

Acest document conține o sinteză a rezultatelor științifice obținute în cadrul proiectului IDEI – 127 / 05.10.2011 (Cod proiect PN-II-ID-PCE-2011-3-0140) pe perioada anilor 2011-2016, în limba română, urmată de un rezumat în limba engleză

This document contains a synthesis of the scientific results obtained within the project IDEI – 127 / 05.10.2011 (project code PN-II-ID-PCE-2011-3-0140), for the period 2011-2016, in Romanian, followed by a resume in English

Sinteză rezultatelor științifice

obținute în perioada octombrie 2011 – septembrie 2016 în cadrul proiectului

IDEI – 127 / 05.10.2011

(Cod proiect PN-II-ID-PCE-2011-3-0140)

Titlu proiect: Spectroscopia unor nucleee atomice mai putin cunoscute

Proiectul a avut ca obiect studiul proprietatilor unor nucleee atomice pentru care datele experimentale ale momentului lipseau sau erau foarte sarace, astfel incat studiile sistematice pe zonele respective ale hartii nucleelor erau practic imposibile. Scopul principal al acestor studii a fost deci acela de a imbogati baza de date de cunostinte asupra sistememlor nucleare. Proprietatile de structura vizate de studiile noastre au fost nivelele energetice nucleare, pentru care obiectivele experimentale de masurat sau interpretat in cadrul unor modele teoretice de structura sunt o serie de observabile precum: energia de excitatie, modul de dezintegrare electromagnetica (prin emisia de radiatii gama), timpul de viata, si altele.

Studiile efectuate in cadrul proiectului pot fi, in mare, impartite in doua categorii: experimentale si teoretice. In cadrul celor experimentale, au fost efectuate experimente specifice, prin tehnici adecvate scopului urmarit (observabilelor de masurat); in cea mai mare parte, determinarile experimentale au fost insotite si de interpretarea lor in cadrul unor calcule efectuate cu diverse modele teoretice. Studiile teoretice au urmarit descrierea unor fenomene de structura nucleara pe zone de masa mai extinse. In cele ce urmeaza vom descrie sumar rezultatele obtinute in cadrul celor doua categorii (mai multe detalii pot fi gasite in rapoartele prezentate pentru fiecare an, la adresa <http://proiecte.nipne.ro/pn2/137-proiecte.html>).

Studii experimentale

Majoritatea studiilor experimentale au fost efectuate in cadrul laboratorului Tandem din cadrul IFIN-Bucuresti, utilizand dispozitivele experimentale dedicate spectroscopiei gama in fascicule accelerate. Alte studii experimentale au fost efectuate in cadrul unor colaborari internationale, la instalatii dedicate din cadrul laboratoarelor de fizica nucleara din Padova si din Muenchen.

Nucleele studiate experimental si principalele rezultatele obtinute au fost urmatoarele:

^{150}Pm : pentru acest nucleu impar-impar a fost stabilita o schema de nivele energetice, *pentru prima oara*, fiind un caz rar de nucleu abordabil prin mai multe reactii nucleare dar pentru care nu era cunoscuta inca nici o stare excitata. Schema de nivele experimentală a fost studiată prin două experimente: unul efectuat la Bucuresti prin studiul radiatiilor gama emise într-o reacție

(p,n), al doilea efectuat la Muenchen la un spectrometru magnetic de foarte buna rezolutie energetica, prin intermediul reactiei de transfer (d, α).

^{95}Pd : pentru acest nucleu a fost stabilita o schema de nivele in domeniul spinilor inalti, utilizand multi-detectorul de radiatii gama GASP de la Padova. Rezultatele au fost interpretate pe baza unor calcule de model in paturi. Un studiu similar a fost facut si pentru nucleul **^{92}Ru** .

^{120}Te si ^{86}Zr : pentru aceste nucleee s-au efectuat experimente care au urmarit determinarea timpilor de viata ai nivelor nucleare (marimi esentiale pentru determinarea probabilitatilor de dezintegrare electromagnetică), utilizand un ansamblu de trei tehnici de masura, astfel incat sa se acopere un domeniu foarte larg de timpi: de la cca 1 picosecunda la cateva nanoseconde. Tehnicile respective au fost: DSAM (masurarea atenuarii deplasarii Doppler), RDM (tehnica distantei de recul) si FEST (metoda de masurare electronica rapida). Toate aceste tehnici au fost dezvoltate in laboratorul de la Bucuresti, masuratorile fiind efectuate cu multidetectorul de radiatii gama ROSPHERE. In ^{120}Te au fost determinate, prin intermediul celor trei tehnici, timpii de viata pentru un numar de 43 de nivele excitate, oferind o baza extrem de solida pentru testarea diverselor modele teoretice. In nucleul ^{86}Zr , au fost masurati timpii de viata ai starilor benzii fundamentale, prin metodele RDM si FEST.

^{166}Er , ^{240}Pu , $^{198,200,202}\text{Hg}$: In aceste nucleee s-a urmarit in principal studiul excitatiilor monopolare (starilor 0^+) utilizand in acest scop reactia cu transfer de doi neutroni (p,t). Experimentele au fost efectuate cu spectrometrul Q3D de la Muenchen. In toate cazurile a fost determinat un mare numar de stari excitate 0^+ pana la energii de excitatie de cativa MeV, majoritatea necunoscute pana la data experimentelor noastre. Explicarea caracteristicilor acestor stari pe baza unor modele de structura nucleara reprezinta inca o provocare deosebita, in acest sens datele respective avand inca potentialul de a fi utilizate si in viitor. De asemenea, in cursul studiilor respective, au fost determinate stari excitate si cu alte valori spin/paritate, precum 1^- , 2^+ , 3^- , 4^+ . Printre concluziile formulate pana in prezent oe baza acestor date se poate cita aceea a unor puternice corelatii octupolare in structura celei de a doua stari excitate 0^+ in nucleul ^{240}Pu . De asemenea, deosebirile observate intre doua nucleee vecine, ^{166}Er si ^{168}Er , par sa indice importante schimbari de structura in jurul numarului de neutroni N=98.

^{28}Si : pentru acest nucleu, au fost masurate sectiuni absolute de populare a diverse nivele excitate prin reactia (α ,n).

Studii teoretice

Studiul structurii fine in dezintegrarea alfa a nucleelor grele. A fost realizata o sistematica a comportarii popularii diverselor nivele excitate din nucleele grele transactinide prin dezintegrarea alfa. In prima faza, a fost evidentiata a comportare ciudata a factorilor de interzicere pentru starea 4^+ , care nu a putut fi descrisa de niciun model teoretic actual. Ulterior, aceasta anomalie a fost folosita pentru a documenta existenta unei inchideri de subpatura deformata in nucleele cu numarul de neutroni N=142, care nu fusese observata anterior.

Studiul rezonantei gigantice a vibratiei de imperechere. Acest studiu a fost intreprins pentru a explica de ce acest mod de excitatie nucleara, prezis teoretic, a fost pus in evidenta doar in nucleele usoare (^{14}C) dar nu a putut fi observat pentru nucleele mai grele.

Studiul excitatiilor joase in nucleee de Ruteniu printr-un model algebraic. Au fost alese pentru studiu nucleele de Ru cu masa in jur de 100, unde se manifesta un pronuntat caracter tranzitional al proprietatilor de structura. Modelul cu care s-au efectuat calculele a fost IBFM

(modelul bosonilor si fermionilor in interactiune). A fost realizata o descriere rezonabila a unui mare numar de observabile de structura in aceste nuclee, cu masa intre 99 si 105 (excitatii energetice, structuri de benzi de rotatie, moduri de dezintegrare gama, probabilitati de tranzitie electromagneticica, factori spectroscopici pentru transfer de un nucleon), cu un numar redus de parametri.

O parte din rezultatele stiintifice mentionate mai sus au facut obiectul a *11 articole publicate in revista ISI Physical Review C* (SUA), sau al unor comunicari la Conferinte Internationale ale domeniului (4 dintre acestea au aparut in Proceedings ale acestor conferinte, fiind recenzate si in baza de date ISI) – a se vedea lista de publicatii atasata acestui raport. Dupa cum s-a mai mentionat deja, sunt inca disponibile date obtinute experimental in cadrul proiectului, spre valorificare in lucrari stiintifice viitoare, cu mentionarea finantarii pe acest proiect.

Synthesis of the scientific results obtained during the period October 2011 – September 2016 within the project

IDEI – 127 / 05.10.2011

(Project code PN-II-ID-PCE-2011-3-0140)

Project title : Spectroscopy of some less known atomic nuclei

The object of the project was the study of the properties of nuclei for which the present experimental data were either missing or very scarce, such that the systematic studies of the corresponding areas of the nuclear chart were practically impossible. The main purpose was to enrich the database of nuclear systems' properties. The structure properties in our studies were the nuclear energy levels, for which the experimental objectives to be measured or interpreted on the basis of nuclear stucture theoretical models were some observables like: excitation energy, electromagnetic decay modes, lifetime, and others.

The studies made within the project can be largely classified in two cathegories, as experimental and theoretical. For the experimental ones, specific experiments were performed, by techniques that were adequate to the observables to be measured; most of the experimental determinations were also interpreted in the frame of different theoretical models. The theoretical studies had as purpose to describe nuclear structure phenomena over extended mass regions. In the following we will present a summary of the results obtwined within the two cathegories (more details can be found in the annual reports presented at <http://proiecte.nipne.ro/pn2/137-proiecte.html>).

Experimental studies

Most of the experiments were performed in the Tandem laboratory of IFIN-Bucuresti, by using the experimental setups dedicated to gamma-ray spectroscopy with aceelerated ion beams. Other experiments were performed within international collaborations, at dedicated installations from the nuclear physics laboratories in Padova and Muenchen.

The nuclei experimentally studied, and the main results are:

^{150}Pm : for this odd-odd nucleus, a level scheme was evidenced for the first time, this being a rare case of a nucleus that could be studied by a number of nuclear reactions for which no excited levels were known. The experimental level scheme was deduced in two experiments: one in Bucharest, by study of the gamma-rays emitted in a (p,n) reaction, the other in Muenchen, at a magnetic spectrograph of very good energy resolution, with the (d, α) transfer reaction.

^{95}Pd : a level scheme of this nucleus was established for the high-spin range, by using the GASP gamma-ray array from Padova. The results were interpreted on the basis of shell model calculations. A similar study was made for the ^{92}Ru nucleus as well.

^{120}Te and ^{86}Zr : for these nuclei a set of exeriments were performed in order to determine the lifetimes of their excited levels – quantities that are essential to determine the electromagnetic decay probabilities, by using a set of measuring techniques such as to cover a large range of time: from cca 1 picosencod to several nanoseconds. These techniques were: DSAM (Dopple shift

attenuation method), RDM (recoil distance method), and FEST (fast electronic timing method). All these techniques were developed at the Bucharest laboratory, and the measurements were made with the gamma-ray array ROSPHERE. In ^{120}Te , lifetimes were determined with all three techniques for a number of 43 excited levels, thus offering an extremely challenging database to test various theoretical models. In ^{86}Zr , lifetimes were determined for states of the yrast band, by the RDM and FEST methods.

^{166}Er , ^{240}Pu , $^{198,200,202}\text{Hg}$: In these nuclei the main purpose was to study the monopolar excitations (the 0^+ states), using for this the two-neutron transfer reaction (p,t). The experiments were made with the Q3D magnetic spectrograph in Muenchen. In all these cases, a large number of excited 0^+ states were determined, most of them unknown before these experiments. The explanation of the characteristics of these states by theoretical models still represents a big challenge for theory, such that these date have a large potential of being used in the future too. Within the same experiments, a large number of other states of spin/parity such as 1^- , 2^+ , 3^- , 4^+ were also determined. Among the first conclusions, one may remind that of possible strong octupole correlations in the second excited 0^+ state in the nucleus ^{240}Pu . Also, the differences observed between two neighbouring nuclei, ^{166}Er and ^{168}Er , seem to indicate important structure changes around the neutron number $N=98$.

^{28}Si : for this nucleus, precise absolute cross sections for the population of excited states via the (α,n) reaction have been measured.

Theoretical studies

Study of the fine structure in the alpha decay of the heavy nuclei. A systematic of the behavior of the population of different excited states of heavy transactine nuclei in the alpha decay was realized. In a first stage, an unusual behavior was remarked for the hindrance factors of the 4^+ state, which could not be described by any current theoretical model. This anomaly was subsequently used to demonstrate the existence of a deformed subshell closure in the nuclei with the neutron number $N=142$, which had not been remarked before.

Study of the giant pairing vibration. This study aimed to explain why this nuclear excitation mode, theoretically predicted, was experimentally observed only in light nuclei (^{14}C), but could not be observed in the heavier nuclei.

Study of low-energy excitations in Ruthenium nuclei by algebraic model. For this study we have chosen the Ru nuclei with mass around 100, where there is a pronounced transitional character of the structure properties. Calculations were performed with the IBFM (Interacting Boson-Fermion model). A reasonable description was achieved for a large number of structure observables in the Ru isotopes with mass between 99 and 105 (such as energy levels, rotational band structures, electromagnetic transition probabilities, one-nucleon transfer spectroscopic factors) with a reduced number of parameters.

A part of the scientific results mentioned above made the object of *11 articles published in the ISI journal Physical Review C* (USA), or of communications at International Conferences of the Nuclear Physics field (4 of these being published within Proceedings of these conferences, also reviewed by ISI) – as one can see in the publication list attached to this report. As already mentioned above, experimental data obtained within the project are potentially available for future scientific articles, with the mentioning of their financing within the present project.