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AIP Physics of Fluids

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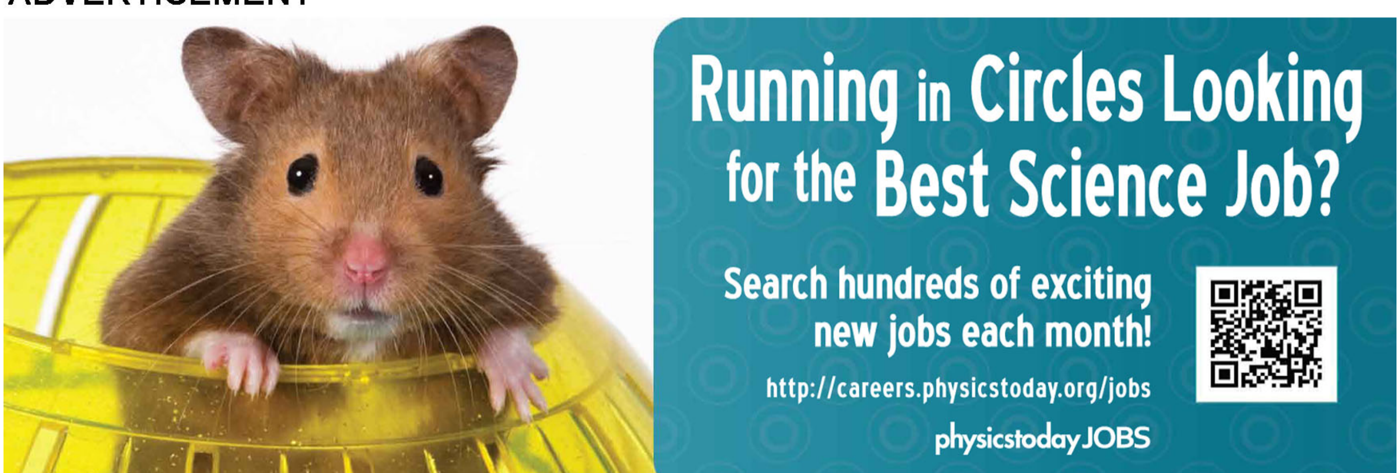

FIG. 1. Formations made by an oil droplet falling through alcohol from drop heights of 25 mm (top) and 50 mm (bottom).

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The elegant patterns formed by fluid droplets falling through a dissimilar liquid were first studied over a century ago.[1] The emerging patterns are driven by hydrodynamic instabilities set up by velocity and density gradients between the liquids. We perform experiments using 3 mm droplets of naphthenic oil released from two heights (25 mm, 50 mm) into isopropyl alcohol. The oil is denser than and miscible in the alcohol ($\rho_{oil}/\rho_{al}=1.17$), which results in the drop descending and eventually diffusing. Images are captured with a digital SLR camera looking at a black background through the tank of alcohol, which is lit from both sides. The difference in index of refraction between the oil and alcohol causes the edges of the oil droplet to appear brighter than the surrounding fluid.

For lower drop heights (top sequence of Fig. 1), the oil droplet behavior resembles that described for miscible drops placed on the surface of a lighter fluid.[2] Initially, large velocity gradients between the droplet and the alcohol cause the droplet to roll up into a vortex ring, which grows into an oscillatory shape as a result of Rayleigh–Taylor instabilities. The unstable ring stretches and then fragments into smaller and smaller rings, which creates cascading tiers of vortex rings, until diffusion takes over.

When released from 50 mm above the free surface (bottom sequence of Fig. 1), the droplet does not immediately cascade into tiers of vortex rings. Initially viscous shear on the outside layer of the oil droplet causes it to form into an upside-down "wine glass" shape. The thin sheet of oil rolls up into the first vortex ring, which expands radially as the droplet continues to descend. The droplet shape elongates as its denser core descends faster than the vortex ring. A second central vortex ring forms at the lowest point of the droplet, and then another ring follows suit thereafter. Each ring remains attached to the others by a thin oil sheet. Rayleigh–Taylor instabilities begin to set up the vortex ring cascade as witnessed in the top image sequence, which ultimately occurs for all of the central rings.

[1] J. J. Thomson and H. F. Newall, "On the formation of vortex rings by drops falling into liquids, and some allied phenomena," Proc. R. Soc. London **39**, 417 (1885).
[2] S. Residori, P. K. Buah-Bassuah, and F. T. Arecchi, "Fragmentation instabilities of a drop as it falls in a miscible fluid," Eur. Phys. J. Spec. Top. **146**, 357 (2007).

