# Interference Pattern of a Thinning Soap Film

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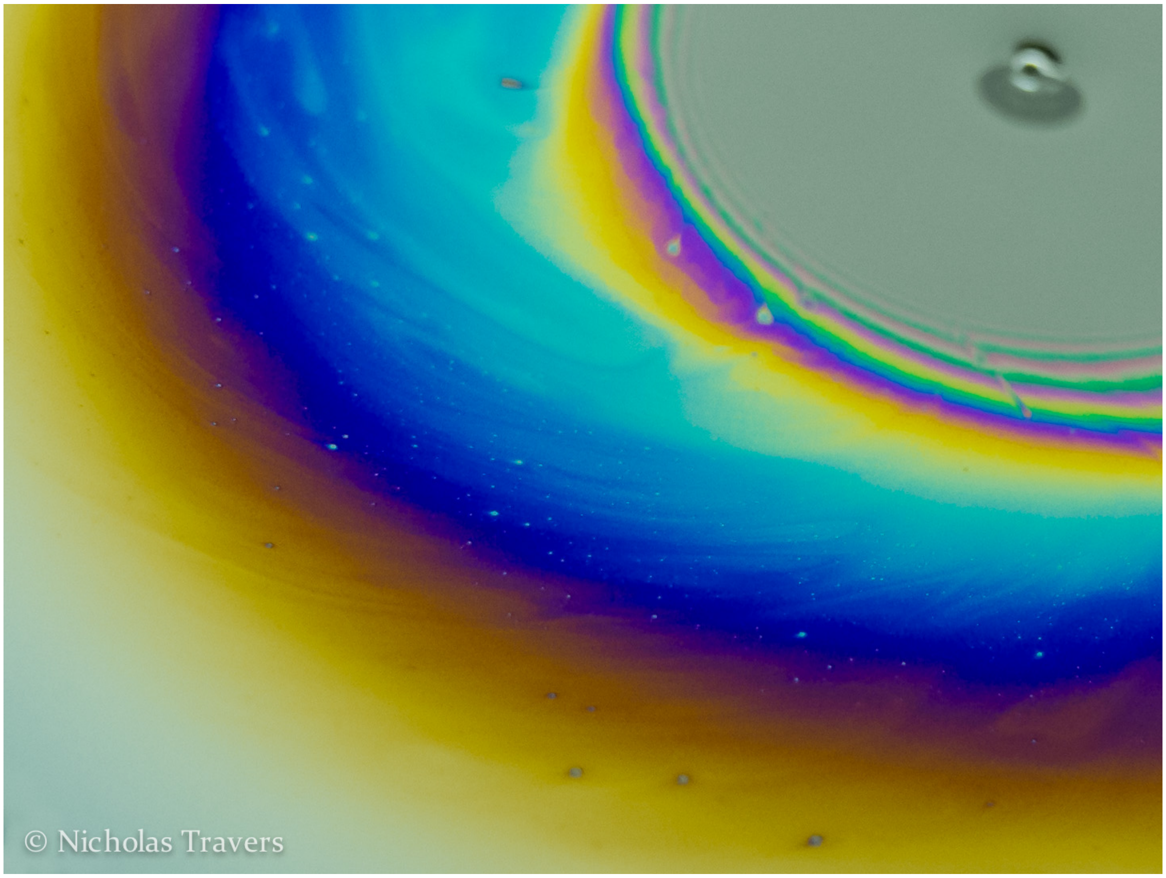
Get Wet Assignment – Flow Visualization 2012

University of Colorado at Boulder



An investigation was undertaken to observe and capture the colorful interference patterns often observed in thin films using digital photographic techniques. The physics and fluid principles involved and demonstrated in the image are discussed. The photographic setup and technique is presented and reviewed. The image was produced for the first assignment, titled *get wet*, of the mechanical engineering course Flow Visualization[1] at the University of Colorado at Boulder. The purpose of the assignment is to encourage students to experiment with fluids and to capture fluid phenomena using an imaging technique in a visually pleasing manner.

## Introduction

A water soap solution can form a film when the solution is forced to spread over a large area. For this investigation a nearly horizontal thin film was formed over the opening of a glass by dipping in soap solution. The imaging setup is outlined in Figure 1. To illuminate the film diffuse white light from a lightbox was used. The light reflected by the film is captured by the camera which was oriented 40° from the surface of the film. The visual patterns of the film were imaged after a lifetime of approximately 1 minute, and the film continued to thin for a further 1 minute before rupturing.

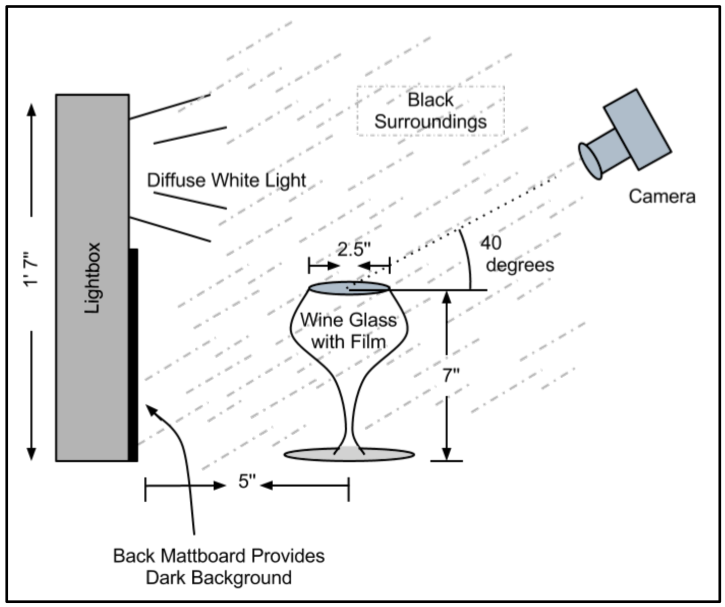



**Figure 1 - Setup used for imaging of soap film suspended in a glass and illuminated by diffuse light from above.**

Soap films are composed of a bulk fluid (water with some soap) bounded at either surface by a layer of soap molecules which are amphipathetic (Figure 2). These molecules, called surfactants, are anions that consist of a carboxyl head, which is hydrophilic and attaches to the water, and a hydrocarbon chain that is hydrophobic and is repelled from the water (Isenberg, 1992). Depending on the concentration and thickness of the film some surfactants remain in the bulk of the fluid. The surface tension of soap solutions is generally one third that of water, and is inversely proportional to the local concentration of surfactant (Isenberg, 1992). Variations in surface tension play a significant role in the flow processes of films. Flow within the film leads to thickness variations which are perceived as color fringes due to interference phenomena.

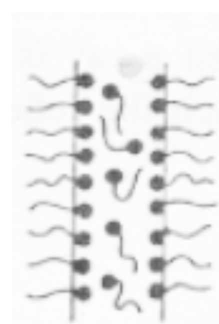


**Figure 2 - Structure of Soap Film, with surfactant layers at film surfaces.**

[1] The flow visualization course website can be found at: http://www.colorado.edu/MCEN/flowvis/

**Interference**

Intense, often iridescent, colors are observed in thin films due to interference phenomena that occur as incident light is reflected off of the top and inner surfaces of a film. The explanation given here is taken from *The Science of Soap Films and Soap Bubbles*, by Cyril Isenberg, and presented in conjunction with Figure 3. For an incoming ray of a given wavelength approximately 4% will reflect off the first surface, labeled A, as ray $C_1$. The remainder is refracted into the film and an additional 4% will reflect off surface B as ray $D_1B_2$, which will refract through surface A and emerge as ray $C_2$ parallel to $C_1$. These two rays will have a phase difference due to: a phase shift of π in the first ray due to reflection off a medium of higher refractive index (the film), and a phase difference due to the increased path length of the second ray. The phase difference *d* can be related to the thickness of the film *t* for a given wavelength λ at a constant angle of refraction θ for a fluid with refractive index μ by:

$$d = 2\mu t\cos(\theta) + \tfrac{1}{2}\lambda \quad (1)$$

When the two rays meet constructive and destructive interference intensifies or diminishes the wavelength's intensity (ii and iii in Figure 3). Constructive interference occurs when two rays of similar phase *(d=nλ)* combine, and deconstructive interference occurs when two rays out of phase *(d=*(n+1/2)λ*)* combine.

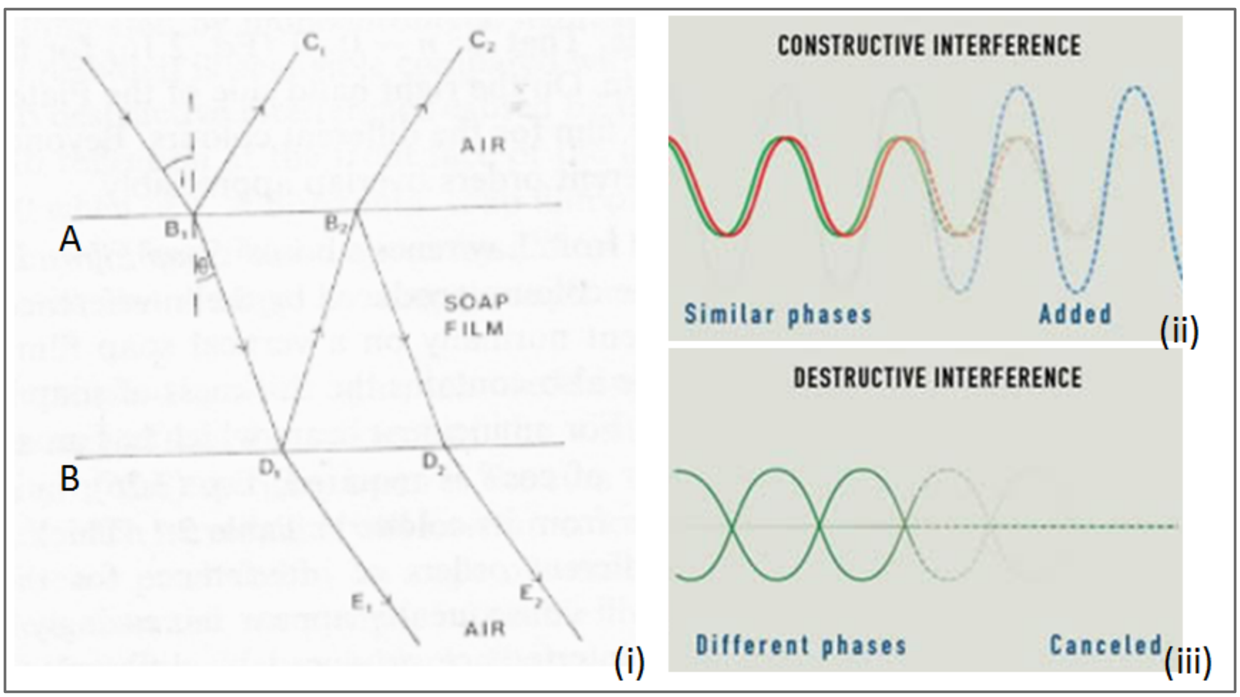



**Figure 3 - Explanation of Interference phenomena due to reflection and refraction of light (Isenberg, 1992; Douma, 2008)**

An inverted color image of the observed color fringes is presented in Figure 4, which identifies the extinct wavelength whose absence gives rise to the color observed. By calculating the thickness of the film for each of the distinct color bands the thickness profile of the film can be approximated. The film thickness profile calculated indicates a thickness of under 300nm for the majority of the film where first order interference occurs, and that the thickness at the center of the film increases to over 2 microns (Figure 4).

The film is thinnest at the edge of the glass, with a thickness smaller than the wavelength of visible light. Due to the reflected ray's phase shift of π most wavelengths in the visible range experience deconstructive interference. As there is a slight path difference the deconstructive interference simply diminishes the intensity of each wavelength; this results in a silver hued thin film with a thickness of approximately 100nm (Couder, Chomaz, & Rabaud, 1989). As the film thickness increases the violet and blue wavelengths are the first to experience full extinction, while the remaining wavelengths combine to form a yellow-orange hue. This behavior repeats for each wavelength and then for multiples of each wavelength to produce the high order interference color fringes observed.


**Figure 4 - Inverted selection of the imaged film with color fringes indicating the wavelength extinguished by interference; the general distribution of film thickness varies from 100nm at left to over 2 microns at the right edge.**

### Flow Interactions

The arrangement of forms in thin films is the result of the interaction between gravity and surface tension forces which cause fluid flow. Overall the weight of the fluid causes the horizontal film to bow inwards with a concave shape. The presence of the water droplet in the upper right of the image highlights the effect of gravity and the importance of surface tension to maintain the film. The effect of gravity is balanced by the surface tension forces which increase towards the edges of the film in a fashion similar to the hydrostatic pressure (Nierstrasz & Frens, 1999). Because the surface tension of water is lower than that of the surfactant, the film will have a greater surface tension where it is thinner and the concentration of surfactant is greatest (Isenberg, 1992).

The calm swirl of color that dominates the imaged thin film is an artifact of decaying chaotic flow in the film, which is the result of marginal regeneration and gravity convection. Both phenomena are driven by a general equilibrium seeking principle: that an element of film with larger surface tension than its neighbors will contract and reduce its surface area, this will cause an increase in the concentration of surfactant, which will result in reduced surface tension (Nierstrasz & Frens, 1999). The effect is that thick areas of the film will tend to contract, drain, and seek similar low surface tension regions; the thin portions of the film will tend to move up the film (against gravity) to seek equilibrium with comparable high surface tension elements (Nierstrasz & Frens, 1999). The swirls seen in the image are remnants of thin and thick film elements that have not yet equalized; their rotation is likely due to a prior imbalanced discharge of thick film elements from the edge of the glass due to marginal regeneration.

The rapid flow of individual elements of the film is evident in two places of the final image. In the fringe of second order purple two thin light blue elements of the film appear to be moving towards the edge of the film based on their wakes. A small violet element, based on the length and width of its wake, also appears to be moving quickly from the thick region of the film towards the edge. Based on their spectra, these elements of the film are thinner than their surroundings. Their thinness could be the result of undissolved particles of the soap solution causing high surfactant concentrations that would lower the surface tension and cause thinning.

**Visualization Technique**

To effectively visualize the interference patterns caused by a thinning film, a soap mixture was made from a common household detergent. The mixture is composed of 1 part Ajax® Lemon scented dish soap, 1 part corn syrup, and 4 parts water. A 1.5cup solution was prepared and allowed to sit uncovered for 24 hours prior to use. The active surfactants in Ajax® are Ammonium C12-C15 Pareth Sulfate, and Lauramidopropylamine Oxide (Colgate-Polmolive Company, 2012). To produce the film a wine glass was inverted and dipped into the solution; when removed excess solution is allowed to drain and a thin film remains over the surface of the glass. The glass was righted and placed in the frame of view in a natural manner. Attempts to reproduce the observed slow vorticity in the film by twisting the glass were unsuccessful. The thin film was lit only by diffuse fluorescent lighting from above (see Figure 1) by means of a light table set on its side.

| Table 1: Camera's Image Capture Settings | |
|---|---|
| Original Image Size | 3648x2736 pixels |
| Final Image Size | 1449x1087 pixels |
| Resolution | 240 pixels/inch |
| Shutter Speed | 1/160 |
| Aperture | f/2.8 |
| ISO Speed Rating | 400 |
| Focal Length | 6.0 mm |
| Lens | 6.0-42.6 mm f2.8 |
| Camera | Nikon P7100 |

The final image is 1449 x 1087 pixels in size, and shows approximately 1.06 x 0.80 inches. The plane of the soap film was approximately 3 inches from the camera and tilted 40 degrees from the camera's line of sight. A fast shutter speed was desired to capture the crisp color fringes without blurring the intricate patterns. The scene was somewhat underlit, requiring that a moderately low ISO setting be used. To capture the most light a large aperture was used. To avoid the noise and color aberrations inherent in low ISO settings, the shutter speed was set to 1/160$^{th}$ of a second and the aperture set to f/2.8 which allowed the ISO to be set at 400. To preserve the colors observed the camera's white balance was first set using a white matt board under the florescent lighting. The camera was in macro mode with an effective focal length of 6mm. The camera used was a NIKON Coolpix P7100 which has a 6.0-42.6mm, f2.8 lens with image stabilizer. The camera settings are summarized in Table 1.

Some editing of the original digital image file was done to produce a clean and visually appealing final image. The most significant edit was to crop the image to show only a portion of the soap film. This was done to highlight details of the rotational fluid motion. To increase the image's visual appeal the crop also created a nonsymmetrical and more visually compelling image. A portion of the glass was edited out from the corner of the final image. To bring out details in the image mild sharpening was done, and the noise from using a 400 ISO setting was reduced using the luminance and detail recovery functions. No color adjustments were made. The initial and final images are appended to this report for comparison.

**Concluding Remarks**

The primary focus of the investigation was to explain the color patterns that occur as a thin film drains. The variation in thickness that causes light interference to produce the intense colors in thin films is well demonstrated by the image, particularly by the repeating color bands that lead to the upper right of the image. The droplet in this area of the photograph gives the viewer context to understand the geometry and scale of the situation, as well as to emphasize the influence of surface tension on the fluid's behavior. While not the primary focus of this investigation, additional interesting flow phenomena are captured by the color variations in the image: the delicate details of the wider color bands indicate rotational flow in the film, while discontinuities in the color bands are instances of gravity convection. The reason for the 'fluorescent' appearance of many of the colors is striking, but compares to images published by others (Florida State University, 2003) (Isenberg, 1992), and no fluorescing agents were identified in the Ajax® detergent used. The image could be improved by bringing more of the subject into focus. However, the narrow depth of field brings more interest to the image and does not compromise the technical information contained therein. Brighter lighting would have benefitted the image by reducing noise, and allowed for more experimentation with shutter speed and aperture. Further images could be made to specifically investigate the lively flow phenomena of marginal regeneration that occurs in thin films. Advanced studies of flow phenomena could be done using the color interference patterns caused by the thin film in a fashion similar to how a wind tunnel or flume is used to visualize flow around obstacles (Yang, Wen, & Lin, 2001).

In successfully realizing the original intent of this investigation, to capture a compelling thin film interference pattern, many more interesting forms were seen. Visualizing instabilities that often form as films thin and drain is fascinating, and demonstrates complex and beautiful physics which should be investigated, admired, and explained further.

**References**

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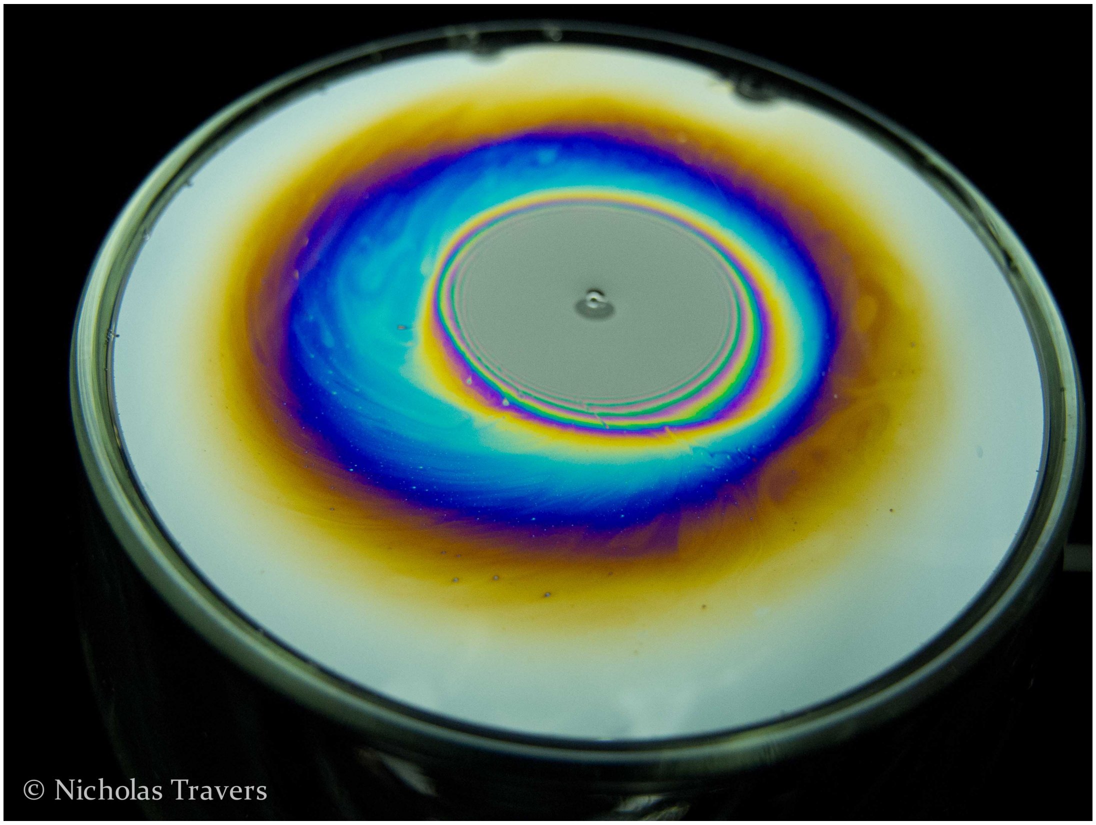
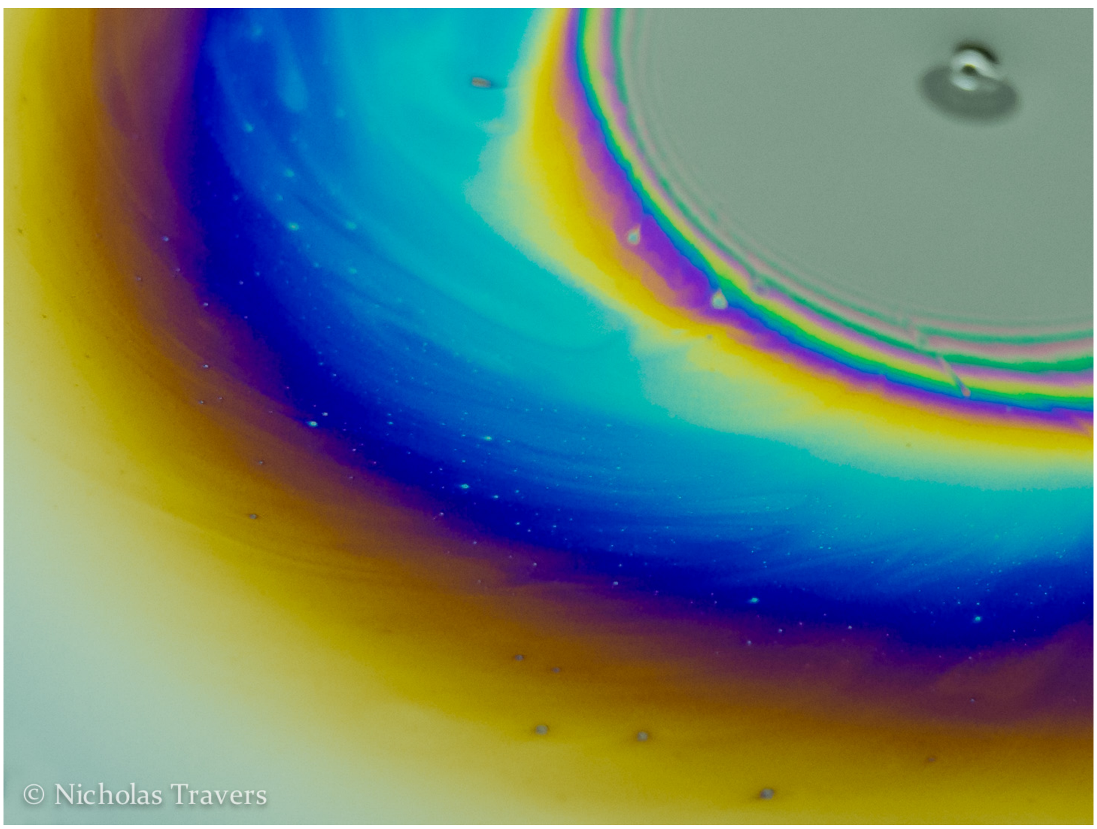



Original, as shot, image of soap film in in a glass.




Edited Image: cropped, removal of glass edge , noise reduction.