Microfluidic Crystals: Impossible Order

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Microfluidic crystals, formed by the introduction of droplets of immiscible fluid into a liquid-filled channel, provide a convenient means to explore non-equilibrium dynamics. Owing to the fact that these systems operate at low Reynolds number (Re), in which viscous dissipation of energy dominates inertial effects, vibrations are expected to be over-damped and contribute little to their dynamics. Against such expectations, we report the emergence of acoustic normal modes ("phonons") in a 1D microfluidic crystal of water-in-oil droplet flowing in a 2D channel at Re~10^{-4}. These phonons propagate at an ultra-low sound velocity of ~100 µm/sec and frequencies of a few Hertz, exhibiting unusual dispersion relations markedly different than those of harmonic crystals. These phonons are an outcome of the symmetry-breaking flow field that induces dipolar-like long-range inter-droplet interactions, similar in nature to those observed in other systems including dusty plasma crystals, vortices in superconductors, active membranes and nucleoprotein filaments. At the crossover between 2D flow and confined 1D plug flow, the phonon spectra of the crystal change anomalously under confinement. The boundaries induce weakening and screening of the interactions, but when approaching the 1D limit we measure a marked increase in the crystal sound velocity, a sign of interaction strengthening. This nonmonotonic behavior of the phonon spectra is explained theoretically by the interplay of screening and plug flow.

REFERENCES

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