Determination of the Limiting temperature of feasible isotopes of Z=120 through NLD and E*

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Introduction

In the study of hot and rotating nuclear system by statistical model incorporating temperature (T) and angular momentum (M), it unravels the phenomenon of nuclear properties and the existence of shell effect at a hot environment. According to Ormand et al.,[1] no compound nucleus seems to exists at temperature above 6-8MeV, i.e. beyond which an equilibrium with an external vapour is no longer possible. Bonche et al.[2] reported that the limiting temperature for ^{208}Pb is around 11MeV. Due to coulomb effects this limiting temperature (T_{lim}) decreases from light to heavy nuclei, while the T_{lim} is almost half of the value of critical temperature (T_c) and the value of T_c was reported as ≈ 16.6 ± 0.86MeV for a systematic infinite nuclear matter [3], which coincides well with Ormand et al.[1]. It is recognised that the nuclear equations of state is associated to T_{lim}, i.e. the maximum temperature of a nucleus can sustain before reaching mechanical instability [4].

The limiting temperature which directly addresses the thermal shell quenching have an impact in modelling of extreme astrophysical events such as neutron star mergers and core-collapse supernovae. That is, understanding nuclear properties at such a high temperature sources leads to disclosing of their origin [5]. Hence systematic studies by treating the nucleus as a thermalized one may extend the nuclear landscape. In this context, the SHN, Z=120 which is in the process of synthesizing at renowned laboratories, is been considered in this work. The neutron magic and quasi magic numbers for Z=120 was reported [6], as N=184 and 178 respectively by an extensive study using our code of statistical formalism. Under thermodynamical conditions, it is necessary to extract the excitation energy and nuclear level density to determine the limit of survival of a nucleus.

Methodology

Since contribution of finite temperature effects is crucial in the evolution of nuclear r-process, nuclear heavy-ion reaction and excited states [5], knowledge of nuclear properties at finite temperature may lead to the understanding of formation of heavy nuclei in the extreme astrophysical events. So, it is ideal to treat the compound nucleus formed in hot fusion – evaporation reaction as a thermodynamical system. Hence to study the superheavy nucleus Z=120, the temperature and rotational effects are incorporated in the statistical model, and is followed in this work. The entropy of the system,

$$S^{N(P)} = -\Sigma_i \left[n_i^{M(P)} ln(n_i^{M(P)}) + (1-n_i^{M(P)}) ln(1-n_i^{M(P)}) \right. \qquad \text{….(1)}$$

and the NLD, $\rho(E^*, M) = \frac{1}{12\sqrt{2\sigma}} \frac{exp(2\sqrt{aE^*})}{a^{1/4} E^{*5/4}}$ ….(2)

where the NLD parameter [7],

$$a(M,T) = S^2(M,T)/4E^*(M,T). \qquad \text{….(3)}$$

The excitation energy, $E^* = E_{tot} - E_{g.s}.$ ….(4)

The thermodynamic temperature,

$$t = (E^*/a)^{1/2} \text{ in MeV.} \qquad \text{….(5)}$$

Results and Discussion

The variation of 't' with T shows a linear trend upto T=3.2MeV with a slope of 0.96371 and from T=3.3MeV it is 0.7193. Such a drop in 't' with increasing T at T=3.3MeV pronounces its dependence on E^* and 'a'. There is a limit in temperature a finite nucleus can sustain. To

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determine this limit, the temperature influenced change in excitation energy, $\Delta E^*(M,T)$ is extracted for ΔT=0.1MeV for the quasi magic and magic isotopes, $^{298,304}120$ (identified in ref [6]) (fig. 1).

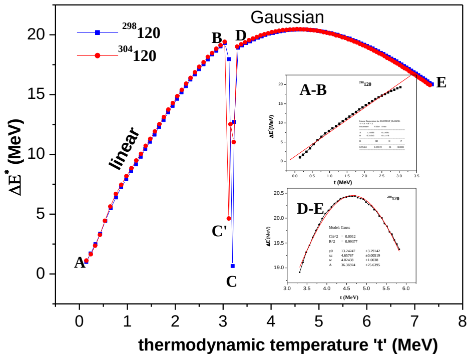

Fig. 1 Response of E^* for the variation of T=0.1MeV determining the Instability temperature of $^{298,304}120$.

For $^{298}120$, the change in excitation energy increases linearly(marked A-B) upto T≈3.1MeV (inserted in Fig.1; fitted with linear) and beyond T=3.4MeV the change in E^* resembles a Gaussian (marked D-E) with a maximum at T≈5.0MeV (inserted in Fig.1; fitted with Gaussian). The drop in ΔE^* at T=3.3MeV (t=3.1985MeV) pronounces the apathetic behaviour of E^* to 't', ie., at thermodynamical equilibrium the heated liquid and vapour surrounding it coexists due to the equal pressure of both phases; a temperature at which the liquid properties are destroyed will be the limiting temperature at which the nucleus loses its structural effect and become vapour/ plasma. This state may be correlated as a signature of hadron-quark transition according to Olive [8]. For $^{304}120$, the limiting temperature is obtained at T≈3.2MeV(t=3.1185MeV) which is 0.1MeV (Δt≈0.08MeV) lower than for $^{298}120$ which indicates the higher stability of $^{298}120$ than $^{304}120$ against temperature.

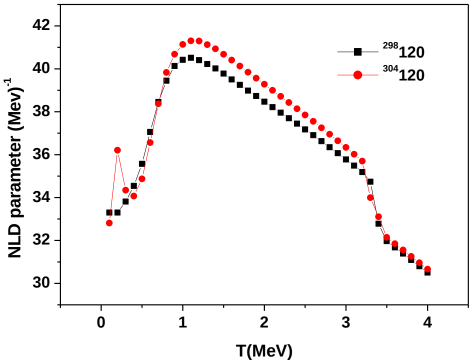

Fig. 2 Limiting temperature of $^{298,304}120$.

It is worth noting here that the nuclei unstable at very low temperatures may become stable with increase of temperature. The NLD parameter value 'a' shows a sudden drop at T≈3.3MeV and T≈3.2MeV for $^{298}120$ and $^{304}120$ respectively(fig-2), which represents the collapse of nuclear existence, which is in coincidence with the prediction of T_{lim} by change in E^* against 't', and is in correlation with Besprosvany and Levit [9], that the nuclei with higher Z or N have T_{lim} < 5.0MeV. These findings may highly useful for the observation of the fused compound nucleus in the synthesis of superheavy elements since the T_{lim} is interpreted as the temperature of the mechanical instability.

Acknowledgement

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