MASTER THESIS proposals 2018-2019

PATH 2: THEORY

1. NUCLEAR STRUCTURE STUDIES WITH SYMMETRY CONSERVING CONFIGURATION MIXING METHOD

Universidad Autónoma de Madrid

Supervisors: Luis M. Robledo (luis.robledo@uam.es)
Tomás R. Rodríguez (tomas.rodriguez@uam.es)

Abstract:

The most widely used phenomenological models to study the structure of atomic nuclei at low-excitation energies are the Interacting Shell Model (ISM)1 and the Self-Consistent Mean-Field (SCMF)2, and its Beyond-Mean-Field (BMF) extensions2. The ISM is currently the method that provides the best description of the spectra of the atomic nuclei due to the exact character of its solutions and the quality of the effective interactions used. However, its applicability is limited to certain regions of the nuclear chart.

The SCMF method is based on the variational principle to solve quantum many-body problems in an approximate manner and it can be applied to study on an equal footing stable nuclei and nuclei far away from the valley of stability. Furthermore, the SCMF methods give a very useful interpretation of the nucleus in terms of intrinsic shapes. However, BMF approximations are needed to describe more accurately nuclear masses, radii, spectra, transitions and decays. State-of-the-art BMF techniques are based on the so-called symmetry conserving configuration mixing (SCCM) methods with density-dependent interactions3.

This Master's Thesis proposal aims at the application of SCCM in the study of the structure of atomic nuclei. In particular, the role of collective coordinates as quadrupole and octupole deformations, pairing degrees of freedom, etc., will be analyzed in regions of current experimental interest (shape-coexistent nuclei, appeareance or degradation of magic numbers far away from stability, etc.).

Bibliography

[1] E. Caurier et al., Rev. Mod. Phys. 77, 427 (2005); T. Otsuka et al., Prog. Part. Nucl. Phys. 47, 319 (2001).

[2] M. Bender et al., Rev. Mod. Phys. 75, 121 (2003); J. L. Egido, Phys. Scr. 91,

073003 (2016).

[3] M. Bender, P.-H. Heenen, Phys. Rev. C 78, 024309 (2008); T.R. Rodríguez, J.L. Egido, Phys. Rev. C 81 064323 (2010); J.M. Yao et al., Phys. Rev. C 81, 044311 (2010).

Requirements

- Good knowledge on Many-Body Theories in Nuclear Physics.
- Computational skills (Linux OS).
- **Programming skills (Fortran, C, Python, or similar).**

2. THEORY OF COLLISIONAL TRANSPORT IN OPTIMIZED STELLARATORS.

CIEMAT, Madrid, Spain

Supervisor: Iván Calvo. Theory Group, Laboratorio Nacional de Fusión, CIEMAT. Madrid (Spain). ivan.calvo@ciemat.es http://fusionsites.ciemat.es/icalvo/

Abstract:

Stellarators are a promising alternative to tokamaks as future magnetic confinement fusion reactors. However, the magnetic field of a stellarator has to be designed very carefully for it to have confinement properties comparable to those of an axisymmetric tokamak; if this is the case, the stellarator is said to be "optimized". In this project, the theory that is needed to calculate collisional transport of particles and energy in optimized stellarators will be studied and extended.

Bibliography: "The effect of tangential drifts on neoclassical transport in stellarators close to omnigeneity", I. Calvo et al. Plasma Phys. Control. Fusion 59, 055014 (2017).

Webpage of one of our ongoing projects:
http://fusionsites.ciemat.es/stellaratortransport/

Required skills: Good physics and mathematics background.

Preferred skills: Scientific computer programming.

3. "SHAPE COEXISTENCE VERSUS SHAPE PHASE TRANSITIONS IN NUCLEI STUDIED VIA TWO-NUCLEON TRANSFER REACTION"

Universidad de Sevilla, Spain

Supervisor: Dr. José A. Lay Valera (lay@us.es)
Supervisor: Prof. Andrea Vitturi (andrea.vitturi@pd.infn.it)

Abstract:

Even though nuclei are made of A separate nucleons interacting between each other, some of them show in their characteristics clear patterns of an underlying collectivity. An example is the fact that nuclei present different shapes: they can be spherical, prolate, oblate... A nucleus will be prolate or spherical depending on the detailed movement of the A nucleons: a doubly closed shell nucleus is always spherical and a large part of open shell nuclei are prolate. If we go along different isotopes from one shell closure to the next one, we will face a shape phase transition: we will start with a spherical nucleus, then we will arrive to an isotope which has a prolate shape and, finally, as we reached the following shell closure, we will end at a spherical nucleus again.

A more controversial point is whether we can have shape coexistence and how to distinguish it from a shape phase transition. In shape coexistence we can have a nucleus whose ground state is, for example, prolate whereas some of its excited states are oblate or spherical. Even more importantly, If these states are close, they can be mixed. A possible tool to distinguish these different cases could be two-neutron transfer reactions. This reaction has been shown to be sensitive to the different shape phase transitions [R. Fossion et al., Phys. Rev. C **76**, 014316 (2007)] since the probability of transferring two particles decreases quite fast when the initial and final nuclei have different shapes.

Along the present project, the student is expected to learn the Interacting Bosson Model and how, within this model, we can study shape transitions and shape coexistence. The student will later calculate intensities for the different two-neutron transfer reactions which will later be calculated within the Distorted Waves Born Approximation.

4. "INTERPRETATION OF INCLUSIVE BREAKUP DATA USING THE ICHIMURA, AUSTERN, VINCENT MODEL"

Universidad de Sevilla, Spain

Supervisor: Dr. Antonio M. Moro (moro@us.es)

Abstract:

The breakup of a nucleus into two or more fragments is an important mechanism occurring in nuclear collisions, particularly when one of the colliding nuclei is weakly bound. The analysis of this kind of processes has provided useful information on the structure of these nuclei, such as binding energies, spectroscopic factors and angular momentum, and has contributed to the understanding of the dynamics of the reactions among composite systems.

When all fragments arising from the projectile dissociation are measured the reaction is said to be exclusive. The observables measured in these reactions, such as the angular or energy distribution of the fragments, can be accurately described with available models, such as the continuum-discretized coupled-channel (CDCC) method, the most sophisticated Faddeev formalism, and a variety of semiclassical approximations.

A different scenario occurs when one or more fragments are not measured, in which case the reaction is said to be inclusive (with respect to the undetected fragments). The evaluation of the angular and energy distribution of the measured fragments becomes much more challenging because of the large number of possible contributing channels. In fact, the models developed to deal with these reactions are scarce and their accuracy not fully tested. One of these models, proposed in the 1980s by Ichimura, Austern and Vincent (IAV) [1] has been recently revisited and implemented by our group [2,3,4,5]. First calculations with this model have shown a very encouraging agreement with exiting data, but further systematic calculations are needed to better establish its accuracy and predictibility.

In this project, we propose to make use of this recent implementation of the IAV model to analyze existing inclusive breakup data, such as (d,px), (^{6,7}Li,a x), (^{7}Be, a x), etc. We will investigate the sensivity and importance on the choice of the different potentials entering the calculation. In particular, we will study the ^{208}Pb(d,px) reaction, employing modern neutron-^{208}Pb dispersive potentials which account for both positive (unbound) and negative (bound) ^{209}Pb states. Calculations will be compared with recent data for this reaction.

Bibliography:

[1] Ichimura, Austern and Vincent , Phys. Rev. C 32, 431 (1985).
[2] J. Lei and A.M. Moro, Phys. Rev. C 92, 044616 (2015); ibid Phys.Rev. C 97, 011601 (2018); ibid Phys. Rev. C 95, 044605 (2017).
[3] G. Potel et al, Eur.Phys.J. A 53, 178 (2017).

[4] A.M. Moro et al,Acta Phys.Pol. B47, 821 (2016).
[5] A.M. Moro and J. Lei, Few-Body Systems 57, 319 (2016).

5. "HOT NEUTRON-RICH NUCLEAR MATTER STUDIED WITH A NEW NUCLEAR ENERGY DENSITY FUNCTIONAL"

University of Barcelona

Supervisors: Xavier Vinas (xavier@fqa.ub.edu) , Artur Polls (artur@fqa.ub.edu) and Mario Centelles (mario@fqa.ub.edu) (University of Barcelona)

Abastract:

Understanding the properties of hot nuclear matter is necessary for the modeling of supernova matter and for discussing the phenomena observed in intermediate-energy heavy-ion collisions. The purpose of this Master Thesis is to investigate the thermodynamical properties of the equation of state of neutron-rich nuclear matter and of nuclei at finite temperature using a recently formulated nuclear energy density functional, which is based on microscopic calculations and accurately reproduces the ground-state properties of nuclei.

6. "STUDY OF NUCLEAR SHAPES IN MEDIUM-MASS NUCLEI WITH A MICROSCOPIC-MACROSCOPIC MODEL"

University of Barcelona

Supervisors: Xavier Vinas (xavier@fqa.ub.edu) and Mario Centelles (mario@fqa.ub.edu) (University of Barcelona)

Abstract

The models of nuclear masses and nuclear shapes are continuously challenged by advances in experimental techniques, which nowadays are extending the nuclear chart to previously unexplored isotopes. The purpose of this Master Thesis is to apply a recently proposed microscopic-macroscopic model, based on the Wigner-Kirkwood method for calculating the shell corrections, to study the nuclear ground-state potential energy surfaces with deformation degrees of freedom for intermediate-mass nuclei, with the goal of predicting the nuclear ground-state masses and shapes of these nuclei. The connection of these results with the interacting boson model will also be analyzed.

7. "COMPOSITE HADRONS IN THE STRANGE AND HEAVY SECTORS"

University of Barcelona

Supervisors: Angels Ramos (ramos@fqa.ub.edu) and Volodymyr Magas (vladimir@fqa.ub.edu) (University of Barcelona)

Abstract:

The phenomenological quark model successfully describes many hadrons as being composed by three bound quarks (baryons) or a quark and an antiquark (mesons). However, there are some hints that some of the observed hadron resonances do not fit in this scheme and they might be better described as an aggregate of two or more hadrons, bound by their mutual attractive interaction. Some examples are the $\Lambda(1405)$ in the baryonic sector or the $D^*(2317)$ in the mesonic sector. In the last decade many hadron resonances that do not fit the conventional quark model picture have bee observed. This project aims at studying several of these unconventional resonances and discuss their possible interpretation as hadron-hadron molecules on the basis of an effective Lagrangian that respects the basic symmetries of QCD.