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MCEN 5151
Team Photo 2
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1 Introduction

This image was created as a result of the second team project for the Flow Visualization course at the University of Colorado at Boulder. The image displays the work of the Liquid Crystal Group of the University of Colorado at Boulder's Department of Physics, lead by Noel Clarke. Renfan Shao, a Research Associate in Noel Clarke's group in the Experimental Condensed Matter Physics, guided us through the steps to conduct the experiment that produced the image. The goal was to visualize phase changes of a single layer of liquid crystals through a microscope and with crossed polarizers, which show the shapes and the colors in incredible detail. The final image is shown in Figure 1.

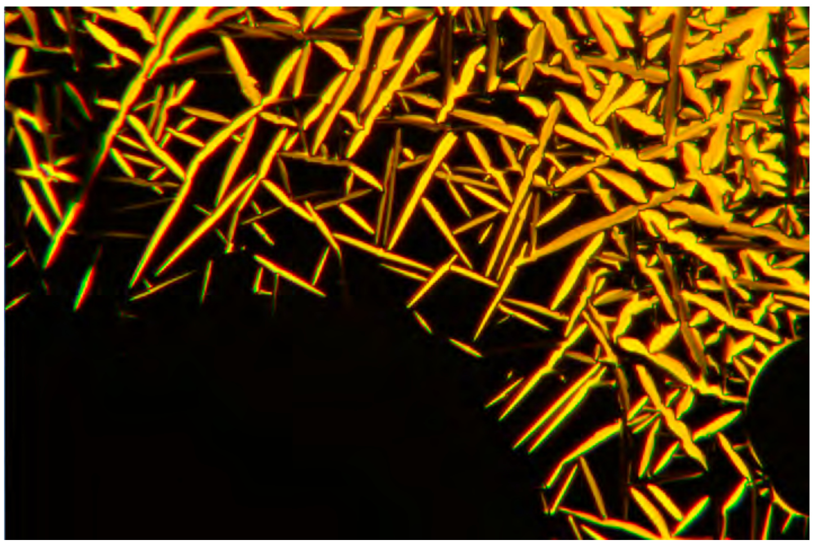

Figure 1: Final Image

The study of liquid crystals is interesting because their occurrence "is closely associated with the molecules of life, such as peptides, DNA, phospholipids, steroids and carbohydrates. All these molecules or derivatives of these molecules can form LC mesophases (mesophases = inter-mediate states between the liquid and crystalline state) under special conditions of temperature (thermotropic LC phases) and concentration (lyotropic LC phases)" [1]. In this experiment, a variation of temperature and therefore phase change is used to alter the orientation of the molecules.

2 Experimental Procedure, Setup, and Visualization Techniques

In this experiment, "thin liquid crystal sample cells [are] placed between two crossed polarizers under an optical microscope, [and] a variety of textures and birefringence colors will be observed" [2]. By taking advantage of the optical properties of liquid crystals, unique images can be created. The primary property that "allows for the visualization of the macroscopic molecular orientation [... is the] anisotropy of the refractive index, or birefringence" [2] of the liquid crystal. The anisotropy is caused by "the combination of long range order (as in crystals) and mobility (as in liquids)...[which can be altered] under the influence of external stimuli" [1] such as temperature change. Therefore, microscopic observations often times "give enough information to determine the structure even if a well-aligned domain is not obtained" [2].

The molecule used in the image is the bent-core liquid crystal shown in Figure 2, which was created specifically for Dr. Clarke's laboratory. The bent-core molecules are shaped as shown and are distinct from traditional rigid-chain liquid crystals that "are functionalized with one or two flexible hydrocarbon tails" [1]. Bent-core liquid crystals are the focus of the research at Dr. Clarke's laboratory.

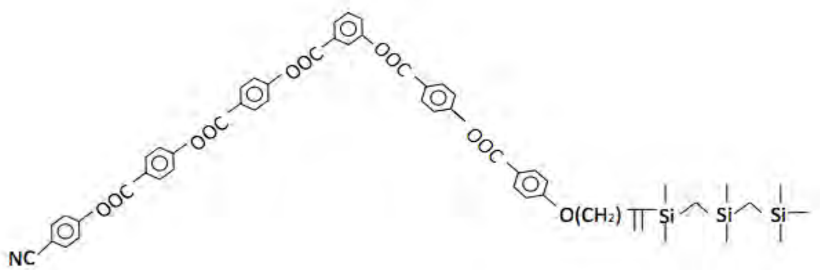

Figure 2: Molecular structure of examined liquid crystal. Diagram made by Jennie Jorgenson.

The sample was prepared by adding a small dash of the liquid crystal to one of the slots on the sample slide, shown in Figure 3, from the end of a metal stirrer.

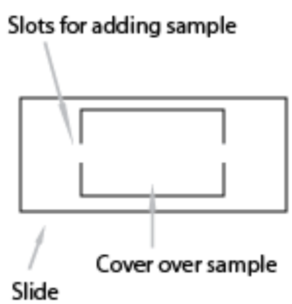

Figure 3: Slide used to hold sample

The slide was allowed to warm on the heat strip to about 160 degrees Celsius, and remained on the heat as the sample was added. As the sample heated, it progressed to fill the area under the cover. Because of the cost of the sample we did not keep filling the cover until full, so that the entire slide was not filled. Once the sample melted into the slide and became transparent, it was removed and two small wires were attached to the slide with scotch tape to later provide a current through the sample. If desired, the thickness of the liquid crystal layer could be calculated given the index of refraction of the liquid crystal and the wavelength of the light [3]. The sample was then placed in the microscope where the temperature and voltage through the slide could be controlled. The temperature was then raised to just over 160 degrees Celsius, which is the transition temperature corresponding to the change to a Columnar (Col) phase for the observed liquid crystal. A schematic is shown in Figure 4 in order to illustrate the changes that occur in the orientation in the various Smectic and Columnar phases. The various phases of the molecule, which occur at different temperatures, have been classified by their optical properties [4].

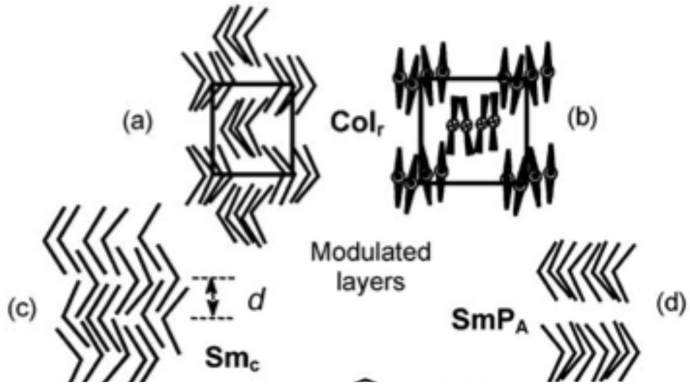

Figure 4: Sample of orientations of bent-core molecules in various phases [1]

During this phase change, the view in the microscope transitioned from a black image to the one captured. A 'blank' image is black because of the cross polarizers. From the known orientation of the cross polarizers, the angle of the orientation of the molecules can be determined, because only molecules at a certain alignment will be shown. In the case of this experiment, particles at 45 degrees from the counter-clockwise from the horizontal will be shown the brightest. Other orientations may still be shown but take other 'shapes' in the image.

The experimental setup consisted of a microscope with a camera attached to it, and a temperature and voltage controlled sample holder. The cross polarizers and light source were also attached as shown in Figure 5.

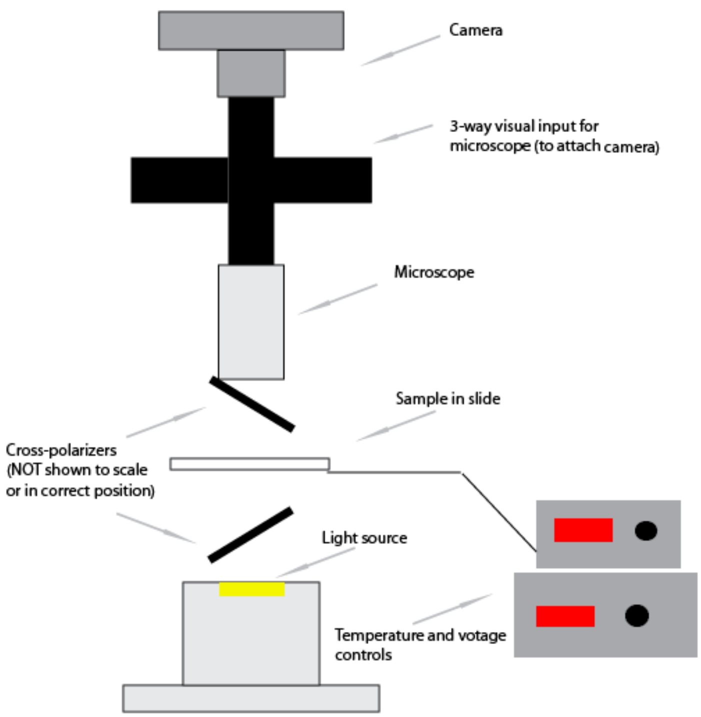

Figure 5: Experimental Setup

As previously mentioned, when viewed by the naked eye, the sample is not visible. The experimental setup makes it possible to see the liquid crystals as shown in the image, and the visualization is realized by altering the sample temperature and by viewing it through cross polarizers and backlighting.

3 Photographic Technique

The photographic technique was constrained by the experimental apparatus, primarily the magnification of the microscope and the cross polarization. The image size was also constrained by the apparatus. The only possibility to change the image was by altering the temperature, and therefore the phase of the sample.

The camera was a Nikon D5000 digital. The focal length and the F-stop shown in the data fie were 0, which seems incorrect, but due to the mounting of the camera I was unable to access it. The exposure time was 1/4. The original and final images are 4288 x 2848 pixels. The actual size of the sample slide was about 15x15 mm, and the magnification was 50x. Photoshop editing was limited to adjusting the contrast and brightness to better show the molecule contours. The original image is shown in Figure 6.

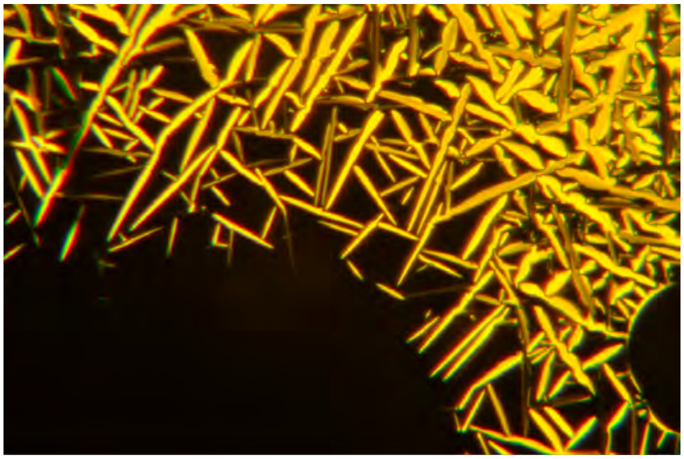

Figure 6: Original Image

4 Conclusion and Remarks

The image reveals the very interesting phenomenon of liquid crystal phase change, and the orientation changes that occur as a result. The visualization technique, namely the cross-polarization and magnification, depict the molecules in a unique and very visually appealing way. I therefore am very fond of the image and think that it does an excellent job showing the physical make up of liquid crystals. I would like to better understand all the research behind the various phases and molecule shapes, but these are extremely specialized fields. The image could be expanded by comparing various molecule shapes or by altering the voltage and therefore the color.

[1] R. Amaranatha Reddy, C. Tschierske. Bent-core liquid crystals: polar order, superstructural chirality and spontaneous desymmetrisation in soft matter systems, Journal of Materials Chemistry. Published online 22 September 2005, DOI: 10.1039/b504400f.

[2] M. Nakata. Liquid Crystal Group, Department of Physics, University of Colorado at Boulder. Available online: http://bly.colorado.edu/lcphysics/textures/

[3] S. Chandrasekhar, Liquid Crystals, Cambridge [England]; New York, NY, USA: Cambridge University Press, 1992.

[4] T. R. Taylox, S. L. Arora, J. L. Fergason, Temperature-dependent tilt angle in the smectic C phase of a liquid crystal, Physical Review Letters. Vol. 25, Number 11. 14 September 1970.