HIGH ENERGY PROTON INDUCED FISSION OF LIGHT NUCLEI*

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Extended TDHF calculation is performed for light rotating nuclei to determine the dynamics of fission. If the model nucleus $^{144}$Nb has 200 MeV excitation energy and $30\hbar$ angular momentum, even such a light nucleus can fission. This circumstance can be the explanation of the facts observed in the case of high energy proton induced fission of light nuclei.

1. Introduction

According to experimental evidence high energy protons can induce fission of even relatively light ($A \sim 120-140$) nuclei [1, 2]. The fission process occurs in peripheral collisions, and the energy required is quite high. For example in the collisions with 200 MeV protons the fission probability is negligible, while in the case of 450 MeV protons it is already significant [2]. At the same time the fission barrier height of such nuclei is quite small, only $\sim 60$ MeV [3]. It is an interesting question, why this additional energy is needed. To understand the fission mechanism in such light nuclei, it is informative to investigate the time evolution of the process. A useful and mathematically tractable method for describing time-dependent processes is the time-dependent Hartree-Fock approximation. The TDHF method is a mean field approximation, the nucleons do not interact with each other directly, but only through a self-consistent, time-dependent one-body potential. It has the disadvantage that two-body collisions are neglected, although they play an important role in the case of fission. Nevertheless, it proved to be a very successful tool for the description of heavy-ion collisions, and this encourages us to try to find a modified version which takes into account two-body dissipation, and remains tractable.

The TDHF equations, determining the single-particle wave functions, are non-linear partial differential equations. To solve such equations we have to give the initial

* Dedicated to Prof. S. Szalay on his 75th birthday
conditions, that is to say the wave functions at time $t=0$. These initial conditions contain all the information about the physics of the process, how the nucleus is excited, etc. One usually starts from the ground state HF wave functions of the nucleus and modifies them in a systematic way to take into account excitation. For heavy-ion collisions the excitation has the form of translational kinetic energy of the target-projectile system. Other collective excitations are rotational or vibrational energy. The latter seems to be the most suitable for the inducement of fission. Giving increasing amounts of vibrational energy to a ground state nucleus one expects that the amplitudes for its deformation will grow and if it reaches the saddle point deformation, it will fission. However, in a mean field approximation, there is no way to change the single-particle level order: if a level was filled in the ground state, it remains filled during the whole evolution of the system. On the other hand in the real nucleus the occupation probabilities of the levels change as it gets more and more deformed due to the two-body collisions. To initiate this two-body dissipation, we assume that the $n_i$ level occupation probabilities are time-dependent. This assumption is outside the validity of a mean field approximation, it cannot be based on a consistent theory, the time dependence of the $n_i$ has to be given by some additional physical consideration.

In the second Section an extended version of the TDHF approximation is given. In the third Section we describe our calculational method for rotating nuclei and in the last Section the results are discussed.

### 2. Extended TDHF equations

The TDHF equations can be written as

$$i\hbar \dot{\psi}_i = \hat{h}_{HF} \psi_i ,$$

where $\hat{h}_{HF}$ is a non-local single-particle Hamiltonian. Using the modified Skyrme force and retaining only the direct Coulomb and finite range Yukawa contributions $\hat{h}_{HF}$ becomes local and can be written as

$$\hat{h}_{HF}^\alpha = -\frac{\hbar^2}{2m} \nabla^2 + U_S^\alpha + U_Y^\alpha + U_C^\alpha ,$$

where $U_S$, $U_Y$ and $U_C$ are respectively the Skyrme, Yukawa and Coulomb force contributions to the single-particle potential. The label $\alpha$ distinguishes neutrons and protons. In the following spin-orbit and pairing forces are neglected.

It can be proven that in the TDHF approximation the total energy is a constant in time [4]. The energy and the mass number has to be a constant also in the modified TDHF approximation. This means that the time-dependent occupation probabilities have to fulfil the requirements

$$\frac{dN}{dt} = \sum_i \frac{dn_i}{dt} = 0 ,$$

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