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Understanding jets of uniform helium droplets along their path of propagation

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Helium droplets have a uniquely simple electronic structure, making them ideal targets for light-matter interaction studies. The recent development of intense X-ray pulses from free-electron lasers (FELs) and High-Harmonic Generation (HHG) sources has opened new ways to investigate individual helium nanodroplets with coherent diffraction imaging (CDI) [1,2]. From the diffraction patterns, the shapes of helium nanodroplets and embedded structures can be retrieved, and via time-resolved approaches, also laser induced dynamics can be investigated. Currently, efforts are leading towards imaging in the timescale of electron motion. For this, the generation of sub-femtosecond pulses with the help of short-wavelength FELs and high-intensity HHG sources is crucial. Due to the limited brightness of short light pulses, single-shot single-particle imaging becomes difficult. Nevertheless, we can aim at getting images with sufficient light signal by taking the average of repetitive diffraction patterns of identical droplets. This is where liquid jets of uniform and repetitive micrometer-sized helium droplets become very helpful [3].

We have shown via shadowgraphy imaging that liquid helium at about 3K, expanding through a micrometer sized nozzle at low stagnation pressures below 1 bar, can occasionally result in the formation of a straight stream of evenly sized and spaced helium droplets [3]. This extremely regular breakup translates in a stable target density at some distance from the nozzle, for example in the interaction region of an experiment, where the droplets can serve as an ideal target system. For the dominant, more irregular forms of jet breakup, we observed that the droplets grow and become more spherical as the distance from the nozzle increases. Especially interesting is the fact that the size distribution of these irregular droplet was found to be bimodal.

In this contribution, we investigate the propagation and evolution of helium droplets with computational simulations. We can explain the droplet growth with a coagulation process, induced by an initial longitudinal velocity distribution of the droplets. This initial velocity distribution is imprinted on the droplet jet from vibrations of the setup, which are especially strong when using a closed-cycle cryostat for cooling the helium. The experimentally found bimodal size structure can be reproduced by assuming an oscillatory motion of the nozzle generating the helium droplets. A new setup using a different, vibration-free flow cryostat, can eliminate these velocity oscillations, as is proved by the more mono-modal size-distribution. However, the previously observed, extremely regular breakup scenarios also seem to be less likely without strong vibrations of the nozzle. This observation hints us towards generating a controlled jet breakup by using a piezo transducer close to the nozzle, which forces a specific frequency onto the system.

[1] Gomez, L., Ferguson, K., Bryan, J. et al., Shapes and vorticities of superfluid helium nanodroplets. Science 345, 906-909 (2014).

[2] Rupp, D., Monserud, N., Langbehn, B. et al., Coherent diffractive imaging of single helium nanodroplets with a high harmonic generation source. Nat Commun 8, 493 (2017).

[3] Kolatzki, K., Schubert, M., Ulmer, A., Möller, T., Rupp, D. and Tanyag, R., Micrometer-sized droplets from liquid helium jets at low stagnation pressures, Physics of Fluids 34, 012002 (2022).

Category

Solid State (Experiment)

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