MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department

Physics: 8.03 Spring Term 1995

Take-Home Experiment #7

THIN FILM INTERFERENCE, WET

Objective In the previous experiment, "Thin Film Interference, Dry", you investigated small scale, static interference phenomena. Here you will have a chance to study larger scale, dynamic phenomena.

Experiments

Chemical Films on Water Fill the 5 inch diameter flower pot saucer with water. Open the sample bottle labeled Coleman fuel. Use the medicine dropper to place a small drop of Coleman fuel at the center of the water surface. Watch the interference pattern evolve using light at near normal incidence. Use both tungsten and fluorescent light. Try the filter.

Initially the film is so thick near its center that no fringes are visible. Is more or less light reflected from this bulk patch of Coleman fuel than from the surface of the surrounding water? What can you conclude about the index of refraction of Coleman fuel relative to that of water?

There is a gradient of film thickness near the edge of the floating patch and closely space fringes may be seen there. As time advances the patch thins and the fringes spread out over the entire patch. Eventually the entire patch disappears. The time that it takes for the Coleman fuel to disappear depends sensitively on the temperature of the water. Interesting effects can be created by allowing the drop to fall several inches before hitting the water.

What is actually happening to the Coleman fuel? One's first thought is that it is all floating on the water and evaporating rapidly. On second thought, how can such a large amount of Coleman fuel form such a thin film? Transfer an equal amount of Coleman fuel to the surface of a clean microscope slide. Under these conditions it forms a macroscopic drop which takes a considerably longer time to disappear (blowing on it gently speeds up the process by increasing evaporation). Oil and water may be immiscible, but Coleman fuel and water are not. Evidently the Coleman fuel, or its major components, are dissolving in the water. Your nose, however, should tell you that evaporation also plays a role.

Try putting the kerosene or the Thin-x (an odorless paint thinner) on a fresh saucer of water. Far less of these materials is required to produce the thin films which give interference fringes. Therefore in these cases it is more convenient to transfer the liquid with a toothpick than with the dropper. The physics is the same as above. The patterns will behave differently, however, since the properties of the added fluids differ.

Discussion: The Parade of Colors In the previous experiment "Thin Film Interference, Dry" we pointed out that as the film thickness increases from zero, interference maxima occur first for the blue, then for green and yellow, and finally for the red. This may tempt one to assume that the light reflected from the thinnest edge of our films should be blue, followed in succession by bands of green, yellow, and red as one goes through the first order of interference. Careful inspection of the thin edge of your chemical films will show that this is not the case. Indeed, the edge looks rather colorless, not unlike the reflection from a silvered mirror. The bands of distinct color seem to occur further inward, where the film is somewhat thicker.

The reason for this counter-intuitive result lies in two facts: the spectral resolution of two beam interference is not high and the visible spectrum spans only a relatively narrow range of wavelengths. The visible spectrum extends from about 400nm to 700nm, somewhat less than a factor of 2 in wavelength (or frequency). For the sake of this discussion let us identify the wavelength of blue as 440nm, green as 510nm and red as 660nm.

Consider a situation where a film thickness of zero gives rise to an interference minimum (for example the two microscope slides of the previous experiment or the Coleman fuel on water in this one) and assume the two reflected waves are of equal strength (almost exactly true for the slides, a fair approximation for the Coleman fuel). Let the film thickness be such that the green light experiences its first intensity maximum in reflection.

a) At that thickness, by what factor is the reflected intensity ratio smaller for the red than for the green? (answer: 0.88)

b) At that thickness, by what factor is the reflected intensity ratio smaller for the blue than for the green? (answer: 0.94)

From this one concludes that there will be little modification of the apparent color of a broad source upon reflection at the first order of interference. The apparent color is modified most when an n^{th} order maximum for one wavelength is accompanied by m^{th} order minima for neighboring wavelengths. But n and m must be modest or too many holes will be cut in the spectrum to make the effect resolvable by the eye. That is the case for thicker films where n is of the order of 6 or more.

Soap Films Take the supplied sheet of artists' sketch paper and cut it into quarters, each about 4.5" by 6". Using the template on the next page as a guide, use the supplied razor blade to make bubble frames. Fold the top of a frame over the wooden dowel and secure it with two paper clips as shown in the illustration. Take two more paper clips and turn them into "S" hooks. After loading the frame with liquid you will need to hang it in a location where the reflection of a bright light (such as a desk lamp or ceiling fluorescent fixture) can be viewed near normal incidence. You may want to rig a horizontal string for this purpose, or you may be able to use a wire clothes hanger. In any case make sure that the fluid that will drip from the bottom of the frame will not soak your textbooks or your roommate's bed.

Dump the contents of the bottle marked "bubble solution" into the plastic plate. Add ten bottle fulls of water to the plate and mix thoroughly. Dip the frame in the liquid to load it, then hang the frame for viewing. As the liquid drains to the bottom of the frame, the bubble stretched across the opening will thin from top to bottom. You should see a series of strongly colored horizontal bands. Eventually, the film across the top of the frame becomes so thin that it appears completely transparent. Under suitable conditions, the film can last ten minutes or more!

If the film thickness decreased smoothly with height, the apparent color of the reflected light would also change smoothly. The appearance, starting at the top, would be black (clear or transparent), silver (or mirror like as discussed above), and then a series of more distinct colors. The progression would be gradual with no sharp boundaries. Yet in this experiment a sharp boundary appears between the transparent region and an adjacent region of finite reflectivity. This suggests a step-like discontinuity in the thickness of the film, from some value larger than one quarter the wavelength of blue light to a value definitely less than a quarter of the blue wavelength. This is, in fact, exactly what is happening.

To understand the sudden change in film thickness upon draining, one must know something about the surface structure of the soap film. A soap or detergent contains large organic molecules with hydrophilic (water loving) and hydrophobic (water avoiding) ends. When mixed with water, these large molecules ionize. A monolayer of the ionized molecules coats the water-air interface as shown in the first figure; the remainder of the ions are dissolved in the bulk fluid. When a thin film is formed, two of these surface monolayers face each other across a gap filled with bulk fluid. This situation is shown in the second figure. When the width of the gap becomes comparable to the range of the Van Dar Waals attraction between the surface monolayers, this geometry becomes unstable. The attractive interaction between the surface layers becomes strong enough to squeeze out the intervening bulk fluid. The surface monolayers snap together to a new equilibrium separation determined by the details of the intermolecular forces. The resulting film thickness profiles as a function of time are sketched in the third figure.

The boundary between the black film and its thicker neighbor can be a dynamic one. If the film settles into a configuration where the boundary is relatively straight (horizontal) you should be able to excite waves on it by tapping the side of the bubble frame. Under other conditions, you may find that the boundary is turbulent. This situation can give rise to a fascinating visual display!

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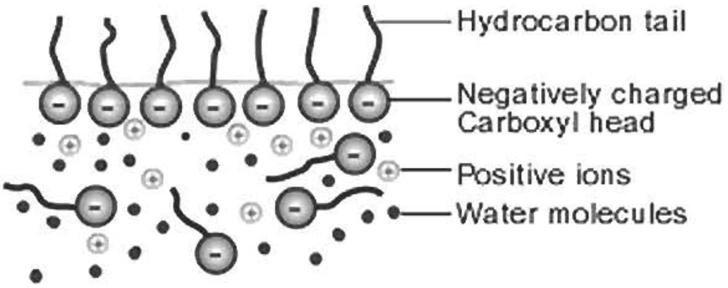
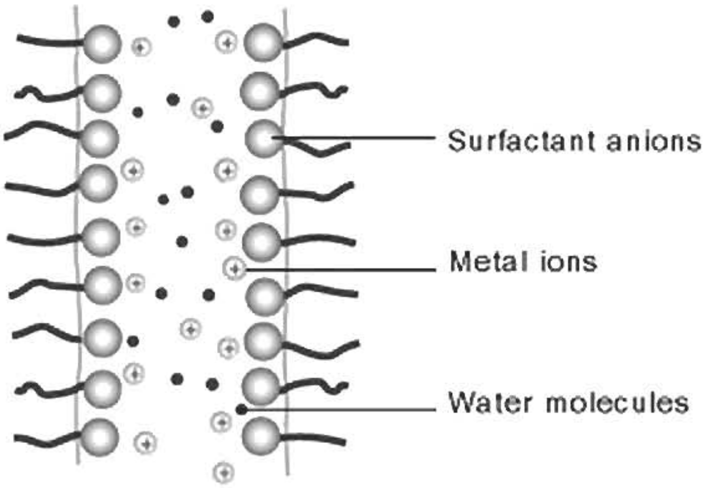
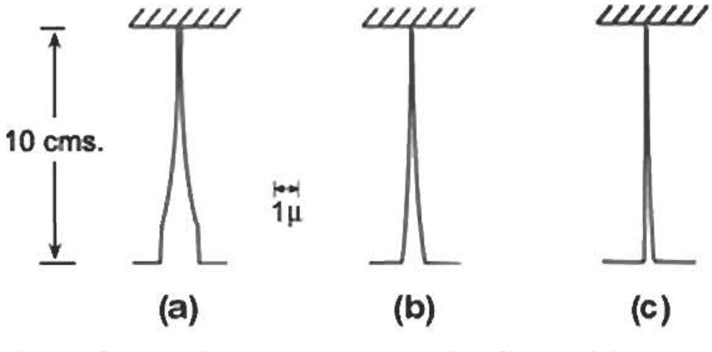


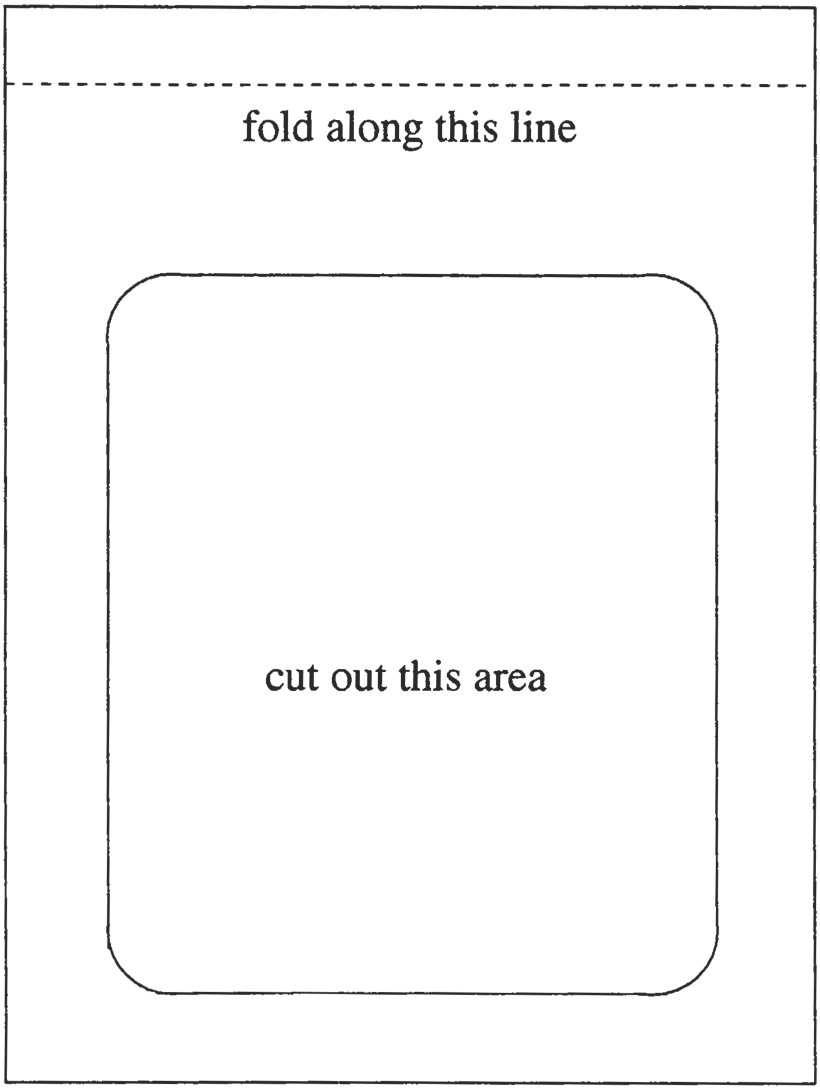
Surface structure of a soap solution.



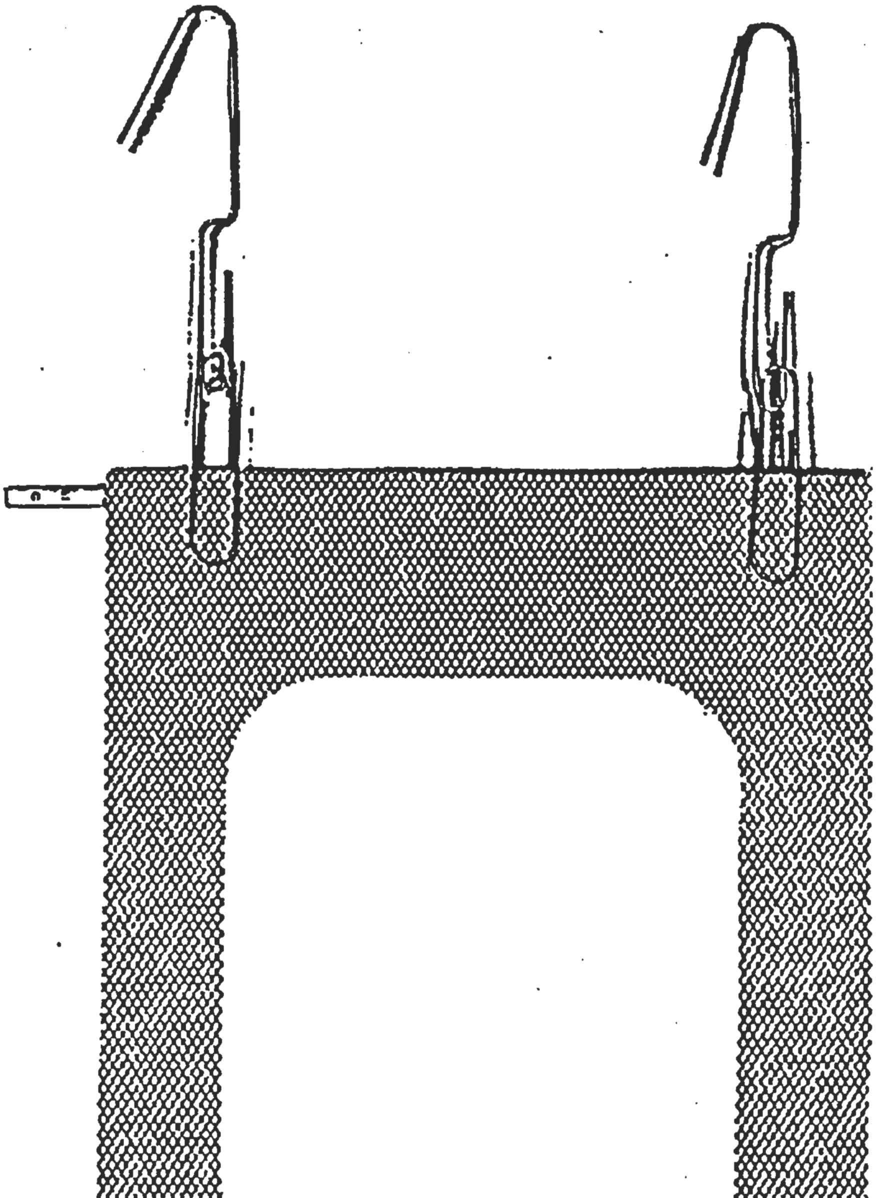
Molecular structure of a typical soap film, containing anionic surfactant molecules plus metal ions and water molecules.



The cross-section of a typical simple mobile film with a height of 10 cm and cross-section of approximately 1 micron:
***(a)** after 40 seconds* ***(b)** after 120 seconds* ***(c)** after 240 seconds*



Template of a bubble frame. Make from heavy artists' sketch paper.



Suggestion for hanging completed bubble frame.