magnification 1200

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Physics Department

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Take-Home Experiment #6

THIN FILM INTERFERENCE, DRY

Objective In this experiment and the next, you will investigate the two beam interference pattern that results when light is reflected at near normal incidence from thin films. The phenomena is not hard to see, and the mathematical derivation is not difficult to follow. However, a true understanding of what is happening only comes by examining a variety of examples.

Experiments

Two Microscope Slides Carefully wash two microscope slides and dry them with a relatively lint free material such as a fresh handkerchief. Align one on top of the other and squeeze them together at one end between your thumb and forefinger. Hold them in front of a dark background (such as the supplied black construction paper) and look at the light reflected by the slides from a broad tungsten (filament) light or from the sky (NOT the sun!). You should see that near your fingers the reflected image is crossed by several interference fringes. Toward the center of the slides, the interference pattern should disappear.

In this case the two interfering waves come from the glass-air and air-glass interfaces between the slides. The phase of the electric field is changed by 180 degrees at one of these reflections and is unchanged at the other. Thus if the separation between the plates was much less than the wavelength of light at a given point, there would be destructive interference between the two beams and the "air film" would be completely transparent at that point. [Note that there would still be reflections from the top of the upper slide and the bottom of the lower slide, so there would still be some reflected image from the assembly as a whole.]

As the air gap grows, there will be constructive interference at normal incidence for light of wavelength λ when the width of the gap is equal to $(m + 1/2)\lambda/2$ for any non-negative integer m. For small gaps (of order 1000 angstroms) this relation is first satisfied for blue light, then yellow, then red as the gap increases. In this region the different thicknesses reflect different colors unequally, thus the reflected light appears colored. As the gap increases further, the interference maxima of different orders (m) overlap and the distinction between different colors is washed out. Eventually the average intensity just approaches that which one would get from the two interior interfaces individually. This is what is happening as you look toward the center of the side assembly. The same effect prevents one from seeing interference fringes from the two surfaces of a single slide, no matter how flat and parallel the surfaces may be.

Sometimes when one opens a new box of microscope slides they are so clean and lint free that several will stick together when removed from the box and interference fringes can be seen across the entire sandwich. It is hard to duplicate this condition after the slides have been handled.

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Of course if the light were monochromatic one would see the interference fringes for any width gap, as long as the surfaces were sufficiently flat and parallel. Laser light which has been been sent through a diffuser to give it a distribution of angles and a finite spatial extent would provide such a source. Although we can not afford to provide each of you with a laser, you can see for yourself the effect of narrowing the spectral distribution of the light.

Perform the same experiment as above, but this time view the fringes through a colored filter. You should be able to see more fringes for the same configuration of the the slides with the filter than without. The fringes should be visible over a larger area of the slides, that is, out to wider gaps. The filter narrows the spectrum by a factor of three or four, so the fringes should be visible for gaps of up to about 5000 angstroms.

Now for a surprise. Repeat the experiment using a fluorescent light as a source. The fringes are visible over a much wider range than in either of the two previous cases. You know the light is not monochromatic because it appears white (the lighting engineers have gone to great pains to achieve that effect). In addition, you can see that your interference fringes are colored! As it turns out, the fluorescent lights have, in addition to a broad continuous spectrum, several bright and very narrow individual lines in the red, green and blue. It is these lines that dominate the interference pattern and allow fringes to be observed over a much larger range of gaps. You still can not see fringes from a single slide (thickness of about one millimeter) this way, but a microscope cover slip (thickness of about 0.15 millimeter) should exhibit fringes under a fluorescent light.

Solid Thin Sheets Try to see interference fringes with a single microscope cover slip under fluorescent light. Each fringe corresponds to a contour of constant thickness. In essence, you are seeing a topographic map of the cover slip. Try some other cover slips; some are flatter than others. Try the same experiment with daylight, then with daylight and a filter. Any luck?

Some transparent solid polymers can be made into very thin sheets which may be uniform enough to exhibit interference fringes. Find a sheet of such material and stretch it over the mouth of a cup or glass to achieve a flat, free standing film. We have supplied a sample of a common kitchen wrap; you should find and test other possibilities. First check to see if the surface smoothness is sufficient to allow you to observe a mirror like reflection of some fluorescent ceiling fixture. If the reflection is distorted on a small distance scale there is local surface roughness which will preclude observing fringes. With some luck you will see a mottled coloring of the reflection indicating interference but thickness variations on a medium scale. If you are fortunate enough to have found a very flat material you will see distinct interference contours, as was the case with the cover slips.

Newton's Rings Any textbook discussing interference mentions Newton's rings. This is the interference pattern seen in reflection when the spherical surface of a lens is resting on a flat uncoated glass surface. The phenomenon is identical to that which you observed with the two microscope slides. In this case, however, the interference pattern is a visually pleasing set of concentric rings. The text may have a photograph of the rings. The accompanying schematic diagram, a cross-section of the lens resting on the flat and the intervening air space, is guaranteed not to be in scale. The reason is that if the interference pattern is to be visible easily to the unaided eye, the radius of curvature of the lens must be very large.

From the discussion of the microscope slide experiment you should know that the center of the Newton's rings, where the two glass surfaces are in contact, should be dark. It is not hard to derive the result that the

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radius of the m^{th} dark ring is given by $r_m = [m\lambda R]^{1/2}$. Here R is the radius of the curved surface. From this one can see that if the radius of the first dark ring is to be 2 millimeters using light of 5000 angstrom wavelength, the radius of curvature must be 8 meters! A plano-convex lens of this radius of curvature would have a focal length of 16 meters. Such long focal lengths are primarily found in large refracting telescopes.

I have done the Newton's rings experiment with high quality laboratory lenses with focal lengths of about a meter. There are three problems: the radius of rings is quite small, the lenses have antireflection coatings so the contrast of the interference pattern is not what it might be, and the lenses are too expensive to use in take home experiments.

In this experiment we get around the above problems by using two inexpensive uncoated lenses. Find the lens with the largest focal length (the flattest one). Clean it carefully and put it curved surface down on a clean microscope slide. Place the slide under a light source so that you can expect to see interference fringes in reflection. You may be able to see a small black dot which indicates the center of the Newton's rings. Now take the other lens and use it as magnifying glass to inspect the ring pattern. In this way you should see a pattern that is as clear as those shown in books. As in the above experiments, see if you can resolve more rings (with larger diameters) if you use a colored filter or a fluorescent light.