Liquid crystal bridges

MILIND P. MAHAJAN, MESFIN TSIGE, P. L. TAYLOR
and CHARLES ROSENBLATT*

Department of Physics, Case Western Reserve University, Cleveland, Ohio 44106-7079, USA

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The liquid crystalline material octylcyanobiphenyl was studied in the form of bridges spanning the space between two solid supports in an immiscible water bath. In the nematic phase the bridge collapses above a certain length-to-diameter ratio, consistent with the behaviour of ordinary Newtonian liquid bridges. The smectic A phase, however, exhibited the formation of very long, stable columns as a consequence of its non-Newtonian behaviour.

1. Introduction

A liquid bridge is composed of a liquid which spans the gap between two solid supports. The bridge may be in vacuum or air, or in an immiscible fluid. Although liquid bridges can be constrained by a variety of different boundary conditions, perhaps the most commonly studied bridge is bounded at the two ends by a pair of equivalent, colinear, right circular cylindrical rods. In this way a bridge in a gravity-free or gravity-compensated environment may adopt a cylindrical shape, with diameter d equal to that of the support rods and length L equal to the separation between the ends of the rods. This condition, of course, applies only to bridges whose volume $V=\pi d^2 L/4$; if material were withdrawn from the bridge, its shape would be pinched in the centre, as the length is constrained by the rod separation and the diameter is constrained by the necessity to wet the ends of the support rods. During the nineteenth century both Rayleigh and Plateau showed theoretically that a cylindrical liquid column in a gravity-free environment is stable against radial shape fluctuations as long as its length to diameter ratio R—this is sometimes known as the 'slenderness ratio'—is less than π [1–3]. For $R \geqslant \pi$ the radial shape fluctuations are unstable, and the bridge catastrophically pinches off and breaks into two pieces. In the intervening years theorists have examined the equilibrium shapes and stability of liquid bridges in the presence of gravity. Under gravity, of course, a vertically-oriented bridge would tend to sag, although it would not collapse for a sufficiently small slenderness ratio R. (For the purposes of this paper, R is defined as the ratio of the bridge length to the bridge diameter *at the two bounding support rods*, i.e. the diameter of the rods themselves.) If the gravitational force could be continuously varied, the originally cylindrical bridge would tend to deform, although both R and the volume of the bridge would remain unchanged. For sufficiently large R the bridge would collapse, although this would occur at $R<\pi$ if gravity were present [4–8]. In order to model this behaviour, it is necessary to introduce the dimensionless Bond number B, viz.

$$B \equiv \frac{g\Delta\rho d^2}{4\sigma}. \qquad (1)$$

Here g is the gravitational acceleration, $\Delta\rho$ is the density difference between the bridge and the surrounding medium, d is the diameter of the two end supports, and σ is the surface tension of the bridge. The parameter B relates the relative importance of gravitational energy to the surface tension. The case $B=0$ corresponds to a completely gravity-free or gravity-compensated environment, such as would obtain in outer space, in a 'drop tube' on Earth, or in a perfectly density-matched liquid bath. Variation of effective gravity may be accomplished utilizing the liquid bath by controlling the Bond number through $\Delta\rho$. For many years this two-immiscible-fluid approach has been the experiment of choice, and is performed in a 'Plateau tank' [6–11]. Often, however, it is necessary to study the fluid bridge in air or vacuum, which requires a space-borne environment [12] or a very tall evacuated drop tower [13] that provides several seconds of free-fall. More recently we demonstrated that a paramagnetic liquid (water doped with the paramagnetic salt $MnCl_2.4H_2O$) could be levitated against gravity in a strong magnetic field gradient [14]. For that experiment the effective Bond number was redefined as $B\equiv(g\Delta\rho-\chi H\nabla H)d^2/4\sigma$, where $\Delta\rho$ corresponds to

*Author for correspondence.