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Melting of Dense Hydrogen during Heavy Ion Beam-Driven Compression

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Until now the thermodynamic and structural properties of hydrogen continue to be understood unsatisfactory. A number of complex high pressure phases at relatively low temperatures has been confirmed [1]. However, conclusive answers on the existence of a plasma phase transition, the dissociation of hydrogen molecules at high densities, the metallization in the solid, and the melting line for pressures above 70 GPa are still missing. A particularly interesting behavior has been predicted for the melting line at high pressures where it has a maximum and its slope changes sign [2]. In Ref. [3], we have shown that these states can be created using cylindrical compression driven by heavy ion beams.

Employing *ab initio* simulations [4] and experimental data, a new wide range equation of state for hydrogen was constructed [3]. This new hydrogen EOS combined with hydrodynamic simulations is then used to describe the compression of hydrogen in LAPLAS targets [5] driven by heavy ion beams to be generated at the FAIR. The results shown in Fig. 1 indicate that the melting line up to its maximum as well as the transition from molecular fluids to fully ionized plasmas can be tested. By carefully tuning the number of particles in the beam, the compression can be adjusted to yield states at the solid-liquid phase transition (compare panels (a) and (b) in Fig. 1). This allows one to test the shape of the melting line beyond its maximum. It was demonstrated [3] that x-ray scattering [6] can be used to distinguish between the molecular solid and liquid phases as well as the metallic states. Hydrodynamic simulations have also highlighted the importance of temperature diagnostics, as it is more sensitive to the EOS than the density based diagnostic methods.

Different materials have been considered as absorber. Although lead might seem to be the natural choice, the simulations show that aluminium is also a feasible option if slightly less compression is sufficient. Moreover, aluminium offers further options for testing by x-ray scattering and, thus, might be favorable compared to lead drivers.

In summary, valuable information on the properties of high-density hydrogen can be obtained by dynamic compression with heavy ion beams. The long standing questions of the plasma phase transition, melting, and metallization can be addressed. The calculated Jupiter isentrope shown in Fig. 1 indicates that such experiments would be also highly beneficial for the giant planet modelling.

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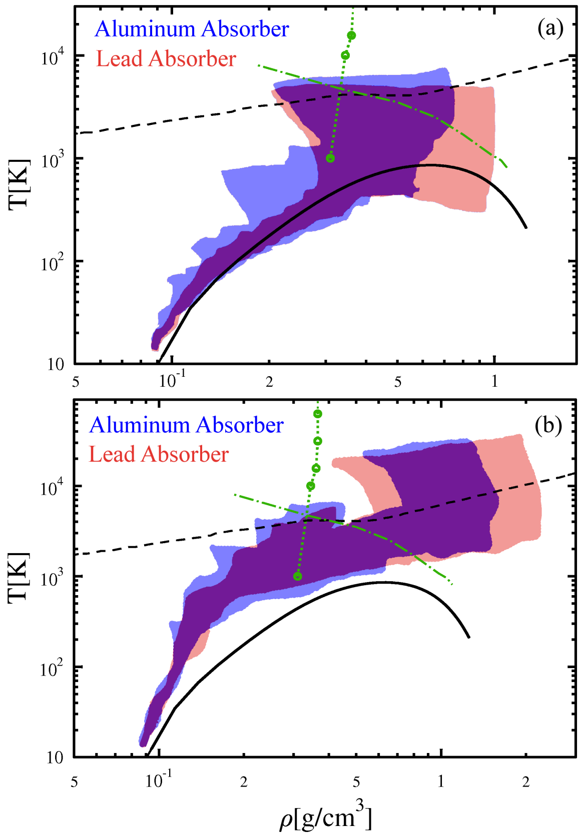

Figure 1: Trajectories in temperature-density space reached in hydrogen for two absorbers and two beam intensities: (a) 10^{11} uranium ions and (b) 10^{12} ions. Shown are also the melting line (solid), the isentrope of Jupiter (dashed) [7], states created by compression using high explosives (dotted) [8], and the transition from molecular to metallic hydrogen (dash-dotted).

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