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Isomorphic lines and isomorphic invariants in dusty plasmas and its applications

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For physical systems where the virial and potential energy exhibit strong correlations, thermodynamic phase diagrams contain a special class of curves called isomorphic lines in addition to conventional isotherms, isobars, and isochores. Along these isomorphic lines, the system's structural and dynamical properties remain approximately invariant under reduced units across different parameters. Physical quantities maintaining this invariance under reduced units are termed isomorphic invariants, effectively reducing their dimensionality in the thermodynamic phase diagram and significantly simplifying the physical description of such systems. To demonstrate that the isomorph theory is applicable to dusty systems, molecular dynamical simulations are performed under various conditions. The simulation results indicate a strong correlation between the virial and potential energy in the two-dimensional (2D) and there-dimensional (3D) dusty plasma systems.

Based on the isomorph theory, the analytical isomorphic curves of 2D dusty systems are derived using the local effective power-law exponent of the dusty systems. From the obtained analytical isomorphic curves, the melting curve of 2D dusty systems is directly determined using only two known melting points [1], the results are shown in Figs. 1(a). The determined melting curve of 2D dusty systems well agrees with the previous obtained melting results using completely different approaches. Furthermore, based on simulation data and theoretical analysis, several isomorphic invariants including two-particle entropy, instantaneous transverse sound speed [2], the results are shown in Figs. 1(b) and (c). and excess isochoric specific heat capacity, are all identified, establishing their scaling laws and practical applications in physical research for 2D and 3D dusty systems.

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References

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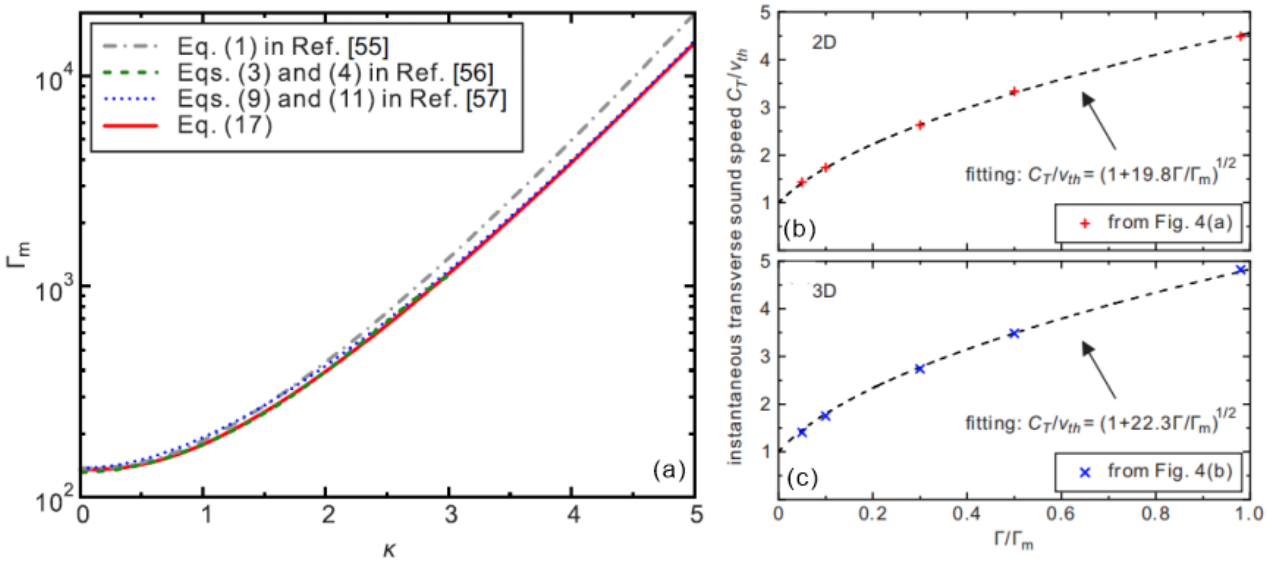

Figure 1. The analytical melting curve (a) derived using isomorphism theory, and obtained reduced instantaneous transverse sound speed C_T/v_{th} for (b) 2D and (c) 3D Yukawa fluids.