General Physics II

Wave Optics

Index of Refraction

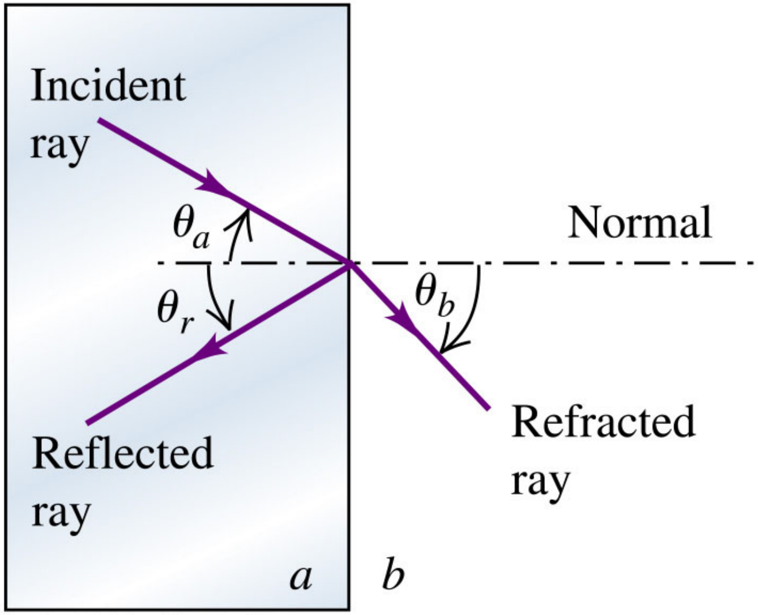
- When light waves arrive at the interface between two transparent media, the waves are partially reflected and partially transmitted. The transmitted wave is called the *refracted* wave.
- The *index of refraction* of a medium is defined by

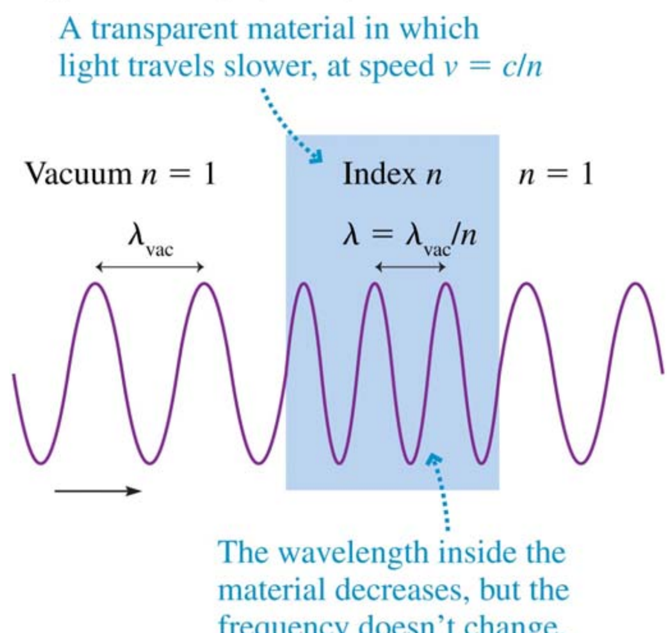
$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}.$$

- The speed of light is greatest in vacuum, so $n > 1$.
- The frequency *does not change between media*, so

$$n = \frac{c}{v} = \frac{f\lambda_0}{f\lambda} = \frac{\lambda_0}{\lambda}.$$

Since $n > 1$, $\lambda_0 > \lambda$, i.e., the wavelength *decreases* in a transparent medium.





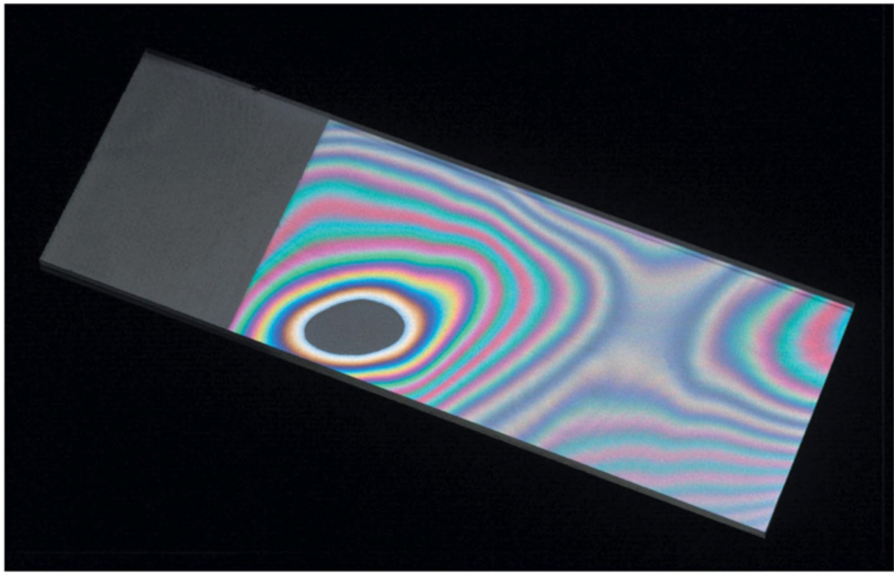
Indices of Refraction

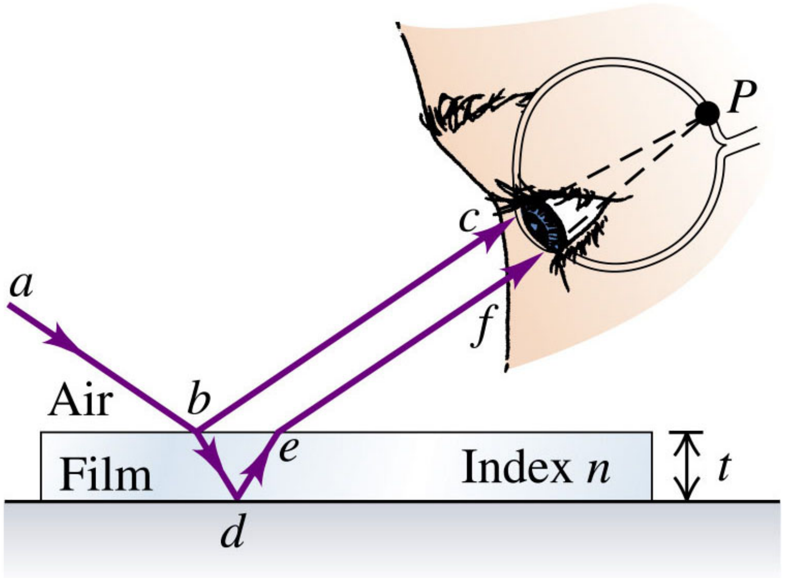
- Vacuum, $n = 1$
- Air, $n = 1.0003$
- Water, $n = 1.33$
- Glass, $n = 1.5 – 1.7$ (Depends on the type of glass.)

- Note that the value of n (except for vacuum) depends on the wavelength of the light.

Interference in Thin Films

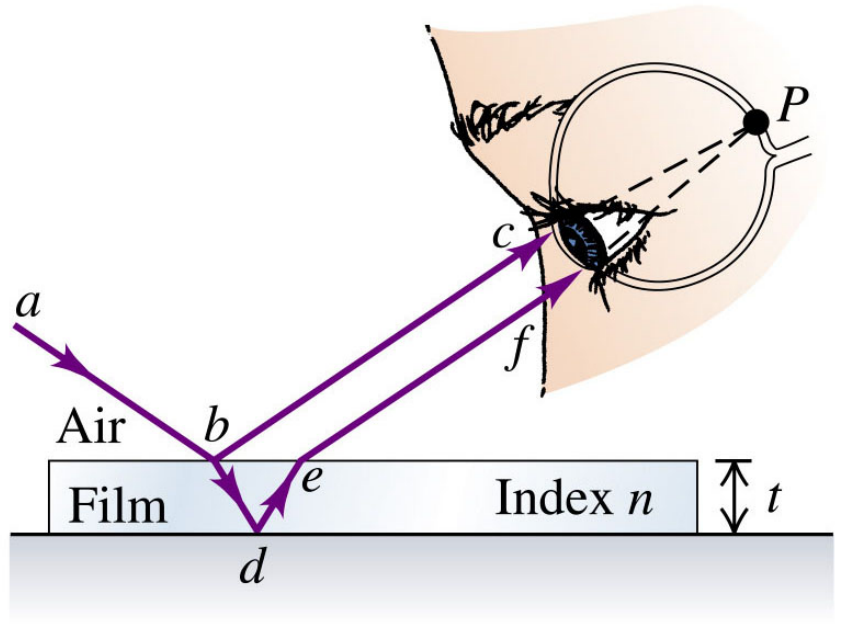
- Thin-film interference is due to the interference of light reflected from the upper and lower surfaces of a thin film. “Thin” means the film thickness is comparable to the wavelength of light in the film.
- The conditions for constructive and destructive interference depend on: (1) the path-length difference and (2) phase changes that may or may not occur upon reflection.

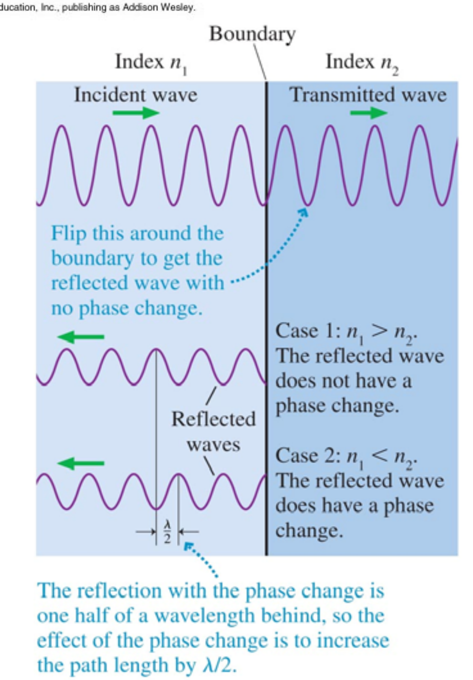




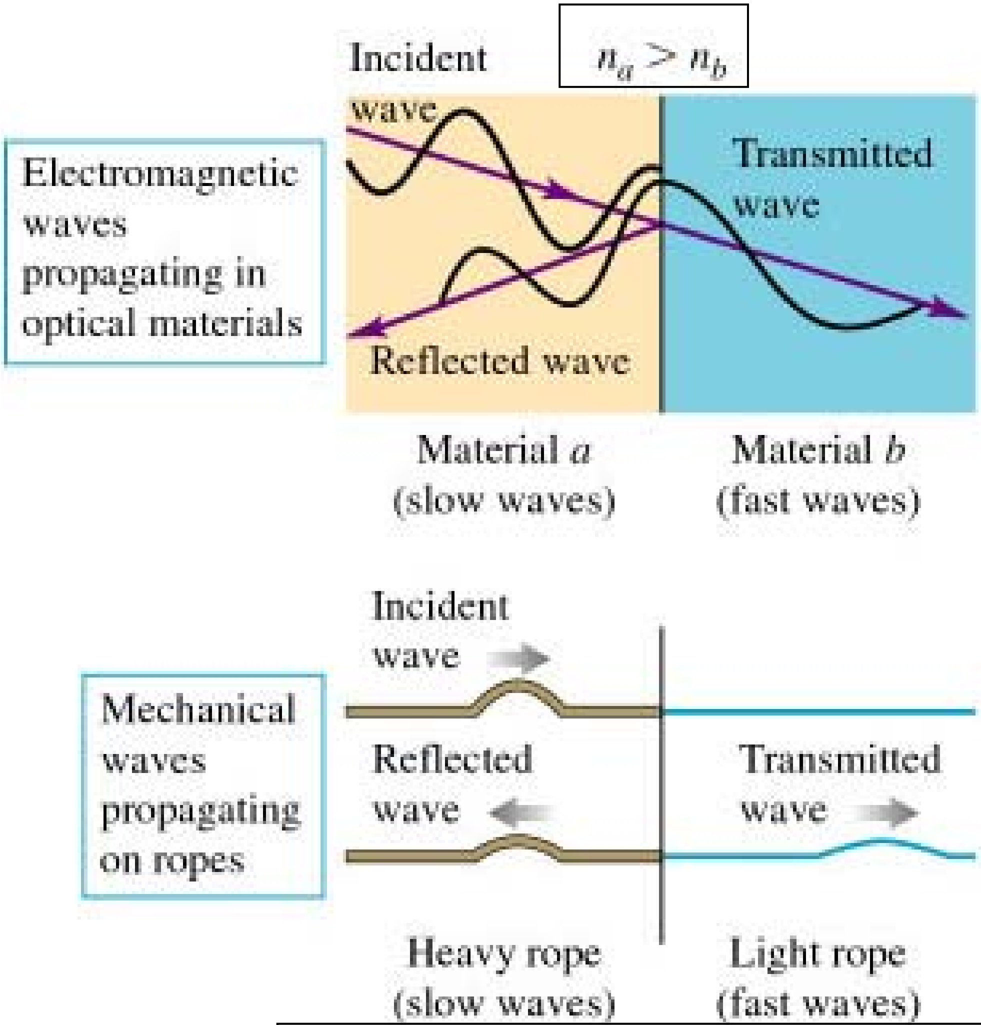
Interference in Thin Films

- For nearly perpendicular viewing (unlike the figure), the wave that is transmitted into the film travels an extra distance $r_2 - r_1 = 2t$, where t is the film thickness. Previously, only this path difference determined the conditions for constructive and destructive interference.
- However, under certain conditions, *a wave reflected at the boundary between two media will undergo a phase change equivalent to a half-cycle shift relative to the incident and transmitted waves*.



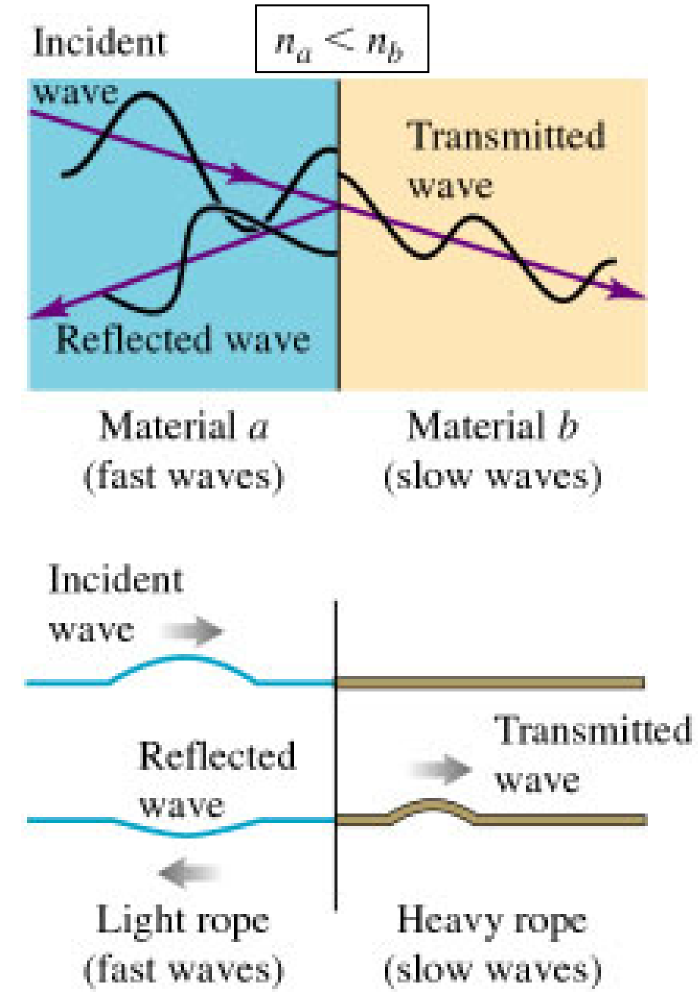


Interference in Thin Films



(a) Transmitted wave moves faster than incident wave: no phase change upon reflection

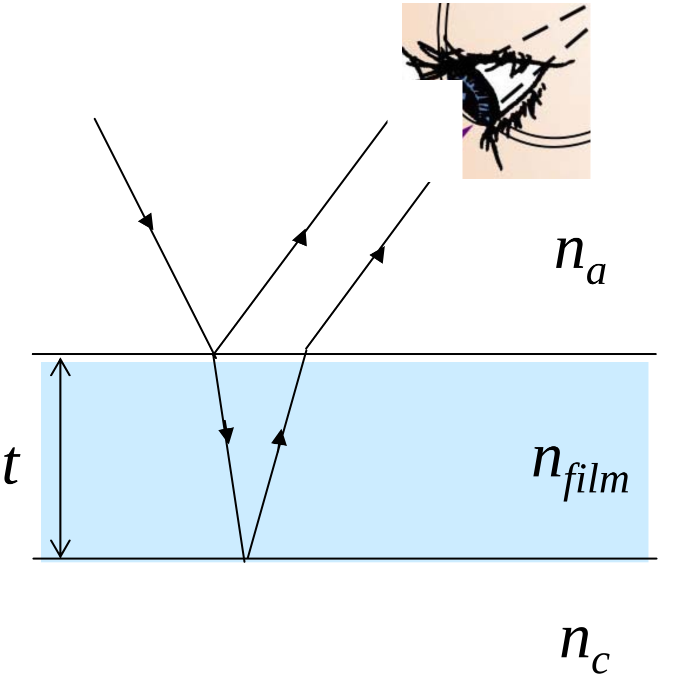
Interference in Thin Films



(c) Transmitted wave moves more slowly than incident wave: half-cycle phase change upon reflection

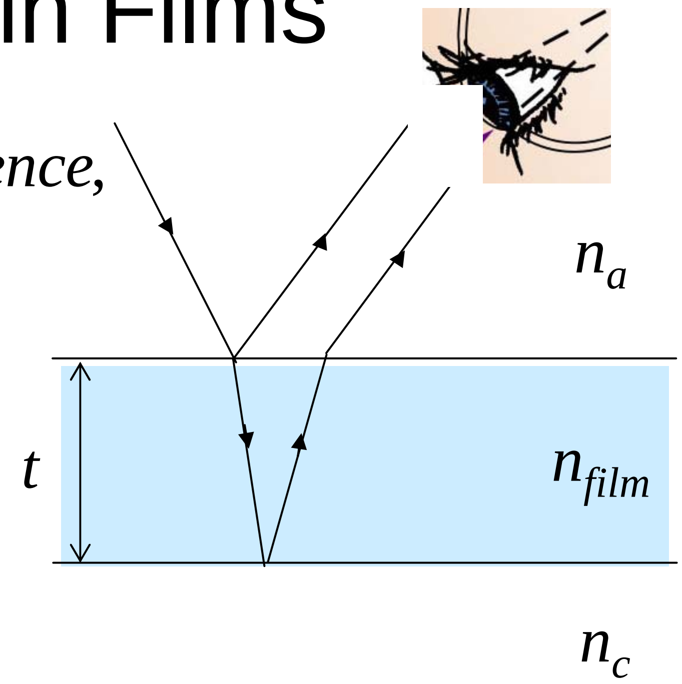
Interference in Thin Films

- *The conditions for constructive and destructive interference have to be determined for each case, considering the values of the refractive indices in the situation.*
- For the situation shown at right, since $n_a < n_{film}$, there is a half-cycle phase shift for the wave reflected at the upper interface, but no phase shift for the one reflected at the lower interface. Thus, in addition to the path difference of 2*t, there is a half-cycle phase shift as well.* Hence, if the path-length difference is an integral number of wavelengths, the waves will *interfere destructively*.



$n_a < n_{film} > n_c$

Interference in Thin Films



Thus, we have

$2t = m\lambda_{film}$, $m = 0, 1, 2, \ldots$ (*destructive interference, half-cycle relative phase shift*)

$2t = \left(m + \frac{1}{2}\right)\lambda_{film}$, $m = 0, 1, 2, \ldots$ (*constructive interference, half-cycle relative phase shift*)

If $n_a < n_{film} < n_c$, then both reflected waves would undergo phase shifts and so there would be no *relative* phase shift. In this case, the conditions for constructive and destructive interference would be

$n_a < n_{film} < n_c$

$2t = m\lambda_{film}$, $m = 0, 1, 2, \ldots$

(*constructive interference, no relative phase shift*)

$2t = \left(m + \frac{1}{2}\right)\lambda_{film}$, $m = 0, 1, 2, \ldots$

(*destructive interference, no relative phase shift*)

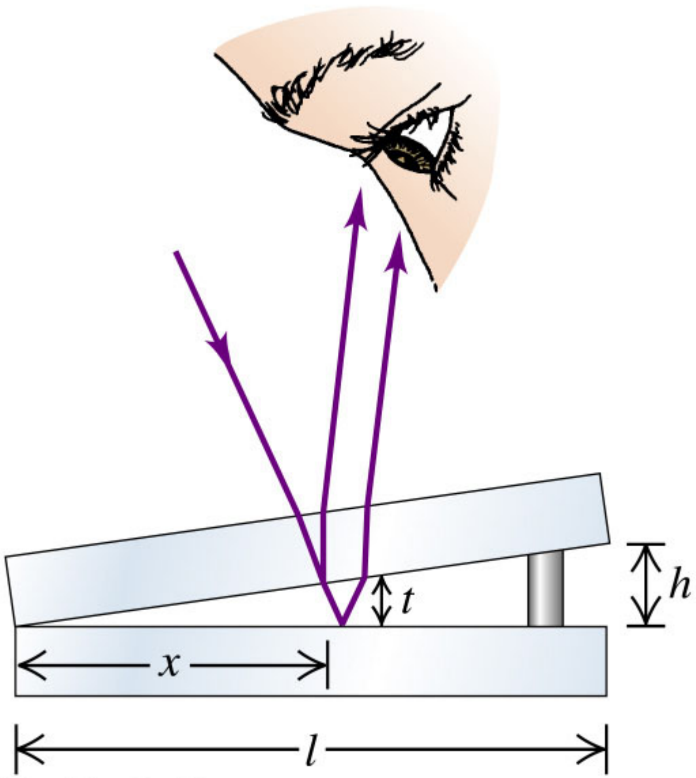
Interference in Thin Films

- Note that

$$\lambda_{film} = \frac{\lambda_{vacuum}}{n_{film}}.$$

- Question: Two pieces of glass have a thin wedge of air between them. What is the condition for destructive interference?

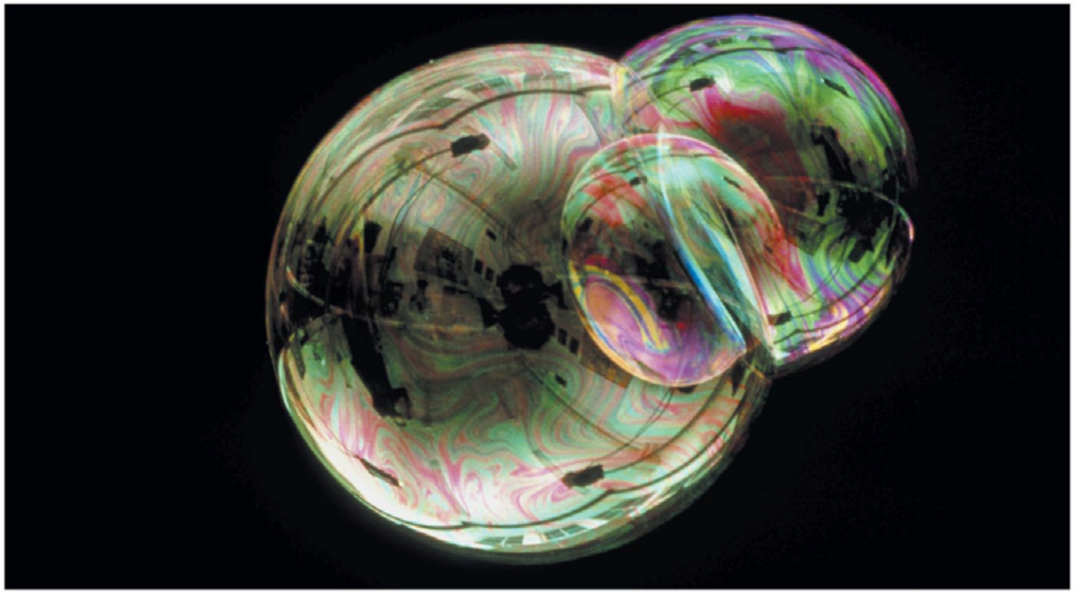
1. $2t = m\lambda_{glass}.$
2. $2t = \left(m + \frac{1}{2}\right)\lambda_{air}.$
3. $2t = m\lambda_{air}.$
4. $2t = \left(m + \frac{1}{2}\right)\lambda_{glass}.$



Workbook: Chapter 17, Question 10

Interference in Thin Films

Air film between two flat glass plates



Soap bubbles (thin water film in air)

A soap film is held vertically in air and is illuminated by white light. (The film is mostly water.) Brilliant wavy colors are seen due to the reflected light. As time progresses, the film drains from top to bottom, and the colors change. Eventually, the top of the film becomes totally black and the black area gradually expands downward. The black region is due to

1. all the colors mixing to produce a very dark overall color.
2. destructive interference because the film is very thin.
3. destructive interference because there is a half-cycle phase shift due to the thickness of the film.

Textbook: Chapter 17, Problem 22