

Interference II: Thin Films

Physics 2415 Lecture 36

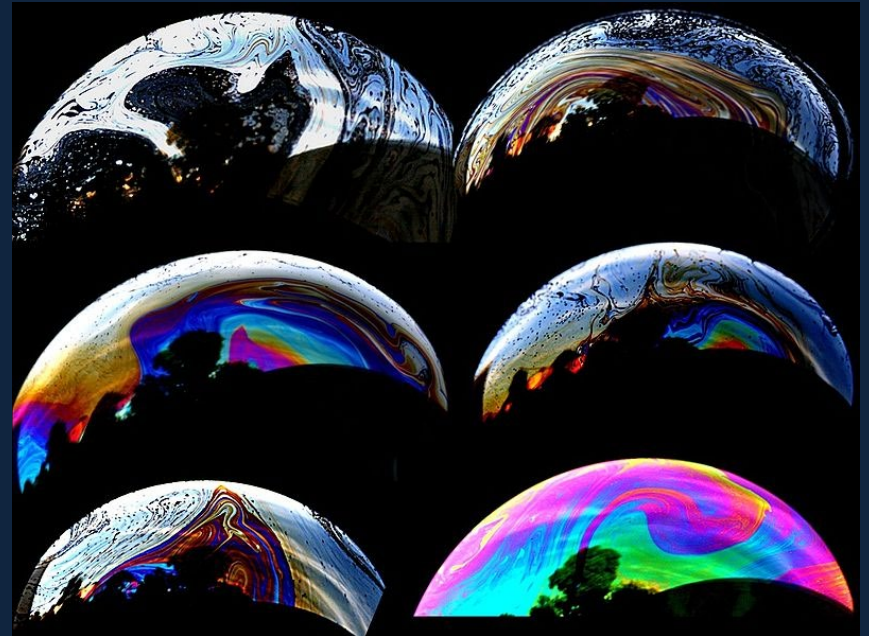
Michael Fowler, UVa

Today's Topics

- Colors of thin films
- Michelson's interferometer
- The Michelson Morley experiment

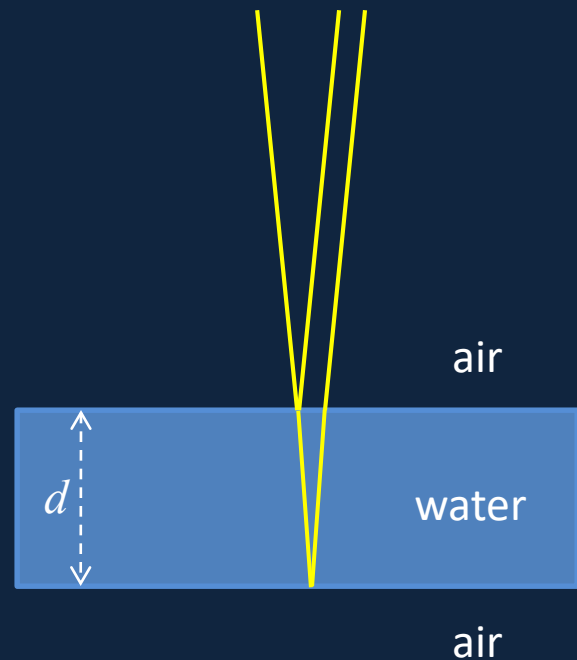
Thin Film Interference Effects

- The colors seen in soap bubbles arise from interference between the reflected light from the two surfaces, which are separated by a distance of order the wavelength of visible light ($\sim 500\text{nm}$).



Thin Film Interference

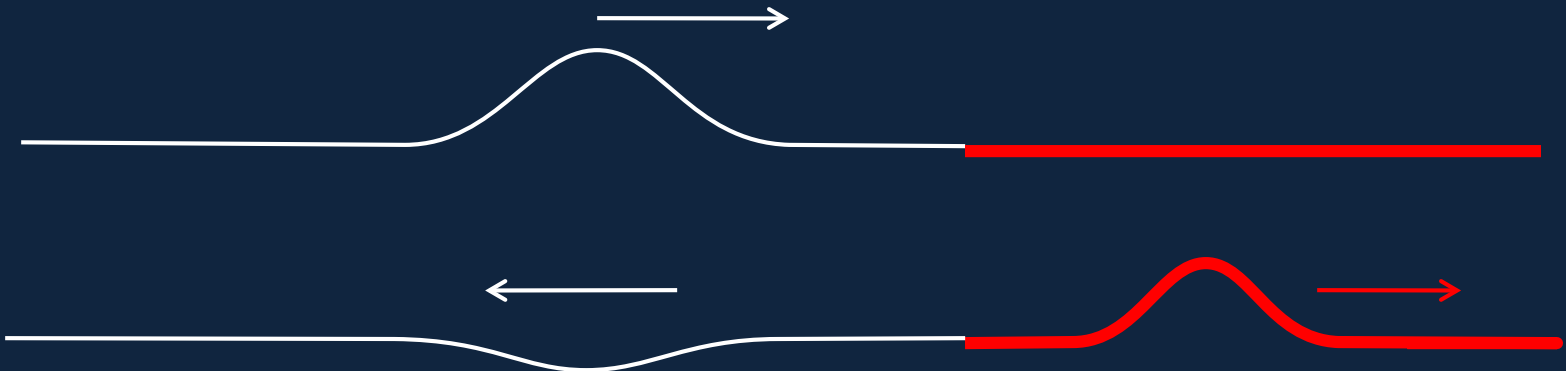
- We'll consider the simplest case of light of wavelength λ incident at almost 90° to the film.
- The path length difference is then $2d$, remember the wavelength in water is λ/n , so the path length phase difference is $4\pi nd/\lambda$.
- But there's another factor...



Reminder: [applet](#)

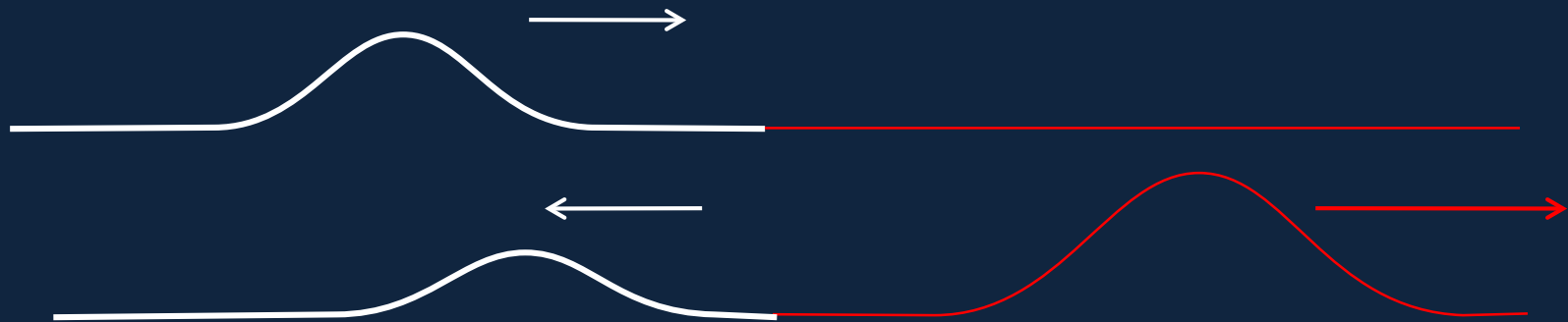
Pulse Transmission and Reflection

- If a wave pulse traveling in a **high speed medium** (light string) encounters a boundary to a low speed medium (**heavy string**) the pulse is partially transmitted, and part is reflected **with opposite sign**:



Pulse Transmission and Reflection

- If a wave pulse traveling in a **low speed medium** (heavy string) encounters a boundary to a high speed medium (**light string**) the pulse is partially transmitted, and part is reflected **with the same sign**:

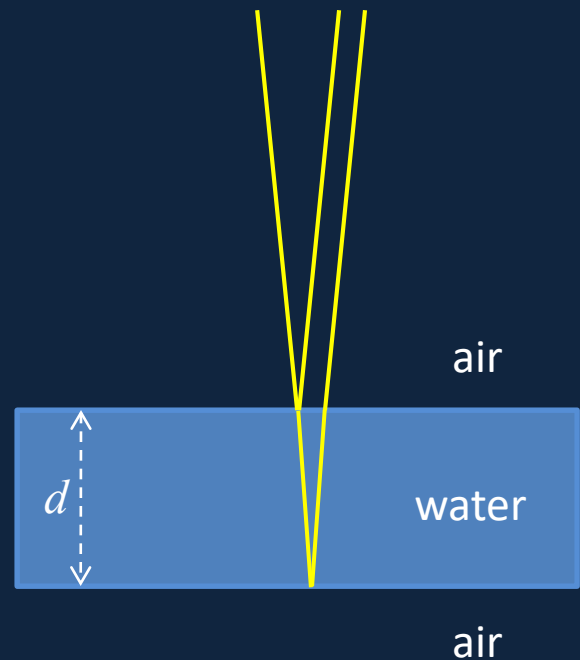


Harmonic Wave Reflection at a Boundary:

- Think of a harmonic wave as a series of crests and troughs:
- On encountering a boundary to a low speed medium (*higher* refractive index!) the reflected crest will be a trough: a phase change of 180° .
- On encountering a boundary to a higher speed medium, the reflected crest will still be a crest, no phase change.

Thin Film Interference

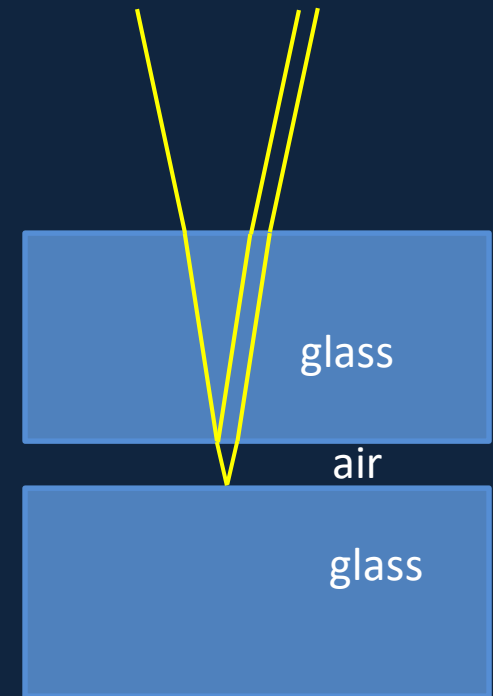
- The path length phase difference is $4\pi nd/\lambda$.
- **But** the light reflected at the first air-water interface is **phase shifted 180°** , that reflected at the second is **not phase shifted**, so the actual phase difference between the two paths is $\pi(4nd/\lambda + 1)$.
- A soap film much thinner than λ will look black! Notice this means the (small) fraction reflected is the same at both surfaces.



A Thin Film of Air...

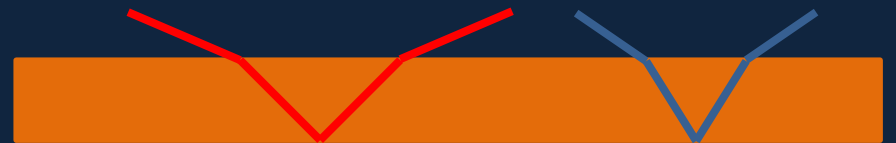
is easy to make—two parallel sheets of glass separated by, say, 500nm, will work.

- Light coming down to the air film from above will be reflected at both surfaces, and the analysis is exactly as above, using now the wavelength in air, and noting that, as before, only one of the reflections is phase shifted 180° .



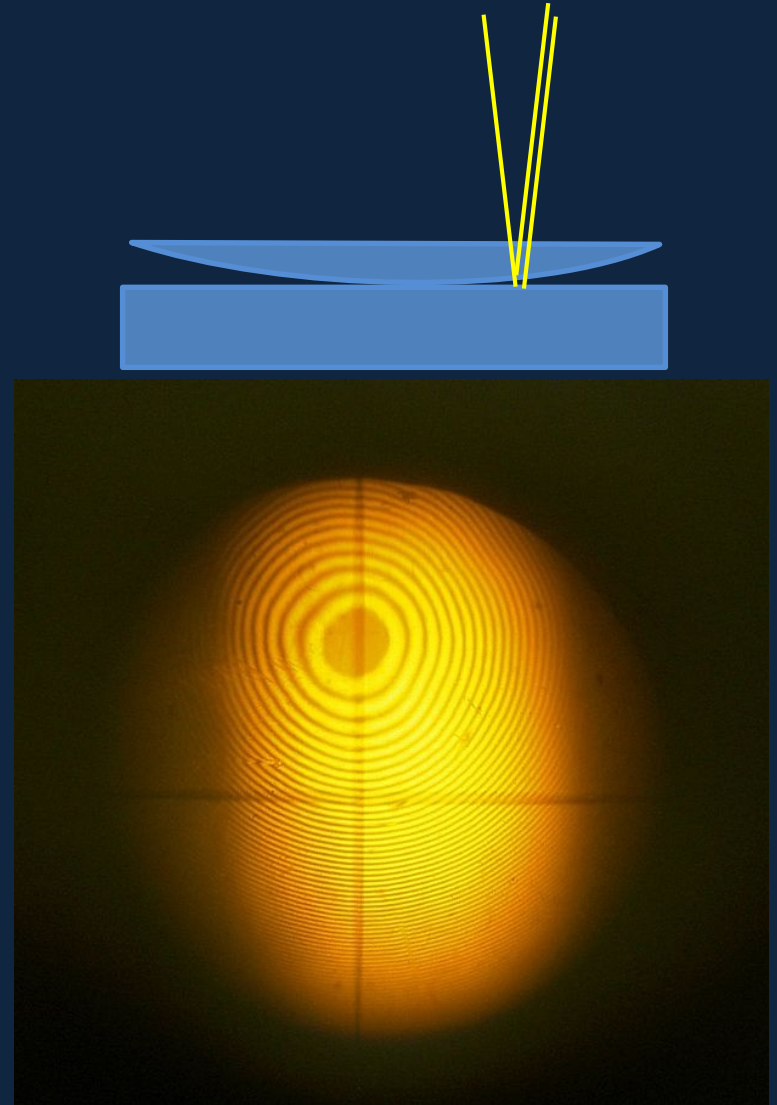
Oil on Water

- Typical oils have a refractive index ~ 1.5 , greater than water (1.33).
- Different colors appear at different angles because the **path length difference between rays reflected from the top and bottom surfaces depends on angle.**



Newton's Rings

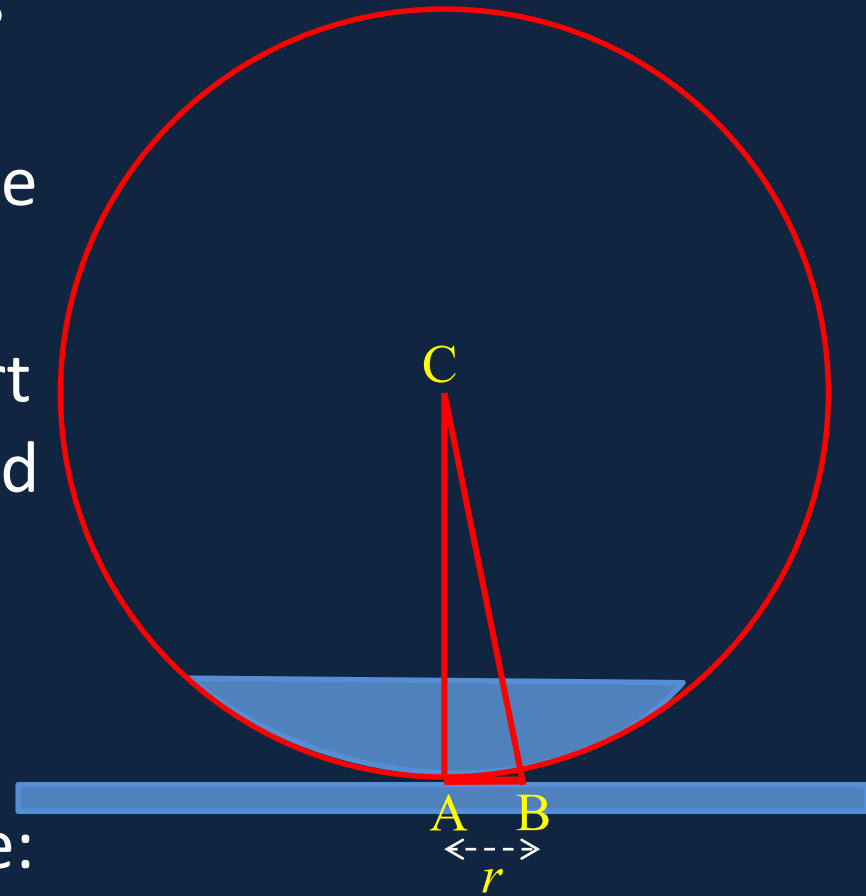
- If a plano convex lens is held firmly against a flat piece of glass and illuminated from above, the thin film of air between the two varies smoothly in thickness from zero at the center, reflected monochromatic light will show a series of light and dark rings as the two reflections successively augment and cancel.



Newton's Rings

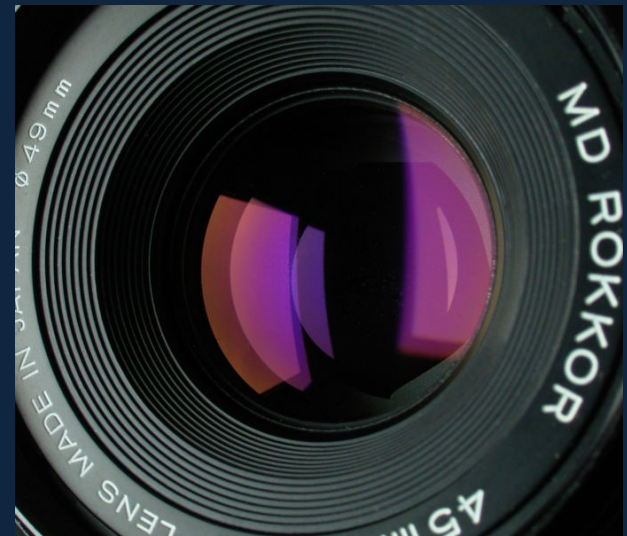
- How do we find the thickness t of the air between the lens and the mirror at **B**, a distance r from the central point **A**?
- The curved lens surface is part of a sphere, radius R , centered at **C**, so **CA** has length R , **CB** length $R + t$ and **AB** has length r .
- **CAB** is a right-angled triangle:

$$R^2 + r^2 = (R + t)^2 = R^2 + 2Rt + t^2, \text{ so } r^2 \approx 2Rt \quad (t^2 \ll 2Rt)$$



Nonreflective Coating

- A layer of material having refractive index ideally the square root of the lens' own, and thickness $\lambda/4$, will eliminate reflection at that wavelength.
- Notice that light at the violet end of the spectrum is still reflected.
- Moths' eyes have a nonreflective coating.

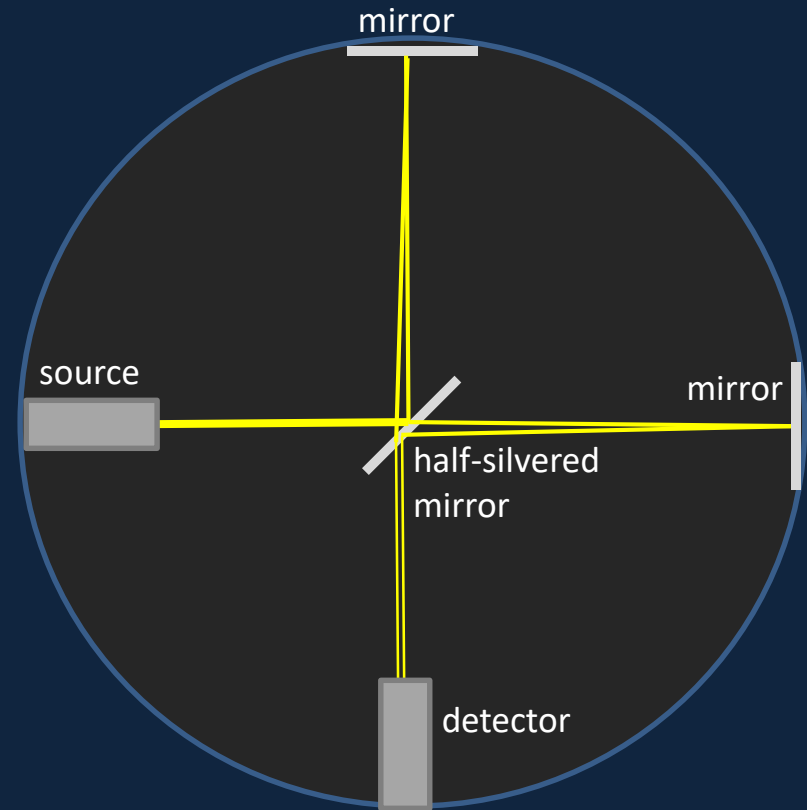


$\lambda/4$ thickness coating, best $n = 1.23$

Lens $n = 1.52$

Michelson Interferometer

- A narrow beam of light is split in two by a half silvered mirror as shown, the two halves are reflected back by two different mirrors, they partially pass through the half silvered mirror to be recombined and then detected. [Applet](#)



- Built long ago to look for the nonexistent aether – now the basic idea of gravitational wave detectors!

Michelson Interferometer

- The two beams entering the detector will interfere constructively or destructively depending on the difference in path lengths.
- A series of light and dark bands (fringes) are observed in the detector.
- Moving one mirror one quarter of a wavelength exchanges the dark and light fringes.
- Small distances can be measured by counting fringe shifts as the mirror is moved.

