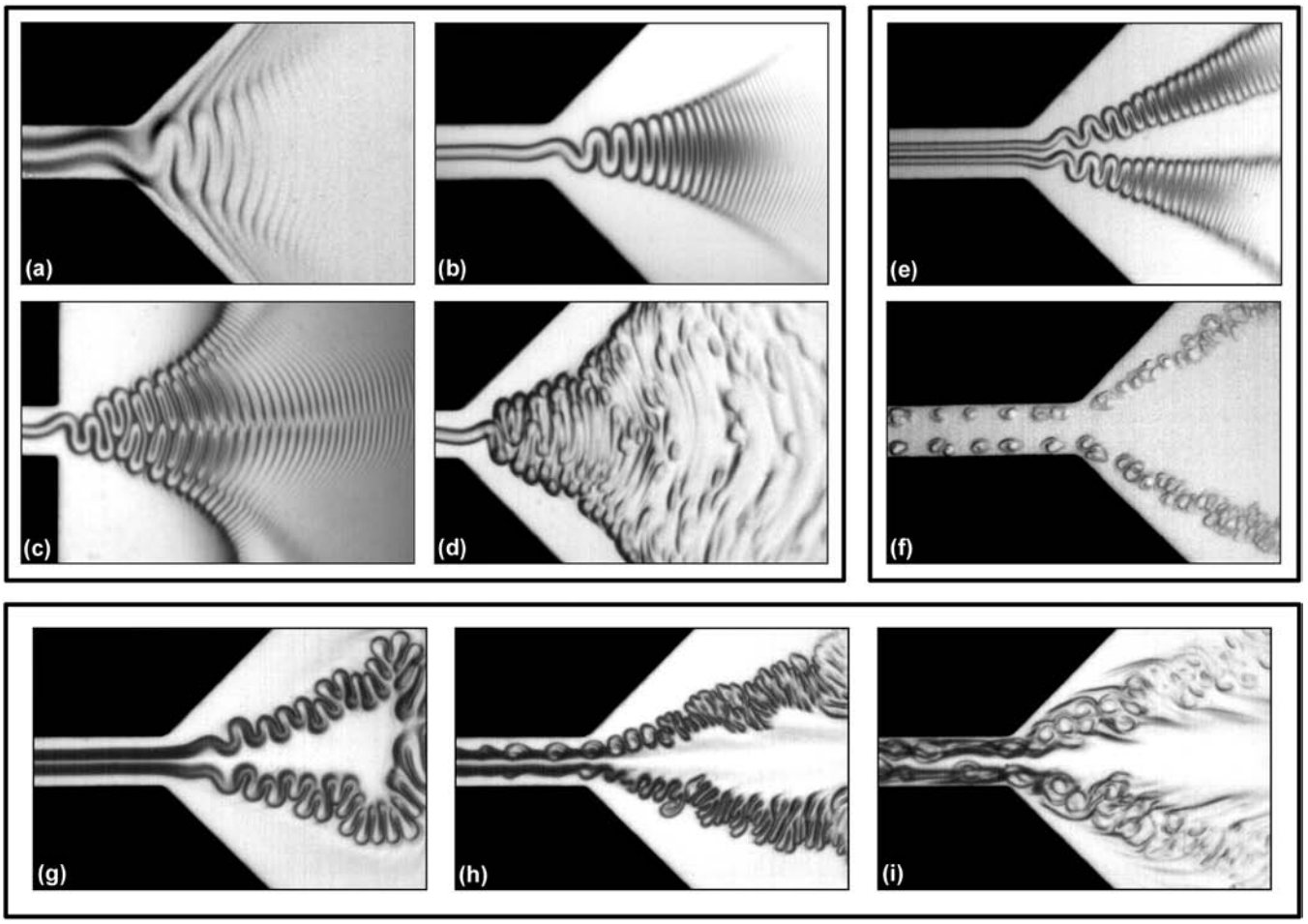

FIG. 1. Folding morphologies of miscible viscous threads. Liquids are indexed symmetrically from the center of the channel outwards. Volume flow rates Q_i are in μl/min; viscosities η_i are in cP. (a) Single folding (strong diffusion): $Q_1=5$, $Q_2=10$, $\eta_1=500$, $\eta_2=0.5$. Striations of high viscosity liquid from the folds are convected outside the folding envelope. (b) Single folding (weak diffusion): $Q_1=5$, $Q_2=25$, $\eta_1=500$, $\eta_2=6$. (c) Subfolding of a thread (period doubling): $Q_1=12$, $Q_2=50$, $\eta_1=200$, $\eta_2=0.5$. (d) Heterogeneous (chaotic) deposition of a thread into a pile: $Q_1=20$, $Q_2=150$, $\eta_1=500$, $\eta_2=0.5$. (e) Multiple folding: $Q_1=5$, $Q_2=5$, $Q_3=15$, $\eta_1=\eta_3=6$, $\eta_2=500$. The threads fold initially in phase. (f) Viscous swirls: $Q_1=20$, $Q_2=1$, $Q_3=20$, $\eta_1=\eta_3=6$, $\eta_2=500$. (g)–(i) Viscous dendrites: $Q_2=10$, $Q_3=25$, $\eta_1=0.5$, $\eta_2=500$, $\eta_3=6$. (g) $Q_1=15$, (h) $Q_1=20$, (i) $Q_1=50$. The least viscous liquid in the center inhibits complete folding, thereby creating dendritic fingering and swirling morphologies (enhanced online).

Folding of viscous threads in microfluidics

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We investigate microfluidic flow morphologies of miscible silicone oils having large viscosity contrasts. At small scales, viscosity dominates the flow behavior and strongly influences the flow patterns. To minimize dissipation, less viscous liquids tend to lubricate more viscous liquids, allowing for the formation of miscible, yet well-defined, threads by hydrodynamic focusing. Once formed, threads emerge from straight square microchannels of width and height $h=100$ μm (micrographs, left side) and encounter a divergence in the channel width, causing a viscous folding instability.[1] By adjusting the flow rates, the viscosities, and the injection scheme, a very large variety of morphologies can be produced. Subfolding is observed in a transition to chaotic heterogeneous folding. Off-center threads in a straight channel experience a shear-induced torque that results in a swirling instability, leading to the detachment and tumbling of viscous swirls.[2] In a more complex configuration using three different viscosities, branched dendritic fingering structures form.

[1]T. Cubaud and T. G. Mason, "Folding of viscous threads in diverging microchannels," Phys. Rev. Lett. **96**, 114501 (2006).
[2]T. Cubaud and T. G. Mason, "Swirling and multiple folding of viscous threads in microchannels," Bull. Am. Phys. Soc. **51**, 901 (2006).

