Anomalously high nuclear temperature from evaporation fragments – a conjecture

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Introduction

Statistical model codes predict increasingly steeper slope of the spectrum of the evaporation nuclear fragments from a compound nucleus as the mass of the evaporation fragment increases. The increasingly steeper slope of the evaporation fragment spectrum implies increasingly lower temperature of the residual nucleus. It has been found from a recent study [1,2] of the extreme back-angle evaporation spectra of alpha, lithium, beryllium, boron and carbon from different compound nuclei near A≈100 (E_X=76-210 MeV) that although the shapes of the alpha spectra agree well with the predictions of the statistical model codes, the spectra of lithium, beryllium, boron and carbon show significantly gentler slopes implying higher temperature of the residual nuclei, even though the spectra satisfy all other empirical criteria of statistical emissions. In Table 1, we show a comparison of the experimentally obtained temperatures from the fragment spectra versus the corresponding statistical model predictions showing highest observed anomaly for lithium.These results could not be understood [1] by adjusting the parameters of the statistical models or from reaction dynamics.

Table 1: Comparison of temperatures (T) derived from the experimental and statistical Model spectra.

System	Fragment	T (MeV)	
		Exp.	Stat. Mod.
^{16}O+^{89}Y E(^{16}O) =96 MeV E_X(^{105}Ag)=76 MeV	^{4}He	2.9±0.15	2.9
	Li	4.5±0.3	2.3
	Be	3.6±0.3	2.0
	B	3.3±0.2	2.1
	C	3.5±0.3	2.2
^{16}O+^{93}Nb E(^{16}O)= 116 MeV E_X(^{109}In)= 93.5 MeV	^{4}He	3.5±0.1	3.4
	Li	4.6±0.2	2.8
	Be	3.9±0.2	2.4
	B	3.6±0.2	2.3
	C	3.5±0.2	2.0
^{3}He+Ag E(^{3}He) =90 MeV; E_X~82MeV	^{4}He	3.0±0.1	3.0
	Li	5.8±0.3	2.8
	B	3.5±0.2	2.6
	C	3.5±0.3	2.6

In order to understand the observed slope anomaly, we propose to examine the statistical model from a quantum mechanical perspective. The wave function of a statistical compound nucleus is a linear superposition of the wave functions of all possible exit channel dinuclear states, where each dinuclear state wave function (a quasi-bound state of a heavy-ion fragment and residual nucleus) is undergoing exponential decay in time with a Breit-Wigner width. In any statistical model, concerned Breit-Wigner widths of the exit channel dinuclear states are assumed to be zero.However this assumption might not be valid for heavy ions like lithium.

The conjecture

We conjecture that the effect of the Breit Wigner widths of the states might be considered by convoluting the standard entropy function with a Breit-Wigner function and then calculating the temperature of the system by the standard method. So for a decaying nuclear system the entropy and temperature might be written as

$$\langle S\rangle \approx \frac{\int_{-\infty}^{\infty}\frac{2\sqrt{aE}}{(E-U)^2+0.25\Gamma^2}dE}{\int_{-\infty}^{\infty}\frac{1}{(E-U)^2+0.25\Gamma^2}dE} \text{ and } \frac{1}{T}=\frac{\partial|\langle S\rangle|}{\partial U} \quad \ldots(1)$$

where Γ, U, a denote Breit-Wigner width, mean energy and level density parameter respectively.

Results and Discussions

Using eq. (1), a plot of the temperature (T) versus the thermal energy (U) for various values of Breit-Wigner width (Γ) is shown in Fig. 1 for A=93 and level density parameter = A/8. The standard statistical model result corresponds to Γ=0. We find that for large values of Γ, the calculated temperature becomes very large for small values of U, but as U increases, the calculated temperature comes down quickly and approaches the statistical model values. In the case of the emission of the lithium fragments from the compound nucleus ^{105}Ag (E_X=76 MeV), we are dealing with the average thermal energy of the residual nuclei (U~35-40 MeV) and in order to explain our slope anomaly corresponding to the experimentally obtained values of T, we shall need Γ~100 MeV. Somewhat smaller values (Γ~50-80 MeV) would be required to explain slope anomalies of other heavy ion spectra. These results imply prompt breakup of lithium, beryllium etc. in the vicinity of the nuclear and Coulomb field of the residual nucleus. Since the lithium nucleus is expected to break apart most promptly compared to carbon, boron or beryllium, the Breit-Wigner width of the dinuclear state comprising lithium and the residual nucleus should be the largest resulting in the highest temperature of the lithium spectrum and largest departure from the standard statistical model prediction (based on sharp Breit-Wigner states), as observed experimentally. On the other hand, the temperature of the alpha spectrum should agree with the prediction of the standard statistical model, because of the expected small Breit-Wigner width of the dinuclear state comprising an alpha and the residual nucleus due to the stability of alpha nucleus in the vicinity of the nuclear and Coulomb field of the residual nucleus. Numerical estimates also show (Fig. 1) that at higher (thermal) excitation energy, the effect of the Breit-Wigner width on the temperature drops very rapidly and the calculated temperature tends to approach the statistical model prediction. So this conjecture regarding convoluting the entropy function with a Breit-Wigner function to calculate the temperature of the residual nucleus has the potential to explain the observed anomaly.Of course, there is an associated problem with this conjecture. The question is how lithium and other particles are coming out from the close proximity of the residual nuclei and reaching detectors satisfying the condition of long lifetime as required by the statistical-emission process if indeed they have such a large Breit-Wigner width corresponding to prompt break-up in the nuclear and Coulomb field. A possible resolution of the puzzle could be the initial quantum mechanical delay (non-exponential decay time scale ~10^{-18}sec for nuclear systems) [3] of the dinuclear states resulting in a long survival time and statistical characteristics.

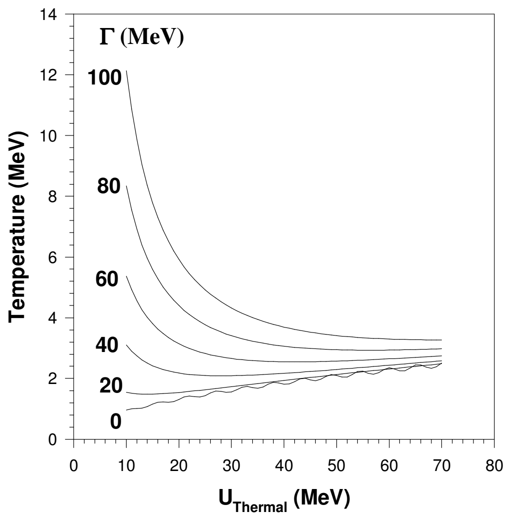

Fig. 1 Plot of temperature (T) versus thermal energy (U) for different values of Breit-Wigner width (Γ) using eq. (1).

A. De acknowledges the support received from collaborative research scheme No. UGC-DAE-CSR-KC/CRS/2009/NP-TIFR02.

References

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