Toroidal Droplets made with Nematic Liquid Crystal

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Overview

Bubbles and droplets existing in nature are found in a spherical shape. This is due to surface tension acting on them to minimize the surface area for a given volume. It is well known, however, that bubbles and droplets can be made into other shapes given that forces are applied to oppose the surface tension. Consider, for example, large bubble-makers that can be found outside of a children's toy store. As the child runs around with the thin layer of film attached to the bubble-maker, the air causes the bubble to make shapes that are usually non-spherical. But if the bubble comes off of the bubble-maker the bubble will assume a spherical shape provided the bubble doesn't pop. Dr. Alberto Fernandez-Nieves and Ekapop Pairam have developed a useful and practical method of creating stable toroidal droplets in order to study their properties. A continuous phase with low viscosity is injected into a rotating viscoelastic continuous phase. The viscous force of the outer phase acting on the inner phase allows the inner phase to form a jet. After the jet has formed a loop due to the rotation and has achieved sufficient volume, the newly formed toroidal droplet will be stable.

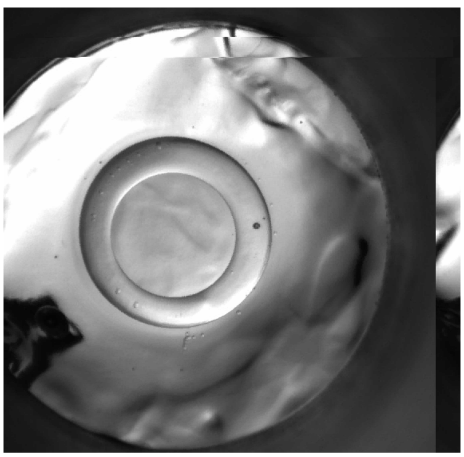

Figure 1: stable torus

This technique will be used to examine the defects of toroidal droplets formed by nematic liquid crystals. Nematic liquid crystal consists of rod-like molecules. In the absence of constraints, they will align themselves parallel to one another allowing us to define their orientation. The orientation of the liquid crystals is given by the director, which is a bi-directional vector assigned to a region in which it can be well defined. When nematic liquid crystals are confined to a curved surface, the topological constraints imposed by the surface causes a distortion in the molecular orientation. In certain regions, the molecular orientation is such that the director cannot be defined. Such regions are called defects, and they can be viewed optically. An interesting application of studying defects is they can be functionalized and made to serve as "bonds" which would allow the fabrication of self-assembling particles with fascinating properties. Dr. Fernandez-Nieves's lab has already studied the defects on a sphere, and they are ready to examine more interesting geometrical objects (i.e. the torus). Unlike the sphere, it is geometrically possible that the liquid crystals constrained to the torus contain no defects. It is possible, however, that defects

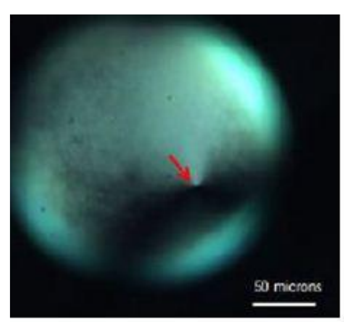

Figure 2: defect on a sphere

are energetically favorable and will form anyway.

Objectives

My project will be to assist the lab in determining whether defects are present on the torus and, if there are defects, their properties. Underlying mathematical theory associated with the topology of the torus gives us an idea about what properties we can expect for the defects. For example, we know that if there are defects, the sum of topological charges of the individual defects must equal the Euler characteristic of the surface. The Euler characteristic can be expressed in terms of the genus g of the surface: $\chi = 2(1 - g)$. For the torus, $g = 1$. Hence, $\chi = 0$. This implies that we expect the sum of topological charge to be zero.

There are even more things to learn. For instance, where will the defects be on the torus? And, a more theoretical question but very interesting, how does the interplay between the geometrical constraints of the torus and the energetic constraints of the physics determine the properties of the defects? In the process of trying to answer this question, there are many things to be discovered. For example, there are two distinct curvatures associated with the torus that can be adjusted: the inner tube radius and the radius of a cross section. I would like to know what kind of effect adjusting the curvatures would have on the defects. I hope, by answering a few of the others the lab has proposed, to advance our understanding of materials in nature existing in non-spherical shapes so that the physics of these objects may be better understood.

Techniques

The method described in the overview will be used to generate a stable liquid crystal torus. Polarized optical microscopy will then be used to examine any defects found on the torus.

Co-Mentor

Physics graduate student Ekapop Pairam will be a co-mentor assisting me with this project.

References:

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Pictures taken from Soft Condensed Matter Lab website:
http://phweb.physics.gatech.edu/research/fernandez/index.html