucleus



Mass number

¹⁸⁶Pb – direct measurement of conversion electrons

- Tota

δ-electron

200

150

100

50

nts / 2 keV

K electrons

electrons

M electron:

Excess electrons

100

- Very clean γ -ray and electron energy spectra (thanks to recoil-decay tagging)
- Calculated electron energy spectra show excess counts => associated with E0 transitions
- The first direct measurement of the $0^+_2 \rightarrow 0^+_1$ and $0^+_3 \rightarrow 0^+_1$ transitions in ¹⁸⁶Pb •



 γ -ray singles energy spectrum



Electron singles energy spectrum

283

200

300

J. Ojala et al., Commun. Phys. 5, 213 (2022)

¹⁸⁶Pb – reassigning the shapes of the 0⁺ states

Based on the $B(E2; 2_1^+ \to 0_1^+) = 6(2)$ W.u.

and the measured branching ratio $I_{\gamma}(2^+_1 \rightarrow 0^+_2)/I_{\gamma}(2^+_1 \rightarrow 0^+_1)$

⇒ Reduced transition probability: $B(E2; 2_1^+ \rightarrow 0_2^+) = 190(80)$ W.u. Typically in this region: B(E2; prolate in-band) = 390(40) W.u.

⇒ Transitional quadrupole moment: $|Q_t(2_1^+ \rightarrow 0_2^+)| = 7.7(33)$ eb Typically in this region: $Q_t(E2; prolate in-band) = 9.0(5)$ eb

> B(E2) =190(80) W.u. Q_t = 7.7(33) eb



The 0^+_2 state a prolate band member

¹⁸⁶Pb – feeding of the excited 0⁺ states from the 2⁺₂ state

Assuming $I(2_2^+ \to 0_3^+) = I(0_3^+ \to 0_1^+) = 26(6)$ and $B(E2; 2_2^+ \to 0_1^+) = 5$ W.u.

 $\Rightarrow B(E2; 2_2^+ \rightarrow 0_3^+) < 200(120)$ W.u.

Consequently, the non-observation of the $2^+_2 \rightarrow 0^+_3$ transition does not exclude the existence of a collective (oblate) in-band transition.

If we further assume B(E2; $2_2^+ \rightarrow 0_2^+$) = 50 W.u. $\Rightarrow I(2_2^+ \rightarrow 0_2^+) = 19(2)$

does not fit within margins.

 \Rightarrow The 0⁺₂ state does not have a notable oblate component.



Mixing of configurations in ¹⁸⁸Pb





In-beam γ -ray spectroscopy on ¹⁸⁸Pb



G.D. Dracoulis *et al.*, Phys. Rev C **60**, 014303 (1999) G.D. Dracoulis *et al.*, Phys. Rev C **67**, 051301(R) (2003) G.D. Dracoulis *et al.*, Phys. Rev C **69**, 054318 (2004)

¹⁸⁸Pb – recoil-gated singles electrons

Assessing the conundrum of the 0⁺ level energies

- Deconvolution based on observed γ-rays
- Includes 200+ individual components
- Excess electrons assigned to E0 transitions
- Direct observation of the $0^+_2 \rightarrow 0^+_1$ transition at 591(2)keV
- No sign of the 0⁺ state at 767keV

 0^+

- All intensity around 724keV assigned to the $2_1^+ \rightarrow 0_1^+$ transition
- Confirm observations by Van de Vel et al., PRC 68, 054311 (2003)





P. Papadakis et al., Phys. Lett. B 858,139048 (2024)

¹⁸⁸Pb – feeding of the 0⁺ state

Relative intensities: $I_{tot}(2^+_1 \to 0^+_1) = 1000 \quad I_{tot}(0^+_2 \to 0^+_1) = 12(2)$ $I_{\gamma}(2^+_2 \to 0^+_2) = 3.4(12) \quad I_{\gamma}(2^+_2 \to 0^+_1) = 117(7)$

Feeding from the prolate band via the 133 keV transition:

$$I_{\gamma}(E2; 2_1^+ \to 0_2^+) < \frac{I_{tot}(E0; 0_2^+ \to 0_1^+) - I_{tot}(E2; 2_2^+ \to 0_2^+)}{1 + \alpha_{tot}(2_1^+ \to 0_2^+)} = 1.5$$

Taking $B(E2; 2_1^+ \to 0_1^+) = 7.5(30)$ W.u. $\Rightarrow B(E2; 2_1^+ \to 0_2^+) < 90$ W.u.

Feeding from the oblate band via the 362 keV transition:

 $I_{\gamma}(2_2^+ \to 0_2^+) = 3.4(12) \text{ and } I_{\gamma}(2_2^+ \to 0_1^+) = 117(7)$ Assuming: $B(E2; 2_2^+ \to 0_1^+) = 0.8 \text{ W.u.} \Rightarrow B(E2; 2_1^+ \to 0_2^+) = 3.1 \text{ W.u.}$

Hindered transition from the oblate band \Rightarrow the $2_2^+ \rightarrow 0_2^+$ transition is not a band member, while the $B(E2; 2_1^+ \rightarrow 0_2^+) < 90$ W.u. allows transition within a band.

 \cdot the 0^+_2 state fits better with predominantly prolate band



Measured B(E2)

Relative B(E2)

IBM B(E2)

Oblate minimum in ¹⁹⁰Pb





Summary

Measured B(E2) values

- T. Grahn, et al., Phys. Rev. Lett. 97, 062501 (2006)
- Present work

IBM B(E2) values

- V. Hellemans et al., Phys. Rev C. 77, 064324 (2008) Extracted ρ^2
 - Based on measured branching ratios and
 - Measured or questimated B(E2) values







New assignments and prospects



- ¹⁸⁶Pb: prolate and oblate O⁺ states swapped
- ¹⁸⁸Pb: 0⁺₁ state reassigned as prolate
- ¹⁹⁰Pb: yrast band reassigned as oblate spherical 2⁺ state discovered prolate and oblate 8⁺ states swapped

Results obtained any conged the picture.

We must question whether the shape assignments of heavier Pb isotopes are correct.

Maybe the onset of oblate deformation starts already at ¹⁹⁴Pb.