Research Group Summary - Professors Volker Oberacker and Sait Umar

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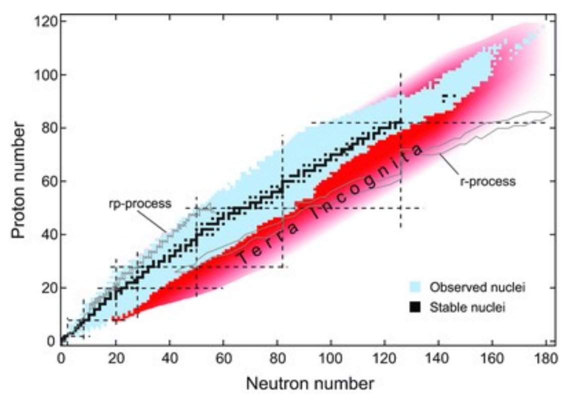
Theory of quantum many-body systems

One basic problem that is common to many areas of physics -- and other natural sciences such as chemistry -- is the quantum many-particle problem. Theorists working in atomic, molecular, and condensed matter physics, in nuclear physics and in some areas of astrophysics face a similar challenge: how to describe the features of interacting quantum many-particle systems in terms of suitable constituent particles and the fundamental interactions between them. Such theories are referred to as "microscopic theories".

The aim of nuclear theory is to study the quantum many-particle aspects of the strong interaction, which is one of the four fundamental forces of nature. Because of the large coupling constant of the strong interaction, the vast majority of nuclear phenomena cannot be treated in perturbation theory and require large-scale numerical calculations. At relatively low energy, an atomic nucleus may be viewed as a system of N point-like protons and neutrons which interact via two-body Coulomb potentials and via two-body / three-body strong nuclear potentials. Most of our work uses "nuclear mean-field theories" such as static Hartree-Fock (HF) and Hartree-Fock-Bogoliubov (HFB) to describe individual nuclei. Reactions between two heavy nuclei are described by the Time-Dependent Hartree-Fock (TDHF) theory.

Nuclear chart: the frontiers of neutron-rich nuclei, and synthesis of new superheavy nuclei

One of the fundamental questions of nuclear structure physics is: what are the limits of nuclear stability? How many neutrons can we add to a given nuclear isotope before it becomes unstable against spontaneous neutron emission (neutron radioactivity)? If one connects the isotopes with zero neutron separation energy, S_n=0, in the nuclear chart one obtains the neutron dripline. Similarly, the proton dripline is defined by the condition S_p=0. Another limit to stability is the superheavy element region around Z=124 and N=184.



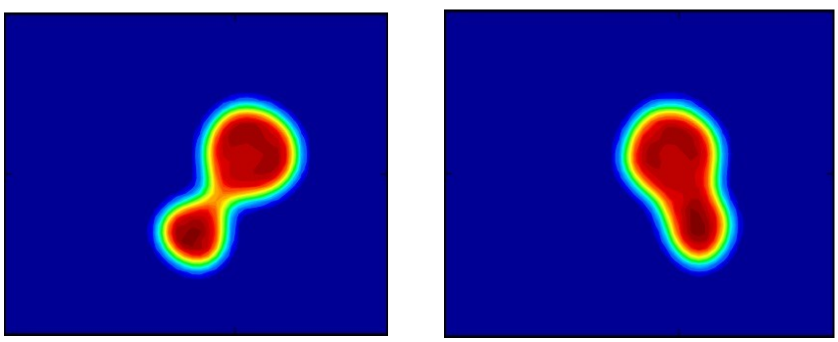
The nuclear chart shows less than 300 stable nuclear isotopes, and about 2700 additional isotopes have been created in heavy-ion accelerators. Nuclei in between the proton and neutron driplines are unstable against beta-decay. Nuclei outside the driplines decay by spontaneous neutron emission or proton radioactivity. The neutron-rich side, in particular, exhibits thousands of nuclear isotopes still to be explored ('terra incognita'). Some of these exotic nuclei can be studied with existing first-generation Radioactive Ion

Beam Facilities. Several countries are constructing new 'second generation' RIB facilities (RIKEN in Japan, FAIR in Germany, GANIL in France). In the United States, construction is under way of FRIB (Facility for Rare Isotope Beams) at Michigan State University.

Numerical calculations of nuclear structure and reactions

Theories predict profound differences between the known isotopes near stability and the exotic nuclei at the driplines: for neutron-rich nuclei, as the Fermi level approaches the particle continuum at E=0, weakly bound neutron states couple strongly to the continuum giving rise to neutron halos and neutron skins. Theories also expect large pairing correlations and new types of collective modes, a weakening of the spin-orbit force leading to a quenching of the shell gaps, and perhaps new magic numbers. Furthermore, Radioactive Ion Beam Facilities will allow us to address fundamental questions in nuclear astrophysics: more than half of all elements heavier than iron are thought to be produced in supernovae explosions by the rapid neutron capture process (r-process). The r-process path contains many exotic neutron-rich nuclei which can only be studied with these new heavy-ion accelerators

Before Professor Oberacker retired, he and Professor Umar worked closely together as a research team. Their main research area is quantum many-body theory of low-energy heavy-ion reactions which is computationally intensive. The most recent research focuses on fusion reactions of exotic neutron-rich nuclei and nuclear reactions related to production of new superheavy elements. Some of this work involves collaborations with faculty at Michigan State and Indiana University, at the University of Frankfurt and Erlangen in Germany, and at Australian National University in Canberra.



A nuclear quantum many-body problem: 3-D TDHF calculation for 48Ca + 132Sn

Specifically, our research concentrates on the following topics:
1. Fusion, capture, and deep-inelastic reactions of neutron-rich nuclei in the vicinity of the Coulomb barrier.
2. Hot and cold fusion reactions leading to superheavy elements.
3. Microscopic dynamic calculation of nuclear excitation energies during heavy-ion collisions.
4. Microscopic study of clusters (e.g. triple-alpha reaction).
5. Microscopic description of nuclear fission dynamics.

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