BUBBLE PINCH-OFF AT HIGH PRESSURES

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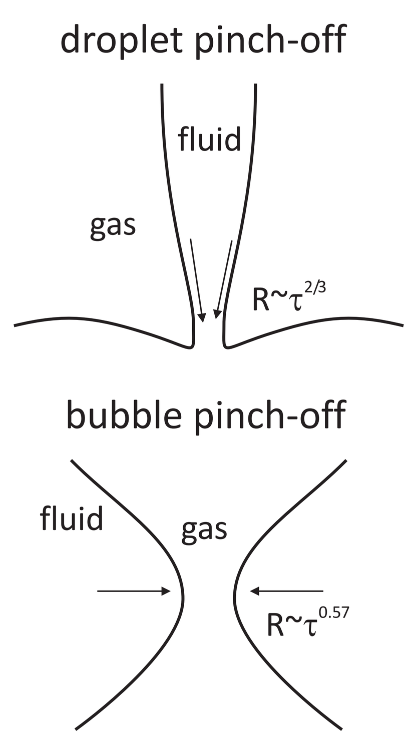


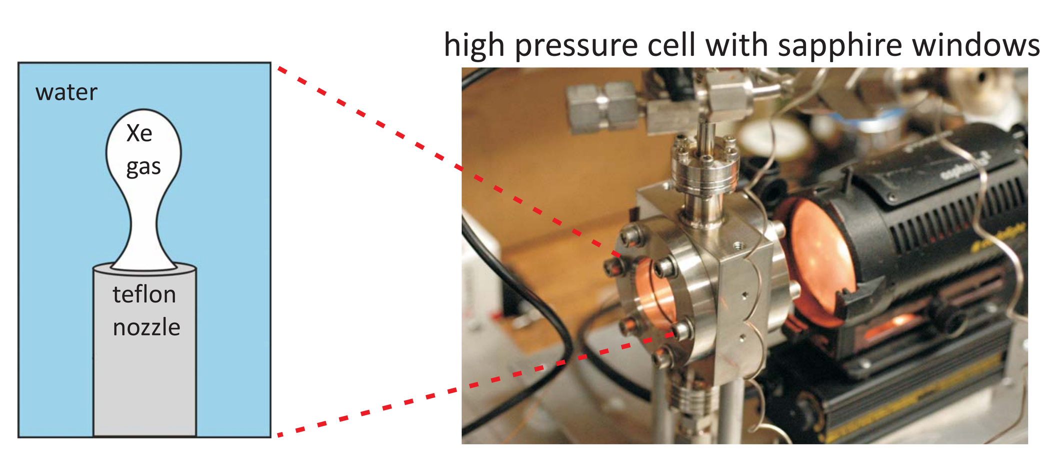
The breakup and eventual pinch-off of inviscid droplet and bubble are two complementary problems with very different dynamics.

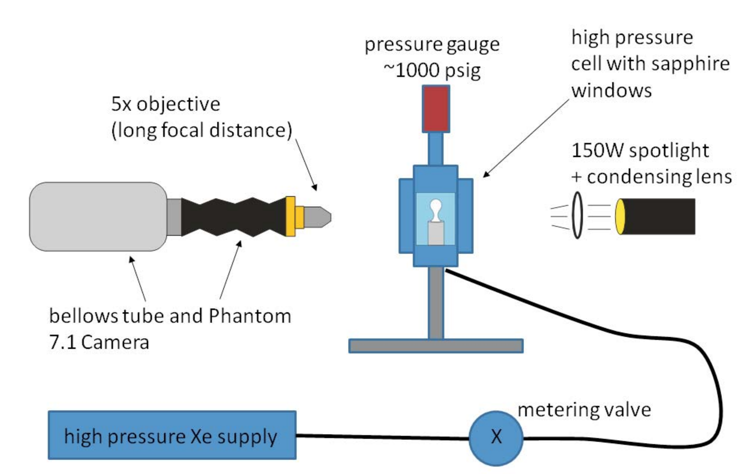
In fluid pinch-off the interface has an overturned profile and the minimum neck radius shrinks in a power-law fashion with an exponent of 2/3, while the minimum neck radius of a bubble shrinks with an exponent ~0.57, and asymptotically approaches 1/2.

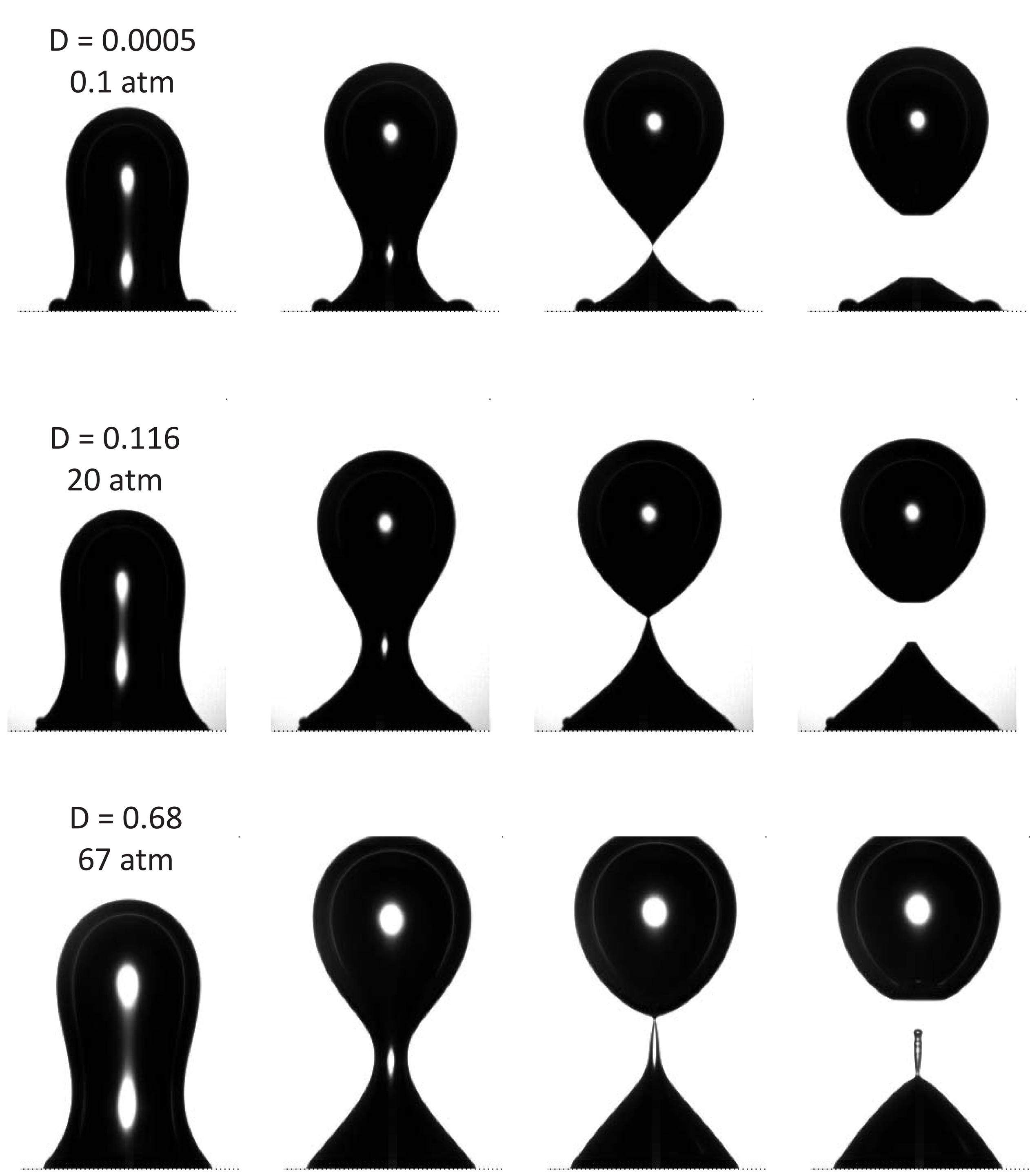
Previously* we have explored the role of fluid viscosity in the pinch-off of air bubbles in water, our goal here is to explore the transition from bubble to droplet pinch-off using experiments and numerical simulations.

*J. C. Burton, R. Waldrep, and P. Taborek. Physical Review Letters 94, (184502).

Xenon Bubbles in Water - Density Effects







The purpose of this experiment is to explore the effects of density on the pinch-off of submerged bubbles.

Unlike a liquid, the density of a bubble can be changed dramatically simply by increasing the pressure.

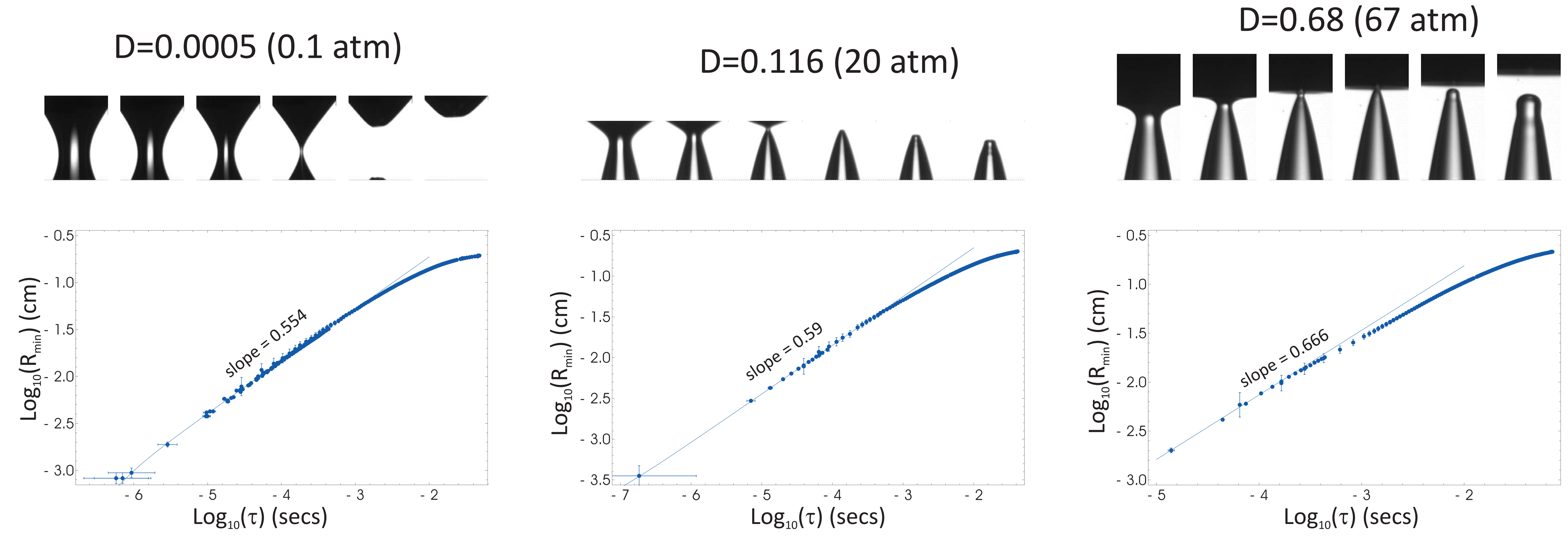
Gaseous xenon was used to change the density ratio D of the system from $D \cong 0$ to $D \cong 0.7$.

A specially designed high pressure cell (~100 atm) was constructed with sapphire windows in order to optically view the bubbles with a high-speed camera.

The three sequences on the left show the evolution of the xenon bubble at three density ratios. The diameter of the bubble is ~6mm.

At high densities, the geometry of the pinching-region is similar to fluid pinch-off.

Time Dependence of Collapse



Measurements of the minimum neck radius (R_{min}) as a function of the time remaining until pinch-off (τ) for three different densities. The pictures are taken from the high-speed videos (~100,000 frames per second) and are zoomed in on the pinch-off region. Our resolution is ~ 2.4 μm/pixel. In general, we see a smooth transition between bubble and droplet pinch-off, and at intermediate densities, the geometries and exponents that we observe fall in between that of bubble and droplet pinch-off.

Numerical Simulations of Bubble Pinch-off

The numerical simulations of pinch-off are performed using inviscid, boundary-integral techniques for initial shapes started from rest.

The density ratio between the interior and exterior fluid can be adjusted. On the immediate right, we see a bubble with a density ratio of D=0.001. As we increase the density ratio to D=0.166, we see an extremely unstable overturned interface. At higher density ratios (D=0.68), we see something qualitatively identical to that of droplet pinch-off.

The power-law exponents for each case is shown in the lower graphs. For D=0.001, we see that there is a transition in the exponent at short times, accompanied by the formation of a satellite bubble.

The data for D=0.166 is more difficult to interpret due to the complex structure, and the D=0.68 case produces a nearly perfect 2/3 power-law.