Phase transitions in the gravitational collapse of dust in Giant Molecular clouds

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Giant molecular clouds (GMC) are large aggregates of Hydrogen gas and dust ranging in size from 0.01 to 50 pc. The dust in these aggregates typically is silicates and/or polycyclic aromatic hydrogen (PAH) dispersed inhomogeneously within the cloud. The gravitational collapse of dust in molecular clouds forms dense dust cores which are surmised to be possible precursors to protoplanet or protostar core formation in GMCs [1, 2, 3]. In HII region of the cloud, the Hydrogen gas is ionized due to large gas temperature typically in the range from 5000 to 10000 K, causing dust grains to become negatively charged. In the paper, we have constructed a model in which particles interact via gravitational as well as screened Yukawa potential due to finite dust charge. It is shown that the canonical ensemble of these particles exists in two states; a high temperature state where particles are distributed homogeneously and a low temperature state where particles form a small dense core. The transition between these two states takes place via a first order phase transition at a temperature smaller than a critical value T_C. Expression for Helmholtz free energy including gravitational and electrostatic energy is constructed and T_C is calculated by equating the free energies of the two states. T_C is shown to be proportional to the number density of the dense core which depends mainly on the size of the particles via the ratio $\Gamma_s = Gm_d^2/q_d^2$. These predictions of the model are verified via particle simulations. Particle simulations [4-8] are a useful tool to capture important kinetic physics. A three-dimensional molecular dynamics (MD) code is developed for this purpose. Simulation results confirm the theoretical predictions. The phase transition is demonstrated in the simulations. The phase transition takes place for a temperature less than T_C which depends on the core number density. For $\Gamma_s = 0.15$ the theory predicts $T_C \approx 1.4$ which is in agreement with simulations. Similarly, theoretical results regarding radial oscillations of the dense core and latent heat of transition are also in agreement with simulation results. Astrophysical implications of the model are briefly discussed.

References

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