Probing the Nuclear Liquid-Gas Phase Transition^G

T. Möhlenkamp for the ALADIN/LAND-Collaboration

Stimulated by the van der Waals behavior of the nucleon - nucleon force the idea of a liquid-gas phase transition in nuclear matter emerged. Here we report on a search for a signal of a phase transition in projectile spectators which are produced in Au+Au collisions at E/A=600 MeV. Time-of-flight and charge information for charged fragments with Z$\geq$2 were provided by the TOF-wall of the ALADIN spectrometer with an efficiency close to 100%. The TP-MUSIC detector, equipped with 48 anode stripes and 18 multiwire proportional counters provided a complete tracking information for 32% (70%) of all detected Z=2 (Z=10) particles. Neutrons emitted from the projectile spectator were detected in the LAND detector.

Following the suggestion of Campi *et al.* we determine the excitation energy from the observed fragment and neutron distributions [1]. For a nuclear system in chemical and thermal equilibrium a temperature scale may be derived from double ratios of two isotope pairs [2]. We, therefore, define a temperature T_{HeLi} in terms of the yield ratios ^{3}He/^{4}He and ^{6}Li/^{7}Li

$$T_{HeLi} = 16/ln[2.18(Y_{6Li}/Y_{7Li})/(Y_{3He}/Y_{4He})]. \tag{1}$$

In order to test this definition we analyzed the results of several decay calculations. The quantum statistical model [3] predicts an almost linear dependence of T_{HeLi} on the actual temperature T. The ratio T_{HeLi}/T varies between about 1.15$\pm$0.05 and 0.9$\pm$0.05 for breakup densities of 0.1ρ_0 and 0.5ρ_0, respectively. Results of sequential evaporation calculations with the code GEMINI [4] and of the microcanonical multifragmentation model of Gross and co-workers [5] predict a rather constant ratio of 0.85$\pm$0.05 between T_{HeLi} and the true temperature of the system. Thus, T_{HeLi} provides a common temperature scale in the evaporation, fragmentation and vapor regimes.

Figure 1 shows T$_{HeLi}$ as a function of the total excitation energy per nucleon. Excitation energy - temperature pairs of this caloric curve extracted for projectile spectators of Au+Au collisions at E/A=600 MeV are marked by the solid points. Data for target residues produced at intermediate energies between E/A=30 and 84 MeV [6] are shown by the open squares. Because of the finite width of the excitation energy distribution and the exponentially decreasing production rate of ^{3}He towards low excitation energies temperatures can not be determined for excitation energies below approximately 2 MeV per nucleon. The only value for T$_{HeLi}$ in the evaporation regime below 2 MeV per nucleon excitation energy is provided by the ^{22}Ne+^{181}Ta fusion reactions at E/A=8.1 MeV [7] and is marked by the triangle in Fig.1.

The caloric curve in Fig. 1 can be divided in three different sections. The rise of T$_{HeLi}$ for excitation energies below 2 MeV per nucleon is compatible with the low-temperature approximation of a fermionic system $T = \sqrt{k \cdot \langle E_0 \rangle / \langle A_0 \rangle}$. Within the range of $\langle E_0 \rangle / \langle A_0 \rangle$ from 3 MeV to 10 MeV an almost constant value for T_{HeLi} of about 4.5-5 MeV is observed. This plateau may be related to the finding of rather constant emission temperatures over a broad range of incident energies which were deduced from the population of particle unstable levels in He and Li fragments. Finally, beyond a total excitation energy of 10 MeV per nucleon a steady rise of T_{HeLi} with increasing $\langle E_0 \rangle / \langle A_0 \rangle$ is seen which may be described by a linear relation $T_{HeLi} = 2/3 \cdot (\langle E_0 \rangle / \langle A_0 \rangle - 2MeV)$. The offset in this relation probably signals a freeze out at a finite density. Depending on the low density equation-of-state the freeze-out in this vapor regime may by characterized by a density between 0.15 and 0.3 of normal nuclear density.

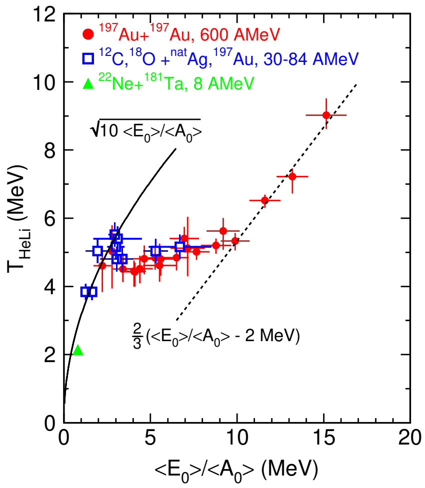

Figure 1: Caloric curve of nuclei.

The observed caloric curve agrees qualitatively with predictions of the Copenhagen multifragmentation model and is reminiscent of the paradigm of a phase transition, the first-order phase transition of bulk H_2O - systems. Whether this observation can be reconciled with a second-order phase transition - which is a prerequisite for the determination of critical exponents - will be an interesting task for future studies.

References

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