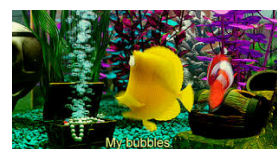## 5.C.2 Thin Film Interference (TFI)

Why are there rainbows on puddles?

BYOB!! (Build Your Own Bubbles)

Take the dropper, and inject air into the soapy water within the beaker. If you do it right, you'll be able to see rainbows on the bubbles!!


MY Bubbles!

Light passing through a thin transparent medium (thin film) undergoes interference when reflections occur at top and bottom surfaces.
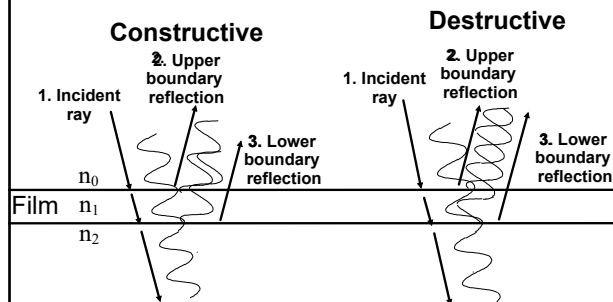
A Note on Drawings

TFI drawings show angles at about 10° to improve conceptual understanding.

TFI happens at all angles: for easier math assume that incident rays are normal to reflecting surfaces.

At an angle

At no angle: hard to tell what's coming and going

n_1
n_2
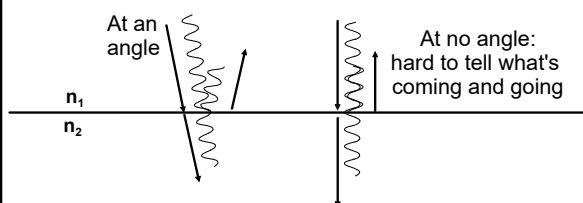
Reflections in Thin-Films

Interference patterns at thin-film boundaries are constructive (maximum reflectance), destructive (non-reflective), or anything between.

Constructive

1. Incident ray
2. Upper boundary reflection
3. Lower boundary reflection

Destructive

1. Incident ray
2. Upper boundary reflection
3. Lower boundary reflection

n_0

Film n_1

n_2

Wavelength Compression Review

As light slows in a film, λ shortens, becoming λ' (frequency is unchanged):

$$\lambda' = \frac{\lambda}{n}$$

λ' = wavelength in second medium (m)	
λ = wavelength in air (m)	
n = index of refraction of film.	

n_0
n_1

Wavelength Decreases
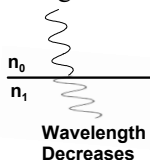
To find n:

$$n = \frac{c}{v}$$

n = index of refraction
c = 3.0 E 8 (m/s)
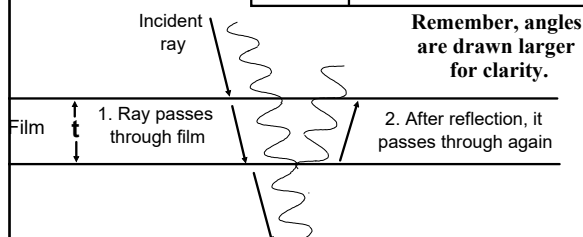v = speed of light in medium (m/s)

Geometric Considerations

The number of wave oscillations while passing entirely through a film determines interference.

Let m (oscillations (order number)) be the ratio of twice the film thickness and λ':

$$m = \frac{2t}{\lambda'}$$

m = number of oscillations
t = film thickness (m)
λ' = wavelength in film (m)

Remember, angles are drawn larger for clarity.

Incident ray

Film t

1. Ray passes through film
2. After reflection, it passes through again

1. Order Example

What is m, when 538 nm light passes through a film (n = 1.4) of thickness 8.65 E -7 m?

First, find λ' (hold on to decimals):

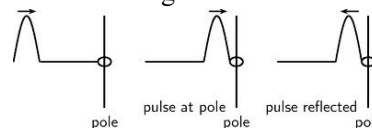$$\lambda' = \frac{\lambda}{n} = \frac{5.38\,E-7\,m}{1.4} = 3.843\,E-7\,m$$

Then find m:

$$m = \frac{2t}{\lambda'} = \frac{2 \bullet 8.65\,E-7}{3.843\,E-7} = 4.5\,oscillations$$
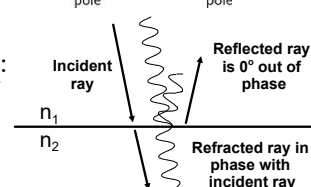
Phase Shift Overview

Analogue: when a pulse reaches a loose string on a pole, there is a 0° phase shift as the loop can go up, then back down during the interaction:
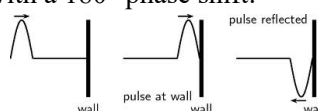

pole   pulse at pole   pulse reflected
                 pole   pole

Light undergoes a 0° shift <u>when $n_1 > n_2$</u>:

Ex: oil to water

Incident ray

n₁
n₂

Reflected ray is 0° out of phase

Refracted ray in phase with incident ray

180 Degree Phase Shift

When a pulse on a tied string reaches a wall, it reflects with a 180° phase shift:

wall   pulse at wall   pulse reflected
                wall   wall

Light undergoes a 180° shift <u>when $n_1 < n_2$</u>:

Ex: air to water.

Incident ray

n₁
n₂

Reflected ray is 180° out of phase

Refracted ray in phase with incident ray
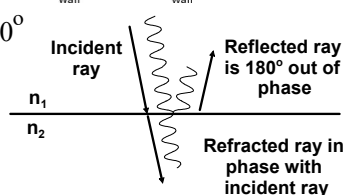
Increasing Index Interference

If: $n_0 < n_1 < n_2$: Resources 8 Table.
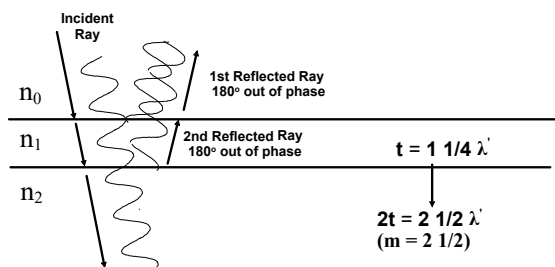and m = whole integer: constructive;
and m = 1/2 integer: destructive.

Whole Integer
Constructive: t = λ'

Incident Ray

1st Reflected Ray 180° out of phase

n₀
n₁
n₂

2nd Reflected Ray 180° out of phase

t = λ'

2t = 2 λ' (m = 2)
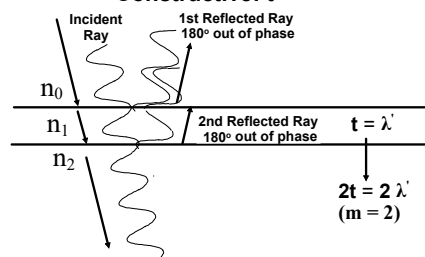
Increasing Index: m = 1/2 Integer Destructive

Incident Ray

n₀
n₁
n₂

1st Reflected Ray 180° out of phase

2nd Reflected Ray 180° out of phase

t = 1 1/4 λ'

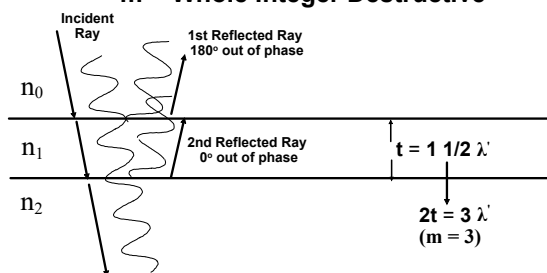2t = 2 1/2 λ' (m = 2 1/2)

Sandwich Index Interference

If: $n_0 < n_1 > n_2$: Resources 8.
and m = whole integer: destructive;
and m = 1/2: constructive.

m = Whole Integer Destructive

Incident Ray

1st Reflected Ray 180° out of phase

n₀
n₁
n₂

2nd Reflected Ray 0° out of phase

t = 1 1/2 λ'

2t = 3 λ' (m = 3)

Sandwich Index: m = 1/2 Integer Constructive

Incident Ray

1st Reflected Ray
180° out of phase

n_0

n_1

2nd Reflected Ray
0° out of phase

$t = 1\ 1/4\ \lambda'$

n_2

$2t = 2\ 1/2\ \lambda'$
$(m = 2\ 1/2)$
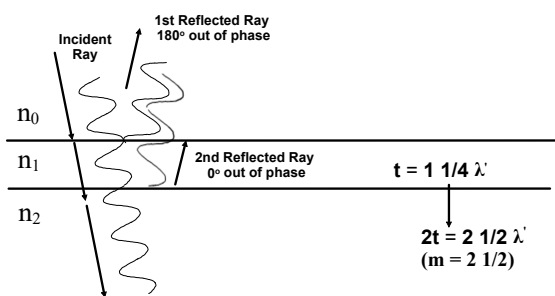
2. TFI Example Part 1

An oil film (n = 1.43) floats on water (n = 1.33).
As light passes through, how many 180° reflections will it undergo?

Light Beam

Air

Oil
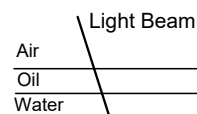
Water

The beam enters a medium of higer optical density at the air/oil boundary, so there's a 180° shift.
At the oil/water boundary, light enters a less optically dense medium, so a 0° shift happens.
Thus, only one 180° reflection happens.

3. TFI Example Part 2

A 1495 nm oil film (n = 1.43) floats on water (n = 1.33).
If λ = 450 nm, what kind of interference is observed?

Air: n = 1.00

Oil: n = 1.43

Water: n = 1.33

Find λ':

$$\lambda' = \frac{\lambda}{n} = \frac{4.50\,E-7\,m}{1.43} = 3.1469\,E-7\,m$$

find m:

$$m = \frac{2t}{\lambda'} = \frac{2 \cdot 1.495\,E-6}{3.1469\,E-7} = 9.50$$

This is a sandwich: a half-wave order number means constructive interference.

Minimum Thickness

The minimum film thickness for interference (whether constructive or destructive) to occur is 1/4 of a wavelength:

$t_{min} = \dfrac{\lambda'}{4}$	t_{min} = minimum thickness (m) λ' = wavelength in film (m)

Add-On Notes:
Decreasing indices of refraction ($n_0 > n_1 > n_2$) work the same as increasing indices.
Switched around sandwich indices ($n_0 > n_1 < n_2$) work the same as what was shown.

Newton's Rings

This phenomenon occurs when a lens is placed on a very planar surface (called an optical flat), such that a differentially thick air gap exists.
As light passes through the air gap, interference happens at different areas, and the trueness of the lens is established based on ring uniformity.

Microscope slide demo.
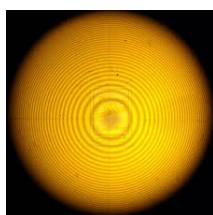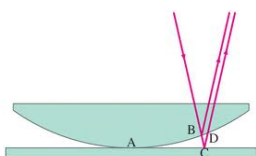
Homework 5.C.2

Problems 5.C.2 in your Booklet
Due: Next Class