

**Cercetari moderne despre structura nucleara,
tranzitii de faza si dezintegrarea beta dubla**

Director: Prof. Dr. A. A. Raduta

Raport de etapa(V): Specific properties of the chiral magnetic bands

Membrii echipei

1. Prof. Dr. Apolodor Raduta, CSI
2. Dr. Alexandru Raduta, CS I
3. Dr. Cristian Raduta, CS II
4. Dr. Ioan Ursu, CS II
5. Dr. Radu Budaca, CS III
6. Dr. Petrica Buganu, CS III

A. Indicatori de performanta

In anul 2015 au aparut in reviste cu indice de impact mare 3 lucrari. De asemenea, a mai fost scrisa o carte avand printre subiectele tratate pe cele ce figureaza drept obiective ale proiectului PNII-ID-2/5.10.2011. Printre obiectivele etapei din anul acesta figureaza scrierea unui cod numeric pentru tratarea benzilor chirale in nucleei par-pare. Lista lucrarilor la care am facut referire mai sus este prezentata mai jos.

- 1) Semi-phenomenological description of the chiral bands in $^{188,190}\text{Os}$, A. A. Raduta and C. M. Raduta, J. Phys. G: Nucl. Part. Phys. 42 (2015) 065105 (16pp)
- 2) Analytical solution for the Davydov-Chaban Hamiltonian with a sextic potential for $= 30$, P. Buganu* and R. Budaca, PHYSICAL REVIEW C 91, 014306 (2015)
- 3) ENERGY SPECTRA, E2 TRANSITION PROBABILITIES AND SHAPE DEFORMATIONS FOR THE EVEN-EVEN ISOTOPES $^{180,196}\text{Pt}$, P. BUGANU1 , A.A. RADUTA1,2, Rom.Journ. Phys., Vol. 60, Nos.1-2, (2015) p. 161-178.
- 4) Nuclear Structure with coherent states, Apolodor Aristotel Raduta, Book, 521 pagini, Springer, Heidelberg, New York, London, ISBN 978-3-319-14641-6, DOI 10. 1007/978-3-

319-14642-3

5) Nd134.f, cod numeric, 50 pagini.

B. Rezultate importante, activitati

In cele ce urmeaza vom descrie pe scurt continutul lucrarilor realizate in anul acesta.

I. Nuclear Structure with coherent states, Springer

Cartea prezinta un interes foarte mare pentru cei ce lucreaza in domeniul structurii nucleare. Intrucat se adreseaza nu numai cercetaorilor din tara dar si din universitatile si institutele din strainatate, prezentarea succint a cartii va fi facuta in limba engleza.

Highlights

Arguments in the favor of coherent state description. Since the coherent state was used for the first time by Glauber for a system of photons, many progresses have been made in extending the concept to other systems with various goals. The ground state properties of a many body system is often described by coherent state as happens within BCS theory, random phase approximation or the time dependent Hartree-Fock (TDHF) formalisms. In general, the dequantization procedure defined by a time dependent variational equation is most reliable when the trial function is of a coherent type. Indeed, only in this case quantizing the classical trajectories the resulting spectrum might be close to that associated with the initial many-body Hamiltonian. Such a treatment can be applied also to quadrupole boson Hamiltonians.

The over-complete property of a coherent state allows for accounts of the dynamics causing the collective motion. Indeed, by expanding the coherent state in a Hilbert space basis, no expansion coefficient is missing. Due to this property, for a quadrupole boson Hamiltonian contributions in the whole boson space are included, which is not the case when a diagonalization procedure is adopted. The useful consequence of the mentioned property is the role of the coherent state as a generating function for a basis of states in the considered Hilbert space.

Here we deal with quadrupole boson Hamiltonians and therefore we use axially symmetric coherent state defined by the quadrupole boson, b_{20}^+ and b_{20} , and simple polynomial

excitations of that. It is generally accepted that the nuclear system behaves more or less classically in a state of high angular momentum. This fact recommends the coherent states as an efficient tool for treating the high spin states. Indeed, it is well known that the coherent states minimize the Heisenberg uncertainty relations, which in fact reflects a classical character. However, the coherent state breaks several symmetries among which the most important are the rotational and the gauge ones. The question is whether restoring these symmetries, the classical properties are preserved or not. This feature is studied in Phys. Rev. C 86, 054307 for the mentioned symmetries and two pairs of conjugate coordinates: the quadrupole coordinate and its conjugate momentum and the boson number operator and the conjugate phase.

Studying a second order boson Hamiltonian within a time dependent variational formalism with a quadrupole coherent state as a trial function, and a constraint, the corresponding classical equation is exactly solvable, which results in having a closed formula for the ground band energies, which generalizes the result of Holmberg and Lipas. In the classical picture the kinetic and potential energies are naturally separated. The potential is just the Davidson potential. Alternatively, the energy can be obtained with the angular momentum projected state, i.e. within an approach of variation after projection. An analytical formula for energies, similar to that resulting in a semi-classical treatment, is obtained. The two very simple formulas have been applied to 44 nuclei covering regions characterized by different dynamic symmetries or, in other words, belonging to various known nuclear phases. In all cases one obtains a very good agreement with the experimental data.

The coherent state description. Being encouraged by the results obtained for the ground band, we extended these ideas to three interacting bands, ground, beta and gamma. We started with an axially symmetric coherent state as a model state of the ground band in the intrinsic frame and two polynomial excitations of that, which are associated to the beta and gamma band. The excitations were chosen such that the three states to be orthogonal before and after angular momentum projection. The three sets of projected states have very attractive properties: 1) they depend on a real parameter which simulates the nuclear deformation. 2) when the deformation is going to zero the functions for the ground band tend to the highest seniority states $| \frac{J}{2} \frac{J}{2} 0JM \rangle$, while those for gamma and beta bands go to the second and third highest seniority states. When the deformation is large the projected wave functions are identical with those provided by the liquid drop model. Moreover, the

continuous link between the two sets of wave functions, in vibrational and rotational limits, is the same as the correspondence established empirically by Sheline and Sakai. Within the restricted boson space of projected states we considered an effective boson Hamiltonian, which yields maximally decoupled bands. For a given J the energies for beta band and gamma band states of odd angular momentum are taken to be the corresponding average values while the states of ground band and gamma band of even angular momenta are obtained by diagonalizing a 2×2 matrix. Energies and quadrupole transition probabilities are given in an analytical form, which in the vibrational as well as rotational limits become very simple. This model is called the Coherent State Model (CSM) and has been applied to a huge number of nuclei belonging to different symmetry regions. Salient features are analytically pointed out within both the laboratory and intrinsic frame.

Several Extension of CSM. The CSM was subject of several extensions: 1) A particle-core Hamiltonian with the core described by the CSM was considered in particle-core space to describe the properties caused by the crossing of the ground, beta and gamma bands with a two quasiparticle-core band where the particle-like angular momentum is aligned to the collective one leading to several backbendings. The model was applied to the Pt region where several states 12^+ have been seen. In a similar spirit we described the one and three quasiparticle bands in even odd nuclei 2) We attached to the quadrupole bosons an isospin quantum number distinguishing the proton-like from the neutron-like bosons. The formalism obtained following a similar path and arguments as for CSM was conventionally called the Generalized Coherent State Model (GCSM). This new approach describes simultaneously the major bands , ground, beta and gamma, and one band built on the top of the scissors state 1^+ . We proved analytically that the GCSM predicts for the total M1 strength, of exciting 1^+ from the ground state 0^+ , a quadratic dependence on the nuclear deformation, which in fact confirms the collective character of the mode. Based on a semi-classical calculations we have derived an analytical expression for the gyromagnetic factor of neutrons which corrects the M1 transition operator towards improving the agreement with the data. The GCSM was the first approach which was extended as to describe the scissors modes in the even-odd nuclei, our predictions being later on confirmed by experiment.

3) Recently, the GCSM Hamiltonian was amended by a mean field, a pairing and a particle-core term consisting of a quadrupole-quadrupole and a spin-spin interaction. The collective magnetic dipole band is crossed by four two quasiparticle magnetic bands which

have a chiral character. The chiral symmetry is broken by the spin-spin term in four different ways, which results in having four twin bands. I just mention that this is the first formalism which treats the twin bands in even-even nuclei.

4) The CSM may be easily extended to the negative parity states if the unprojected state of ground band is replaced by a product function of two coherent states, one of quadrupole and one of octupole type. In this way the unprojected ground state violates not only the rotational symmetry but also the space reflection symmetry. Therefore, in the laboratory frame we have to restore not only the rotational symmetry but also the parity. In this way, instead of three bands described by the CSM we have three pairs of parity bands. The space was enlarged by adding two dipole parity partner bands. We kept the principles governing the CSM in constructing the generating functions for independent bands and the effective Hamiltonian. Thus, the extension provides a realistic description of four rotational bands, four of positive and four of negative parity. The properties of these bands have been studied in several publications. Excitation energies of these bands as well as $B(E2)$, $B(E1)$ and $B(E3)$ values have been described for a large number of nuclei.

5) Adding to the Hamiltonian used at 4) an odd particle we extended the description to the odd nuclei. Here we describe realistically six rotational bands, three of positive and three of negative parity bands. One points out that one pair of parity partner bands exhibits a chiral symmetry.

Projected spherical single particle basis Averaging a particle core-Hamiltonian with a coherent state one obtains a deformed mean field which resembles the Nilsson Hamiltonian. On the other hand averaging the particle-core Hamiltonian with the spherical single particle wave function one obtains a boson Hamiltonian which admits the axially deformed quadrupole coherent states as eigenfunctions. This suggest that projecting out the good angular momentum from the product function of a spherical shell model state and an axially deformed quadrupole coherent state might be an efficient basis to treat the particle core-Hamiltonian. From the projected states we succeeded to select a basis. This basis can be used to treat particle-like Hamiltonians. Indeed, when the matrix element of a particle operator is calculated, first the boson factors are orthogonalized leading to a factor depending on nuclear deformation. In particular, the average of the particle-core Hamiltonian with an element of the projected spherical basis gives a set of single particle energies whose deformation dependence is similar to that of Nilsson model states. Moreover, when

the deformation is going to zero the single particle energies go to those of spherical shell model. Therefore the defined basis has the nice property that recovers the shell model basis in the vibrational limit, while when the deformation goes apart from zero the Nilsson model energies are obtained. This feature allows us to treat in an unified fashion the spherical and deformed nuclei. This was tested by describing the scissors-like modes and the rate of the $2\nu\beta\beta$ decay. A systematic analysis including 190 nuclei from all regions of the nuclides periodic table, is presented in a very recent paper submitted to Annals of Physics (NY).

A phenomenological solvable model. Starting from the Bohr-Mottelson Hamiltonian written in the intrinsic coordinates supplemented by a specific potential term, by expanding the rotational and potential terms in series of the variable γ around its static values, 0^0 and 30^0 , we obtained a separable form for the differential equations associated to the dynamic deformation variables, which are fully solvable. Thus, the equation in γ is satisfied by the spheroidal or Mathieu functions. Regarding the β variable, the equations used are alternatively those for a sextic oscillator potential with a centrifugal barrier included, an infinite square well or a Davidson potential. Solutions were used to describe the ground, beta and gamma bands energies and E2 transition probabilities for axially deformed and triaxial nuclei, respectively.

Comparison with other models A special chapter is devoted to the comparison of our methods and some phenomenological models which are very popular in the field nuclear structure: a) The liquid drop model b) The deformed liquid drop the model of Greiner and Faessler c) The model of Gneuss and Greiner d) The Interacting Boson Approximation proposed by Arima and Iachello. e) The model of Lipas and Hapakowski f) The methods developed by the group of Bonatsos for interacting rotational bands g) The two rotors model proposed by Lo Iudice and Palumbo h) Nilsson model i) The phenomenological solvable models mentioned above.

The book covers the essential features of a large variety of nuclear structure properties of both collective and microscopic nature. Most of results are given in an analytical form which give a deep insight of the considered phenomena. The detailed comparison with all existent nuclear structure models provides the readers a proper framework and, at a time, the perspective of new developments. The book is very useful for young as well as for experienced researchers. Due to the selfcontent exposure, the book can be succesfully read and used also by the undergraduate students.

II. Descrierea benzilor chirale in $^{188,190}\text{Os}$

Spectrele rotationale apar ca o reflexie a unei ruperi spontane de simetrie, cand nucleul capata o deformare statica. Proprietati fundamentale cum sunt forma nucleara, distributia densitatii de masa si de sarcina in interiorul nucleului, momentele electrice si magnetice, spectrele colective, pot fi evidențiate in urma interactiei sistemului nuclear cu un camp electromagnetic. Cele doua componente ale campului sunt folosite pentru a investiga proprietatile nucleare de natura electrica sau, respectiv magnetica. La sfarsitul secolului trecut, atat starile de tip scissors [1, 2] cat si cele de tip spin-flip [4] au fost intens studiate de mai multe grupuri. Starile de tip scissors au fost excitate in experimente de ciocnire inelastica (e,e') la unghiuri inapoi si sunt localizate in regiunea 2-3 MeV, in timp ce starile de tip spin flip sunt vazute in experimente de tip (p,p') la unghiuri inainte si sunt asteptate sa apară in intervalul de 5-10 MeV. Ecitatiiile de tip scissors descriu oscilatiile unghiulare in antifaza ale protonilor si neutronilor, taria tranzitiei M1 din starea fundamentala fiind proportionala cu deformarea nucleara la patrat. Acest lucru confirma caracterul colectiv al excitatiei. Despre acest subiect s-au scris multe lucrari, de aceea este dificil de citat toate contributiile. Mentionam totusi, articolele de sinteza din Refs. [3, 4].

Deoarece taria totala a modului scissors este proporcionala cu deformarea nucleara la patrat, s-a crezut mult timp ca proprietatile magnetice colective sunt in general asociate cu deformarea sistemului nuclear. Acest lucru nu este adevarat din cauza benzilor magnetice pentru care raportul intre momentul de inertie si valoarea $B(E2)$ pentru excitarea starii 2^+ din starea fundamentala 0^+ , $\mathcal{I}^{(2)}/B(E2)$, are valori mari de ordinul $100(\text{eb})^{-2}\text{MeV}^{-1}$. Aceasta valoare mare poate fi justificata de existenta unui moment magnetic dipolar transversal (adica perpendicular pe momentul cinetic total), care induce tranzitii magnetice dipolare mari dar nu momente cvdrupolare de sarcina [5]. Intr-adevar indicatiile experimentale arata ca benzile magnetice dipolare prezinta valori mari pentru valorile $B(M1)$, $B(M1) \sim 3 - 6\mu_N^2$, si valori mici pentru $B(E2)$ (a se vedea Ref.[6]). Aceste stari sunt diferite de starile de tip *scissors*, ele fiind mai de grada de tip *shares*(foarfece cu bratele curbate). Un sistem cu moment magnetic transversal dipolar mare poate consta intr-un miez triaxial la care sunt cuplati un proton intr-un orbital prolate si un neutron intr-un orbital de tip oblate. Momentumul cinetic al protonului-particula este orientat de-alungul axei mari a miezului, in timp ce orbitalul oblate este caracterizat de un moment cinetic orientat de-alungul axei mici. Pe

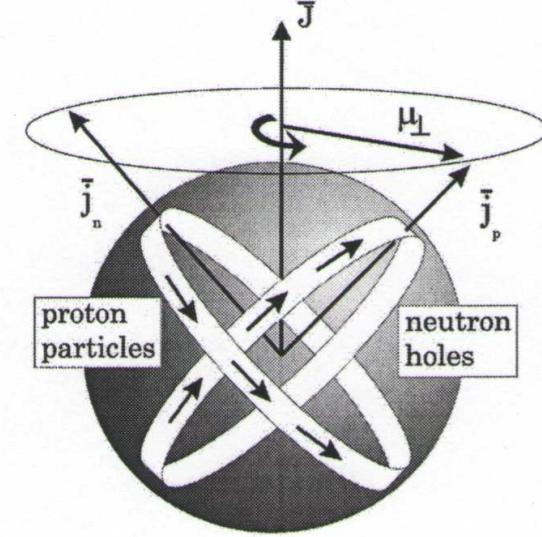


FIG. 1: Rotatia magnetica. Protonii dintr-o stare de tip particula cu j mare si neutronii dintr-o stare de tip gaura formeaza circuite ce inconjoara un miez aproape sferic. Cele doua momente cinetice \vec{j}_p si \vec{j}_n genereaza un moment magnetic transversal $\vec{\mu}_\perp$ perpendicular pe momentul kinetic total \vec{J} . Datorita valorii negative a factorului gyromagnetic neutronic, componente transversale ale momentelor magnetice protonic si neutronic se insumeaza, in timp ce componentele paralele se scad. Datorita momentului magnetic transversal mare, interactia cu un camp electromagnetic poate excita sistemul intr-o stare dipolară magnetica.

de alta parte pentru nuclee triaxiale cu $\gamma \approx 30^\circ$ momentul de inertie maxim corespunde axei intermediare si-n consecinta momentul kinetic al miezului este orientat dupa aceasta axa. Aceasta situatie este sugerata grafic de figura 1.

Interactia intre un orbital prolate si unul oblate este repulsiva ceeace mentine cele doua orbite indepartate una de cealalta. Din aceasta cauza, situatia in care momentele cinetice ale protonului si neutronului sunt perpendiculare este favorizata. Un moment magnetic dipolar transversal maxim se poate realiza atunci cand de exemplu j_p este orientat de-alungul axei mici a miezului, j_n de-alungul axei lungi a miezului iar miezul se roteste in jurul axei intermediare, aceasta fiind axa de moment de inertie maxim. Sa presupunem ca cele trei momente cinetice formeaza un triedru drept. Daca Hamiltonianul ce descrie sistemul in interactie format din proton, neutron si miez, este invariant la transformarea ce schimba triedul drept intr-unul stang, ce se realizeaza prin schimbarea orientarii uneia

dintre componentele triedrului, spunem ca sistemul prezinta o simetrie chirala.

Ca intotdeauna o simetrie este identificata in situatia cand aceasta este *rupta*, adica celor doua triedre, drept si stramb, le corespund energii diferite. Deci o signatura a simetriei chirale pentru un sistem triaxial este existenta a doua benzi $\Delta I = 1$, de energii foarte apropiate. Marind momentul cinetic total, are loc o aliniere graduala a momentelor cinetice \vec{j}_p si \vec{j}_n la momentul cinetic total \vec{J} si in consecinta se dezvolta o banda magnetica.

Problema care ne-o punem in aceasta lucrare este daca solutia pentru cele trei momente cinetice ortogonale, asociate cu miezul, un orbital prolate si unul oblate, care determina $B(M1)$ mari intre starile benzii magnetice, este unica. De remarcat ca sistemele descrise pana acum sunt cele impar-impare.

In trecutul apropiat starile magnetice de tip spin-flip au fost studiate de mai multe grupuri [1–10]. Grupul nostru a studiat benzile dipolare cu $K^\pi = 1^\pm$ folosind un Hamiltonian de bozoni cvadrupolari si octupolari si un set de stari model obtinute prin proiectia paritatii si momentului cinetic dintr-o stare fundamentala deformata atat cvadrupolar cat si octupolar [11]. Am aratat ca banda 1^+ are caracter magnetic in timp ce banda 1^- este de natura electrica. Intr-o alta publicatie [18] am aratat ca benzile partenere de paritate au proprietatea ca incepand de la o valoare critica a momentului cinetic, starile au proprietatea ca momentele cinetice asociate bozonilor cvadrupolari si respectiv octupolari, sunt ortogonale. Este de asteptat ca adaugand la Hamiltonianul fenomenologic un set de nucleoni in interactie, sa se poata realiza o configuratie in care momentul cinetic transportat de nucleoni sa fie perpendicular pe planul momentelor cinetice cvadrupoalare, respectiv octupolare. Prima tentativa pe aceasta directie a fost realizata in Ref.[19].

Modelul pe care-l propunem in aceasta lucrare consta intr-un miez fenomenologic cu doua componente, protoni si neutroni, descris in termeni de bozoni cvadrupolari, si doua cvasiparticule avand momentul cinetic total orientat de-alungul axei de simetrie a miezului. Am analizat posibilitatea ca sistemul celor trei momente cinetice sa poata forma un triedru drept si in consecinta sa poata fi asociat cu tranzitii magnetice dipolare de probabilitate mare. Hamiltonianul model ce descrie sistemul particula-miez in interactie are urmatoarea expresie:

$$\begin{aligned} H = & H_{GCSM} + \sum_{\alpha} \epsilon_{\alpha} c_{\alpha}^{\dagger} c_{\alpha} - \frac{G}{4} P^{\dagger} P \\ & - \sum_{\tau=p,n} X_{pc}^{(\tau)} \sum_m q_{2m} \left(b_{\tau,-m}^{\dagger} + (-)^m b_{\tau m} \right) (-)^m - X_{sS} \vec{J}_F \cdot \vec{J}_c, \end{aligned} \quad (0.1)$$

Daca in Hamiltonianul de mai sus se negligeaza termenul de interactie spin-spin, Hamiltonianul resultant prezinta o simetrie chirala. Termenul spin-spin violeaza aceasta simetrie. Intr-adevar schimband succesiv semnul momentelor cinetice J_F , J_p , J_n se obtin trei interactii distincte diferite de cea intituala. Asociind la fiecare din aceste interactii o banda rotationala se obtine un set de patru benzi "gemene" cu proprietatea ca oricare doua dintre sistemele corespunzatoare sunt legate intre ele printr-o transformare chirala. Doua dintre benzile mentionate sunt degenerate, motivul constand in aceea ca interactia fiind asimetrica in raport cu permutarea proton-neutron elementul sau de matrice diagonal este nul. Este remarcabil faptul ca marind spatiul starilor cu starile de doua cvasiparticule cuplate cu o stare din banda fundamentala, atunci in acest spatiu largit exista doua benzi aditionale care nu au partitatea la permutarea p_n , numar cuantic bun. Una dintre aceste doua benzi prezinta proprietati chirale, adica tranzitii $M1$ intense in banda.

Sistematica rezultatelor experimentale a stabilit un set de criterii necesare pentru determinarea caracterului chiral al benzilor "gemene": 1) Benzile partenere sunt aproape degenerate. 2) Parametrul de clusterizare energetica practic nu depinde de momentul kinetic. 3) Comportarea de cluster a rapoartelor $B(M1)/B(E2)$ and $B(M1)_{in}/B(M1)_{out}$, unde $B(M1)_{in}$ si $B(M1)_{out}$ noteaza tranzitiile magnetice dipolare ($M1$) in banda si intre benzi. Conform ultimelor analize se pare ca aceste criterii sunt numai necesare dar nu si suficiente, benzile partenere in anumite circumstante apartinand la forme nucleare distincte departate una de alta.

Aceste criterii au fost verificate in aplicatiile numerice pentru ^{192}Pt , ^{188}Os si ^{190}Os . Probabilitatea de tranzitie redusa $B(M1)$, in banda, are valori mari, ajungand pana la $7\mu_N^2$. Modelul propus prezice existenta a patru benzi gemene. Proprietatile prezise de acest model au fost comparate cu cele obtinute prin alte metode. Subliniem faptul ca toate formalismele existente se refera la nuclei impar-impare in timp pe modelul nostru descrie proprietatile chirale in nuclei par-pare.

Pentru a face un studiu sistematic al acestor benzi in diferite regiuni ale tabelului periodic sunt necesare date experimentale, care deocamdata nu prea exista. Formalismul de mai sus a facut obiectul lucrarii:

Semi-phenomenological description of the chiral bands in $^{188;190}\text{Os}$, A. A. Raduta and C. M. Raduta, J. Phys. G: Nucl. Part. Phys. 42 (2015) 065105 (16pp) Apreciam ca lucrarea realizata contine ipoteze noi si ca acestea vor stimula extin-

derea masuratorilor pentru benzile chirale in nuclee par-pare.

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III Soluie analitica pentru un Hamiltonian de tip Davydov-Chaban cu potential sextic si $\gamma = 30^0$

Este propusa o solutie analitica pentru un Hamiltonian Davydov-Chaban cu un potential de oscilator sextic pentru variabila β si variabila $gamm$ fixata la valoarea de 30^0 . Modelul rezultat este numit conventional drept model Z(4)-sextic. Pentru hamiltonianul mentionat exista solutie exacta pentru benzile fundamentala si beta, in timp ce pentru banda γ sunt adoptate anumite aproximatii. Datorita proprietatii de scaling solutia pentru energii si rapoartele de tranzitii BE(2) depind de un singur parametru modulo un numar intreg care limiteaza numarul de stari luate in considerare. Pentru anumite restrictii, ce conduc la potentiiale mai simple, energiile si rapoartele BE(2) sunt independente de parametri de fitare. Energiile si tranzitiile BE(2) prezise de modelul z(4)-sextic au fost studiate ca functie de sigurul parametru liber, rezultatele fiind prezentate in detaliu pentru anumite cazuri speciale. Aplicatiile numerice se refera la izotopii $^{128,130,132}\text{Xe}$ si $^{192,194,196}\text{Pt}$ isotopes. Se obtine un acord calitativ cu experienta. In cazul izotopilor Xe se evidențiaza o tranzitie de faza.

Lucrarea descrisa pe scurt mai sus a fost publicata in **PHYSICAL REVIEW C 91, 014306 (2015), Analytical solution for the Davydov-Chaban Hamiltonian with a sextic potential for $\gamma = 30$, P. Buganu and R. Budaca**

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IV Spectrul energetic, probabilitatile reduse de tranzitie cvadrupolare si deformarea de forma in izotopii par-pari 180196Pt

Izotopii par-pari 180196 Pt au fost studiați cu două modele solubile pentru variabilele intrinseci cvadrupolare, numite Davidson și formalismul sferoidal (SDA) și respectiv Davidson și Matiew Approach (DMA). Sunt analizate energiile benzilor fundamentala, beta și gama, probabilitatile reduse de tranzitie între nivelele energetice ale acestor benzi precum și variațiile de formă a suprafetei nucleare de la un izotop la altul și respectiv de la o bandă la cealaltă. Rezultatele numerice sunt comparate cu cele experimentale preum și cu cele teoretice obținute recent cu ajutorul altor formalisme.

Unul dintre modelele sovabile la care am facut referire mai sus, denumita (DMA) constă în urmatoarele. Pentru variabila β s-a folosit potentialul Davidson care conduce la o ecuație pentru polinoamele Laguerre generalizate. Ca potential în variabila γ se folosește o funcție periodica cu minim în $\gamma_0 = 30^\circ$ acestuia corespundu-i o ecuație diferențială care admite drept soluție funcția Mathieu.

In cazul nucleelor cu simetrie axială potentialul ales pentru variabila gamma conduce la o soluție exactă care este de tip funcție sferoidală. Împreună cu potentialul Davidson pentru variabila β acestea definesc modelul DSA. Rezultatele numerice pentru izotopii par-pari menționati sunt comparate atât cu datele experiente de aceiași autori prin alte metode.

Rezultatele descrise succint mai sus au făcut obiectul lucrării **ENERGY SPECTRA, E2 TRANSITION PROBABILITIES AND SHAPE DEFORMATIONS FOR THE EVEN-EVEN ISOTOPES 180196 Pt, P. Buganu and A. A. Raduta, Rom. Jour. Phys. vol. 60, Nos.1-2, (2015), p.161-178.**

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c. Cercetari in curs de desfasurare

Grupul condus de Prof. Dr. Apolodor Raduta continua studiul benzilor magnetice cu simetrie chirala. Astfel este in curs de desfasurare studiul izotopior par-pari $^{136,138}\text{Nd}$ unde exista date experimentale. In aceste cazuri sunt studiate doua benzi dipolare in interactie definita prin cuparea a doua qp din patura $h11/2$ la stari din banda fundamentala si respectiv la stari din banda fenomenologica dipolară proton-neutronic. Se estimeaza ca vor fi generate 6 benzi magnetice caracterizate prin tranzitii dipolare magnetice puternice in fiecare bands. De asemenea vor exista tranzitii rezonabil de mari intre starile de doua qp cuplate la stari din banda fundamentala si respectiv starile de doua qp cuplate la starile din banda colectiva dipolară.

Un alt subiect tratat de grupul nostru este de constructie a unei baze de stiri colective de tip QRPA deformate. Este cunoscut ca deformand campul mediu al miscarii uniparticul se obtine modelul Nilsson. Starile uniparticula Nilsson pot fi folosite pentru un tratament QRPA conducand la stari QRPA deformate. Acest procedeu prezinta dezavantajul ca restaurarea simetriei la rotatii este extrem de dificila. O metoda distincta originala consta in aceea ca deformarea se produce in campul mediu in reprezentarea de cvaziparticula. In felul acesta cvasiparticulele au un moment cinetic determinat dar fara proiectie m bine definita. Starile QRPA obtinute cu aceasta baza de cvaziparticule sunt deformate dar restaurare simetriei la rotatie este mult mai simpla si tractabila. In felul acesta se estimeaza ca se obtine o contributie majora la domeniul ansamblelor de "many body".

D. Implicarea tinerilor cercetatori.

Dupa cum reiese din lista de publicatii, tinerii cercetatori, Radu Budaca si Petrica Buganu sunt co-autori la lucrările realizate in cadrul proiectului in anul la care se refera prezentul raport. De asemenea cei doi colaboratori au participat la conferinte internationale unde au

avut comunicari stiintifice.

E. Dificultati intampinate in derularea proiectului: Nu

F. Impact economic si social.

Cercetarile efectuate au un caracter fundamental. De aceea produsul final este cunoasterea. Dupa cum rezulta din prezentul raport precum si din lucrarile stiintifice atasate, ipotezele teoretice avansate sunt 100% originale si de aceea plus valoarea activitatilor echipei reprezinta o contributie importanta la dezvoltarea cunoasterii in domeniu, la imbogatirea tezaurului creatiei stiintifice romanesti. Suntem convinsi ca pe plan international aceste rezultate vor avea un ecou favorabil si prin aceasta vizibilitatea stiintei romanesti va fi imbunatatita. Aceste rezultate contribuie, de asemenea la formarea unui mediu academic propice unor cercetari ulterioare de varf pe plan mondial. Un exemplu il constituie perfectionarea tinerilor cercetatori din echipa. Este interesant de mentionat ca la debutul proiectului, cei doi tineri erau doctoranzi incepatori. In intervalul scurs, cei doi au sustinut tezele de doctorat, si au fost promovati, succesiv in functiile de cercetator stiintific (CS) si cercetator stiintific III(CSIII). Acest lucru dovedeste ca atmosfera in grupul Prof. Dr. Apolodor Raduta este incurajatoare pentru tinerii cercetatori intr-un domeniu destul de complex si dificil.

G. Diseminare, mobilitati

Rezultatele prezentate mai sus au fost prezentate in seminariile laboratorului sau la workshopuri internationale cum sunt conferintele internationale de structura nucleara din Croatia (Dubrovnik) si Bulgaria (Sofia).

20.11.2015

Prof. Em. Dr. Apolodor Raduta