

TEMPERATURE DISTRIBUTIONS IN NUCLEAR COLLISIONS

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It has been suggested that nuclear temperatures can be characterized by the relative population of bound states of reaction products emitted in nuclear collisions. By assuming that the populations of these states are given by Boltzmann distribution, the ratio of the populations should be related to the temperature kT as:

$$R = (2 \times I + 1) / (2 \times J + 1) \times \exp(-dE/kT)$$

where I and J are the spins of the two states, and dE is the energy difference between the states. Based on this assumption the technique has been developed and employed for studies of the bound states populations at various projectile target combinations and broad range of projectile energies. The technique has been also extended to the measurements of the populations of the unbound states. The studies which have attempted to determine nuclear temperatures from the measurements of bound and unbound state populations have reported inconsistent results. The measurements of the populations of unbound states systematically give the temperatures around 4 or 5 MeV, while those of bound states indicate the temperatures between .5 and 1. MeV for projectile energies in the range $E=20A-80A$ MeV. In the same time it is observed that the temperatures obtained from the measurements of these populations are much significantly lower than the apparent temperatures inferred from the measured kinetic energy distributions of the reaction products, usually ranging between 10 and 20 MeV.

Several models were tried in order to resolve these discrepancies. It was recognised that the presence of the sequential decay of the unbound states of heaviest nuclei hardly destroys the accuracy of the temperature measurements, especially in the case when the ratios which involve the ground state populations are in question, since in that case it can not be expected that the Boltzmann distribution describes the observed population ratio. The success of the thermal multi-source model in the interpretation of the thermal, in its appearance, spectra of the light particles and complex fragments emitted in heavy ion nuclear reactions at intermediate energy strongly suggests the considerations of the similar models in the interpretations of the discrepancies involved. Recently, the reflections of the model of two sources at the different temperatures on the understanding of the experimental results were discussed.

The proposed model based on the following statements can significantly contribute to the better understanding of the nature of the discrepancies of the phenomena involved:

1. The assumption of Boltzmann distribution implies the thermodynamic approach in analysing the emission of particles from an intermediate nucleus or thermodynamically equilibrated piece of the nuclear matter. In this case the population ratio reflects the temperature T of the final nucleus. The unbound states of residual nuclei populated through the emission of the light particles or the complex fragments from intermediate hot thermodynamically equilibrated piece of nuclear matter are positioned at higher energies than the bound states of the same residual nuclei. Consequently the corresponding temperatures will reflect these energy level positions indicating the different temperatures for the different excitation energies of the final nucleus.

2. The assumption that the intermediate nucleus or the equilibrated piece of excited nuclear matter decays in channel $X+x$, where X is residual nucleus and x is the ejectile, and that the temperature is determined from population ratio of the given excited and ground states of the composite fragment x , implies that in the case of pure binary-collision model:

a.) the ground state or the given excited state of the complex fragment x can be populated by fragment X which is in its ground or some of the excited states or what is, from the point of view of the mass-energy balance of the reaction, the same

b.) the corresponding excited states of fragment X can be populated by fragment x which is in its ground state or is just excited to the level of the given excited state.

The population ratio of the ground and the given excited state can be measured and using standard techniques the information about the temperature and the velocity of the moving source can be extracted from the experimental data. The different modes of building of the partners in the $x+X$ exit channel of the nuclear reaction will have the different Q values and consequently the different kinetic energies in the CM system. This also means the different slope of the spectra in the laboratory system. The results of the analyses based on the statements of this model show that the temperatures extracted from the population ratios, shape of the spectra and the apparent temperature inferred from the measured energy distributions of the reaction products are in agreement with the most probable Q value distribution calculated for the analysed nuclear reactions in the range of the projectile energies between 20A and 60A MeV.

References:

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