Hydrodynamic simulations of ion-beam heated foils for opacity measurements at FAIR*

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Opacity measurements in ion-beam heated warm dense matter (WDM) will provide a valuable benchmark for the diverging theoretical models and clarify the influence of strong plasma coupling on the absorption coefficient in this regime. Intense ion beams shooting on a thin high-Z foil can be used to create a nearly isothermal sample of WDM, which is needed for frequency-dependent opacity measurements [1]. For this application the influence of a metastable (MS-) compared to an equilibrium equation of state (EQ-EOS) on dynamics of matter passing through the liquid-vapor two-phase region was analyzed.

The simulations were done with the RALEF-2D code [2] using Bismuth as the target material. For generating the MS- and EQ-EOS the FEOS code [3] was used with soft-sphere parameters $\mathrm{m} = 0.8$ and $\mathrm{n} = 3.35$. Following the considerations of Ref. [1] the thickness of the foil was chosen to be $0.3\,\mu\mathrm{m}$ assuming specific energy depositions $\varepsilon_{dep} = 6$, 8 and 10 kJ/g within a 100 ns pulse as expected for the "day one" experiments at FAIR. The simulations were performed in 1D with 100 Lagrangian cells, where in Fig. 1 cell 4 refers to one at the border and cell 50 to one in the middle of the foil. Comparing MS- and EQ-EOS phase trajectories for $\varepsilon_{dep} = 10$ kJ/g on the specific volume-pressure $(v - p)$ plane in Fig. 1 a different behaviour in the two-phase region is visible. Nevertheless after leaving the two-phase region the phase trajectories of the MS case approach the corresponding EQ case trajectories and are nearly identical at $t \geq 52\,\mathrm{ns}$. The simulations show that in case of $\varepsilon_{dep} = 10$ kJ/g after $t = 52$ ns and in case of $\varepsilon_{dep} = 8$ kJ/g after $t = 60$ ns the center of the foil is heated to a temperature $T = 1$ eV. This results in a plasma coupling parameter of $\Gamma \approx 1.1$ corresponding to a mean ion charge of $Z \approx 0.9$. In the case of $\varepsilon_{dep} = 6$ kJ/g the temperature of 0.9 eV is reached after the 100 ns pulse. The density and temperature profiles for the $\varepsilon_{dep} = 10$ kJ/g beam after 52 ns can be seen in Fig. 2. As it was expected from Ref. [4] where isothermal expansion of an ideal gas is treated analytically, the density profile is Gaussian-like. The simulation of the metastable branch of the EOS through the unstable spinodal region, as can be seen in Fig. 1, is technically feasible, due to the fact that the region where $c_s^2 \leq 0$ (gray shaded) is not being crossed by the phase trajectory of any cell of the MS calculation for energy depositions higher than 2 kJ/g. Hence, a special treatment of the liquid-vapor two-phase region as proposed in [3] is nonessential in the considered cases for the correct prediction of plasma parameters at $T \approx 1$ eV.

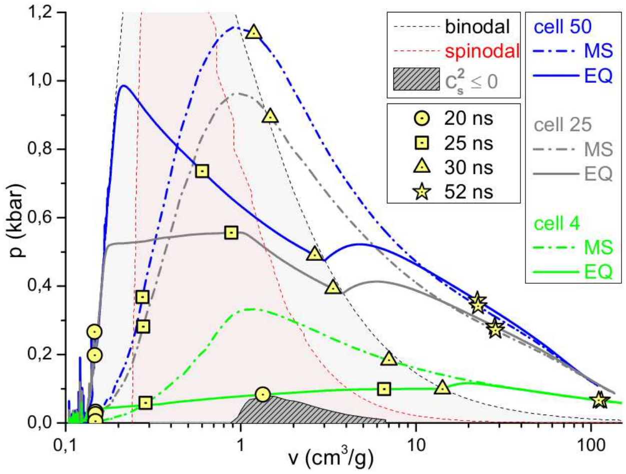

Figure 1: Phase trajectories in the $(v - p)$ plane for $\varepsilon_{dep} = 10$ kJ/g of three selected Langrangian cells with EQ- and MS-EOS.

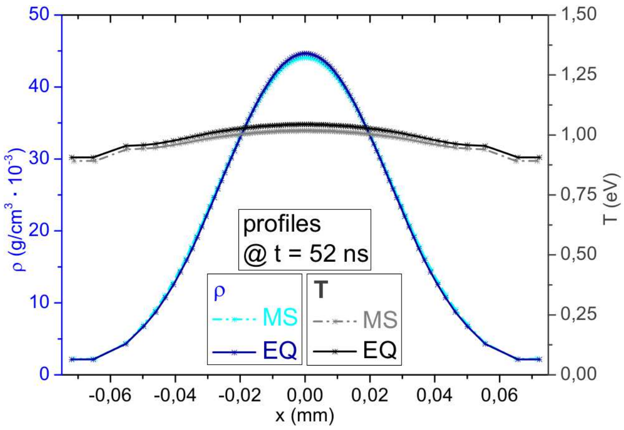

Figure 2: Density ρ and temperature T profiles for $\varepsilon_{dep} = 10$ kJ/g at $t = 52$ ns for EQ and MS branch.

References

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