Effect of Temperature on Bubble Nuclei

G. Saxena[1*] and Mamta Aggarwal[2]
[1]Department of Physics, Govt. Women Engineering College, Ajmer - 305002, India and
[2]Department of Physics, University of Mumbai, Kalina, Mumbai-400098, India

Bubble structure in nuclei has been recently a focus of nuclear physics world after its first experimental evidence in ^{34}Si [1]. However, a substantial information regarding the cause of such structure of central depletion in nucleonic density have been gathered by many theoretical attempts in the last two decades [2–6]. The unoccupancy of the s-state near the Fermi surface is trusted as one common and important cause of such central depletion. Recently, a remarkable development on bubble phenomenon fell out using various models like the relativistic Hartree-Fock-Bogoliubov (RHFB) theory [7], ab-initio self consistent Green's function many-body method [8], nuclear density functional theory [9], Skyrme Hartree-Fock mean field consistently incorporating the superfluid pairing [10], and the relativistic mean-field models [11–13].

Over and above, the quenching of bubble due to temperature (T) is studied within the Skyrme Hartree-Fock mean field consistently incorporating the superfluid pairing and it is found that central depletion becomes less pronounced as T increases and completely disappears when T reaches a critical value of around 4 MeV [10]. This study of quenching of bubble due to increase in temperature [10] is the only study so far as per our knowledge and addressed for ^{34}Si and ^{22}O only. Since the bubble phenomenon is believed to exist in all mass regions of periodic chart including superheavy region, therefore, a comprehensive study is required to visualize the temperature effect on bubble phenomenon or central depletion. With this objective, in this letter, we present our results of anti bubble effect of temperature by using relativistic mean-field (RMF) plus state dependent Bardeen-Cooper-Schrieffer (BCS) theory [11–14] for the first time. Our results of density distributions are presented in detail with the variation of temperature.

To incorporate the temperature (T) degree of freedom in our RMF formalism [11–13], we calculate the occupation probabilities v_j^2 in the formula of particle number condition ($\sum_j (2j+1)\, v_j^2 = N$) using the following equation

$$v_j^2 = \frac{1}{2}\left(1 - \frac{\varepsilon_j - \lambda}{\tilde{\varepsilon}_j}[1 - 2f(\tilde{\varepsilon}_j, T)]\right) \quad (1)$$

with

$$f(\tilde{\varepsilon}_j, T) = \frac{1}{(1 + exp[\tilde{\varepsilon}_j/T])} \quad (2)$$

and

$$\tilde{\varepsilon}_j = \sqrt{\left(\varepsilon_j - \lambda\right)^2 + \Delta_j^2} \quad (3)$$

The function $f(\tilde{\varepsilon}_j, T)$ represents the Fermi Dirac distribution function for quasi particle energies $\tilde{\varepsilon}_j$. For our calculations, model Lagrangian density with nonlinear terms for σ and ω mesons has been used along with delta function pairing interaction V=-V$_0\delta(r)$ (here V$_0$=350 MeV fm^3) which has been adequately applied for successful description of magic and bubble nuclei [11–13].

Straightforward, to investigate temperature dependence on bubble phenomenon, we pick potential candidates of bubble in all the regions of periodic chart including superheavy domain. These candidates are reported by many theoretical or experimental studies [1–9] with central depletion in proton in ^{34}Si and ^{46}Ar. In a very recent systematic study of ours [12], using RMF+BCS approach, we have identified few more candidates of bubble viz. ^{22}Si, ^{56}S, ^{58}Ar, ^{184}Ce etc. and very common

*Electronic address: gauravphy@gmail.com

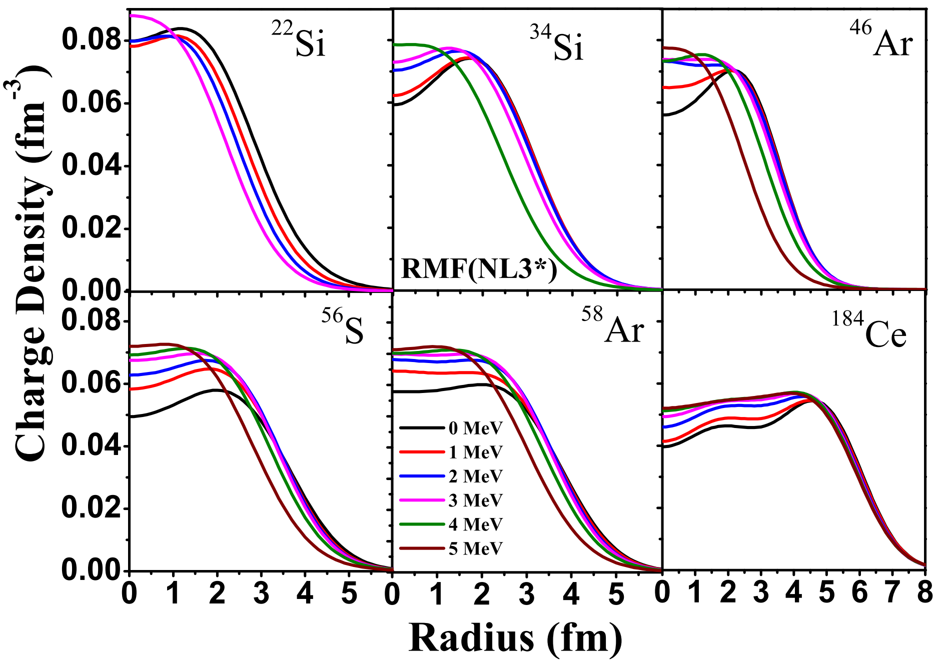

FIG. 1: (Colour online) Charge density of ^{22}Si, ^{34}Si, ^{46}Ar, ^{56}S, ^{58}Ar and ^{184}Ce vs. radius at different temperature T using RMF approach with NL3* parameter.

central depletion in charge density of superheavy nuclei. Without going into the details of formation of bubble, which is fairly described along with many other properties in the literatures mentioned above, we plot radial variation of charge density of ^{22}Si, ^{34}Si, ^{46}Ar, ^{56}S, ^{58}Ar and ^{184}Ce for different temperature (T) varying from 0 to 4 MeV. It is evident form Fig. 1 that for all the isotopes considered the depletion decreases as temperature increases and it gets washed out completely for the T 4 MeV. The gradual pattern of density with respect to temperature is clearly revealed from the figure. It is gratifying to note here that for ^{34}Si this critical temperature 4 MeV is also reported by Tan *et al.* [10].

G. Saxena and Mamta Aggarwal acknowledge the support provided by SERB (DST), Govt. of India under YSS/2015/000952 and WOS-A scheme respectively.

References

[1] A. Mutschler *et al.*, Nature Physics 13 (2017) 152.
[2] B.G. Todd-Rudel *et al.*, PRC 69 (2004) 021301(R).
[3] M. Grasso *et al.*, PRC 76 (2007) 044319.
[4] E. Khan *et al.*, NPA 800 (2008) 37.
[5] Y. Z. Wang *et al.*, Chin. Phys. Lett. 28 (2011) 102101.
[6] J. M. Yao *et al.*, PRC 86, 014310 (2012).
[7] J.J. Li *et al.*, PRC 93 (2016) 054312.
[8] T. Duguet *et al.*, PRC 95 (2017) 034319.
[9] B. Schuetrumpf *et al.*, PRC 96 (2017) 024306.
[10] L. Tan Phuc *et al.*, PRC 97 (2018) 024331.
[11] G. Saxena *et al.*, IJMPE 26 (2017) 1750072.
[12] G. Saxena *et al.*, Accepted in Phys. Lett. B (2018).
[13] G. Saxena *et al.*, Submitted to JPG (2018).
[14] G. Saxena *et al.*, PLB 775 (2017) 126.