Results

Articles published

1) New Dynamical pair breaking effect,
M. Mirea,
***Physics Letters B* 680, 316 (2009) [impact factor 4]**
2)Inertia for two-center nuclear shapes parametrization,
M. Mirea, R.C. Bobulescu, P. Marian,
***Romanian Reports in Physics*, 61 (2009) 646 [impact factor 0.3]**

Proceedings

1) Landau-Zener effect in the Th neutron-induced fission cross section,
M. Mirea and L. Tassan-Got,
in 4th International Workshop on Nuclear Fission and Fission-Products Spectroscopy, Cadarache, France, 13-16 May 2009, Eds. A. Chatillon et al, AIP Conference Proceedings 1175, 2009, page 227,

Preprints

1) Cranking mass parameters for fission,
M. Mirea, R.C. Bobulescu,
Preprint Arxiv:0909.2098v1 [nucl-th] (2009)
2) New Dynamical pair breaking effect,
M. Mirea,
preprint ArXiv:0907.1347v1 [nucl-th] (2009)

Project description The central problem in a dynamic treatment of nuclear systems is similar to that encountered in the kinetic theory of gases. In principle, the system is isolated and a detailed analysis is effectuated using only several essential collective variables. These variables manage in the same time the behavior of many other intrinsic variables. Once the set of collective variable fixed, this being itself a no trivial problem, the study in a time dependent regime must realized. In this context, it is mandatory to analyze the influence and the behavior of the dissipation, that is the flow of energy and

orbital momentum from collective modes in intrinsic ones. This kind of investigation, being very complex, is attacked rarely. In classical systems characterized by a large number of particles, as those encountered in the statistical theory of gases, this flow of energy is irreversible, degrading finally as heat. In a similar manner, some classical descriptions of the nuclear motion are realized, the dissipation being introduced in term of the Rayleigh dissipation function. This function, having a value equal to the half of the rate of the energy transfer from collective degrees in intrinsic ones is quadratic in the collective velocity. In an alternative way, it is possible to solve directly the Navier-Strokes equations. In this kind of approaches, the viscosity coefficients are determined by comparisons with experimental data. This kind of classical description is not sufficient, because in the treatment of nuclear systems we must start from a microscopic point of view, that offered by quantum mechanics. As a difference from the classical systems, where the possibility to determine the viscosity coefficient from the kinetic theory equations exists, an analogous derivation from the Schrodinger equation for many body systems was not yet performed. In fact, due to the relatively small number of particles in a nucleus, the deviations from an irreversible behavior can be large allowing the energy to vary freely in both directions between collective and intrinsic coordinates. It can be concluded that the motion of any macroscopic physical system is not governed only by conservative and inertial forces, but also by frictional ones. From a classical point of view, these frictional forces describe the interaction of the system under consideration with other system that are not taken into consideration explicitly. These systems can be the surrounding media or the internal structure. In this sense, the concept of friction is a natural extension of the notion of collective coordinate [1]. From an historical point of view, in 1950 [2] it was shown for the first time that friction could have a major effect in nuclear physics reflected in the descriptions of damping phenomena. A short time later in the reference [3], a possible derivation of the viscosity forces encountered in fission during the descent of the nuclear system from the saddle point to the scission was suggested. They proposed a mechanism called level slippage caused by residual interactions. In this mechanism, the population of the levels is changed leading to the excitation of the nuclear system. The dissipation determined with the promotion of nucleons from one level to another, known as Landau-Zener effect, was computed for the first time in ref. [4] for even-even systems. More evolved forms in determining microscopically the dissipation were realized within the time dependent Hartree-Fock-Bogoliubov equations [5,6]. Boson pairs realize Landau-Zener transitions on virtual levels by virtue of residual interactions within strength of the order of the pairing gap. In ref [7], the authors of the present proposal generalized the time dependent Hartree-Fock-Bogoliubov equations for systems with seniority one. If the pairing effect is neglected, these equations reduce to the Landau-Zener equations for an independent particle system. If seniority 0 is taken into consideration, the equations reduce to the well-known form of the time dependent Hartree-Fock-Bogoliubov equations. Up to now, in the microscopic dynamics calculations realized with the time dependent Hartree-Fock-Bogoliubov method, the residual interactions that cause the Landau-Zener effect are neglected, leading to a very unpleasant effect: even in the case when the generalized coordinates vary extremely slowly, the system cannot reach the ground state in the final stage of the process. In the case of the generalized time dependent Hartree-Fock-Bogoliubov equations [7], both pairing and residual interactions leading to the Landau-Zener effect are taken into account. These last interactions are produced between levels characterized by the same good quantum numbers associated to some symmetries of the system. In this case, a non-zero probability that the system reaches the ground state after the disintegration exists. The treatment of the pairing residual correlation was done in the BCS approximation, using a monopolar pairing force. Through this approximation the treatment of this correlation is simplified in a way similar to that used in the independent particle model, that is using a mean field potential obtained by taking into account independent quasiparticles.

Ingredients to solve such equation are the single particle levels that can be obtained from self-consistent theories or within mean field phenomenological potentials. In this context, it is possible to use an evolved form of the Woods-Saxon potential [8] generalized for two-centers in order to obtain the single-particle levels as function of the collective variables. A realistic shell potential deformation dependent is crucial in the collective phenomena analysis as vibrations, nuclear dynamics (calculation of the mass parameters), with a lot of applications in fission, heavy-ion emission or alpha disintegration. A very important problem is an adequate description of the nuclear shapes and to fix the collective variables. It is well known that a nuclear parametrization can be used in disintegration calculations if the next conditions are fulfilled [9]: *(i)* the three primordial degree of freedom associated to elongation, necking and mass asymmetry are taken into account. *(ii)* A sphere and two tangent fragments are allowed configurations. *(iii)* The necking is an independent parameter. All these conditions will be fulfilled by our parametrization given by smoothly joining two ellipsoids with a toroidal surface. We have five degrees of freedom, the deformations of the fragments given by the eccentricities of the two ellipsoids, the mass asymmetry given by the ratio between the semi-axes of the ellipses, the necking characterized by the curvature of the toroid and the elongation given by the distance between the centers of the fragments. To determine the single particle levels, a good choice is to work with the two center Woods-Saxon model. This model was developed recently [10] and represents an amelioration of superasymmetric two center shell model [11] because a more realistic potential is used. This model is able to determine the single particle energy levels for a single deformed nucleus or for a system given by two separated deformed nuclei. In the last case, a superposition of the two levels schemes belonging to the two nuclei is obtained. A so good behavior cannot be obtained within the Woods-Saxon potentials within one single center [12]. In some evolved parametrizations, as the universal one, the radius parameters for the single particles and pairing mean fields are different. At hyperdeformations, this difference lead to an inconsistency in the overlap of the geometric forms of the two fields, the surfaces being very different at the ends and superimposed in the vicinity of the center of mass, where the two fragments can be tangent. This inconsistency is avoided in the two center shell model. We can mention that the Woods-Saxon model of ref. [8] allows us to obtain the levels in the vicinity of the Fermi energy (within two oscillator bases not orthogonal from the beginning) while our model possesses an orthogonal basis for the two centers.

Dissipation plays an important role in all nuclear disintegrations in the whole range of mass-asymmetries, including fission, cluster emission and alpha disintegration. In the case of fission, it is well known that the barrier in the actinide region exhibits a double humped shape. This double barrier, postulated in the frame of the microscopic-macroscopic model, supplied explanations for a great number of experimental results. At excitation energies close on the tops of the barriers, the properties associated to the double shape are more pronounced than in other energy domains. A great number of intermediate resonances appears in the threshold region. These energies are also the most interesting for the actual an new generations of nuclear power plants, that is from thermal neutrons up to several MeV. These resonances cannot be evaluated correctly in the frame of actual models. Actually, for data evaluations, only two ingredients are of major importance: the penetrability of a parametrized barrier in order to reproduce experimental data and a good model for the level density. Using a hypothesis dating from 1939 [13], it is considered that the cross section is proportional to the number of transition states. Moreover, to reproduce the resonant structure of the cross section, many transition states are introduced by hand. The population of these transition states is considered to be one [14]. An imaginary potential is introduced in phenomenological way in the region of the second well to simulate as better as possible the widths of the resonances. Due to the complexity of the realistic treatment of the fission process, the single particle effects and the dynamics of the process are neglected despite the fact that these quantities drastically affect all observables. A synthesis of the actual theories can be found in ref. [15].

Recently, we proposed a new formalism. The nuclear fission is a complex process that implies drastic changes of the nuclear shape. To investigate the properties of the nuclear fission and of all connected phenomena, the structure and the dynamics of the fissioning nucleus must be understood. It is known that different properties of fission, as the heights of the barriers, the half-lives for the spontaneous processes, the isotopic distribution of fission fragments, are strongly dependent on fine details of the nuclear structure. In order to treat the resonant structure of the cross section, we analyzed the rearrangement of the single particle levels starting with the initial state of the compound nucleus formed by neutron bombardment up to the moment when the nucleus emerges from the double barrier in its way to scission. Excitations produced by residual interactions and the corresponding barriers were determined. The probabilities for the penetration of each barrier and the population of each transition state were computed dynamically using a system of coupled differential equations that take into account the level slippage effect [16]. The model was validated because we succeeded to obtain the best agreement with experimental data for the fine structure of the 0.7 MeV resonance in the neutron-induced cross section of ^{230}Th [17]. This phenomenon was known as the Th anomaly and lead to the concept of triple barrier in evaluations. The developed models showed, in principle, some deficiencies of the actual theories used for evaluation purposes [18]. Following the single particle levels rearrangement due to fission, the levels with lower values of the intrinsic spin (projection ½) that are initially located in the vicinity of the Fermi level will arrive in the final states in a very unfavorable energy configuration after filling the two potential wells. This is a consequence of the fact that the number of levels with intrinsic spin ½ under Fermi energy in the parent is always lower than the same number in the two wells. Consequently, the probability to form a system through a transition with spin ½ will always be hindered and will have large excitation energy. A larger barrier is obtained for these transitions and the penetrability of the barrier will decrease. In actual evaluation models, always the transition states possess energies proportional to those in the fundamental state, without intersections, no matter the spin. The calculations we realized in [18] with the time dependent Hartree-Fock-Bogoliubov equations of motion for the dissipation energies for different transition states showed that the dissipation is maximal for low specialization energy values and minimal for larger specialization energies. As a consequence, the corrections of the adiabatic barrier, that is the sum between the dissipation energy and dissipation, will lies in a smaller interval as believed up to now for different transition states. That is, the different transition states will be characterized by closer transition probabilities than those calculated with the actual evaluations. This behavior can be an explanation for the new experimental values obtained for the neutron induced fission cross section of ^{234}U obtained in the frame of the international project n-TOF CERN (where we are members) where a supra-barrier resonant structure (not of statistical nature) was obtained [19]. The work proposed in this project would improve our participation in this project.

Concerning the superasymmetric disintegrations, as cluster emission or alpha decay, a way of the dissipation manifestation is the fine structure phenomenon. If the fine structure phenomenon is well known in the case of alpha decay, it was evidenced for the ^{14}C emission only in 1989 [20]. Surprisingly, only 15 % transitions to the ground state were obtained and 81 % to the first excited state. All the theoretical models based on structure interpretation, on preformation evaluation, on collective approximations, on non adiabatic mechanisms, on Q value modifications in unified fission theories, on coupled channel calculations or R matrix approximations failed to explain this phenomenon without appealing to empirical renormalizations, as shown in ref [21] where all these investigations were analyzed by the authors of this proposal. In this reference it is shown that the best agreement with the experimental data can be obtained by solving the Landau-Zener equations of motion used in this proposal to evaluate the dissipation. Also, the investigation of the dissipation for alpha decay was never realized, despite the fact the phenomenon is known from 1989, when Rosemblum observed that the ranges of alpha particles in air have different values. We will investigate these phenomena. As an example, we will analyze the fine structure in alpha decay of deformed nuclei. In a phenomenological description of emission processes one supposes that the dynamics of emitted particles obeys the Schrodinger equation with some potential defined at any distance. The major role in decay processes is played by the interplay between the energy of the emitted particle (Q-value) and the Coulomb barrier [22]. In order to extract the effect of the barrier one defines the Hindrance Factor (HF) as the ratio between decay widths to ground and excited state, divided to the corresponding Coulomb penetrabilities. The most general approach to describe emission process from deformed nuclei is the coupled channels method. The first computations of the alpha-decay widths in deformed rotational nuclei within the coupled channels approach were performed in Ref. [23]. Later on, in Ref. [24] hindrance factors were estimated in deformed nuclei by using an approximation of the coupled channel procedure, given by the Froman approach [25] and a simple phenomenological ansatz for the preformation factor.

Several calculations estimated the alpha-core potential by using the double folding procedure in Refs. [26,27] and more recently in [28]. This kind of potential was used to estimate ground state to ground state half lives within the spherical approach in Ref. [29]. In Ref. [30] the densities in the double folded alpha-core potential were computed within the relativistic mean field theory. In all these works it was concluded that the strength of the nucleon-nucleon force should be quenched (i.e. the Coulomb barrier should increase) in order to describe the right relation between the half life and Q-value. When the interaction is derived from scattering data one implicitly supposes that the fragments are already born. This is in contradiction with the fact that at small distances only the parent nucleus exists. One way to simulate this situation is to introduce a repulsive core, giving vanishing values of the inter-fragment wave function for these distances. It turns out that this procedure is not enough to reproduce the absolute values of experimental data [31,32] and the ratio between theoretical and experimental half-lives, defining the phenomenological spectroscopic factor [33] is less than unity. This means that the used alpha-daughter potential is too low and the nuclear part of the interaction is too strong (too negative). By quenching the effective nucleon-nucleon interaction it is possible to increase the Coulomb barrier in the region of the touching configuration, in order to reproduce experimental half lives. In several recent papers [34,36] we analyzed the double fine structure of emitted fragments in the cold fission of ^{252}Cf within the coupled channels formalism. We found out that the yields to excited states in both fragments are very sensitive to nuclear structure details such as the mean field deformation and difusivity. Unfortunately there are only few available experimental data to be analyzed in this field [37]. On the other hand there are a lot of high precision data on alpha-decay fine structure to rotational levels, see e.g. [38] and these data we are going to analyze in this project.

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Project objectives

1. **Alpha decay fine structure in deformed nuclei**. The aim of this project is to extend the coupled channels technique used in Refs. [34-36] (of previous section) in order to analyze the alpha-decay fine structure in all known deformed even-even emitters.The main objectives are the following: (I) We will develop the main ingredients of the stationary coupled channels formalism describing alpha decay fine structure to rotational states and transitional states, including the computation of the alpha- core potential within the double folding procedure. (ii) We will give a systematics on measured alpha-decay widths to ground as well as excited states in even-even emitters. (iii) We will make predictions for those nuclei were the intensities to low-lying states were still not measured. (iv) We will compare phenomenological with microscopic spectroscopic factors in even-even deformed emitters.
This analysis is aimed to be the most complete one in the literature.

2. Nuclear inertia for the two center Woods Saxon model. As mentioned, extremely performant numerical codes for single particle models, recently realized in the frame of other projects, are at our disposal. To characterize dynamically the disintegration processes we need also the values associated to the mass parameters as function of the variations of the generalized coordinates. To determine the nuclear inertia, up to now, we worked with a numerical code realized by us based on the Werner-Wheeler approximation. This approximation is valid for an ideal, irrotational, nonviscous, hydrodinamical and incompressible fluid. To obtain more realistic results it is required the use of effective masses based on the **cranking model** with pairing effects. It is proposed to realize such numeric code associated to the Woods-Saxon model with five degrees of freedom.

3. Fine structure in superasymmetric disintegration processes. Another objective **is to explain the fine structure in the cluster emission and alpha decay** and to evaluate the effect of nuclear dissipation in these processes. The models based on the preformation possibility of a particle did not succeeded to explain satisfactory the fine structure in the ^{14}C emission. We will investigate of the fine structure in superasymmetric processes by taking into consideration the time dependent Hartree-Fock-Bogoliubov equations of motion. For the first time, information about dissipation will be obtained in superasymmetric disintegrations.

4. Generalized time dependent Hartree-Fock-Bogoliubov equations for pair breaking. As mentioned, the time dependent Hartree-Fock-Bogoliubov equations were generalized for nuclear systems with one unpaired nucleon. In order to determine the pair breaking probability during the disintegrations it is extremely important that a differential system of equations, developed on the same principle, characterizes systems with two unpaired nucleons together with seniority 0 ones, the coupling between them. Such Hartree-Fock-Bogoliubov time dependent system will allow the perfect knowledge on how pair breaking is realized during any disintegration. That will allows us to understand how the dissipation, the kinetic energy of fragments is varied as function of the isotopic distribution of fragments for the fission process, the emissions of neutrons and protons during the process, problems without a solution yet.

5. Dissipation effect in the fission cross section. Another primordial objective is to obtain new information on the basic mechanisms produced in nuclear fission. This can be obtained by mixing high resolution experimental data with new theories that take into account modifications of the structure of the nuclear systems during all the disintegration process. The new experimental values concerning the cross section of 234U(n,f) obtained in the n_TOF program present a supra-barrier resonant structure that is not of statistical nature. Phenomenological and statistical models based on saddle points nuclear densities cannot explain the rich structure up 20 MeV. However, new methods are required to understand deeply the fission phenomenon. Using di-nuclear fields of high complexity, it is possible to obtain the rearrangement of intrinsic levels beginning from the compound nucleus up to the asymptotic configurations of two separated nuclei. The rearrangement of levels in conjunction with constraints given by constants of motion cause the apparition of single particle effects as previously mentioned. These dynamical effects determine excitations of the nucleus. Each excitation gives rise to a specific fission barrier and consequently to a resonant structure in the fission cross section. The Th anomaly was explained in this context. With this model it is possible to obtain the spin and the parities of the resonances, i.e., it will be possible to realize comparisons with the angular distributions that will be measured in n_TOF phase two. Moreover, the model offers the possibility to determine the yields in the isotopic distribution of the fission fragments. The mixing between theory and experiment will make possible an improvement of data evaluations. This activity is important in the actual context, when a better determination of data evaluations is required for trans-uranium elements and other relevant isotopes for the Th cycle for the new generation of accelerator driven systems. This objective is formulated in connection to our activities in the frame of the n_TOF project.