Dynamical evolution of the ground state configurations of nuclei used in heavy-ion collision calculations

M. R. Morker, S. S. Godre*
Department of Physics, Veer Narmad South Gujarat University, Surat – 395007, India
** email: ssgodre@yahoo.com*

Introduction

In classical microscopic approaches for heavy-ion collisions such as ***C**lassical **M**olecular **D**ynamics* (CMD) [1], ***C**lassical **R**igid-**B**ody **D**ynamics* (CRBD) [2,3] or microscopic ***S**tatic **B**arrier **P**enetration **M**odel* (SBPM) [4] the initial conditions require specification of positions of all the nucleons in the given collision partners. The ground-state (g.s.) configurations of colliding nuclei such as ^{24}Mg, ^{208}Pb [2, 5] obtained by a potential energy minimization procedure *STATIC* [1] with a soft-core Gaussian form of NN potential with potential parameter set P4 has been used in heavy-ion fusion studies [1-4].

In the procedure *STATIC* the nuclei in g.s. are obtained by generating a random distribution of all the nucleon positions in a sphere of given radius and then cyclically minimizing the total potential energy of the nucleon configurations with respect to small displacements of the individual nucleon coordinates. Total binding energy (BE) is the total potential energy. Rms-radius (R_{rms}) and deformation parameter (β_2) are calculated from all the nucleon positions [5].

For $A \geq 5$, a number of static isomeric configurations exist. Therefore, a large number of randomly generated different initial configurations are required to be considered. These configurations correspond to static equilibrium in the sense of a local minimum potential energy configuration for the corresponding initial configuration.

Out of this large number of configurations, a configuration corresponding to the desired g.s. properties is chosen for the heavy-ion collision calculation in the SBPM and CRBD model calculations. However, when these configuretions are used in the CMD model then at large initial separations where the ion-ion potential is small or negligible, these nuclei undergo their own dynamical re-adjustments towards a dynamical equilibrium.

In the present paper we investigate the dynamical evolution of ^{24}Mg and ^{208}Pb nuclei which are used in ref. [2, 3] for ^{24}Mg + ^{208}Pb collision calculations. We also generate configurations of these nuclei which are dynamically "cooled" by re-setting all the nucleon velocities equal to zero after every small time step; ie, effectively removing any internal kinetic energy that is generated during evolution and thus cooling the system [1]. We also investigate their long time dynamical evolution. These "cooled" nuclei are used in a ***t**hree-**s**tage **C**lassical **M**olecular **D**ynamics* (3S-CMD) model simulation of ^{24}Mg + ^{208}Pb reaction in ref. [8].

Results and Discussion

Figs. 1-3 show the calculated BE, R_{rms}, and β_2 respectively, for dynamical evolution of the "hot" ^{24}Mg nucleus used in ref. [2]. While the changes in the BE are very small, it shows periodic structure which is similar to that in R_{rms} and β_2. This indicates that the nucleons are undergoing small vibrations about their mean positions and collectively the whole nucleus is in some small vibrational excitation.

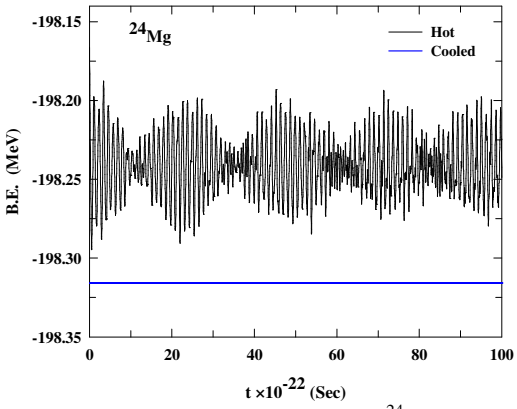

Fig. 1: Calculated B.E. of ^{24}Mg.

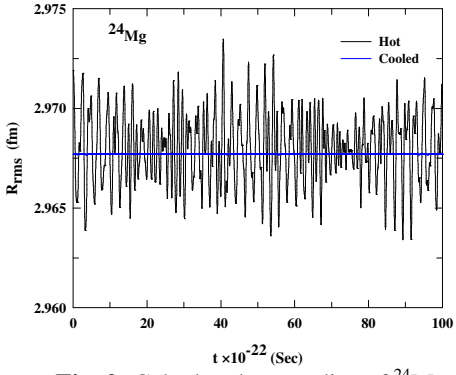

Fig. 2: Calculated rms radius of ^{24}Mg.

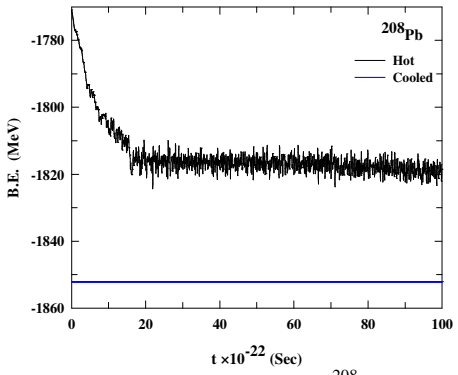

Fig. 4: Calculated B.E. of ^{208}Pb.

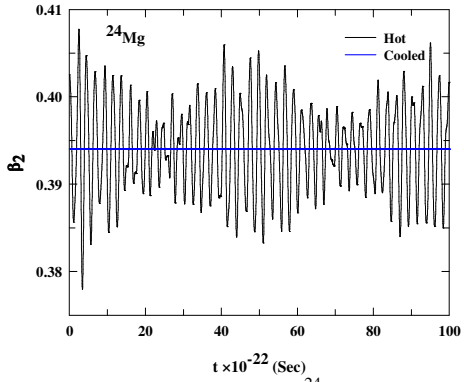

Fig. 3: Calculated β_2 of ^{24}Mg.

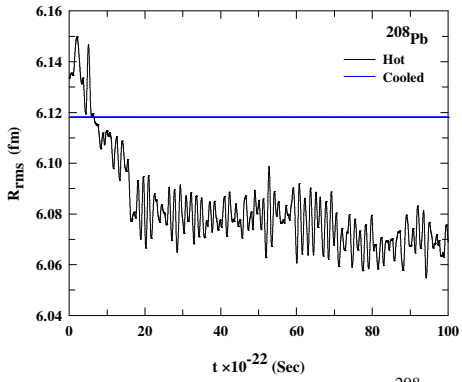

Fig. 5: Calculated rms radius of ^{208}Pb.

Figs. 1-3 also show the calculated values of the BE, R_{rms}, and β_2, respectively, for the long time dynamical evolution of the isolated "cooled" ^{24}Mg nucleus that is used in ref [8].

Figs. 4 and 5 show the calculated BE, and R_{rms}, respectively for the dynamical evolution of the "hot" ^{208}Pb nucleus used in ref. [2]. The nucleons of this nucleus undergo large re-arrangement and the potential energy of the nucleus decreases (becomes more attractive) along with an increase in the velocities of all the nucleons. After about t= 20x10^{-22} s the system achieves an equilibrium value with random fluctuations about its mean value. Similarly, as the potential energy decreases the nucleus becomes more compact with decrease in its rms radius.

Figs. 4 and 5 also show the calculated values of the BE, and R_{rms}, respectively, for the long time dynamical evolution of the isolated "cooled" ^{208}Pb nucleus that is used in ref [8]. We see that the BE of this nucleus is increased due to the dynamical "cooling" and it has become more compact in radius.

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References

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