Instituto de Estudos Avançados da Universidade de São Paulo

Workshop "The Nucleus-Nucleus Interaction and Reactions With Exotic Nuclei, a workshop dedicated to the Memory of Paulo Roberto Silveira Gomes"

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ABSTRACTS

Excitation of Giant and Pygmy dipole states in neutron-rich systems with isoscalar probes

Andrea Vitturi

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We give estimates for the population of Giant and Pygmy dipole states in neutron-rich nuclei via inelastic processes induced by nuclear isoscalar probes. In the former case this is possible due to the occurrence of the neutron skin (and actually providing an estimate of its extension), while is the latter case this possibility arises from the isoscalar/isovector mixed character of the pygmy states. Both macroscopic and microscopic models are used for the description of the dipole response. Following experimental findings, special attention is given to the possible separation of the pygmy region into a "mainly isoscalar" and a "mainly isovector" parts in spherical nuclei, as well as to the splitting of the dipole pygmy strength into the K=0 and K=+/-1 components in very neutron-rich deformed nuclei.

Present and future experiments with RIBRAS

Alinka Lepine
(IF-USP)

The high-lying resonances in 9Be were studied by measuring the excitation functions of reactions (p,p), (p,d), (p,d*) and (p,alfa) of the 8Li + p system. The simultaneous analysis by R-matrix formalism of these 4 channels allowed the determination of properties of these resonances.
The upgrade of the detection sytems of RIBRAS will be also described, with several new large area, segmented Si telescopes (DSSSD) and a neutron wall being tested and installed. These new detectors will allow us to realize exclusive break-up measurements of our radioactive beams, as 6He, 7Be, 8B, 8Li, 10Be etc. on heavy and light targets and study the effect of break-up on the different reaction channels.

Resonant reactions in nuclear astrophysics with the Trojan horse method

Aurora Tumino

The knowledge of energy production and nucleosynthesis in stars requires a precise determination of the nuclear reaction rates at the energies of interest. To overcome the experimental difficulties arising from the small cross sections at those energies and from the presence of the electron screening, the Trojan Horse Method has been introduced. The method represents one of the most powerful tools for experimental nuclear astrophysics because of its advantage to measure unscreened low-energy cross sections of reactions between charged particles, and to retrieve information on the electron screening potential when ultra-low energy direct measurements are available. This is done by selecting the quasi-free (QF) contribution of an appropriate three-body reaction A + a → c + C + s, where $ is described in terms of clusters x +s. The QF reaction is performed at energies well above the Coulomb barrier, such that cluster x is brought already in the nuclear field of A, leaving s as spectator to the A+x interaction. The THM has been successfully applied to several reactions connected with fundamental astrophysical problems as well as with industrial energy production. I will recall the basic ideas of the THM focussing on resonant reactions with stable and exotic beams and show some recent results.

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Inclusive deuteron breakup reactions

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In a deuteron-induced reaction, competition between elastic and inelastic breakup, absorption of only a neutron or a proton and absorption of the deuteron must be taken into account to determine the inclusive proton and neutron emission cross sections, as well as the formation or not of a compound nucleus [1]. The breakup-fusion reactions – those in which either only a neutron or a proton is absorbed – are particularly complex, forming compound nuclei with a wide range of excitation energies and angular momenta. We use the zero-range post-form DWBA approximation to calculate the elastic and nonelastic breakup cross sections [2-5] and estimate the breakup-fusion cross section. We compare the energy and angular momentum dependence of the breakup-fusion compound nucleus formation cross section with the corresponding neutron-induced cross sections and calculate the differential 238U(d,pf) cross section using the EMPIRE-3 nuclear model code [6]. Finally, we discuss how the formalism describing two-body fragmentation can be extended to take into account reactions in which the projectile dissociates into three fragments [7].

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Pigmy resonances, symmetry energy and neutron stars

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The electric dipole (E1) response of exotic nuclei has ben studied for several decades, leading to the famous discovery of the giant dipole resonance in 1947 and of the double giant resonance in 1993. In the last three decades the focus of this research is on the pygmy dipole resonance (PDR) appearing in neutron-rich nuclei, and it was possibly discovered in the late 1980's. I will discuss how the PDR has been firmly identified experimentally and how it has theoretically been linked to the physics of neutron stars. In particular, one has shown that it displays sensitivity to bulk properties of the nuclear matter, such as the symmetry energy in the equation of state of asymmetric nuclear matter

Sensitivity of breakup observables and fusion to sub-zeptosecond resonance lifetimes

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Nuclear reaction dynamics at energies near the fusion barrier is sensitive to the quantum structure of colliding nuclei. For reactions involving weakly bound nuclei, the presence of low energy unbound states leading to cluster breakup is crucial. If the states have decay lifetimes comparable to the reaction timescale (~10-21s), then the reaction observables (particularly fusion) depend sensitively on the location of the decay with respect to the collision partner. Recent measurements at the Australian National University have allowed detailed investigation of sub-barrier breakup in reactions with 6Li, 7Li and 9Be with a wide range of targets. Helped by breakup simulations, experimental observables have been identified that probe the location of breakup. Sensitivity even to sub-zeptosecond decays is found. These results provide clear insights into near-barrier reaction dynamics of weakly bound nuclei.

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Investigation on the projectile break-up mechanism in 7Li + 208Pb reaction around the Coulomb barrier

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Interactions of the most weakly bound stable nuclei, 6,7Li and 9Be, display a range of anomalous behaviors, all attributed to the low break-up threshold. For instance, projectiles break-up into their cluster constituents is expected to be highly probable. Projectile dissociation in the field of the target nucleus is a topic of continued interest also because of its application to the determination of radiative capture cross section of astrophysical interest. Over the last decade, with the availability of secondary radioactive ion beams, the role played by projectile break-up has become a major research issue [1]. Understanding the reaction mechanisms of loosely bound projectiles and the coupling of their break-up on various channels therefore becomes very important. Projectile break-up modifies the accepted picture for complete fusion of strongly bound nuclei. Measurements involving the projectiles 6,7Li, 6He with α+x cluster structure show significantly larger cross sections for the inclusive alpha particle production [2] compared to the production of the complementary fragment (x). This indicates that there are mechanisms other than α+x breakup responsible for the inclusive production of alpha particles[3,4].

In this presentation, the different outgoing channels leading to break-up of the projectile at the beam energy from 31 to 39 MeV for the system 7Li+208Pb will be discussed. An interpretation for α spectra from projectile break-up will be proposed and that will shed light on the implications of the higher binding energy of 7Li with respect to 6Li on the exclusive break-up.

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Exploring the single particle structure of 10Li by the d(9Li,p)10Li reaction

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The study of the unbound system 10Li is of great interest since the knowledge of its structure is a crucial ingredient in the description of the two-neutron halo nucleus 11Li. Despite the significant amount of experimental information gathered during the last years, the properties of the 10Li continuum remains unclear, to the extent that even the energy and the spin-parity of the ground state are still controversial [1,2]
We have investigated the 10Li structure via the 9Li(d,p)10Li transfer reaction in inverse kinematics at TRIUMF [3]. A 100 MeV 9Li beam, produced by the ISAC-II facility, impinged on a CD2 target. The recoiling protons were detected at backward angles by the LEDA array of silicon strip detectors [3], thus allowing the study of the 10Li emitted in the crucial region at forward angles. Protons are detected in coincidence with the 9Li fragments produced from the breakup of the corresponding
10Li. 9Li fragments have been detected and identified by using a ΔE-E telescope of S2 annular DSSD detectors located downstream the target.
The 10Li excitation energy spectrum was reconstructed with significant statistics up to about 4 MeV, allowing, for the first time, to explore the completely unknown high excitation energy region. The highly segmented detection system allowed to also measure the angular distributions of the observed resonances at forward angles. The comparison with an extended mean-field approach, where the pairing correlations are introduced [4], allows to disentangle the s, p and d orbital contributions in the different portions of the energy spectrum.

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Is the complete fusion suppression energy independent?

Jesus Lubian
(If – UFF)

In a recent years many works have shown that the complete fusion of the reaction of weakly bound nuclei with medium-heavy and heavy targets is hindered for about 30 - 40%, when compare to benchmark UFF (Universal Fusion Fusion). Is this systematic valid for the reaction with light and medium targets? Here we want to prove that for the reactions of weakly bound projectile with lighter targets the hindrance is much more lower, or does not exist at all.

Neutron +19C elastic scattering near critical conditions for an excited 20C state

Lauro Tomio
(IFT-UNESP)

Low-energy properties are investigated for the neutron19C elastic s-wave scattering, near the critical condition for the occurrence of an excited bound state in 20C, within a neutron-neutron+18C configuration, by considering finite-range potentials. The results for the s-wave scattering amplitude present universal scaling features, with the variation of the 19C binding energy for fixed 20C binding and neutron-neutron singlet virtual state energies. The scaling of the effective-range parameters and the pole position of k.cot{\delta_0^R) are in general consistent with the scaling obtained with a zero-range potential.Perspective applications of the analysis to other similar three-body imbalance-mass systems will also be discussed.

São Paulo potential: twenty years later

L. C. Chamon
(IF-USP)

The São Paulo potential is a theoretical model for the nuclear interaction between heavy nuclei. The model has been successfully used in elastic scattering data analyses for many systems and in a very wide energy range. Due to the lack of adjustable parameters, the São Paulo potential can also be assumed as a standard bare interaction in applications involving coupled-channel calculations. We will present a brief review of the São Paulo potential and will show some examples of application in heavy-ion reactions.

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Fusion function: an efficient procedure to reduce fusion data

L. F. Canto
(IF-UFF, UFRJ)

The traditional reduction methods to represent the fusion cross sections of different systems are flawed when attempting to completely eliminate the geometrical aspects, such as the heights and radii of the barriers, and the static effects associated with the excess neutrons or protons in weakly bound nuclei. We remedy this by introducing a new dimensionless universal function, which allows the disentanglement of the static and dynamic aspects of the low binding energy of the weakly bound collision partner. We discuss the application of this reduction procedure to collisions of weakly bound projectiles with targets in different mass ranges. The extension of the method to reaction cross sections is briefly discussed.

Study of reactions involving weakly-bound nuclei

Leandro Gasques
(University of São Paulo, Nuclear Physics Department)

Recently, an experimental campaign was performed at the Laboratório Aberto de Física Nuclear of the University of São Paulo. Various angular distributions were obtained at energies around the Coulomb barrier for the 10,11B+120Sn reactions. Besides the elastic scattering, other reaction channels, such as projectile and target-like excitation, and transfer of nucleons, were observed. Details on the experiment, and a theoretical analysis performed within the coupled-channel formalism, will be presented.

Instrumental developments to study weakly bound and exotic nuclei reactions at USP

Marcos Aurelio Gonzalez Alvarez
(University of Seville)

We present two new detection and adquisition systems dedicated to study nuclear reactions at the Open Laboratoy of Nuclear Physics of the University of São Paulo (USP), in Brazil. SATURN (Silicon Array and Telescopes of USP for Reactions and Nuclear applications) has been coupled to the 30B experimental beam line and reaction chamber, to study weakly bound nuclei reactions. STAR (Silicon Telescopes Array of RIBRAS) has been developed to be coupled to the 45B experimental beam line and the RIBRAS (Radioactive Ions Beams in Brazil) system, to study exotic nuclei reactions. In 2016, the first experimental campaign using SATURN was performed with the aim of studying the 7Li, 10,11B weakly bound nuclei reaction on 120Sn. In 2017, the E-125 experimental campaign will be performed with the aim of studying the 6Li, 9Be weakly bound nuclei reaction on 120Sn. In order to test STAR and better explore the 9Be+120Sn nuclear reaction, SATURN and STAR systems will be mounted in the same 30B nuclear reaction chamber. For the future, STAR should be coupled to RIBRAS for studying new exotic nuclear reactions. SATURN and STAR could also be coupled to the Neutron Wall system for coincidence measurements of charged and neutron particles.

Recent results on light nuclear systems; progress and problems

Martin Freer
(School of Physics and Astronomy, University of Birmingham, Birmingham, B15 2TT, UK)

It might feel as though a complete understanding of light nuclei should have been reached by now, and may be it should. However, and on the contrary, these systems have become the testing ground where state-of-the-art theory meets the incredibly rich spectrum of structural possibilities that light nuclei present. Such systems are dominated by correlations which are the finger-print of the strong interaction which generates everything from the collective to single-particle behavior and also examples where these mix. These correlations are manifest is cluster-like states and molecular exchange of neutrons between clusters (mixed bosonic and fermionic modes). This talk will be a review of the recent results of the Birmingham group, where they are helping to improve our understanding of nuclei such as 12C, 14C and 12Be and where open questions remain

Low energy Nuclear Physics at the French Atomic energy committee (CEA)

Nicolas Alamanos
(Saclay, France)

Experimental and theoretical investigations in the domain of low energy nuclear physics at CEA/IRFU-Saclay will be presented. Contributions of the Institute (IRFU) at facilities under construction like the SPIRAL2 accelerator in France or the FAIR facility in Germany will be discussed with emphasis to major technical contributions of the Institute

Breakup of three-cluster systems

Pierre Descouvemont
(ULB, Belgium)

The breakup of 6He, 9Be and 17Ne are investigated in the CDCC framework. We use a three-cluster model for 6He (=alpha+n+n), 9Be (=alpha+alpha+n) and 17Ne (=15O+p+p), and simulate the breakup by three-body pseudostates. These 3 systems cover different situations: 1, 2 and 3 charged particles, respectively. The separation between nuclear and Coulomb breakup is also discussed.

Halo EFT and nuclear astrophysics

Renato Higa
(IF-USP)

Light and medium nuclei far from the stability line have proven to be fascinating and mysterious systems where quantum effects dominate and conspire to form loosely bound structures. Many of these nuclei are pivotal in describing relevant processes in astrophysics, mainly in the very low-energy Gamov band where dedicated experiments have many technical difficulties to access. Within the halo effective field theory framework, these experimental barriers turn into theoretical gifts. I will highlight some of astrophysically important radiative reactions and results of t

Recent results from RIBRAS

Rubens Lichtenthalar
(IF- USP)

Results of elastic scattering experiments using exotic 6He, 8B, 7Be secondary beams will be presented. Continuum Discrtized Coupled Channels calculations seem to reproduce quite well most of the the angular distributions without the need of parameter variations. A systematics of the nuclear radii obtained from total reaction cross sections allow a comparison between exotic and stable projectiles. Recent results of the 7Be+9Be scattering and the two neutron elastic transfer reaction 9Be(7Be,9Be)7Be will also be presented.

Suppression of complete fusion in reactions involving weakly bound nuclei with an empirical coupled-channel model

Shan-Gui Zhou
(Institute of Theoretical Physics, Chinese Academy of Sciences)

Abstract: Complete fusion excitation functions of reactions involving breakup are studied by using the empirical coupled-channel (ECC) model with breakup effects considered. An exponential function with two parameters is adopted to describe the prompt-breakup probability in the ECC model. These two parameters are fixed by fitting the measured prompt-breakup probability or the complete fusion cross sections. The suppression of complete fusion at energies above the Coulomb barrier is studied by comparing the data with the predictions from the ECC model without the breakup channel considered. The results show that the suppression of complete fusion is roughly independent of the target for the reactions involving the same projectile.

Characteristic structure of weakly bound and unbound neutron-rich nuclei

Takashi Nakamura
(Department of Physics, Tokyo Institute of Technology)

I present the recent experimental studies on nuclei near and beyond the neutron drip line to probe their characteristic structures. The results to be shown are based on the experiments performed at RIBF at RIKEN. First topic is on the neutron halos. I present the study on deformation-driven p-wave halo configuration revealed in 29Ne[1],
31Ne[2,3] and 37Mg[4] using the breakup reactions at intermediate energies. I also present the results on two-neutron halo nuclei, 19B and 22C, using the reaction cross sections [5] and the breakup reactions. Then, for the unbound nuclei, I will report on the recent experiments to investigate structures of 25-28O. In particular I will focus on 26O[6], which has been found to have extremely small decay energy with respect to the two neutron emission, and thus may have strong two-neutron correlation. Finally, I will provide perspectives on experimental studies on nuclear near the neutron drip line.

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Borromean Exotic Nuclei and Efimov Physics

Tobias Frederico
(Instituto Tecnológico de Aeronáutica)

We will revise the main aspects of the Efimov phenomenawith respect to the universal properties that a three-body system exhibit in the limit of large scattering lengths. The Efimov physics is reflected in the appearence of universal scaling laws for observables associated with the long range part of the wave function. In particular we are going to discuss 22C and its neutron halo distribution, as well as, other Borromean nuclei like 11Li and 14Be. Some novel perspectives on the reaction of these nuclei with a heavy targets, considering a four-body formulation, will be adressed. The aim is to put forward possible evidences of the Efimov physics in building the relevant cross-sections involving the halo neutrons and the core.

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A Systematic Approach to Halo and Cluster Nuclei

U. van Kolck
(Institut de Physique Nucleaire d'Orsay and University of Arizona)

Halo and cluster nuclei display a separation of scales between the sizes of tight subsets of nucleons ("cores") and of the entire system, which form an ideal playground for effective field theories (EFTs). I present the systematic framework to describe these nuclei with Halo/Cluster EFT, a low-energy version of QCD whose degrees of freedom are nucleons and cores that provides a generalization of simple, successful models with short-range interactions. In this EFT, light, halo and cluster nuclei are arrangements with, respectively, no, one, and multiple cores. I discuss in particular core-size effects, which become more important as cores become heavier.