MASS AND ISOSPIN DEPENDENCE IN MULTIFRAGMENTATION*

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A systematic study of mass and isospin effects in the breakup of projectile spectators at relativistic energies has been performed with the ALADiN spectrometer at the GSI laboratory (Darmstadt). Four different projectiles ^{197}Au, ^{124}La, ^{124}Sn and ^{107}Sn, all with an incident energy of 600 A MeV, have been used, thus allowing a study of various combinations of masses and N/Z ratios in the entrance channel. The status of the project and first results are presented and discussed

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1. Introduction

The importance of isospin, in particular for any interpretation of multifragmentation as a manifestation of the liquid-gas phase transition in nuclear matter has been widely discussed in recent years. Different isotopic compositions are predicted for the coexisting liquid and gas phases, with the

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gas being more neutron rich than the liquid in asymmetric matter [1]. This difference stems from the decrease in the symmetry energy in nuclear matter as the density is decreased. The expected magnitude of this density dependence, however, is model dependent and very poorly constrained by existing data [2].

In a series of experiments [3,4], multifragment decay of projectile spectators has been studied with the ALADiN forward-spectrometer at the SIS accelerator (GSI). The isotropy of the fragment emission in the decaying spectator rest-frame suggests an emission from a thermodynamical equilibrated source. In these collisions, energy depositions are reached, which cover the range from particle evaporation to multifragment emission and further to the total disassembly of the system, the so-called Rise and Fall of multifragment emission [3]. The most prominent feature of the multi-fragment decay is the universality of the fragment multiplicites and the fragment charge correlations. The loss of memory of the entrance channel is an indication that equilibrium is attained prior to the fragmentation stage of the reaction. It will be interesting to investigate whether the observed universality of spectator decays includes the invariance with isospin.

Besides the isospin, also the mass of the system may play an important role for fragmentation observables of the reaction. It has been suggested that the dependence of the breakup temperature on the excitation energy (caloric curve) is governed by the *limiting temperature* [5, 6]. In lighter systems the limiting temperature is higher, mainly so because the Coulomb energy is reduced. Experimental evidences of a decrease in the limiting temperature determined for several systems in central collisions have been found [7, 8]. On the other hand, SMM calculations predict nearly mass-invariant temperatures for the coexistence region [9]. The comparison of two systems with different mass should, therefore, permit distinguishing whether the breakup temperature is determined by the binding properties of the excited hot nuclear system or by the phase space accessible to it by fragmentation.

2. The experimental setup

The most recent ALADiN experiment has been devoted to investigating isotopic effects in the decay of projectile spectators at relativistic energies. In order to extend the range of isotopic compositions of the excited spectator systems, secondary beams have also been used. This and the clean separation of the spectator sources in rapidity make this type of reaction unique for studying the isospin dependence of nuclear multifragmentation. Four different projectiles, all with an incident energy of 600 A MeV, have been investigated allowing a study of various combinations of masses and N/Z ratios in the entrance channel: ^{124}Sn, ^{197}Au, ^{124}La and ^{107}Sn. The two latter beams have been delivered by the FRagment Separator (FRS) of the

GSI as products of the fragmentation of a primary ^{142}Nd beam at 1.1 A GeV on a ^{9}Be production target.

A cross sectional view of the used setup is shown in Fig. 1. The isotopic composition of the secondary beams was determined and monitored from the magnetic rigidity measured at the FRS, from a velocity measurement along the 80-m flight path between the FRS and the ALADiN setup, and from the charge measurement with the TP-MUSIC IV detector.

Projectile fragments entering into the acceptance of the magnet are tracked and identified in the TP-MUSIC IV detector and in the time-of-flight (TOF) wall. Neutrons emitted in directions close to $\theta_{\rm lab} = 0°$, are detected with the Large-Area Neutron Detector (LAND). The dash-dotted lines represent the beam directions before and after the deflection by 7° in the field of the ALADiN magnet.

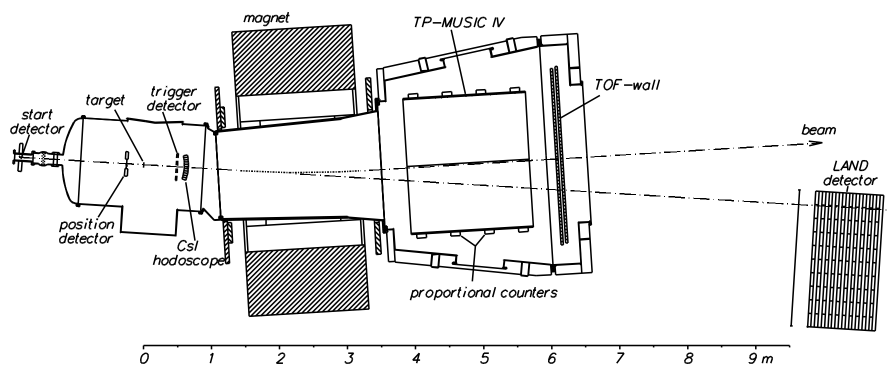

Fig. 1. Cross sectional view of the ALADIN setup: the beam enters from the left and passes thin time- and position-detectors before reaching the target.

The measurement of the charge and the momentum vector of all projectile fragments with $Z \geq 2$ has been performed with high efficiency and high resolution with the TP-MUSIC IV detector [10].

Using the reconstructed values for the momentum vector and path length, the charge of the particle measured by the TP-MUSIC detector, and the time of flight given by the TOF-wall, the mass of each detected charged particle can be calculated. Single mass resolution for charges up to 12 is obtained, corresponding to a mass resolution $\Delta A/A$ of approximately 4.0% (FWHM) for light fragments.

3. Gross properties of the multifragment decay

In order to investigate to which extent the isotopic composition of the excited spectator affects the gross properties of the multifragmentation pattern, charge partitions and multiplicity distributions have been analyzed, as well as the mean N/Z of medium size fragments, and the results have been compared with the SMM prediction. In Fig. 2, the obtained correlation between the mean multiplicity of intermediate-mass fragments, $\langle M_{\mathrm{IMF}}\rangle$, and the variable Z_{bound} for the ^{107}Sn, ^{124}Sn and ^{124}La systems is shown (left panel).

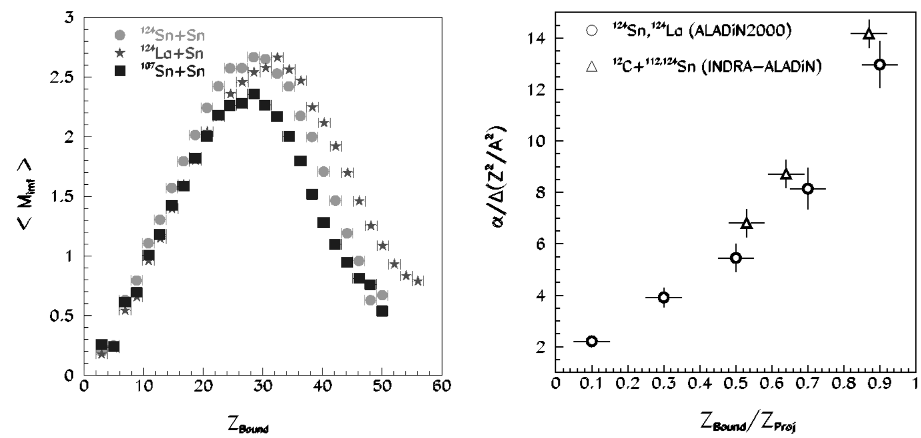

Fig. 2. Left panel: Experimental Rise and Fall of multifragmentation correlating the mean multiplicity of intermediate-mass fragments and Z_{bound}. Right panel: Isoscaling coefficient α divided by the initial isotopic composition of the system as a function of Z_{bound} normalized to the charge of the projectile.

The global universality of the Rise and Fall behavior is preserved. Some distinct differences can nevertheless be observed: at small excitation energies (large Z_{bound} values) the curves end, as expected, approximately at the charge of the original projectiles. However, the slope of the curve is steeper in the case of the ^{124}Sn. This effect can be understood by considering that in the case of the neutron-rich system, heavy residues with low excitation energy will predominantly emit neutrons, a channel that is suppressed in the case of the two neutron-poor nuclei. In these latter cases, peripheral collisions are more spread out towards smaller values of Z_{bound}, thus leading to a slower rise of $\langle M_{\mathrm{IMF}}\rangle$. This effect, as well as the corresponding difference in the Z_{bound} distribution, is in good agreement with the SMM predictions supporting the idea of overall equilibrium of the system at the breakup [11].

4. Isoscaling

The experimental study of particle and fragment production with isotopic resolution has led to the identification of isoscaling [12–15], observed by comparing product yields from reactions which differ in the isotopic composition of the projectiles or targets or both. It refers to the exponential dependence of the measured yield ratios $R_{21}(N, Z)$ on the neutron number N and proton number Z of the detected products. The scaling expression $R_{21}(N, Z) = Y_2(N, Z)/Y_1(N, Z) = C\ \exp(\alpha N + \beta Z)$ (with α and β isoscaling parameters) describes rather well the measured ratios over a wide range of complex particles and light fragments [13]. The ratios of the fragment yields with $Z = 4$ measured for the two projectile spectators ^{124}Sn and ^{124}La and integrated over chosen intervals of energy obey the law of isoscaling. The slope parameters α can be determined from the scaled isotopic ratios $S(N) = R_{21}(N, Z)/\exp(\beta Z)$.

As shown in Fig. 2 (right panel) it decreases considerably with impact parameter. In the figure the α parameter has been scaled with the initial isotopic compositions of the systems in order to compare the current data with the one obtained for $Z \leq 4$ from the analysis of the target spectator fragmentation at 600 A MeV studied with the INDRA detector at the GSI [16].

Of particular interest is the connection of the isoscaling parameters with the symmetry-term $E_{\mathrm{sym}} = \gamma(A - 2Z)^2/A$ in the nuclear equation of state which has been consistently established with several methods [12, 17, 18]. In the grand-canonical approximation the coefficient γ is proportional to the isoscaling coefficient α, to the temperature of the system and inversly proportional to the isotopic composition of the system at the breakup [12]. Assuming a slow rise of the temperature with centrality, as already established in the fragmentation of projectile spectators [4], it will not compensate the observed decrease of the isoscaling parameter with impact parameter, therefore, confirming the recent observation [16] on the decrease of the symmetry-term with excitation energy.

5. Conclusions and outlook

First preliminary results from the most recent ALADiN experiment devoted to the investigation of mass and isospin effects in multifragmentation have been reported. Global quantities as, *e.g.*, the mean multiplicity of intermediate-mass fragments exhibit small but significant variations with the isotopic composition of the fragmenting projectile.

A very clear first-order isotopic effect is also visible from the mean neutron multiplicity: more neutrons are produced in the case of the neutron-rich system. Neutrons will be important for establishing the mass and energy balance, in particular for calorimetry. In this respect, it is crucial to identify the spectator neutrons and to distinguish them from the fireball ones.

Moreover, in the grand-canonical approximation it can be demonstrated that, from the ratio of the neutron yields the symmetry term of the nuclear equation of state can be determined once the temperature and the isotopic composition of the systems are known [12]. In this respect, neutron analysis could allow to investigate the symmetry-term dependence on the excitation energy of the system, in a similar way as with the isoscaling analysis [16].

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