Theoretical Physics

Nuclear structure and nuclear reactions in low energies

New developments in radioactive beam acceleration and large detector arrays have allowed not only the study of new nuclear systems, but also a much better knowledge of some spectroscopic observables. Hence, there are new possibilities to develop and test many body techniques applying in some cases previously developed solutions to new systems.

- Since the nuclear stability line departs from N ≈Z for A > 40, previous detailed spectroscopic studies of those type of nuclei had been performed in lighter systems. This can be and is being studied using shell model techniques, either with large-scale calculations or schematic models based in group theoretical classifications as well as within a collective description of the relevant degrees of freedom.
- Some phenomena related to octupole or tetrahedral degrees of freedom are more noticeable at the onset of quadrupole deformation regions. We are using our experience on these types of excitations to find a relation between the relative influence of the T=1 and T=0 channels of the nuclear interaction, the effects of octupole components in the deformed systems and the alpha-like correlations.
- It has been possible to study the thermal character of giant resonances built on top of nuclear excited states. From the experimental data of giant dipole resonances results an excess of low energy photons, which is at odds with the predictions of simple models. Analysis of excitations of giant resonances using relativistic heavy ion collisions.
- The existence of neutron skin in neutron reach nuclei has been studied in connection with the excitation of isovector dipole and quadrupole giant modes via isoscalar nuclear probes. In the case of large neutron excess, important contributions are obtained for the nuclear excitation and constructive interference is found between nuclear and Coulomb contributions.

Chaos and complex systems

- Quantum Maps. Quantum maps provide the simplest, yet highly non-trivial, arena for the investigation of the quantum properties of chaotic systems. As simple models of Poincaré sections of realistic Hamiltonians or of time dependent "kicked" systems, they provide a testing ground for semiclassical approximations, correlations, universalities, localization, etc. We have developed techniques for the construction, semiclassical behavior and phase space description of the baker's map, the Smale horseshoe, cat maps, etc.

- Quantum Billiards. Billiards in 2-D provide some of the best realistic models where wave and particle behavior can be studied and related. Besides their intrinsic theoretical interest they describe the behavior of ballistic electrons in mesoscopic cavities or of light in optical microcavities. The group has studied extensively the highly excited spectrum of plane chaotic billiards and its semiclassical description in terms of periodic orbits. A very efficient "scaling" method for the precise calculation of very excited eigenstates has been developed, which is now the best available. A theory of short periodic orbits is under active development with aim of taming the exponential increase in the number of periodic orbits needed for the semiclassical description of spectral properties.
- Quantum Algorithms. Studies of quantum algorithms viewed as quantum maps. Thus, we can apply semiclassical techniques, phase space analysis, and long time behavior characteristics of quantum maps to the operation of quantum circuits, providing a novel approach in this area.
- Transport Phenomena in Mesoscopic Systems. Application of the general methods of chaotic dynamics to the study of mesoscopic systems. We have studied persistent currents and the effects of surface roughness in ballistic cavities and the statistical properties of the fluctuations in the total energy in a non-interacting fermion system.
- Chaotic Scattering at the Nuclear Coulomb Barrier. There are interesting and characteristic anomalies in the heavy ion cross sections and angular distributions at backwards angles that can be interpreted as arising from chaotic scattering due to the coupling of intrinsic and translational degrees of freedom at Coulomb barrier energies. We have modeled these processes and proposed experiments to test these characteristics.

Field theoretical methods in strongly interacting systems

Nuclear structure problems related to the description of the double beta decays have been investigated. Special attention was paid to the difficulties related to the treatment of the zero modes associated to the breaking of isospin symmetry. For this purpose a formalism based on the use of BRST symmetry was developed.

- The spectrum and decays of- baryon resonances have been investigated using the large Nc expansion of QCD.
- Some properties of the QCD chiral phase transition at finite temperature and chemical potential using non-local extensions of chiral quark models. We have made predictions for the position of the “tricritical point” (chiral limit) and the “end point” and the phase diagram in the temperature density phase.
- The problem of the center of mass in many-body nuclear systems has been revisited. Once the counter terms needed to satisfy translational invariance were determined, collective variables have been introduced. The problems associated with the overcompleteness and divergences were solved using BRST invariance. The formalism has been applied to the calculation of some electroweak operators relevant to muon-electron conversion process.

- Another topic, which has been extensively studied, is that of nuclear microscopical models and approximations in connection to their use in predictions for observables in exotic electroweak processes such as double beta decay.
- Investigations concerning the edge states in the fractional Quantum Hall Effect. In particular, different predictions of the two classes of theories currently used to describe these states have been studied. We have also considered a Chern-Simons theory in 2+1 dim to describe the quasiparticles in the Pfaffian states.

Inhomogeneous Quantum Fluids

The investigation of the structure and stability of helium systems is the object of many theoretical and experimental works. Mainly two different theoretical approaches for investigating helium systems have been successfully employed in the literature:

- A self-consistent variational formalism based on the use of interatomic potentials within the framework of the theory of correlated basis functions in conjunction with the hypernetted chain expansion, and,
- A semiphenomenological approach which uses a density functional. In this semiphenomenological description the energy of the systems is written in terms of a functional depending of the density. Among the properties of inhomogeneous superfluid 4 He, we have mainly studied the stability of helium films. This feature is determined by variational properties of the chemical potential which is introduced in order to impose the conservation of the particle number *N* when solving the equation for the density profile, and by the requirement of a negative surface tension. The behavior of films adsorbed onto solid planar substrates of alkali metals has been studied. The calculations were carried out by using the density functional formalism. Results indicate that it is not possible to establish whether the surface of Rb is wetted by 4 He at T=0 K. Now, we are focusing our attention on helium systems with cylindrical geometry. In this case a stability criterion consistent with basic equations of the thermodynamics was derived.