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Superfluid 4He droplet coalescence dynamics: Can quantum vortices be nucleated?

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In this work we study the possibility for quantum vortex nucleation upon droplet coalescence. Quantum vortices have been experimentally observed in coherent X-ray diffraction of individual very large droplets (VLD, ˜108 to 109 4He atoms) formed in the expansion of liquid helium jets into vacuum. Vortex nucleation was attributed to shear forces on the walls of the nozzle. Another possibility to nucleate vortices could be droplet coalescence, in which angular momentum L into the merged droplet depends on the collision impact parameter and velocity. For smaller droplets, which are formed upon helium gas expansion into vacuum, this would be the only possibility to nucleate quantum vortices. We have simulated the collision of superfluid 4He droplets using 4He-TDDFT. This is a semi-empirical method describing the helium density at equilibrium (static version) or during real time dynamics, which has proven to be the best compromise between accuracy and the ability to simulate superfluid helium droplets of realistic size , Francesco et al. [1] . A realistic simulation of the collision process between VLD is beyond the TDDFT possibilities. We have focused instead on collisions of smaller droplets of 500 atoms, in order to explore the possibility for vortex nucleation in these smaller droplets. In addition, this could shed some light on the ability for this mechanism to contribute to vortex nucleation in VLD, using rescaled dimensions. The relative droplet velocity was taken from the (small) droplet velocity spread observed in a recent experiment by Kolatzki et al. [2] (Δvjet/v ≈ 1 %). The velocity of the jet (30 (0.3)< vjet < 300(3) m ps−1) depends on the expansion conditions, with the higher velocities corresponding to the smaller droplet range. Various values of the impact parameter and relative velocity have been tested. For instance, b=3R/2 (R being the sharp density radius of He500, R=17.6 Å) and v=20 m/s, corresponding to L=1850 ħ, should give the possibility to nucleate one vortex (L=Nħ for a linear vortex going through the center of a cylindrical droplet of N atoms). We find that not only one, but two vortices were nucleated, at the contact points between the colliding droplets. This surprising result is general for the range of impact parameters and velocities explored. It originates from the distortions of the merged droplet and the vortex location away from its center. Two different estimates of the amount of angular momentum contained in these vortices in the distorted drop are presented and discussed.

[1] Francesco Ancilotto et al,International Reviews in Physical Chemistry,
36:4.621, 707,2017
[2] Katharina Kolatzki et al Phys. Fluids 34, 012002 (2022)

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