A drop of spectroscopy

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The phenomenon

Droplet coalescence in a bath can be delayed by oscillating the bath vertically with an amplitude A and a frequency f between 20 Hz to 400 Hz : the droplet bounces on the interface [1,2]. The droplet deformation is enhanced by considering a low viscosity droplet on a high viscosity bath.

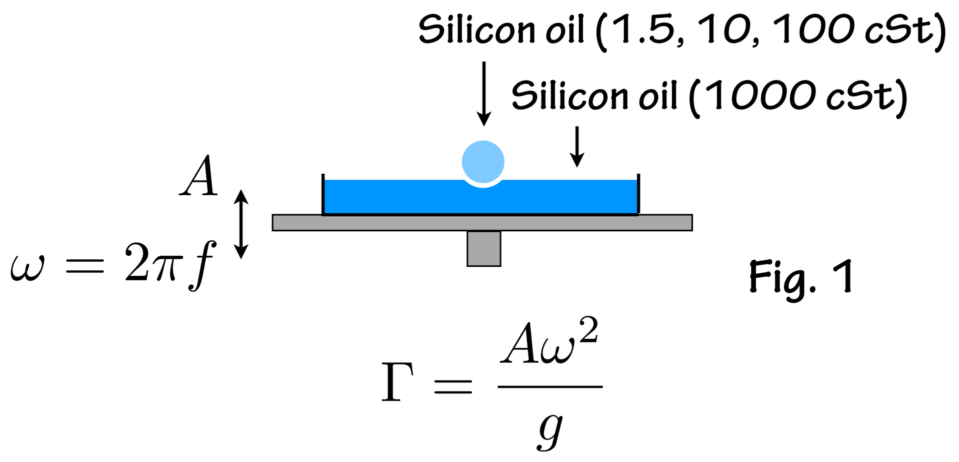
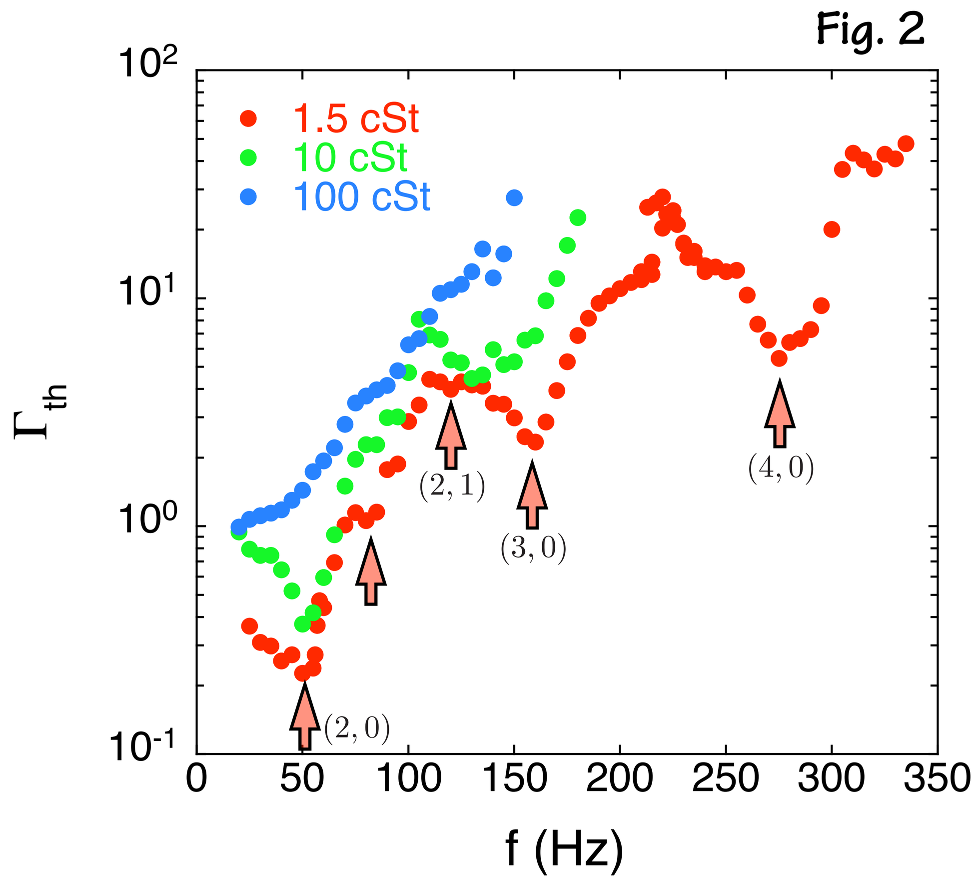


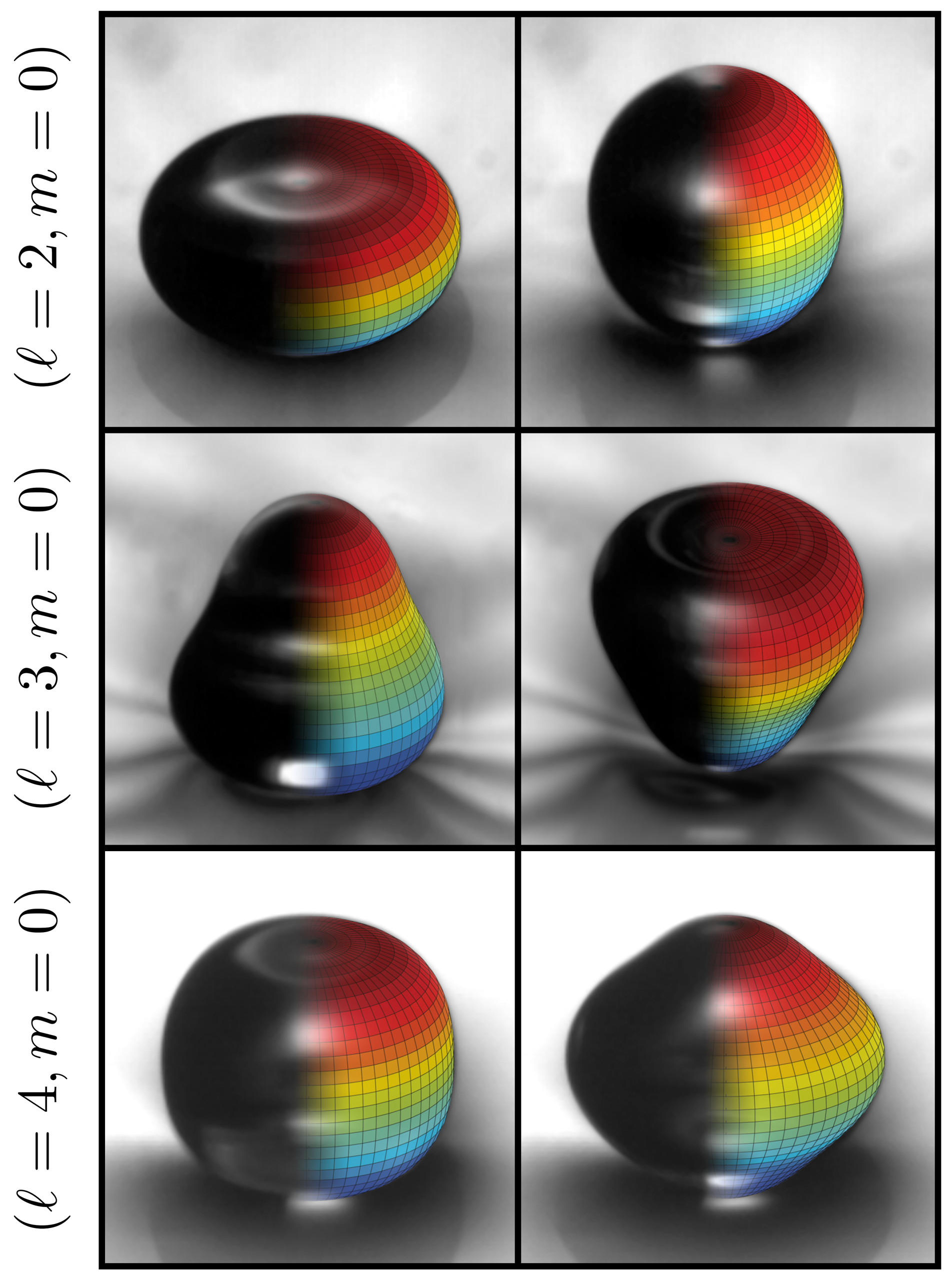
Fig. 1

Bouncing threshold

The bouncing of the droplet only occurs when the reduced acceleration Γ is higher than a threshold value Γ_{th} which depends among other on the forcing frequency f, the droplet radius R, and the viscosity ν. In Fig. 2, the threshold Γ_{th} is represented as a function of the forcing frequency for various droplets viscosities. For high viscosity droplets, Γ_{th} increases monotonically and scales as f^2 [1]. For low viscosity droplets, $\Gamma_{th}(f)$ presents extrema that suggest a resonance phenomenon.



Resonant modes



Spherical harmonic solution superposed to the experimental pictures.

Fig. 3

Specific modes are observed at minima of the $\Gamma_{th}(f)$ curve. They are analogous to the natural modes of deformation expressed by Rayleigh in terms of spherical harmonics $Y_{l,m}$. Modes m = 0 and ℓ = 2, 3 and 4 are observed (Fig. 3).

The droplet may be considered as a damped driven harmonic oscillator :

- surface tension is the restoring force,
- viscosity is the damping process.

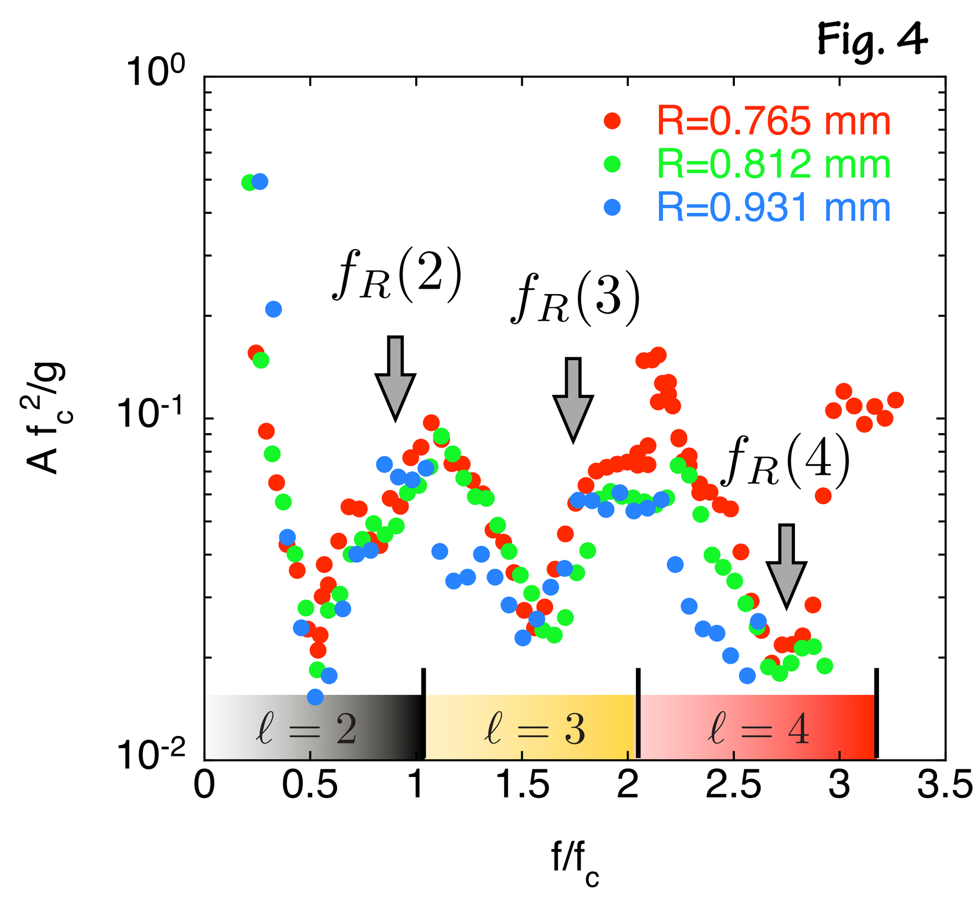
Natural frequencies scale as the capillary frequency f_c :

$$f_c = \sqrt{\sigma/m} \quad \text{with} \quad m = 4\pi/3\rho R^3$$

More precisely, the dispersion relation specifies the natural " Rayleigh" frequency f_R related to a ℓ-mode :

$$\left(\frac{f_R(\ell)}{f_c}\right)^2 = \frac{1}{3\pi}\ell(\ell-1)(\ell+2)$$

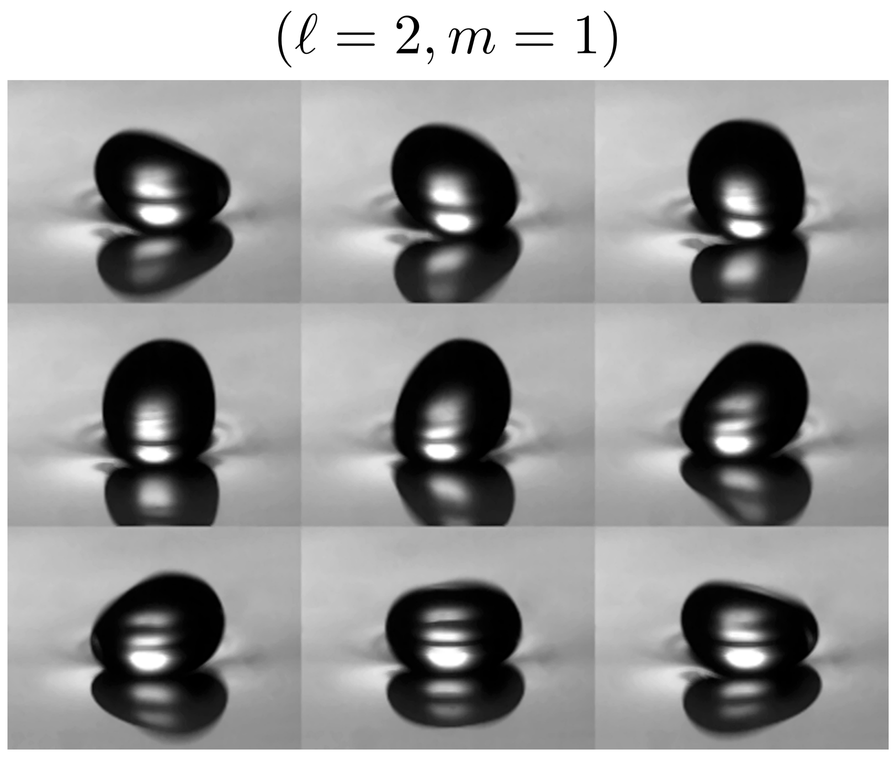
Usually, $f_{Resonance}(\ell) = \alpha f_R(\ell)$; α being a multiplication factor which depends on the geometry of the excitation [4, 5].



When $f = \alpha f_R(\ell)$, the droplet stores the whole energy provided by the oscillating bath in deformation and dissipates it due to enhanced internal motion : the droplet resonates. It is impossible to make the droplet bouncing in the mode (ℓ,m=0), Γ_{th} should diverge. Experimentally, a maximum is found at $f = \alpha f_R(\ell)$ as m ≠ 0 modes are excited.

Displacement mode : The Roller

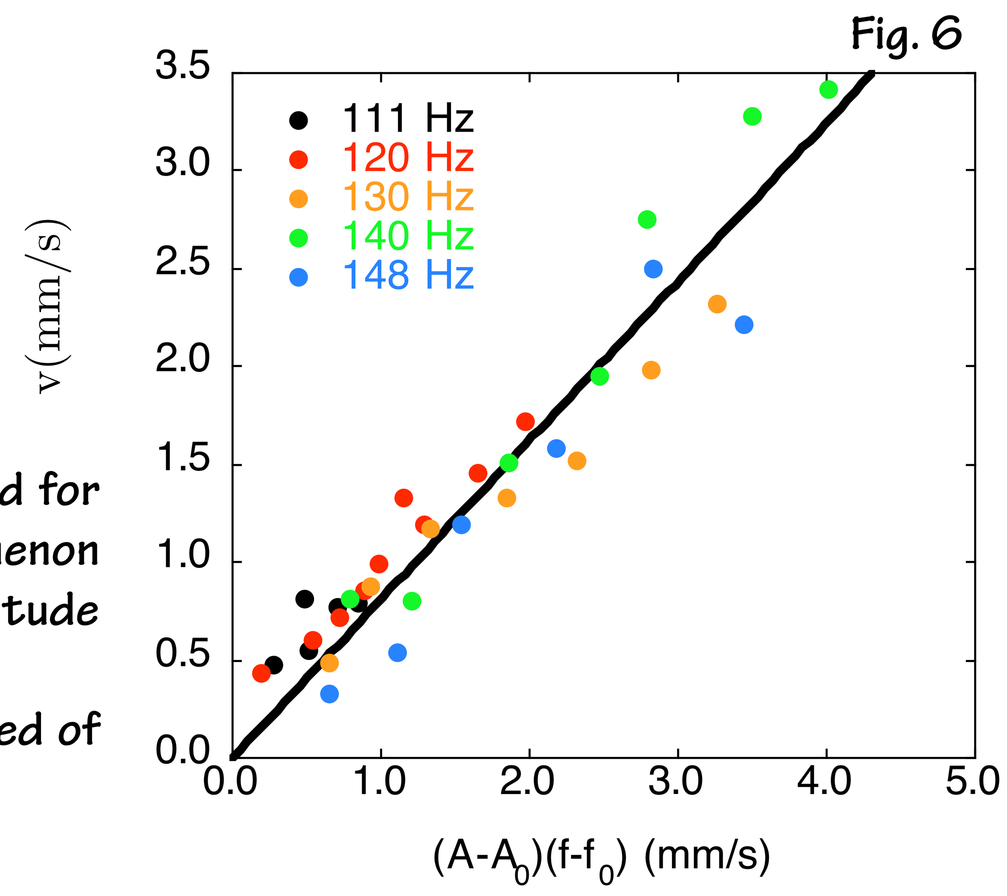
$(\ell = 2, m = 1)$



Snapshots of a Roller — Fig. 5

At the first maximum of the $\Gamma_{th}(f)$ curve (115 Hz for 1.5 cSt droplet), the droplet moves along a linear trajectory. The mode of deformation, related to ℓ = 2 and m = 1, induces the internal rotation of the liquid.

The initial horizontal speed v of the droplet has been measured for various frequencies and amplitudes of the bath. The phenomenon only occurs above a cut-off frequency f_0 = 103 Hz and an amplitude threshold A_0.
The speed v scales with $(A-A_0)(f-f_0)$, the reduced maximum speed of the bath.



Conclusion

1. Extrema of the bouncing threshold curve of low viscosity droplets are related to a resonance phenomenon.
2. A model which explains the first minima for the mode of deformation (ℓ = 2, m = 0) has been developed in [3].
3. A new mode of displacement for low viscosity droplets has been discovered that can be generalised to a wide range of droplet sizes, the Roller. This self-propelled mode allows manipulation without contact.

References

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