Nuclear Physics

Heavy Ion Physics and Accelerator Mass Spectrometry

This group focused its activities on the study of basic aspects of nuclear reaction mechanisms and on applied research in connection with the analytical technique known as accelerator mass spectrometry (AMS). Even though the subjects covered by these two lines are very different, they share similar instrumental and methodological requirements as far as the performance of the actual experiments is concerned.

The nuclear-reaction line consists mainly of two main sub-projects:

Search for chaotic behaviour in nuclear reactions: Theoretical studies predict that, under certain conditions, nuclear scattering might exhibit peculiar behavior associated with the quantum manifestation of chaotic phenomena. Therefore, wwe continue our study of the $^{16}O + ^{28}Si$ system for which a chaotic behaviour in certain energy- range has been proposed suggested. The obtained experimental results have been compared with the theoretical two-dimensional patterns obtained for the elastic and inelastic cross sections as a function of the energy and the scattering angle for that system.

Subcoulomb fusion barrier distributions: Fusion cross sections at energies close to or below the Coulomb barrier present behaviours which are related to various structural aspects of the nuclei involved in the collision. These features become particularly noticeable when the results are analyzsed in terms of the so called “barrier distributions”. We are investigating several reaction systems with the aim of identifying the effect of the inelastic and transfer channels in the barrier distributions obtained from the measurement of quasi-elastic excitation functions at backward angles.

The other research line has a more applied character and it is related to the use of the Tandar particle accelerator as an extremely sensitive mass spectrometer. (AMS). Recently, During the last we have measured and studied the cross-section ratios for multiple ionization processes, in particular, using chlorine beamsmas on nitrogen targets. Moreover, we continue our research on the stellar production of ^{26}Al, in collaboration with the Technical University of Munich, Germany-

“Potential Barriers Modified by Coupling in the Analysis of the Nuclear Fusion Process”

M.R. Spinella, J.E. Testoni, O. Dragún and H.D. Marta

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The behavior of several relevant physical quantities calculated on the basis of coupled--channel wavefunctions are used in the study of fusion barrier distributions. The introduction of potential barriers modified by coupling effects makes possible the decoupling of the wave equations. This procedure leads to a view of the fusion barrier distributions that does not require to consider channels related to states which are admixtures of the ordinary ones. The $^{16}O + ^{144}Sm$ system has been selected as a paradigmatic case in the comparison between the theoretical and experimental data. For the sake of simplicity, the elastic and just an inelastic reaction channel are taken into account. The characteristics of the barrier distributions are analyzed on the basis of the modified potential barriers and the spatial behavior of physical quantities such as fusion rates, sources or sinks, and the incoming and outgoing currents in the different channels.

“On the Slope Anomaly in Heavy Ion Transfer Reactions

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

*Nuclear Physics **A697** (2001) 107*

We discuss a semiclassical model of transfer reactions in heavy ion collisions, in which the nuclei are assumed to move along classical trajectories governed by the Coulomb and the real part of the optical potential. The model, originally proposed for the case of spherical nuclei, is here extended to deformed ones. It takes into account tunneling around the point of closest approach of the collision partners, and the effect of other channels is included as an absorption due to the imaginary part of the optical potential. The interplay between absorption and tunneling effects explains both the observed energy dependence of the transfer probabilities at large distances, and the so-called “slope anomaly” in neutron transfer reactions.

“Signature Inversion in $pi_{13/2}$ Ä $ni_{13/2}$ Structure in ^{178}Ir”

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*Eur. Phys. J. **A10** (2001) 245-248*

High spin states in ^{178}Ir were investigated by means of in beam ray spectroscopy techniques using the multidetector array GASP. Excited states of ^{178}Ir were populated through the ^{159}Tb(^{24}Mg, 5n) fusion evaporation reaction at E(24Mg) = 131-141 MeV. Several rotational bands were observed. Among them, the $\pi i13/2 \otimes \nu i13/2$ structure has been identified up to spin 36. This band exhibits an anomalous signature splitting and a signature inversion around spin 25.

“Chaos and Nuclear Scattering: An Experimental Study of the ^{16}O+^{28}Si System”

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

*Revista Mexicana de Física **47**, Suppl.2 (2001) 65-69*

In this contribution, we present the results of measured cross sections for the elastic and inelastic scattering of ^{16}O by ^{28}Si in two energy regions, one close to the Coulomb barrier and the other well above. Fine enough 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 qualitative aspect of the resulting experimental patterns, as well as their evaluation via a mathematical procedure which is particularly sensitive to the relevant differences, lead to the tentative conclusion that both types of behavior do appear, although an unambiguous confirmation is still lacking.

Ion Tracks in an Organic Material: Application of the Liquid Drop Model”

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*Nucl. Inst. and Meth. for Phys. Res. **B173** (2001) 455-462*

The liquid drop model (LDM) was developed to perform radiation damage studies in metals in an ionic energy range where molecular dynamics cannot be used because of computational restraints. In this work, the model is extended in an effort to explain the observation of tracks in organic insulators in an energy range where other theoretical models fail. The detector material was Makrofol E and the studied ions had specific

energies between 1.4 and 100 keV/n. The tracks were observed via a replica method by transmission electron microscopy. The electronic, as well as the nuclear energy deposition by an individual ion were considered, then the thermal spike evolution is studied. The LDM predicts track diameters much larger than previous models. Most of these tracks now can be developed. Although the model still has free parameters and shows some discrepancies with experimental data, its agreement is better than that obtained through the consideration of other models.

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 but not necessarily of the other disciplines) and tries to contribute in other areas generating interdisciplinary and partly technological activities. Applications to biomedical and environmental problems are being pursued. On this sector, we can distinguish three lines: a) Trace element analysis; b) Development of a heavy ion microbeam; c) 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 employed 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, problems studied have been, among others, metabolic alterations in living species related to presence of Zn and multielement determination in cancer tissue samples.

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. Since our last survey, Pb concentration in Buenos Aires diminished by a factor of about 20 after the introduction of unleaded gasoline in Argentina, a behavior similar to that observed in other large cities around the world.

Heavy ion microbeam

The heavy ion microbeam is now installed and ready. First irradiations using this facility have been performed. Multielementary maps with micrometric spatial resolution have been obtained for several samples using the microPIXE technique. This microbeam in conjunction with nuclear and atomic techniques of excitation and detection like PIXE, PIGE, HIRBS (Heavy Ion Rutherford Backscattering), STIM (Scanning Transmission Ion Microscopy), etc., allows the quantitative determination of the multielement composition, the modification of properties and structural characterization of different systems with a spatial resolution of the order of one micrometer.

Feasibility Studies related to Cancertherapy

• Protontherapy

The charged particle beams have definite 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 external proton and Li beams have been produced at the TANDAR laboratory and a program to irradiate small animals and cell cultures was started in collaboration with radiobiology personnel. Relative Biological Effectiveness (RBE) associated with p and Li beams of different energies was determined for different tumor cell lines. In particular the Li beams aim at simulating the effects of the Li fragment being emitted in the BNCT reaction (see below).

• 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 10B(n,alpha)7Li. 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 immediate 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 development of accelerator-based neutron sources. There is a generalized perception that if BNCT is to become an option for cancer treatment 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. A LiF neutron production target has been built and neutron flux determinations have been performed both trough the activation method and through the detection of the 478 keV gama ray following the BNCT reaction. The latter method will serve to monitor on-line the dose delivered to a tumor. We have studied the 13C(d,n) reaction as a candidate for accelerator-based BNCT trough a collaborative project with scientists from the Laboratory for Accelerator Beam Applications at MIT. We have also started to explore the possibility of developing a low-energy (2 MeV), high-current (20 mA) proton accelerator for BNCT.

Basic research on nuclear structure

This program includes several high-spin nuclear structure topics of current interest. One is the study of coupling schemes 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 include aligned pseudospins as means to produce twin bands (i.e. bands with very similar transition energies) in neighboring nuclei. During the course of these investigations a very interesting result was obtained, namely twin bands but with very different moments of inertia (non-identical twin bands). Also the problem of signature inversion has been the subject of several investigations. Finally, we mention the study of the octupole instability in the actinide region. The aim has been here to map out the reflection asimmetry 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.

"In Phantom Dosimetry using the $^{13}C(d,n)^{14}N$ Reaction for BNCT"

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The use of $^{13}C(d,n)^{14}N$ reaction at E_d = 1.5 MeV for accelerator-based boron neutron capture therapy (AB-BNCT) is investigated. Among the deuteron-induced reactions at low incident energy, the $^{13}C(d,n)^{14}N$ reaction is one of the best because of the advantages of carbon as a target material and its large cross section. The deuteron beam was produced by a tandem accelerator at MIT's Laboratory for Accelerator Beam Applications (LABA). The resulting neutron spectra were evaluated in terms of RBE-dose rates at different depths inside a water-filled brain phantom using a heavy water moderator and lead reflector assembly. Dosimetry results were obtained using the dual ionization chamber technique for fast neutrons and photons and bare and cadmium-covered gold foils for the thermal neutron flux. The RBE-doses in tumor and healthy tissue were calculated from experimental data assuming a tumor ^{10}B concentration of 40 ppm and a healthy tissue ^{10}B concentration of 11.4 ppm. All results were simulated using the code MCNP, a Monte Carlo neutron and photon transport code. Experimental and simulated results are presented at 1,2,3,4,6,8 and 10 cm depths along the brain phantom centerline. An advantage depth of 5.6 cm was obtained for a treatment time of 56 minutes assuming 4 mA deuteron current.

"Metabolic Alterations without Metal Accumulation in the Ovary of Adult Bufo Arenarum Females, observed after Chronic Exposure to Zn^{2+}, followed by Toxicity to Embryos"

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Long-term exposure of aquatic organisms to metals, even those considered as micronutrients, may affect their metabolism and produce them sub lethal effects. We evaluated the effects of chronic exposure of adult amphibian (Bufo arenarum) females to 4 mg/L of Zn2+ (ZnSO4.H2O) in Ringer solution, on the concentration of Zn and Fe, the activity of the key enzyme of the pentose phosphate pathway: glucose-6-phosphate dehydrogenase and glutathione content, both in the liver and ovary of these animals. We also performed early embryonic development studies by in vitro insemination from both control and treated females. Zn exposure rendered lower Zn concentrations in the ovaries than did exposure of animals to Ringer solution without metal addition (96.9 ± 49.7 vs 149.23 ± 46.4 Zn mg/wet tissue g). Zn and Fe concentrations correlation was positive and linear in the ovary while it was negative and non linear in the liver of the studied females. The activity of the enzyme glucose6-phosphate dehydrogenase decreased (0.0599 ± 0.0109 vs 0.0776 ± (0.0263 mmol of NADPH/min.mg of proteins) and the endogenous glutathione content increased (0.02679 ± 0.00488 vs 0.01767 ± 0.0074 mg/10 mg of proteins) in the ovary but remained unaltered in the liver as a consequence of Zn treatment. Our results suggest the existence of different mechanisms of regulation of Zn and Fe concentrations in the ovary and in the liver of adult Bufo arenarum females. Binding of Zn to low molecular weight proteins, as metalothioneins, may occur in the liver, thus protecting this organ from toxic effects. In the ovary Zn should be able to bind high molecular weight proteins, like glucose-6-phosphate dehydrogenase, and produce oxidative stress leading to the observed increased in endogenous glutathione content. Inhibition of the pentose phosphate pathway in the ovary by Zn can be responsible of the reproductive failure that we detected through embryos survival studies during early life stages (81.3 ± 6.3 % of survive from control females vs 63.1 ± 13.8 % of survive embryos from Zn treated females at the branchial circulation stage of development).

“Systematic features of signature inversion in doubly odd nuclei”

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The signature inversion phenomenon in odd-odd nuclei is reviewed for the regions of mass numbers A @ 80, 130 and 160. The angular momentum, frequency and moment of inertia estimated at the signature inversion point are analyzed. The correlations found of these quantities with other nuclear parameters are discussed.