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TEMPERATURE MEASUREMENTS WITH ISOTOPIC AND KINETIC THERMOMETERS *

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We study the correlation between apparent temperatures which can be measured in an experiment and initial ones, within the sequential statistical model. We extract temperature from slopes of kinetic energy spectra of light charged particles and from isotopic double ratios. We find that due to the chain of emissions and side-feeding the various apparent temperatures significantly differ from each other and from the initial one. We also find that the model works well even for very high excitation energies.

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1. Introduction

It was already shown at this school [1, 2] how to measure nuclear temperatures and what are the newest results of such measurements: several caloric curves measured in the $^{36}Ar + ^{58}Ni$ reaction at 95MeV/A. There are significant differences between them, both within one method and between two methods used (fig.2 in [1]). We also have seen that one obtains different caloric curves applying the same 'thermometer' to different reactions [2].

This puzzling picture rises the question of the relationship between apparent temperatures and the initial ones. Apart from dynamical effects, two mechanisms influence the apparent temperature and we will establish quantitatively their respective effects:

1. Emission chain - the excited nucleus lowers its temperature after each act of emission. The higher is the excitation energy the longer is the

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emission chain and in consequence the bigger is the discrepancy between initial and measured emission temperature.

2. Particle decay of some levels (side-feeding). This removes the parent fragment from measurement and increases the number of daughter particles, influencing also their energy spectra. The probability of reaching particle unstable levels increases with excitation energy.

2. Model

We applied the standard evaporation model [3] The charge (or mass) of the emitter is chosen according to the experimental distribution, its excitation energy, $E*$, is chosen randomly and the initial temperature, T_{ini}, is calculated from the formula $T_{ini} = \sqrt{10 * E^*/A}$ (solid line in fig. 1). Fragments with Z<6 and A<10 are emitted in discrete states. Heavier fragments decay until the excitation energy is exhausted or until they decay into fragments with Z<6 and A<10. All discrete states decay at the end of calculation. The maximum width of the states included in the calculations is a free parameter.

3. Results

To demonstrate the role of emission chain and side-feeding we stopped the code after the first emission - this is first chance emission (FCE). In this way we have an access to the initial temperature provided that, to use isotopic thermometers in the right way [4], we take only fragments emitted in the ground state: fig. 1a,b. The two next steps (not shown) are: 1^o inclusion of excited fragments, and 2^o particle decay of discrete levels. We observe a decrease of the apparent temperature calculated from isotopic double ratios. This change is however quite moderate and the calculated temperature follows the initial one. The slope parameters are slightly lower when side-feeding is included.

A quite different situation is obtained when the full evaporation chain is studied. When the population of all excited states is allowed, but the decay of discrete states is not, two caloric curves increase almost linearly but the apparent temperatures stay under T_{ini} (fig. 1d). The temperature obtained from ^{6}Li/^{7}Li-^{3}He/^{4}He behaves quite differently: above $E^*/A \approx 9$ MeV it increases fast. This is caused by an increase of the yields of ^{3}He and ^{7}Li to the expense of ^{4}He and ^{6}Li. When side-feeding is switched on, the yield of ^{4}He increases much, which lowers significantly the apparent temperature (fig. 1f) and makes the calculated curve similar to the experimental one (fig. 2 bottom left).

The slope parameters are much less influenced by both disturbing pro-

cesses (Fig. 1c,e). Especially protons (not presented) and deuterons keep a good memory of T_{ini}. For heavier elements there is a strong increase of temperature at high excitation energy.

Having the width of discrete states included in the code we have the possibility to study the influence of in(ex)cluding some states. In fig. 2 we present results obtained by including states with $\Gamma < 0.5$, 2.0 and 4.0 MeV (which correspond to life times > 400, 100 and 50 fm/c) and compare them with the data [5].

To reproduce temperatures from p/d-^{3}He/^{4}He one has to include very broad (short living) states, while d/t-^{3}He/^{4}He requires to exclude states with Γ >0.5 MeV. Temperatures from ^{6}Li/^{7}Li-^{3}He/^{4}He suggest a change in the time scale: broader states should be included as excitation energy increases. It seems that each 'isotopic thermometer' is related to different 'time scales', but this point is not established since the widths of several high excited levels are not well known and some levels are likely not known at all. $\Gamma < 2$ MeV gives a reasonable overall fit and was used in fig. 1.

4. Conclusions

Both emission time sequence and feeding from discrete state decays have large effects on caloric curves measured with 'isotopic thermometers'. Secondary decays (side-feeding) reduces apparent temperature values while emission chain changes the shape of the caloric curve for Li-He thermometer in such a way that it could easily mimic a liquid-gas phase transition.

Slope parameters from kinetic energy spectra of light particles keep a good memory of the initial temperature (but they may be perturbed by the mixture of several sources and collective expansion).

The simple model of evaporation which includes emission of excited fragments in discrete states works well even for very high excitation energies. The temperatures obtained with different 'isotopic thermometers' might be related to different time scales of particle emission and decay. These time scales vary from 50 fm/c (fast disintegration) to 400 fm/c (sufficient for statistical evaporation).

Finally we emphasize the predicting power of this model by presenting our calculations for ALADIN data [6] in fig. 3. The only change we had to make was to include the dependence of the source mass on excitation energy, which we read from experimental points presented in [6] (A/Z ratio 2.5 for all E^* was assumed). A good agreement is seen.

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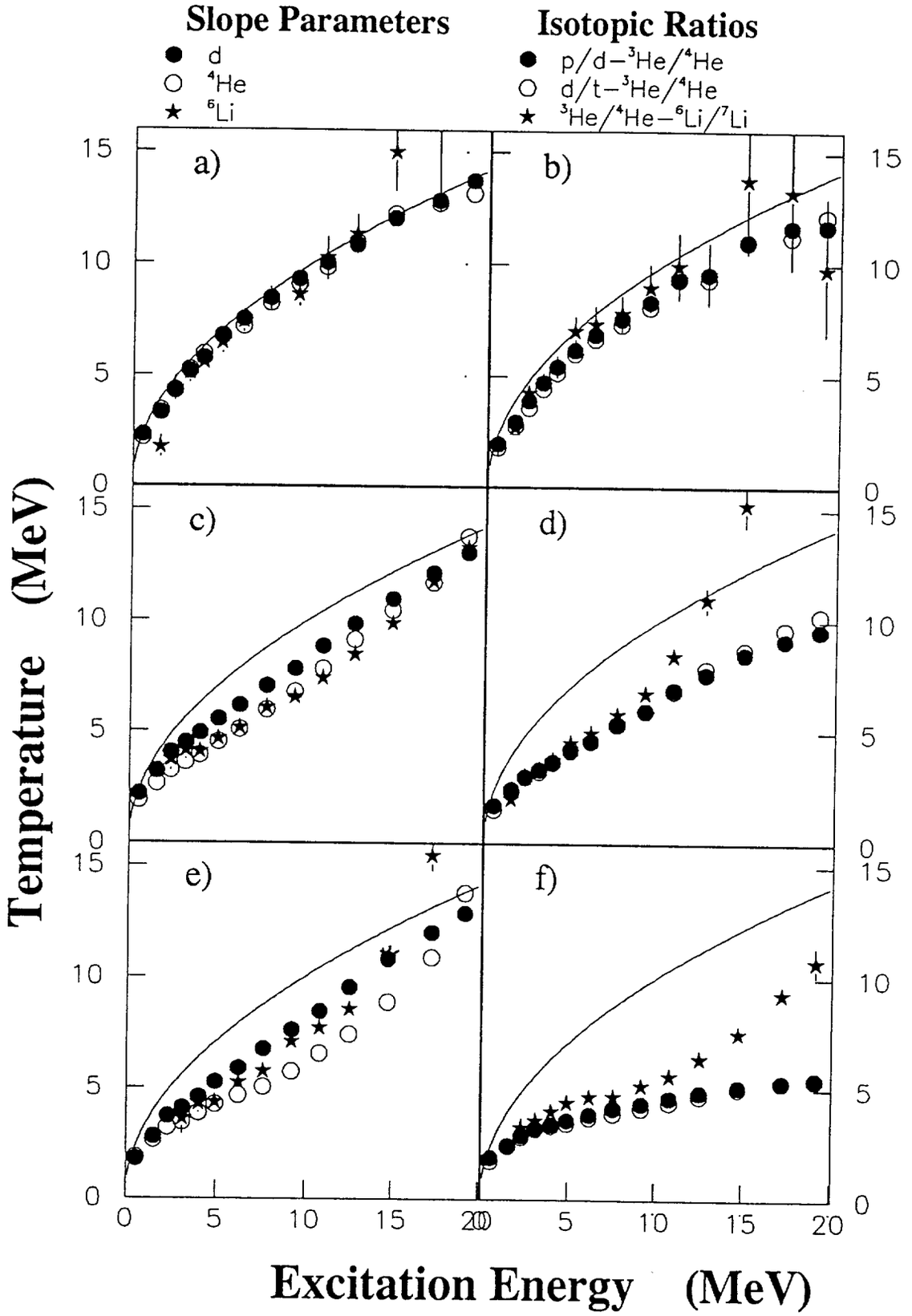

Fig. 1. Caloric curves calculated with an evaporation code. Temperatures are extracted from slope parameters (left hand side - a,c,e) and double isotopic ratios (right hand side - b,d,f) at different stages of the calculation, a,b) FCE taking into account only particles emitted in their ground state, before decay of discrete states. c,d) Emission Chain taking into account all particles, before decay of discrete states. e,f) Emission Chain after decay of discrete states. The solid line represents the relation between T_{ini} and E^* $T_{ini} = \sqrt{10 * E^*/A}$

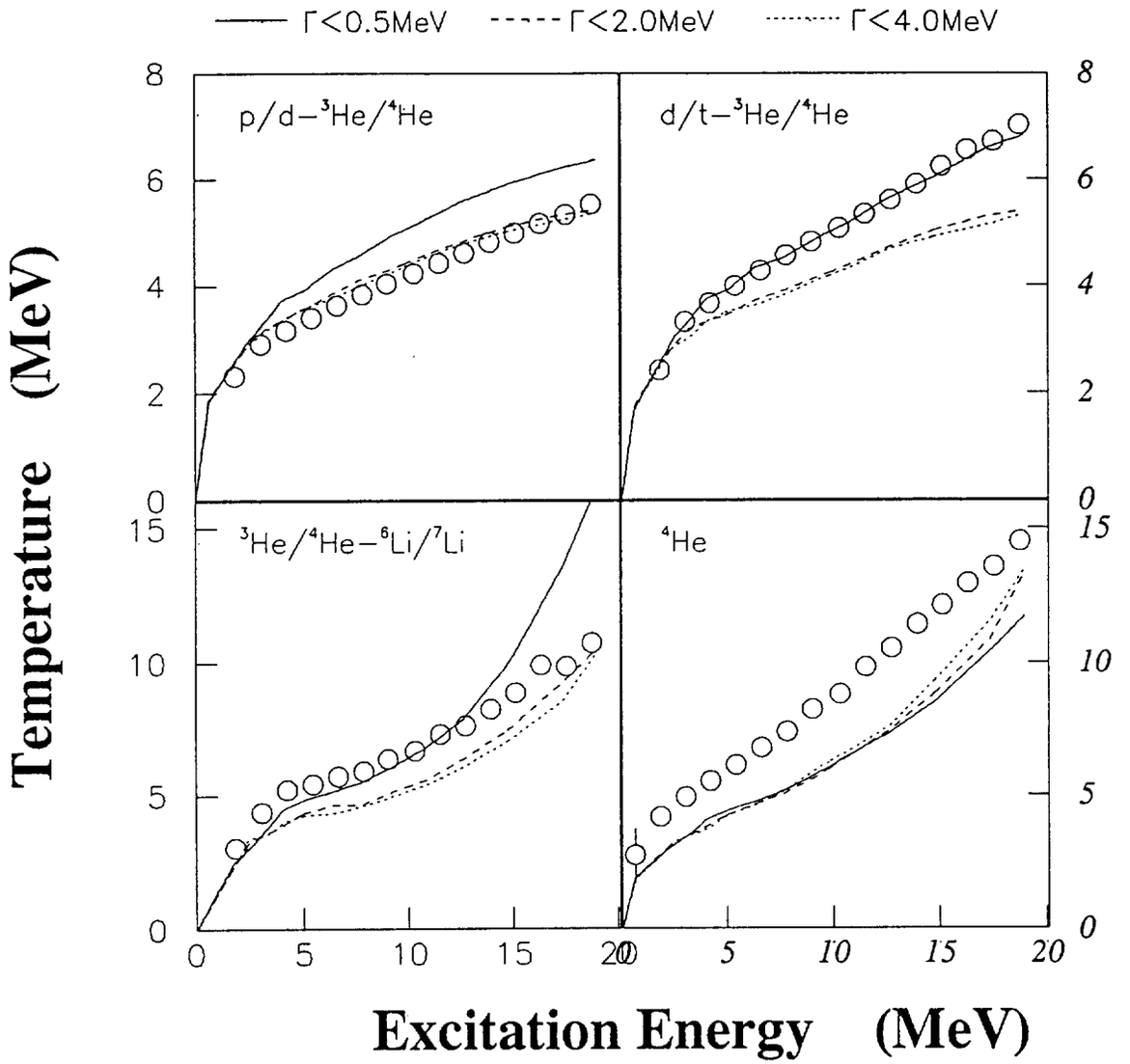

Fig. 2. Dependence of the calculated 'apparent' temperature on the maximum width of discrete states included in the calculations. Points represents experimental data [5].

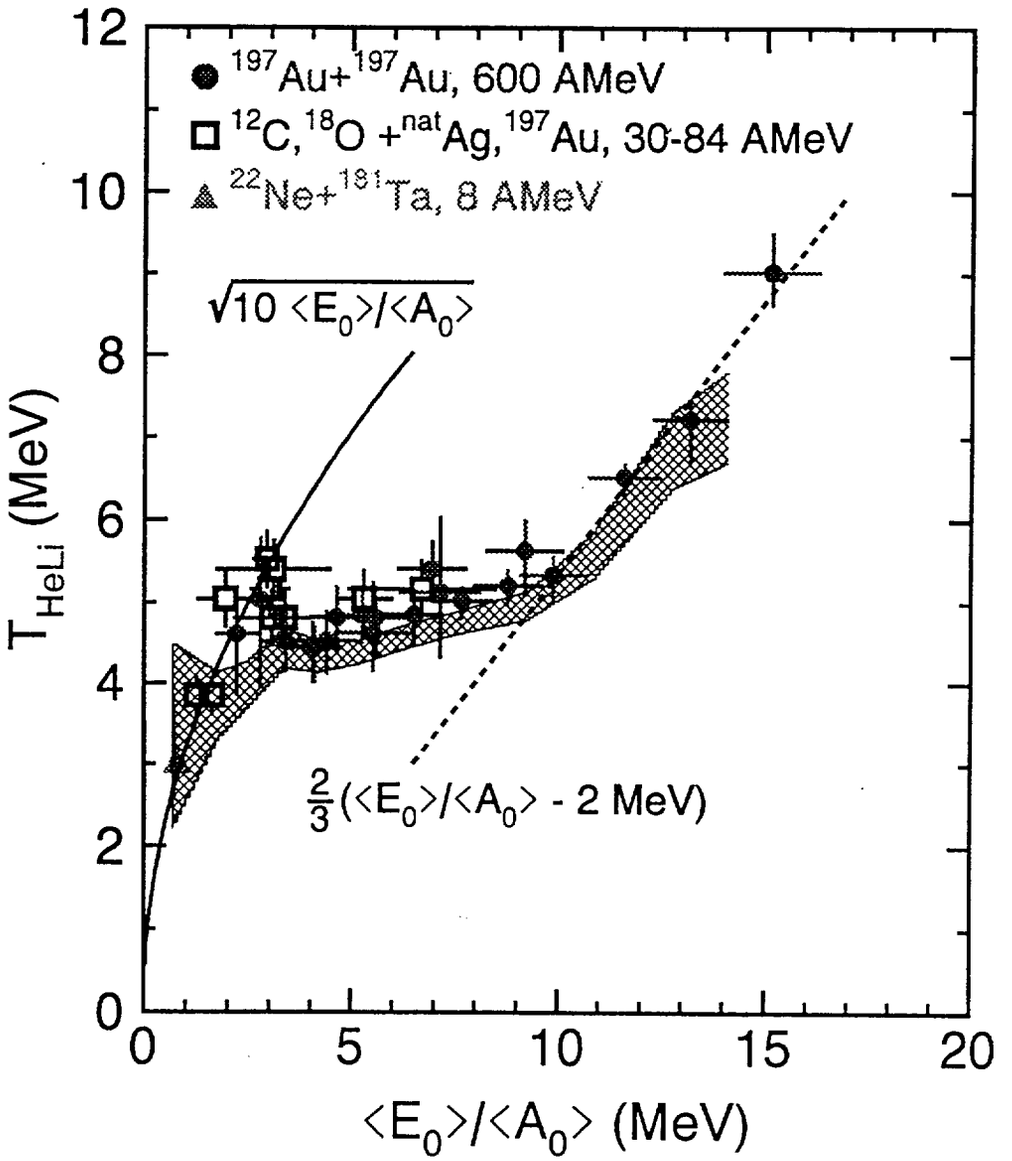

Fig. 3. Results of theoretical calculations made with our evaporation code (the shaded area represents statistical errors) compared with the experimental data [2].