Direct Observation of Unidirectional Rotation of Cholesteric Droplets Subjected to a Temperature Gradient

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ABSTRACT

When a droplet of chiral liquid crystals (LCs) is subjected to a temperature gradient, the droplet unidirectionally rotates its texture along the heat flux. The optically detected textural rotation indicates that the constituent LC molecules rotate their direction without changing the center of gravity or the rotation is accompanied by translational molecular motion. Although the difference is simple, distinguishing them is not easy. A recent experiment showed that a micron-sized particle adhered onto a rotating LC droplet exhibited a steady rotation around the droplet center, which suggests that the heat flux could drive the rigid-body rotation of the cholesteric droplet.

INTRODUCTION

From windmills to molecular motors, there are many rotary devices driven by various linear flows. One such example can be found in chiral liquid crystals (LCs), through the Lehmann effect [1]. About a century ago, O. Lehmann, using a home-made polarizing microscope, discovered that a cholesteric LC droplet subjected to a temperature gradient unidirectionally rotated its texture along the heat flux. This textural motion has been interpreted to mean that the constituent LC molecules rotate their direction without changing the center of gravity, i.e., pure director rotation [2]. But it is also possible that the molecular rotation is accompanied by hydrodynamic flow, causing a rigid-body rotation of the droplet. From an academic point of view and also for future applications, it is desirable to distinguish the types of motion and, if possible, to control them. One general method to detect hydrodynamic flow in an anisotropic media is fluorescence recovery after photobleaching (FRAP). Although FRAP has been applied to rotating cholesteric droplets, up to now a convincing result has not been obtained [3, 4]. Another conventional method to visualize flow fields is to disperse marker particles in a fluid and to trace their motion. In this report, we present a recent experiment investigating the rotation of cholesteric droplets under a temperature gradient by tracing micron-sized particles adhered onto those droplets [5].

Unidirectional rotation of particles attached to cholesteric droplets driven by heat flux

A cholesteric LC compound containing a small number of micron-sized particles is sandwiched between glass plates coated with PMMA (poly(methyl methacrylate)). In a coexisting temperature region of the cholesteric and isotropic phases, hemispherical cholesteric droplets form in the isotropic phase, and the tracer particles tend to adhere on the surfaces of the droplets as schematically shown in Fig. 1. Under optical microscopy with linearly-polarized incident light, the droplet is observed as shown in Fig. 2, in which the stripe texture corresponds to the helical structure whose axis is denoted by the white arrow. When the sample was subjected to a temperature gradient in the direction shown in Fig. 1, the helical axis exhibited clockwise rotation. In Fig. 2, one can notice that the blue particle adhered onto the droplet rotated with the helix in phase without disturbing the texture. More quantitatively, Fig. 3 shows the temporal angu-

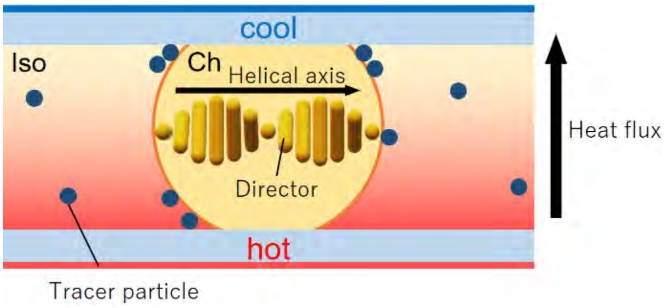

Fig. 1: Schematic figure of the sample. The cholesteric droplet is coexisting with the isotropic phase and most of the tracer particles adhere onto the droplet's surface. Along the temperature gradient, heat is transferred from the bottom to the top.

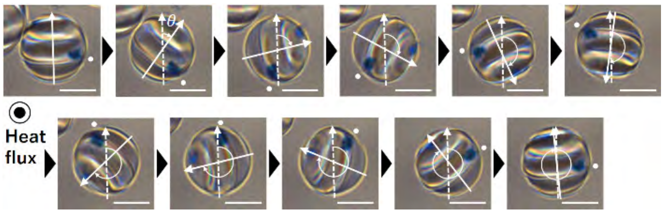

Fig. 2: A cholesteric droplet subjected to a temperature gradient of 4mK/μm, observed by optical microscopy. The white arrow indicates the helical axis and the white bar shows 10 μm. The images were taken every 1 min.

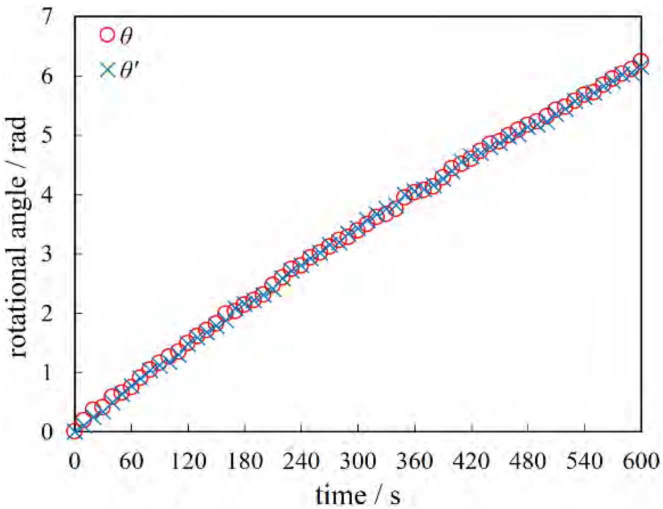

Fig. 3: The temporal changes of the angle of helical axis θ and that of the particle θ'.

lar changes of the helical axis and the particle, which perfectly overlap each other. The fact that the particle rotated in phase with the helix without causing any orientational distortion suggests that the droplet rotated as a rigid-body.

Unusual flow fields

Tracing particles is a simple method to investigate flow fields. However, attaching micro-particles on the cholesteric droplets is not so simple because the interfacial tension between the LC and isotropic phases is small. The careful selection of an appropriate material enabled the particles to adhere onto the droplets and also to disperse in the isotropic phase, which visualized the flow fields not only in the droplet but also in the isotropic phase. Contrary to one's expectation, the particles fluctuating in the isotropic phase did not show any directional motion, even when near the rotating droplets. Since the Reynolds number of the system is small, if the isotropic phase behaves as usual fluid, the rotating droplets should generate a rotational flow in the vicinity of the surfaces. To the puzzling question regarding why the flow was not detected in the isotropic phase, there is no certain answer at this stage, but the boundary condition at the cholesteric-isotropic interface may not be usual. As another possibility, it is pointed out that pure director rotation is able to transport particles by sliding, in a way similar to motor proteins. To reveal the full picture regarding the rotation of cholesteric droplets, further investigation is necessary.

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