FINITE TEMPERATURE EFFECTS ON THE EVAPORATION BARRIERS IN COMPOUND NUCLEUS DEEXCITATION BY α PARTICLE EMISSION

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A hot compound nucleus deexcites by emitting particles and γ-rays. The emission probability and the energy distribution of the particles can be calculated, within the statistical model, using the principle of detailed balance. It turns out that the emission probability of the particle is proportional to the inverse cross section. For instance if we look at the emission probability of an α particle by the compound nucleus ${}^{A}_{Z}X$, it is proportional to the inverse cross section of the α particle on the residual nucleus ${}^{A-4}_{Z-2}Y$. This cross section has to be calculated using the interaction potential between the α and ${}^{A-4}_{Z-2}Y$. These potentials are taken from α-nucleus scattering data where the target is not excited. Such a situation is different from the one encountered in the deexcitation of a compound system where the residual nucleus has a temperature which can amount to several MeV.

We would like to show here, in a semiquantitative way, that the fusion barrier between an α and a nucleus can be substantially reduced when the temperature is large. Consequently this will lead to an enhancement of the inverse cross section and therefore of the probability of α emission by the compound nucleus. As a typical example we have calculated the interaction potential between an α and a Pb nucleus, in the sudden approximation, using the energy density formalism at finite temperature[1]). The neutron and proton densities of the α particle have been taken to be a gaussian with a root mean square radius equal to 1.672 fm [ref.[2])]. For a given temperature T the neutron and proton densities of the ${}^{208}_{82}Pb$ nucleus have been obtained from the modified Thomas-Fermi approach of ref.[3]) extended to finite temperature in the same way as in ref.[4]). The densities, assumed to be Fermi distributions, were obtained by minimizing the free energy. Although the energy density formalism cannot describe an α particle (the binding energy obtained with the gaussian densities is -20.15 MeV instead of -28.3 MeV) we believe that the interaction potential is not so badly calculated since the binding energies are subtracted. Indeed we are in a situation similar to heavy ion collisions when there is a small overlap between the two nuclei.

In fig. 1 is shown the nuclear part of the interaction potential between the α and the $^{208}_{82}$Pb nucleus, for different values of the temperature, as a function of the distance R separating the α and the Pb nucleus. In fig. 2 is shown the total interaction potential (nuclear plus Coulomb) for different temperatures. At zero temperature the calculated fusion barrier is equal to $\sim$ 21 MeV. This value is not so far from the one obtained in ref.[5]) from a systematics of the fusion barriers (20.2 ± 0.6). This indicates that the way we are calculating the interaction potential is not so unreasonable. When the temperature increases, the fusion barrier decreases and at the same time the position R_F of the barrier is shifted at larger distances. In a simple classical picture the fusion cross section is given by :

$$\sigma_F = \pi(R_F + \lambda\!\!\!^{-})^2 \left(1 - \frac{V(R_F + \lambda\!\!\!^{-})}{E}\right) .$$

This means that σ_F calculated with a finite temperature interaction potential is larger than when it is calculated with a zero temperature interaction potential. To give an example, let us consider the emission of an α particle of $\sim$ 25 MeV by the compound nucleus leading to a Pb residual nucleus with a temperature of $\sim$ 3 MeV. Then the above formula will predict an increase of $\sim$ 35 % of the fusion cross section. Consequently the emission probability will also be increased by this amount.

In ref.[6]) a large set of mean energies and angular anisotropies for evaporative α emission have been analysed to obtain barriers to evaporation. The authors noticed that these barriers are often substantially smaller than the corresponding empirical s-wave fusion barriers. They have interpreted this as a clue for the existence of deformed emitters. From the present study we believe that finite temperature effects also play an important role which goes into the same direction. Therefore the values of the deformation parameters obtained in ref.[6]) have to be considered as an upper limit.

We have shown, that a calculation, which takes into account finite temperature effects in the potential energy between an α and a residual nucleus, lowers the fusion barrier. This increases the α probability emission for the compound nucleus compared to the case where this effect is neglected. We believe that such an effect should be taken into account in evaporation codes.

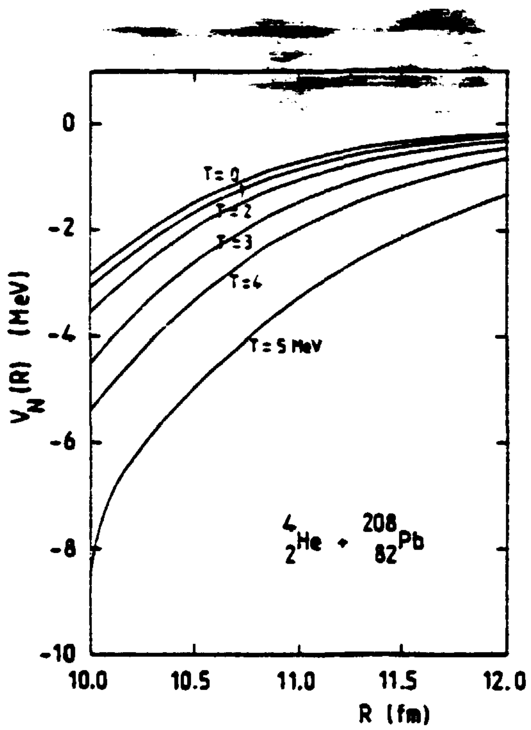

Fig. 1 - Nuclear part of the interaction potential for ^4He + ^{208}Pb *(at different values of the temperature) as a function of the distance between the two nuclei.*

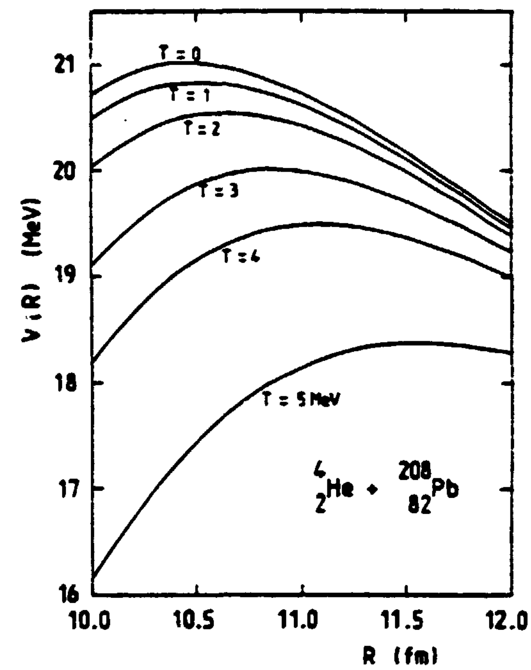

Fig. 2 - Same as fig. 1 but for the total interaction potential.

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