Compound nucleus decay and the liquid to vapor phase transition

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The construction of a phase diagram, and in particular of a pressure-temperature diagram for a nuclear system leads to the inevitable question: What is the meaning of pressure when the nuclear system is facing vacuum? This question has presented itself in many equivalent guises in the literature and in endless discussions. It amounts to asking: a) whether there is a gas phase in equilibrium with a liquid for the reactions in question; and b) whether this gas phase is thermodynamically characterizable.

For a compound nucleus the answer is no to a) and yes to b). And this is not contradictory.

To see this point, consider the interface between a liquid and saturated vapor. From the liquid side we can specify with standard theories (e.g. compound nucleus decay rate, the equation for electrons emitted from a hot filament, etc.) the emission flux of particles emitted from the surface. From the vapor side, we can write down the return flux into the liquid knowing the temperature, pressure/concentration and composition of the vapor. At equilibrium, by definition, the vapor to liquid flux matches physically and chemically the liquid to vapor flux. Thus, the saturated vapor acts, so to speak, as a mirror reflecting back elastically all the particles emitted by the liquid. This is the only role of the vapor.

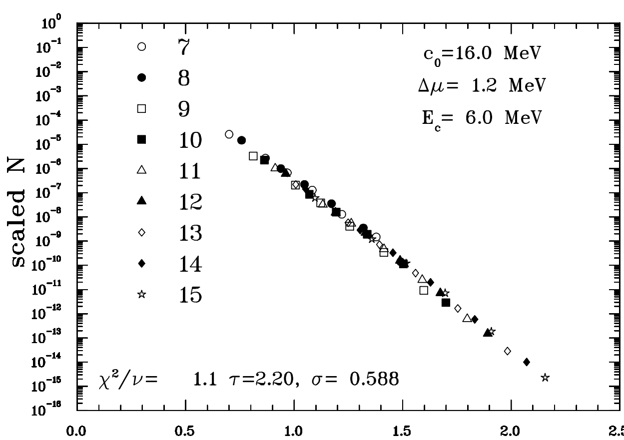

FIG. 1. The "Fisher" scaled yield distribution versus the scaled temperature [2] for complex fragments with atomic number from Z =7 to 15 emitted from the compound nucleus ^{76}Se formed in the reaction ^{64}Ni+^{12}C at the 88 inch cyclotron.

If we remove the vapor and hold the liquid at a fixed temperature, the liquid continues emitting particles as if the vapor were still present. Thus, the saturated vapor is completely characterized by the flux from the liquid side, even if the vapor itself is not physically there. So it is that we can unequivocally speak of the phase transition for a glass of water (or a nucleus) evaporating in a dry atmosphere or equivalently in vacuum.

In this light, compound nuclear decay becomes suddenly relevant to the liquid to vapor phase transition. In the past, we have studied the evaporation of complex fragments from well characterized compound nuclei [1]. It should be possible to cast these results in terms of Fisher's scaling. This is done in Fig. 1 for the reaction of Ni+C. As in the case at AGS energies [2], the scaling is very good and the extracted parameters σ and τ, as well as the surface energy coefficient c_0, are very close to those of the other systems. From this example we see in these low energy reactions a very interesting source for further characterization of the phase transition, in particular for anchoring the parameters of Fisher's model to the well established $T = 0$ parameters of the liquid drop model.

[1] T. S. Fan, *et al.*, Nucl. Phys. A **679**, 121 (2000).
[2] J.B. Elliott *et al.*, Phys. Rev. Lett. **88**, 042701 (2002).