Study of atomic nuclei structure in extremal states

C. SUMMARY OF PROJECT No. 2013/11/B/ST2/04087

1. Research project objectives/ Research hypothesis

The aim of the present project is theoretical investigation of the structure of atomic nuclei which are far from beta stability, possess large deformation or rotate rapidly. The main goal of our investigations could be prediction of new possible phenomena which can occur in nuclei in such extremal conditions. Results of the project will also serve for testing the nuclear models and will enable to tune their parameters. Finding of the exact position of the proton and neutron drip lines is important for understanding of astrophysical processes in stars as well as for experimental physicists preparing accelerator experiments with radioactive beams. Hitherto results obtained by our group have shown that the macroscopic-microscopic model with the Lublin-Strasbourg-Drop (LSD) is very suitable for such type of investigation as it is a theory with a small number of adjustable parameters which in addition possess a clear physical meaning. Parallel, for comparison, we are going to perform extended calculations within the Relativistic Mean Field (RMF) theory. Our investigations performed with the LSD model have shown that the fissioning nuclei with growing deformation or very rapidly rotating become beta unstable in spite of the fact that in the ground state they were beta stable. We would like to study consequences of this fact for the fission fragments mass, charge and kinetic energy yields. Another effect of this unexpected for the first sight instability should be additional enhancement of the neutron emission from very deformed, hot and rotating nuclei. This effect will have for sure important influence for the fission dynamics of hot, rotating compound nuclei which are produced in reaction of the heavy-ion fusion. It means that our investigation will be also important for physicist who synthesize new super-heavy elements. Elaborated in our group model for the alpha and cluster decays based on the classical Gamow theory has reproduced well all experimentally measured half-lives of nuclei in spite of the fact that it contains only one (for decays of even-even nuclei) adjustable parameter: the charge radius. We are going to use this model for studying of decays of neutron-deficient or rapidly rotating and very elongated nuclei. It should allow to obtain good estimates of probability of the alpha emission from such states.

2. Research project methodology

We are going to perform our investigation in the macroscopic-microscopic model and within the RMF theory. The parameters of our Lublin-Strasbourg-Drop (LSD) model were adjusted in 2003 known at that time binding energies of atomic nuclei. In spite of the fact that the LSD model describes well the nuclear ground state mases and the fission barrier height we would like to begin our research from a readjusting of the model parameters to presently known masses of nuclei. In addition we are going to modify slightly our model by excluding the global effect of pairing interaction from the nuclear liquid drop energy. Myers and Swiatecki, authors of the modern version of the liquid drop model, have assumed that the total pairing correlation energy is already contained in the liquid drop binding energy to which they have added the odd-even pairing effect and of course the shell energy corrections. Our last years studies suggest that it was not the best assumption as it leads e.g. to a wrong estimate of the energy of fissioning nucleus around the scission point. It is worth to mention here that in the Extended Thomas-Fermi (ETF) approximation one obtains parameters of the liquid drop or droplet models by a lepdodermous decomposition of a selfconsistent nuclear energy functional without taking into account the effect of the pairing correlations. We are going also to use the Strutinsky method with some important our modifications to evaluate better the shell corrections in nuclei far from beta stability. Our microscopic calculations will be performed using the Yukawa-folded (YF) single-particle potential which is generated by the Yukawa forces from the liquid drop density distribution.

This consistency of the shape of the liquid drop and the single-particle potential is especially important in the region of the scission point. Our estimates obtained within LSD+YF model will be compared with similar results obtained within the RMF theory.

3. Expected impact of the research project on the development of science, civilization and society

Results of our investigations should be important for a better understanding of astrophysical processes in stars which are responsible for production of heavier elements. Another astrophysically important outcome should be better estimate of the nuclear symmetry energy in nuclear matter. Other, more practical, effect of our study will be the better reproduction of the measured distributions of masses, charges and kinetic energies of the fragments produced in the spontaneous fission as well as in fission of hot and rotating nuclei. These results should allow for better description of new types of reactions accompanying to the nuclear fission. Our project is strictly bound with the newest experimental research with radioactive accelerator beams.