The distribution of nuclear matter during fission

Abstract for the general public

Nuclear fission is a decay in which a heavy atomic nucleus splits into two smaller ones. In this process, a lot of energy is released from a nucleus. That's why its most important application is nuclear power plants. Only nuclei with a large number of protons and neutrons can fission, for example, uranium and neptunium. We can obtain a lot of information about the structure of the nuclei and the nature of nuclear interactions by studying this decay in experiments. The role of fission is important in determining the stability of isotopes. We can find the half-lives of the nuclides that make up the heaviest elements. This is necessary to determine how many elements are in the periodic table. So far, we have discovered that nuclides with atomic numbers of up to 118 can be produced in the laboratory. The heaviest element synthesized recently has been named oganesson.

Many laboratories around the world perform experiments studying the fission process. Half-lives, the masses of the resulting fragments and their kinetic energies, and other observables are measured. The role of the theoretical models, on the other hand, is to describe the process and to explain and predict the results of experiments. This is not an easy task, as a heavy atomic nucleus is a system of several hundred nucleons governed by quantum mechanics. We explain the fission process as a quantum-mechanical process of tunneling the potential barrier. The barrier forms during the gradual increase of elongation of the nucleus from a sphere-like shape in the ground state. An increase in energy initially accompanies this process. Then a nucleus begins to constrict, thereby reducing its energy. Finally, the nucleus ruptures, and two fragments are created. Depending on the internal structure, the nucleus of each isotope can take different shapes by splitting into fragments of the same or different masses. The deformation energy calculated for each isotope indicates the unique characteristics of the decay of such a nucleus.

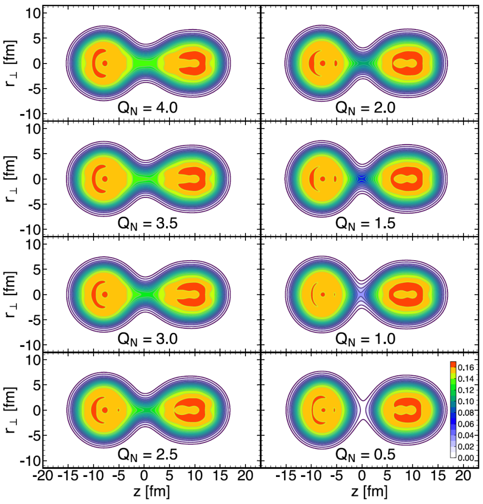

Figure 1 The distribution of nuclear matter during rupture of ^{258}No into fragments.

In this project, we want to analyze what shapes nuclear matter takes during fission. Our research should answer several questions about the distribution of nucleons in a fissioning nucleus. Do fragments prefer to be spherical, elongated, or pear-shaped before splitting from a mother nucleus? How thin can the neck between them be before the rupture? Are protons and neutrons evenly distributed in both fragments, and why do we observe different isotopes among the fission products? What does the surface of the nucleus look like: does the density of nuclear matter decrease uniformly in all directions from saturation density in bulk to zero at a distance?

We want to answer these questions using the advanced Hatree-Fock-Bogolyubov theory, which describes the nucleus as a quantum-mechanical system of nucleons moving in the mean-field generated by themselves. This theory belongs to the self-consistent models, in which the distribution of nuclear matter is calculated to minimize the total energy of the system. This guarantees that the shape of the nucleus will be optimal for the given constraints, i.e., the conditions we want to analyze during splitting (e.g., elongation or reflection asymmetry of the nucleus). Thus, the Hatree-Fock-Bogolyubov theory is a very good tool for studying the distribution of nuclear matter during fission, as it is calculated without prior assumptions.