Liquid gas phase transition: Effect of surface energy

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Introduction

The liquid gas phase transition at intermediate energy nuclear reactions is a well studied phenomenon. Different theoretical models [1,2], both statistical and dynamical have confirmed the transition in the temperature range of 5 to 6 MeV from liquid to gaseous phase as the excited nuclear system fragments. The Bethe-Weizsacker mass formula [3] which is commonly referred to as liquid drop model has successfully explained different ground state properties of the nucleus and is widely used to calculate the binding energy of medium to heavy mass nuclei at zero temperature and normal nuclear density. This mass formula has been successfully implemented in statistical models like Canonical Thermodynamical Model(CTM) the Statistical Multifragmentation Model (SMM) and others in order to throw light on the nuclear multifragmentation process. In this work we would focus on observables like mass distribution and total multiplicity which are related to the nuclear liquid gas phase transition. The pertinent question one can ask is that how is the phenomenon of phase transition dependent on the liquid drop model parameters which dictates the fragmentation pattern. Is the transition temperature sensitive to the parameters of the liquid drop model? These questions motivated us to reexamine the nuclear phase transition process in the framework of the liquid drop model.

One of the important term determining the path of fragmentation is the surface tension or the surface energy coefficient. The competition between the surface term and the excitation energy term of the fragments ultimately dictates the fragmentation pattern, or in other words the liquid gas phase transition. The surface term for obvious reasons favours larger fragments while the other term promotes breaking up into smaller pieces. This establishes the direct connection of the liquid drop model parameters with the phenomenon of phase transition and motivates us to examine in details the effect of these parameters on the later The results from this study can lead to more refined calculation of those parameters of the liquid drop model term which dominates in deciding the phase transition in order to have detailed knowledge about the nature of the transition and its characteristics. In the results presented in this work, we have used the temperature derivative of multiplicity in order to pinpoint the transition temperature .The multiplicity derivative [4] has already been established both theoretically and experimentally as a convincing signature of nuclear liquid gas phase transition.

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Results and discussions

We consider the disintegration of a system of mass number A_0 = 67 and proton number Z_0=32 which is expected to be formed from the central collision of ^{58}Ni with ^{9}Be without considering pre-equilibrium emission. We have used the canonical thermodynamical model(CTM) [5] which incorporates the liquid drop model for calculation of ground state binding energy in our study. The surface energy term of the liquid drop model is expected to have a significant role in deciding the phase transition. In order to examine this we have first calculated the derivative dM/dT of total multiplicity M as a function of temperature T for three different values of the surface energy coefficient (a_{s0}) keeping all other parameters fixed. This is displayed in Fig. 1 which shows that the peak in the distribution shifts to the right as one increases the surface energy coefficient. This is quite justified as the surface term will try to hold the nucleus together and hence its increase implies more energy(or temperature) is required for the phase transition from liquid to gas. This explains the shift in transition temperature to the right and the magnitude of shift is about 2 MeV for change in surface coefficient from 15 to 21 MeV. This is quite a significant shift and is expected to affect the transition in a profound manner. This interesting aspect further motivated us to probe deeper into it and calculate the mass distribution (well studied experimental signature) at these

different values of the surface coefficient (15, 18 and 21 MeV) at a fixed temperature T=5 MeV. This is shown in Fig.2(a) and aptly confirms our conclusion that at higher values of the surface energy coefficient the system is in a coexistence phase and the mass distribution resembles a typical 'U' shape as it should be. With the decrease in the value of a_{s0}, the system slowly converts to gaseous phase resulting in disappearance of the peak on the liquid(right) side. In fact surface energy plays a role equivalent to excitation energy (or temperature) in dictating the nuclear liquid gas phase transition as will be evident from the figures 2(a) and 2(b). The next figure 2(b) shows the change in mass distribution for a fixed surface energy coefficient a_{s0} = 18 MeV as we change the temperature from T = 4 to 6 MeV. The change in mass distribution of the fragments as we change the temperature(keeping surface energy fixed) is exactly similar to the change as we change the surface energy (keeping temperature fixed). A small change in the surface energy coefficient leads to some major change in the mass distribution as is evident from Fig. 2(a). This explains the magnitude of shift of transition temperature as observed in Fig(1). The exact equivalence of these two figures throws light on the equivalent roles of surface energy and temperature in dictating the phase transition of the nuclear system. The effect of the increase in excitation energy or temperature is equivalent to that of the decrease in the surface energy coefficient. Since surface energy term is crucial in fixing the phase transition parameters, hence proper evaluation of its strength as well as temperature dependence is extremely important in order to have better knowledge about the transition temperature. This study thus establishes that it is the surface energy term of the liquid drop model which needs to be determined with more precision using microscopic calculation for better understanding of the phase transition process. The detailed study of this as well as effect of other parameters of the liquid drop model can be found in [6]

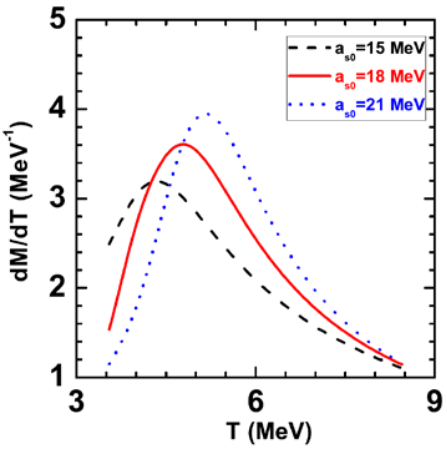

Fig. 1 Dependence of the multiplicity derivative on the surface energy coefficient a_{s0}

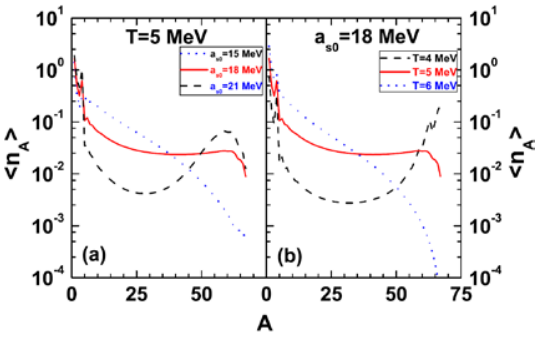

Fig. 2 Mass distribution (a) for different surface energy coefficients (b) for three different temperatures

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