Nuclear Physics

Nuclear Spectroscopy

The activities of the group include two sets of different problems. Both subjects utilize in general similar nuclear spectroscopy techniques and the same heavy ion beams produced by the TANDAR accelerator.

The first set of problems corresponds to applied research (from the point of view of nuclear physics) and tries to contribute in other areas generating interdisciplinary and partly technogical activities. Applications to biomedical and environmental problems are being pursued. On this sector, we can distinguish three lines:

trace element analysis, development of a heavy ion microbeam, feasibility studies on novel accelerator-based cancer therapy modalities.

The second set of problems is in the field of basic research on nuclear structure.

Trace Element Analysis

The most frequently used techniques are PIXE and PIGE (Particle Induced X-ray (Gamma) Emission). The first one is a high sensitivity multielement analysis technique based on the heavy ion excitation and detection of characteristic X-rays of the elements present in samples of diverse origin. In biomedicine, the most important application has been a study of the correlation between the aluminium concentration and the incidence of Alzheimer's disease. As far as environmental problems are concerned the PIXE technique has been applied to the determination of lead concentration and other polluting agents in atmospheric aerosols of Buenos Aires city and surroundings. The PIGE tecnique, which utilizes gamma-rays of nuclear origin induced by heavy ions, is an interesting alternative in the case of very light elements. We have applied it for the detection of boron traces in connection with BNCT (Boron Neutron Capture Theory)

Heavy ion microbeam

We aim at implementing in one of the beam lines of the TANDAR accelerator a facility which could be characterized as a nuclear microscope, i.e., a heavy ion micropobe. This microbeam in conjunctionwith nuclear and atomic techniques of excitation and detection like PIXE, PIGE, HIRBS (Heavy Ion Rutherford Backscattering), STIM (Scanning Transmission Ion Micrsocopy), etc., will allow the quantitative determination of the multyelementary composition, the modification of properties and structural characterization of different systems with a space resolution of the order of a micron.

Feasibility Studies related to Cancertherapy

- **Protontherapy**

The charged particle beams have definte advantages compared to other types of radiation (like gamma rays) for tumor treatment. In some cases, like eye melanoma, spectacular success has been achieved. This technique is known as protontherapy. There is interest to stimulate activity which may eventually lead to the introduction of this modality in our country. In this context an external proton beam has been produced at the TANDAR laboratory and small animal and cell culture irradiations were started in collaboration with radiobiology personnel.

- **Boron Neutron Capture Therapy (BNCT)**

With the proton or deuteron beams available at the TANDAR accelerator it is possible to generate a neutron flux that can be used to carry out feasibility studies related to a possible therapy by boron neutron capture, BNCT, based on the very high cross section of the capture reaction $^{10}B(n,\alpha)^{7}Li$. The idea is to load selectively a tumor with boron and irradiate it with neutrons. The "microexplosion" associated to each reaction has a high lethality for cancer cells affecting only the immediately surrounding tissue. In the past BNCT has been based exclusively on nuclear reactors for research and treatment. There is however currently a strong tendency and important progress towards the develpment of accelerator-based neutron sources. There is a generalized perception that if BNCT is to become an option for cancer teatment it would be necessary to have accelerator-based neutron sources, not only due to their much lower cost and complexity

but also because the implantation of a nuclear reactor in a hospital would not be acceptable given the public perception in relation with this type of facility. We have started to explore the neutron production via protons of relatively low energy (some MeV) on a lithium target.

Basic research on nuclear structure

This program includes several high-spin nuclear structure topics of current interest. One is the study of coupling schenes of valence nucleons in deformed nuclei, in particular in doubly odd species, in which we have recently found connections to the identical band problem. Here our attention is focused on structures which included aligned pseudospins as means to produce twin bands in neighboring nuclei. Also the problem of signature inversion has been the subject of several investigations. Finally, we mention the study of the octuple instability in the actinide region. The aim has been here to map out the reflection asymmetry degree of freedom to reach the predicted maximum in this deformation and to establish the limits for performance of in-beam spectroscopic studies in the presence of a very severe fission competition.

Application of heavy ions backscattering spectrometry to diffusion studies

R.A. Perez, G. García Bermúdez, D. Abriola, F. Dyment and H. Somacal

The feasibility of using HIRBS (Heavy--Ion Rutherford Backscattering Spectrometry) to measure the concentration profile induced by the diffusion of one element in other is analysed. The principal advantage of HIRBS over conventional RBS (Rutherford Backscattering Spectrometry) is the improved mass resolution for the analysis of high atomic number samples. This property allows us to measure the diffusion profile deep into the sample avoiding surface effects that could perturb the diffusion process. The application of HIRBS to diffusion measurement makes it possible to bridge the gap between different techniques, such as RBS and the serial sectioning technique.

** Diffusion and Defect Forum **143** (1997) 1335.*

Transition strengths in ^{86}Nb and ^{86}Zr

R.A. Kaye, J. Adams, A. Hale, C. Smith, G.N. Sylvan, S.L. Tabor, G. García Bermúdez, M.A. Cardona, A. Filevich and L. Szybisz

Mean lifetimes of states in ^{86}Nb and ^{86}Zr produced by the ^{58}Ni(^{32}S,3pn)^{86}Nb and ^{58}Ni(^{32}S,4p)^{86}Zr reactions at 130 MeV have been measured using the recoil-distance method. The B(E2) strength of 11(2) W.u. for the $8^+ \rightarrow 6^+$ transition in ^{86}Nb implies weak collectivity at low excitation energies for the π = + yrast band. The weak dipole transition strength of the $8^+ \rightarrow 7$ decay suggests that the configuration for the 7 state is different from that of the other yrast states. In general, the B(E2) rates obtained for transitions in ^{86}Zr agree with those previously published, thus supporting the suggestion of a weakly collective structure based on shell-model excitations at low energies. Hartree-Fock-Bogolyubov cranking calculations indicate a spherical shape for low-spin vacuum configuration states in ^{86}Zr.

** Physical Review C **57** (1998) 2189.*

Lifetime mesurements in ^{135}Pr

S. Botelho, W.A. Seale, L.G.R. Emediato, J.R.B. Oliveira, R.V. Ribas, N.H. Medina, M.N. Rao, E.W. Cybulska, M.A. Rizzutto, F.R. Espinoza-Quiñones, G. García Bermúdez, H. Somacal, and M.A. Cardona

Lifetimes of low-lying levels in the ΔI=2 band built on the $\pi h_{11/2}$ state in the Z-odd nucleus ^{135}Pr were measured with the Doppler-shift recoil-distance technique. Reduced transition probabilities B(E2) were extracted in order to calculate the deformation parameters. These values were compared to theoretical results of the total Routhian surface (TRS) calculations. While the quadrupole moments obtained for the $\pi h_{11/2}$ excited levels below the first backbend in ^{135}Pr are very similar to those of the ^{134}Ce core, TRS results predict a quadrupole moment of about 50% larger for the core.

** Physical Review C **58** (1998) 3726.*

Collective structure in ^{70}As

G. García Bermúdez, J. Doring, G.D. Johns, R.A. Kaye, M.A. Riley, S.L. Tabor, C.J. Gross, M.J. Brinkman and H.Q. Jin.

High-spin states in ^{70}As were populated using the ^{58}Ni(^{16}O,3pn) reaction at 70 MeV energy. Lifetime measurements of the $11^+ \rightarrow 9^+$ 980.7 keV and $13^+ \rightarrow 11^+$ 1342.7 keV transitions using the Doppler-shift attenuation method determined that both are enhanced E2 transitions. This measurement indicates the onset of deformation

with increasing spin in ^{70}As, as has been seen in neighboring nuclei.

** Physical Review C **56** (1997) 2869.*

Pseudo-spin doublet aligned structure in doubly odd ^{186}Ir

M.A. Cardona, M.E. Debray, G. García Bermúdez, D. Hojman, A.J. Kreiner, H. Somacal, A. Burlon, J. Davidson, M. Davidson, G. Levinton, J.M. Kesque, M. Ozafran, M. Vazquez, A. Romo, D.R. Napoli, D. Bazzacco, S.M. Lenzi, N. Medina, C. Rossi Alvarez, N. Blasi, G. Lo Bianco, J. de Boer, D. Frischke and H.J. Maie

^{186}Ir has been restudied through the ^{180}Hf(^{11}B,5n) reaction at 65 MeV using in-beam *gamma*-ray and conversion-electron spectroscopy. The unfavored component of the doubly decoupled band was established and shown to be consistent with a description in terms of the $\pi\ h_{9/2} \otimes \nu$[411 1/2,3/2] structure, i.e., the coupling of an aligned proton and a neutron pseudospin doublet.

** Physical Review C **55** (1997) 144.*

Transition strengths in odd-odd ^{80}Rb

M.A. Cardona, G. García Bermúdez, G.N. Solomon, R.A. Kaye and S.L. Tabor

Lifetimes of levels in ^{80}Rb have been measured using the Doppler shift attenuation method. The high-spin states have been populated through the ^{55}Mn(^{28}Si,2pn) reaction at 90 MeV. Collective enhancement was observed in the B(E2) values of the two most populated bands while the B(M1) values of the yrast band exhibit a large alternating pattern . Transition quadrupole moments were deduced from E2 transition strengths and compared with those predicted by Woods-Saxon cranking calculations.

** To be published in Physical Review C*

Signature inversion in odd-odd nuclei around A=80.

G. García Bermúdez and M.A. Cardona

Signature inversion in odd-odd nuclei have been found systematically in regions of mass number A ≈ 80, 130 and 160, and although several explanations have been proposed to interpret this phenomenon, it is still not well understood. The data of electromagnetic properties obtained through lifetime measurements, will be very useful to elucidate this phenomenon. In the present work, we review several lifetime studies that measured the B(M1) strengths in the mass A ≈ 80 region. The results show that the alternating pattern in the B(M1) strengths is preserved across the signature inversion region. Also is reviewed the critical angular momentum, frequency and moment of inertia at the signature inversion point for several mass regions. The correlations among these and other nuclear parameters are discussed.

** To be published in Acta Physica Hungarica New Series*

Pixe analysis of atmospheric aerosols in the city of Buenos Aires

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Lead pollution present in atmospheric aerosols in the city of Buenos Aires was measured in 1989, using Heavy Ion PIXE. Since then, environmental conditions have changed significantly. The usage of unleaded gasoline was introduced, and the utilization of compressed natural gas as car fuel has increased. Recently, a new sampling campaign of atmospheric aerosols has started, partly in collaboration with the Greenpeace Foundation. The present studies reveal that lead pollution in Buenos Aires has significantly decreased since 1989. The concentrations of other elements are determined as well.

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Accumulation of Zn in toad ovaries. Effect on carbohidrate metabolism.

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Females of the toad Bufo Arenarum accumulate Zn when they are maintained in a cage besides the Reconquista river (province of Buenos Aires). Ovulation occurs normally when these animals are injected with homologous hipophysis, as compared to control ones. Oocytes from these females can not only be fertilized but also develop until they reach the gastrula stage. Significant inhibition (27 %) of embryonic development can be observed from the muscular response stage on. *In vivo* simultaneous microinjection with Zn and [U-^{14}C]Glucose rendered a decrease in the incorporation of the label in glycogen as well as in CO_2. Glucose-6-P dehydrogenase activity was inhibited *in vitro* by Zn at 1,53 mM, a

concentration similar to the ones accumulated in the ovary and microinjected into the oocytes en the previous experiments. Our results are in agreement with an inhibitory effect of Zn on early developmental stages of th embryos, probably due to deficient production or NADPH, ribose-5-phosphate and ATP.

High-spin states in doubly odd ^{162,164}Lu

M.A. Cardona[1,2], J. Davidson[3,4], D. Hojman,[1,2,4] , M.E. Debray[1,2], A.J. Kreiner[1,2,4], H. Somacal[1,2], M. Davidson[3,4], D.R. Napoli[5], D. Bazzacco[6], N. Blasi[7], R. Burch[5], D. De Acuña[5], S.M. Lenzi[6], G. Lo Bianco[7], J. Rico[5] and C. Rossi Alvarez[6]

High-spin states in ^{162}Lu and ^{164}Lu have been studied by means of in-beam gamma-ray spectroscopy techniques using the multidetector array GASP. The excited states have been populated through the ^{139}La(^{28}Si,5*n*)^{162}Lu and ^{139}La[$^{29(30)}$Si,4(5)*n*]^{164}Lu reactions.Level schemes were constructed for both nuclei. Configurations for the rotational bands have been discussed. Alignments, band crossing frequencies, and $B(M1)/B(E2)$ ratios have been analyzed in the framework of the cranking model. The systematic evolution of the signature inversion in the $\pi h_{11/2}$ X $\nu i_{13/2}$ structure is reviewed.

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Band termination and second backbending in ^{50}Cr

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High-spin states in ^{50}Cr have been investigated with the reaction ^{24}Mg(^{32}S, a2p) at 130 MeV bombarding energy, using the 4 π GASP g-ray array plus the 4 π charged-particle detector ISIS. The level scheme has been extended up to the 18^+ state at 17.954 MeV excitation energy. Several high-spin states which de-excite by emitting high energy γ-rays have been identified. A second backbending is observed at I=18$\hbar$, well above the 14^+ state which exhausts the total spin available in a pure $(f_{7/2})^{10}$ configuration.

Phys. Rev. C ***56*** *(1997) 1313*

Nonidentical twin bands in doubly odd ^{170}Lu

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The doubly odd nucleus ^{170}Lu has been studied using the ^{164}Dy(^{11}B,5n) reaction at 63 MeV bombarding energy. A near yrast level scheme was constructed comprising 11 rotational bands. Among them, the $\pi h_{9/2}$ x $\nu i_{13/2}$ staggered semidecoupled structure has been established up to I = 30. The doubly decoupled band $\pi h_{9/2}$ x $\nu 1/2^-$ [521] and a Newby shifted K = 0 band were also found. A set of three bands resembles a band structure present in the neighboring odd-A isotopes. One of these shows a striking similarity in transition energies to $\pi 1/2^+$[404] band in ^{171}Lu and hence this pair has been cataloged as *twin bands*. However, their extracted moments of inertia appear to be very different and therefore they cannot be considered identical bands in the usual sense.

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Alternating parity bands in ^{218}Fr$_{87}$

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States in doubly odd ^{218}Fr have been studied using in-beam α-γ coincidence spectroscopy techniques mainly through the ^{209}Bi(^{18}O, 2αn) fusion-evaporation reaction at 94 MeV bombarding energy, using the 8π GASP-ISIS spectrometer at Legnaro. ^{218}Fr shows a band structure, with interleaved states of alternating parities connected by enhanced B(E1) transitions. Tentative spin assignments and the relation between the structure of ^{218}Fr and its isotone ^{220}Ac are discussed.

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High-spin states and band structures in ^{182}Pt

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Excited states in ^{182}Pt have been studied via the heavy-ion reactions ^{170}Yb(^{16}O,4n), ^{162}Dy(^{24}Mg,4n), and ^{163}Dy(^{24}Mg,5n). γ-ray coincidence measurements were performed with arrays of HPGe detectors at the McMaster University Tandem Accelerator Laboratory (^{16}O-induced reaction) and the Institut de Physique Nucleaire, Orsay (^{24}Mg-induced reactions). The ground-state rotational band has been extended to I=26$\hbar$, and six new band structures have been identified and assigned quasiparticle configurations. The γ-vibrational band and the band built upon the first excited 0^+ state have also been extended. Properties of the rotational bands are compared with cranked-shell-model and total-Routhian-surface calculations. Evidence concerning shape-coexistence at low spin and band crossings at high spin is discussed.

** Phys. Rev. C **55** (1997) 1175.*

Transition strengths and signature inversion in odd-odd ^{74}Br

G. García Bermúdez, M.A. Cardona, A. Filevich, R.V. Ribas, H. Somacal and L. Szybisz

Lifetimes of states in ^{74}Br produced by the ^{60}Ni(^{16}O,np) reaction at 50 MeV have been measured by using the recoil-distance method. From these experiments several reduced transition strengths for the low energy states have also been determined. The results show that the alternating pattern in the B(M1)strengths of the yrast positive parity band is preserved across the signature inversion region.

** Physical Review C **59** (1999) 1999.*

A dipole band in ^{124}Xe

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High-spin states in ^{124}Xe were populated by means of the ^{110}Pd(^{18}O,4n) reaction. In-beam γ rays were measured using the GASP spectrometer. A dipole band, similar to those previously found in other nuclei of this mass region, was identified in ^{124}Xe.

** Z.Phys. A**359** (1997) 347.*

Evidence for enhanced aluminum concentration in brain tissue from Alzheimer's disease patients using PIXE

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The Particle Induced X-Ray Emission (PIXE) analytical technique with ^{16}O ion beams (18 MeV) was applied to the study of elemental composition at different brain regions of patients with a confirmed post-mortem diagnosis of Alzheimer's disease and in samples from control subjects. The results obtained in the actual study show a clear correlation between occurrence of Alzheimer's disease and the presence and increased concentration of aluminum (Al).

High-spin states in doubly odd ^{176}Re and signature inversion in $\pi h_{9/2}$ x $\nu i_{13/2}$ structures

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High-spin states in doubly odd ^{176}Re were investigated by means of in-beam gamma-ray spectroscopy techniques using the multidetector array GASP. Excited states of ^{176}Re were populated using the ^{165}Ho(^{16}O,5*n*) reaction at a beam energy of 101 MeV. Seven rotational bands have been observed and their configurations have been discussed. Alignments, band crossing frequencies, and electromagnetic properties have been analyzed in the framework of the cranking model. Signature inversion phenomena in the $\pi\, h_{11/2}$ x $\nu i_{13/2}$ and $\pi h_{9/2}$ x $\nu i_{13/2}$ structures are discussed. In the latter case signature inversion is traced to a large repulsive

matrix element of the $p - n$ force acting in the maximally aligned $J = 11$ state.

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Excited states and terminating bands in ^{123,124}I

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High spin states in ^{123,124}I were populated via the ^{116}Cd(^{11}B,xn) reaction at 38 MeV bombarding energy and via the ^{110}Pd(^{18}O,pxn) reacion at 75 MeV energy. γ-ray energies, intensities, γγ coincidences and DCO ratios were measured with the GASP spectrometer. The level schemes were extended considerably. Band terminations were observed for both nuclei. In ^{123}I the rotational band, which is built on the $\pi h_{11/2}$ single-particle state was extended to spin I=(35/2)$^-$; at higher spin the level spacings and the feeding pattern were found to become irregular, indicating a sudden change of structure. The 39/2$^-$ state and a higher-lying 43/2$^-$ level were interpreted as aligned oblate states. In ^{124}I a decoupled band was found to terminate in the same spin region. Total Routhian surface calculations were performed which support the occurrence of a band termination.

** Acta Phys.Hung.N.S. **6** (1997) 275.*

Band termination in ^{123}I

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High-spin states in the nucleus ^{123}I were populated by the ^{110}Pd(^{16}O,p4n) reaction at 75 MeV. γ-ray energies, intensities, γ– γ coincidences, and directional correlation ratios were measured. The rotational band built on the $\pi h_{11/2}$ single-particle state was extended to spin I=35/2$^-$; at higher spin the level spacings and the feeding pattern were found to become irregular, indicating a sudden change of structure. The 39/2$^-$ state and a higher-lying 43/2$^-$ level were interpreted as aligned oblate states, in line with the systematics of the lighter odd-*A* iodine isotopes. Total Routhian surface calculations were performed and were found to support the occurrence of a band termination. Higher-lying levels that feed the $h_{11/2}$ band were identified, reaching spin I>47/2 and an excitation energy of about 9 MeV.

** Physical Review C **56** (1997) 1629*

Detection of ^{10}B in biological samples through the Particle Induced Gamma ray Emission technique (PIGE).

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The applicability of the ^{10}B(p,p')^{10}B* reaction, using 7.2 MeV protons, for the detection of ^{10}B in biological samples has been studied. The proton beam was produced by the 20 MV Tandem accelerator TANDAR at CNEA. The samples studied were cell cultures and tumoral tissues. A detection limit of about 10 ppm was achieved.

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Nuclear structure of neutron-deficient Au and Pt isotopes from high-resolution laser spectroscopy at ISOLDE

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Atomic spectroscopy measurements were carried out using the COMPLIS setup installed at the ISOLDE-BOOSTER facility. Hyperfine structure (HFS) spectra and isotope shift (IS) values were obtained for the neutron-deficient ^{178}-^{185}Pt and for ^{184}Au^{g,m}, providing deformation parameters β, magnetic moments μ and spectroscopic quadrupole moments (for $I \geq 1$) Q_s . In Pt isotopes, a deformation drop for A=178 and an inverted odd-even staggering for the charge radius around the neutron mid-shell N=104, have been observed very clearly. Furthermore, deformation changes δβ between isomeric and ground states for ^{183}-^{185}Pt and ^{184}Au have been put forward. Thus, the influence of the proton-neutron coupling on the δβ value in

^{184}Au relatively to that in its isotone ^{183}Pt has been determined. Besides, the $h_{9/2}$ proton state that is decoupled from the core in ^{183,185}Au, becomes the 3/2 [532] state strongly coupled in ^{184}Au. The spin and parity values I^{π} = 3+ have been assigned to the ^{182}Ir ground state from internal conversion electron measurements to prepare atomic spectroscopy studies in the Ir isotopic series.

** Acta Phys.Pol. B **30** (1999) 1393*

Study of $f_{7/2}$ N=Z nuclei with GASP

C.A. Ur, S.M. Lenzi, D. Bucurescu, A. Gadea, D.R. Napoli, D. Bazzacco, F. Brandolini, J.A. Cameron, M.A. Cardona, G. de Angelis, D. Hojman, S. Lunardi, M.A. Nagarajan, M. De Poli, C. Rossi Alvarez, C. Svenson.

New results on the high spin structure of the N=Z nuclei ^{48}Cr and ^{52}Fe are presented. Experiments were performed using the GASP array in coincidence with the 4π charged particle detector ISIS which allows a better selection of the reaction channel γ–γ–*particles* and γ–γ–γ–*particles* coincidences.

** Prog. Part. Nucl. Phys. **38** (1997) 223*

High-spin state spectroscopy in ^{143}Tb

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The ^{143}Tb nucleus has been studied with the ^{92}Mo (^{54}Fe,3pγ) reaction at 240-MeV incident energy, extending the systematics of odd-A, N=78 isotones to higher Z. For the yrast band, excited states up to a spin of $59/2^-$ have been observed. The first allowed backbend occurs at a rotational frequency of $\hbar\omega$=0.38 MeV. Three- and five-quasiparticle structures were identified, similar to those seen in lower mass *N*=78 isotones. Two of these structures have characteristics typical of mixed proton-neutron oblate configurations with one pair of aligned $h_{11/2}$ neutrons. In addition, two bands consisting of stretched E2 transitions have been observed with no known analogous structures in neighboring nuclei. The results are discussed in terms of the cranking model.

*Phys. Rev. C **60** (1999) 054304-I*

Changes of shape and second backbending in ^{50}Cr

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The nucleus ^{50}Cr has been studied, following the reaction ^{24}Mg(^{32}S, *α2p)* at 130 MeV bombarding energy, with the γ-ray array GASP plus the *4π* charged-particle detector ISIS of the Legnaro National Laboratory. We have identified several high-energy transitions above 4 MeV and constructed a complex level scheme up to the 18+ state. The yrast band of ^{50}Cr shows a rotational-like structure at low spin consistent with a prolate deformation. At *I* = 10 the first backbending can be understood in terms of a change of shape from prolate to triaxial: with increasing angular momentum, the four protons drive the nucleus into prolate deformation while the two neutron holes drive it into the oblate direction. At I = 14 the nucleus reaches the maximum angular momentum that can be constructed with 4 protons and 6 neutrons in the isolated $f_{7/2}$ shell. This is consistent with the fact that at high rotational frequency, the spins of the valence particles in a high-j shell become increasingly aligned along the rotational axis. The nucleons thus rotate in orbits near the equator of the core, making an oblate, non-collective state. The generation of high angular momentum by such a mechanism is energetically favoured and at *I* = 14 the valence-particle spins become fully quantized along the rotational axis which gives rise to a band-termination state.

** International Symposium on Exotic Nuclear Shapes, Debrecen, Hungary, May 1997*

Coupling modes in doubly odd nuclei: the case of 172Ta

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High-spin states in doubly odd ^{172}Ta were investigated in two different experiments by means of in-beam γ–ray and internal-conversion electron spectroscopy techniques. Excited states of ^{172}Ta were populated using the ^{159}Tb(^{18}O,5n) and ^{165}Ho(^{12}C,5n) reactions at beam energies of 93 and 79 MeV respectively. Eleven rotational bands, including twin bands in the normal deformation regime, have been observed and their

configurations discussed. Three isomeric states have been found and their half lifes measured. Alignments, band crossing frequencies and electromagnetic properties have been analyzed in the framework of the cranking model.

Collective versus single-particle degrees of freedom in $1f_{7/2}$-shell nuclei

S.M. Lenzi, C.A. Ur, D.R. Napoli, F. Brandolini, D. Bazzacco, D.M. Brink, D. Bucurescu, J.A. Cameron, M.A. Cardona, G. de Angelis, M.De Poli, A. Gadea, D. Hojman, S. Lunardi, G. Martinez-Pinedo, N.H.Medina, M.A. Nagarajan, C. Rossi Alvarez and C.E. Svensson

In this work we will present recent data in several $1f_{7/2}$ nuclei obtained with the γ array GASP and the particle detector array ISIS at the Legnaro National Laboratory. High spin states in ^{48}Cr, ^{50}Cr, ^{52}Fe, and other neighboring nuclei have been observed. Life times have been measured in most of them which are compared with shell model calculations. Along the yrast bands, these nuclei present several interesting phenomena as backbending, bandcrossing, changes of shape, spin inversion and band termination. Non yrast bands have also been observed in most of these nuclei that can be interpreted as particle hole excitations involving the $1d_{3/2}$ shell.

New Spectroscopy and Nuclear Structure 1997, Copenhagen, Denmark, September 1997

Deformation change between isomeric and ground states of isotones N=105

J. Sauvage, N. Boos, L. Cabaret, J. Crawford, H.T. Duong, J. Genevey, A. Gizon, D. Hojman, G. Ruber, F. Ibrahim, P. Kucher, A. Knipper, M. Krieg, F. Le Blanc, J.K.P. Lee, J. Libert, D. Lunney, 0. Margujer, J. Oben, J. Oms, J. Pinard, J.C. Putaux, M. Rarridhane, B. Roussiere, V. Sebastian, A. Wojtasiewicz and the ISOLDE collaboration

The properties of the ^{182}Ir and ^{184}Au doubly-odd isotones are compared. Results on conversion-electron measurements performed with a high resolution spectrograph for the ^{182}Pt and ^{183m}Pt β^+/EC decays are also presented. They confirm the $\pi\otimes\nu$ configurations proposed for the ^{182}Ir ground state and the ^{184}Au isomeric and ground states. It is also shown that the anomaly observed in ^{184}Au cannot be explained by the influence of the V_{pn} residual interaction but would be rather due to a small deformation change either between the isomeric level and the ground state of ^{184}Au or between ^{184}Au and its neighbouring odd-A nuclei.

** International Workshop on Hyperfine Structure and Nuclear Moments of Exotic Nuclei by Laser Spectroscopy, Poznan, Poland, February 1997*

Heavy-Ion Physics And Accelerator Mass Spectrometry

The field of interest of our research group includes two lines that are well differentiated as far as their final goals are concerned, but which share to a large extent a variety of methodological and instrumental aspects.

One of these research lines addresses the different aspects that come into play when two nuclei collide at low energies (i.e, at energies close or somewhat below that of the corresponding Coulomb barrier). It comprises the following projects:

1) Search for chaotic behavior in nuclear reactions: Theoretical studies predict that, under certain conditions, nuclear scattering might exhibit peculiar behavior associated with the quantum manifestation of chaotic phenomena. In order to elucidate this problem we have studied the reaction 16O + 28Si and we have compared the experimental with the theoretical two-dimensional maps for the elastic and inelastic cross sections as a function of the energy and the scattering angle.

2) Transfer reactions at near-barrier energies: This project involves the experimental and theoretical study of the transfer probabilities as a function of the distance of closest approach between the colliding nuclei, with emphasis on the so called "slope anomalies".

3) Subcoulomb fusion-barrier distributions: Fusion cross sections at energies close to or below the Coulomb barrier present behaviors which are related to various structural aspects of the nuclei involved in the collision. These features become particularly noticeable when the results are analyzed in terms of the so called "barrier distributions". We have studied several reaction systems with the aim of identifying the effect of transfer channels in the barrier distributions obtained from the meassurement of quasi-elastic scattering at backward angles.

The other research line relates to an application of the heavy-ion accelerator Tandar to mass spectrometry. The isotopic-analysis technique known as AMS ("Accelerator Mass Spectrometry") is

extremely sensitive for the identification and quantitative determination of very low concentration of nuclear species, in particular long-lived radioactive isotopes, in samples of interest for various disciplines. The activities that we have undertaken in this period in the field of AMS have been related, to a large extent, to the adaptation of different techniques and procedures associated with the heavy-ion accelerator, since it has been originally designed for nuclear-physics research. The need for this work arises mainly from the fact that AMS involves the acceleration of extremely weak beams which are therefore "invisible" for the usual beam-control devices of the accelerator. As far as the applications are concerned, we have studied chlorine 36 contents in rainwater samples collected at different latitudes in the southern hemisphere. These measurements provide information on transport processes between the stratosphere and the troposphere. We have also started studies of the radioactive isotope nickel 58 in meteorite samples, aimed at the determination of the irradiation history before and after the arrival of this extraterrestrial material to our planet. We have also started preliminary work for the determination of the concentration of iodine 129 in environmental samples which can be useful in monitoring human activities in the nuclear field.

Average angular momentum in compound nucleus reactions deduced from isomer ratio measurements

O.A. Capurro, D.E. DiGregorio, S. Gil, D. Abriola, M. di Tada, J.O. Fernández Niello, A.O. Macchiavelli, G.V. Martí, A. J. Pacheco, J.E. Testoni, D. Tomasi, I. Urteaga

We have measured the ratio of the yields for the metastable and ground states of ^{119}Te produced in the fusion-evaporation reactions ^{110}Pd(^{12}C,3n) and ^{115}In(^{7}Li,3n) by off-line observation of delayed γ-ray emission. The absolute cross sections for the formation of the metastable (J_π = 11/2-, $T_{1/2}$ = 4.68 d) and ground (J_π = 1/2+, $T_{1/2}$ = 16.05 h) states were determined at energies close to the Coulomb barrier for both systems. We have deduced the average angular momentum from these isomer ratio measurements through statistical model calculations. The deduced mean angular momentum agrees quite well with those calculated by a simple fusion model. The expected constant value of the average total angular momentum at subbarrier energies was confirmed for the ^{12}C+^{110}Pd system. The predicted variation of the mean orbital angular momentum with the reduced mass of the entrance channel was also verified.

** Phys. Rev. C **55** (1997) 766.*

The AMS program at the TANDAR accelerator

D.E. Alvarez, J.O. Fernández Niello, M. di Tada, A.M.J. Ferrero, G.V. Martí, O.A. Capurro, A.J. Pacheco, J.E. Testoni, D. Abriola, A. Etchegoyen, E. Achterberg, M. Ramírez

The accelerator mass spectrometry (AMS) program that is under development using the 20UD electrostatic accelerator TANDAR at Buenos Aires is presented. Tests and measurements in order to evaluate and to improve the accelerator performance are described. Preliminary measurements have been done by tuning 14C beams using as detection system DE-E telescope. For the detection of heavier isotopes some new developments are being currently implemented in a quadrupole-dipole-dipole (QDD) magnetic spectrometer. Furthermore, work is in progress to construct a time-of-flight system using two micro-channel plates prior to the entrance to the QDD spectrometer.

** Nucl. Inst. B **123** (1997) 39.*

Absorption and tunneling effects in one- and two-proton transfer reactions

H.D. Marta, R. Donangelo, D. Tomasi, J.O. Fernández Niello, A. J. Pacheco

We analyze proton transfer data for the ^{12}C + ^{197}Au system. We show that the interplay between absorption and tunneling effects explains the observed energy dependence of the transfer probabilities at large distances, including the apparently anomalous behavior at high energies.

** Phys. Rev. C **55** (1997) 2975.*

Analytical determination of aluminium-26 in biological materials by accelerator mass spectrometry

S.J. King, C. Oldham, J. Popplewell, R.S. Carling, J.P. Day, L.K. Fifield, R.G. Cresswell, K. Liu and M. di Tada.

Studies of the biological chemistry of the aluminium can gain significantly from the use of the log-lived isotope ^{26}Al as a tracer, although the cost of the isotope often precludes its determination by radiochemical counting techniques. Accelerator Mass Spectrometry (AMS) provides an ultra-sensitive method of determination, free form isobaric interference from atomic (^{26}Mg) or

molecular species. The source materials for AMS can be aluminium oxide or phosphate, both of which can be readily prepared at a sufficient level of purity from biological substrates. Natural aluminium (^{27}Al, 100%) is added to the preparations as a chemical yield monitor and to provide the reference for the isotope ratio measurement. ^{26}Al/^{27}Al ratios can be determined over the range 10^{-14} - 10^{-7}, implying a limit of detection for ^{26}Al of around 10^{-18} g. The preccision of measurement and long-term reproducibility are 5% and 7% (RSD), respectively. Chemical methodologies for routine measurements on blood and urine samples have been developed.

** Analyst **122** (1997) 1049.*

Comment on experimental fusion barrier distributions reflecting projectile octupole state coupling to prolate and oblate target nuclei

C.H. Dasso and J. Fernández Niello

The authors comment on the Letter by J.D. Bierman et al., Phys. Rev. Lett. 76, 1587(1996), and show the method by which they have been constructed is not the most appropriate.

** Phys. Rev. Lett. **78** (1997) 3975.*

Methodological issues in the radiocarbon dating of rock paintings

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Chemical and isotopic analyses have been made of pigment samples from two separate rock art sites in Argentina. The purpose of the study has been to establish the feasibility of extracting carbonaceous material from the samples which will permit reliable radiocarbon dates for the time of painting. Two sites, Catamarca and Río Negro, present quite different problems. Most of the paper is concerned with Catamarca, and here we have shown that the paint pigments contain very little or no organic binder, but they do contain calcium oxalate derived from local cacti, and calcium carbonate derived probably from local plant ash. We describe a method to purify carbon extracted from the calcium oxalate, and present the dates obtained on both components. We show that, though rare, natural deposits containing both calcium oxalate and calcite do occur, but that they are very distinct in both ^{13}C and ^{14}C compositions, and we argue that they are very unlikely to contaminate the pigments to such an extent that the ^{14}C dates are altered. For the Río Negro site we show that the ground for the paint pigments contains carbon derived from fires burnt inside the cave, and discuss how analytical methods provide information to develop a strategy for extracting material, from both ground and pigment, for more reliable dating.

** Radiocarbon **40** (1998) 35*

Role of the gamma degree of freedom in subbarrier fusion phenomena and effective barrier distributions

C.H. Dasso, J. Fernández Niello and A. Vitturi

We investigate subbarrier fusion phenomena in the presence of triaxial static deformations and under conditions of γ instability. It is found that the distributions of effective barriers can reflect in a distinct way a general quadrupole profile specified in terms of both β_2 and γ. Fusion cross sections as a function of energy are, on the other hand, rather insensitive to the gamma-degree of freedom.

** Phys. Rev. C **55** (1997) 2112.*

Slope anomaly in neutron transfer reactions

H.D. Marta, R. Donangelo, D. Tomasi, J.O. Fernández Niello, A. J. Pacheco

We study one- and two-neutron transfer probabilities in heavy-ion reactions within a semiclassical model. As in the case of the already studied proton transfer reactions, the interplay between absorption and tunneling effects qualitatively reproduces the overall properties of these probabilities and in particular the so-called slope anomaly observed in these reactions.

** Phys. Rev. C **58** (1998) 601.*

Average angular momentum in fusion reactions deduced from evaporation-residue cross sections

O.A. Capurro and D.E. DiGregorio

Average angular momenta of compound nucleus were deduced from measured evaporation-residue cross sections on the basis of statistical model calculations. We have applied this method to the following systems: ^{4}He+^{197}Au, ^{16}O+^{147,149,152,154}Sm, ^{32}S+^{138}Ba, and ^{48}Ti+^{122}Sn. For some of these systems, the average angular momenta were compared with those extracted from early gamma-multiplicity measurements. A reasonable agreement was found between the values of the deduced average angular momentum

obtained from both methods, giving support to the validity of the present method. The average angular momenta for all the systems exhibit the energy dependence predicted by a standard fusion model calculation.

* *Physical Review C* ***57*** *(1998) 430.*

Search for experimental evidence of chaotic behavior in nuclear scattering

G.V. Martí, A.J. Pacheco, J.E. Testoni, D.Abriola, O.A. Capurro, D.E. Di Gregorio, J.O. Fernández Niello, E. Achterberg, D.E. Alvarez,

Angular distributions for the elastic and inelastic scattering in the ^{16}O + ^{28}Si system have been measured in two energy regions, one close to the Coulomb barrier and the other well above. Fine steps in both bombarding energy and scattering angle make it possible to compare the data with the theoretical calculations that predict, for each of these regions, distinctive cross-section patterns in correspondence with the classical occurrence of either regular or chaotic regimes. The experimental results show specific differences between the two explored energy ranges in qualitative agreement with the theoretical predictions.

* *Phys. Lett. B* ***447*** *(1999) 41.*

AMS measurements of South American rainwater samples

J. O. Fernández Niello, D.E. Alvarez, A.M.J. Ferrero, O.A. Capurro, D. Abriola, G.V. Martí, A.J. Pacheco, J.E. Testoni, R.G. Liberman, K. Knie, G. Korschinek

Accelerator mass spectrometry (AMS) is one of the most powerful applications of heavy-ion beams in fields not directly related to their specific use in nuclear physics research. AMS applies to a diversity of fields like material sciences, medicine, archaeology, and environmental studies and has been grown in importance since its begining in the early eighties. The development of this highly sensitive technique at the electrostatic accelerator of TANDAR laboratory has recently been accomplished. Aiming at environmental applications and as a part of the AMS activities of the TANDAR laboratory, we have established a research program using the radioisotope ^{36}Cl as an atmospheric tracer, in cooperation with the AMS group of the Technical University of Munich.

* *Acta Phys. Pol.* ***30*** *(1999) 1629.*

Observation of a $(\nu^{7/2}[514])^2$ crossing in ^{180}Os

R. Lieder, Ts. Venkova, S. Utzelmann, W. Gast, H. Schnare, K. Spohr, P. Hoernes, A. Georgiev, D. Bassacco, R. Menegazzo, C. Rossi-Alvarez, G. De Angelis, R. Kaczarowski, T. Rzaca-Urban, T. Morek, G.V. Martí, K.H. Maier, S. Frauendorf

High-spin states in ^{180}Os have been populated by means of the $^{150}Nd(^{36}S,6n)$ reaction at 177 MeV and studied with the gamma spectrometers OSIRIS and GASP. Eight known bands have been extended to higher spins and a new strongly coupled band has been discovered. Configuration assignements of the bands have been carried out in the framework of the tilted-axis cranking model utilizing experimental ratios of reduced transition probabilities B(M1)/B(E2). The investigation of the alignment behaviour of the bands revealed that besides the well-known first band crossing caused by the alignment of an $i_{13/2}$ quasineutron pair, a second band crossing occurs in four of the bands. The crossing frecuency is greater than 0.38 MeV and the alignment gain is fairly small, ranging between 2*h*. The crossing can consistently be explained as a two-quasineutron $(\nu^{7/2}[514])^2$ alignment. This crossing has been observed for the first time.

* *Nucl. Phys. A* ***645*** *(1999) 465*

Kinetics of uptake and elimination of silicate acid by a human subject: a novel application of ^{32}Si and accelerator mass spectrometry

J. Popplewell, S.J. King, J.P. Day, P. Ackrill, L.K. Fifield, R.G. Cresswell, M. di Tada and K. Liu.

Silicon is possibly important in human physiology in protecting against the toxic effects of aluminium, but the kinetics of uptake and excretion of silicic acid, the bioavailable form, are not well characterised. We have used ^{32}Si as a tracer in a human uptake experiment to determine a gastrointestinal uptake factor for silicic acid, and to elucidate the kinetics of renal elimination. Urine collections were made for extending intervals from 2 to 12 h over 2 days following ingestion by a single human subject of a neutral silicic acid solution containing tracer levels of ^{32}Si ($t_{1/2}$ approx 150 y). Silicon was isolated as SiO_2 and the ^{32}Si content determined by accelerator mass spectrometry (AMS), using a gas-filled magnet technique to eliminate a prolific isobaric interference from 32S. Silicon uptake appears to have been essentially complete within 2 h of ingestion. Elimination occurred by two

simultaneous first-order processes with half-lives of 2.7 and 11.3 h, representing around 90% and 10%, respectively, of the total output. The rapidly eliminated ^{32}Si was probably retained in the extracellular fluid volume, whilst the slower component may represent intracellular uptake and release. Elimination of absorbed ^{32}Si was essentially complete after 48 h and was equivalent to 36% of the ingested dose. This establishes only a lower limit for gastrointestinal absorption as, although there was no evidence for longer term retention of additional ^{32}Si, the possibility could not be excluded by these results.

* *Journal of Inorganic Biochemistry* ***69*** *(1998) 177.*

Evaluation of fusion cross sections at near-barrier energies using a coupled-channel formalism

J.E. Ttestoni, O. Dragun, M.R. Spinella, H. Hassman

A coupled-channel formalism is presented which allows to calculate, simultaneously, cross sections corresponding to elastic, inelastic, transfer of two neutrons and fusion. The nuclear excitations are considered as rotations in the real space and the two-neutron transfer as a rotation in a *gauge* space. The target as well as the proyectile are considered to have zero spin. For different reaction channels the formalism permits to obtain wave functions, angular distributions of differential cross sections, total cross sections, excitation functions and spin distributions.

A coupled-channel analysis of scattering, two-neutron transfer and fusion in medium heavy-ion collisions

J.E. Testoni, O. Dragun, H Massmann, M.R. Spinella

Scattering, two-neutron transfer and fusion processes are analyzed in the scope of a coupled-channel formalism using collective excitations in the real and a gauge space. A small set of collective states simplifies the calculation of form factors allowing an easy evaluation of interesting physical quantities such as cross-sections, probability densities, currents, fusion rates, spin distributions and probability sources and sinks in the different channels. The availability of these quantities makes possible an insight that clarifies the underlying reaction mechanisms. In particular, a barrier, modified by the coupling between channels, is introduced, permitting an interpretation of relevant characteristics of the interaction processes. The system ^{18}O+^{60}Ni is specifically studied at energies of E_{lab}=63 and 65 MeV for the scattering and two-neutron transfer, respectively, and at energies around the Coulomb barrier for fusion. In this case, it can be observed that the presence of the transfer channel plays a catalytic role in the enhancement of the fusion cross—section by incrementing the contribution of the dispersion channels.

* *Nucl. Phys. (in press)*

Barrier distribution for the ^{32}S + ^{110}Pd system derived from the quasi-elastic scattering excitation function

O.A. Capurro, J.E. Testoni, D. Abriola, D.E. Di Gregorio, G.V. Martí, A.J. Pacheco and M.R. Spinella

We measured the quasi-elastic scattering excitation function for the 32S + 110Pd system at a backward angle and at energies around the Coulomb barrier. A fine enough energy step was adopted in order to obtain a representation of the barrier distribution through the first differentiation of the data. Our results were compared with the barrier distribution that was deduced from fusion data for the same system.

* *Phys Rev. C (in press)*