THIN FILM INTERFERENCE

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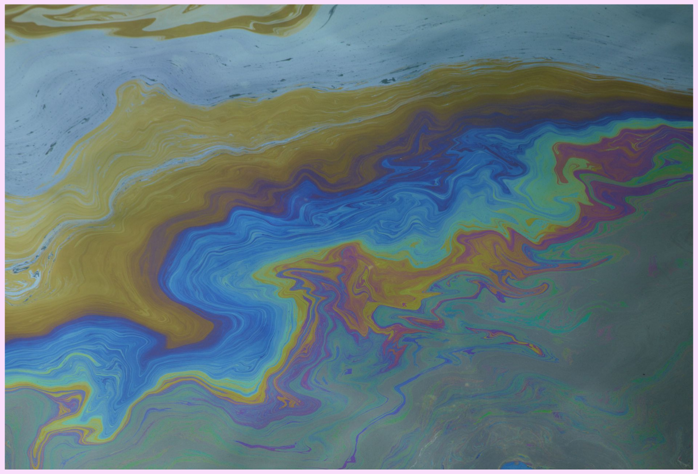
SPH 4UE

What are Thin Films?

- The swirling colours of the spectrum that can be found on oil spills, soap bubbles and CDs occur because light is being reflected by or transmitted through a thin film, causing an optical interference



History

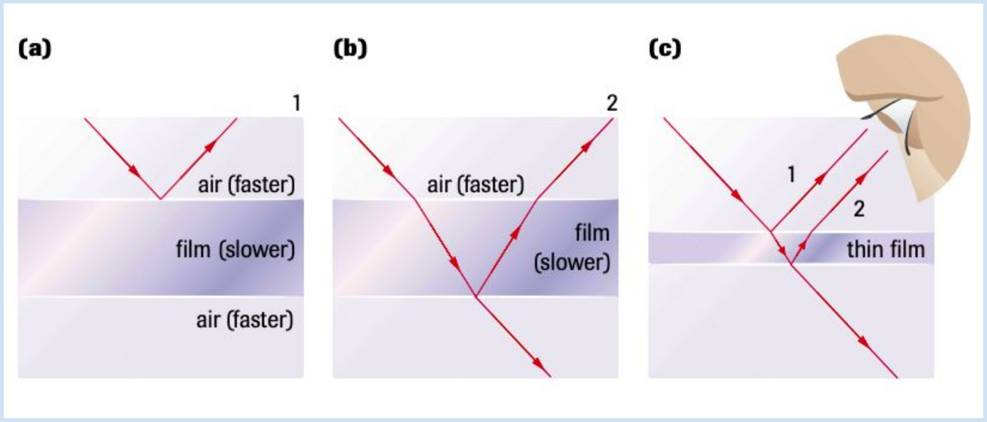
- Discovered by English scientist **Robert Hooke** in **1665**
- One day, he wondered why peacock feathers shine iridescent in light
- After accidentally dropping it in water, it no longer shone iridescent, surprised Hooke decided to look into the phenomenon

What is Interference?

- When switching mediums, the light wave goes through a process of **partial-reflection**

- Fast medium ⇒ slow medium
  - Waves are phase shifted by 180°

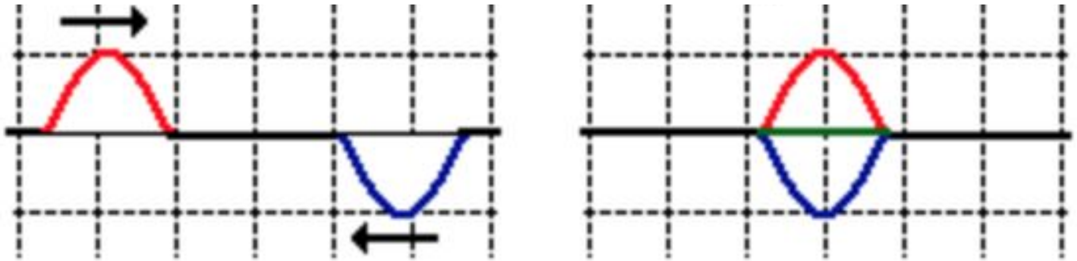
- Slow medium ⇒ Fast medium
  - No phase shift



Types of Interference

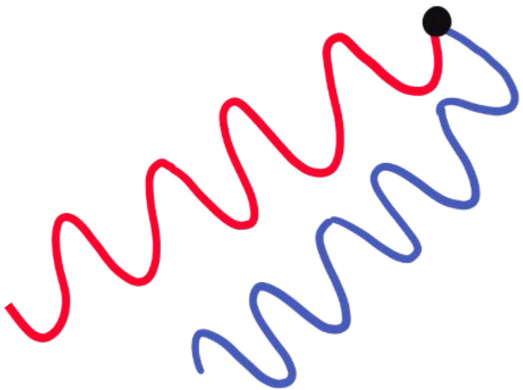
Constructive Interference: Occurs when two interfering waves have a displacement in the same direction.

Destructive Interference: Occurs when two interfering waves have a displacement in opposite directions.



Path Difference

Path Difference: The difference in distance travelled by two rays at a given point in time.

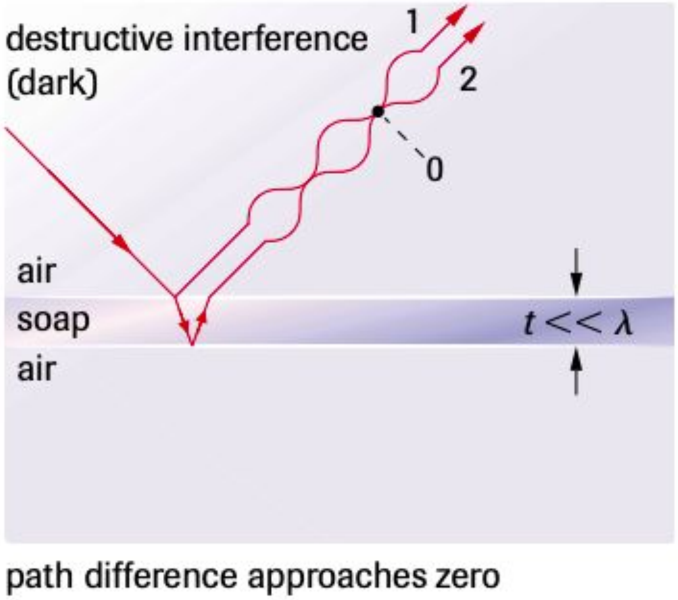


$5\lambda - 4\lambda = \lambda$ ➡ Constructive Interference

$4\lambda/2 - 4\lambda = \lambda/2$ ➡ Destructive Interference

Reflection: Destructive Interference

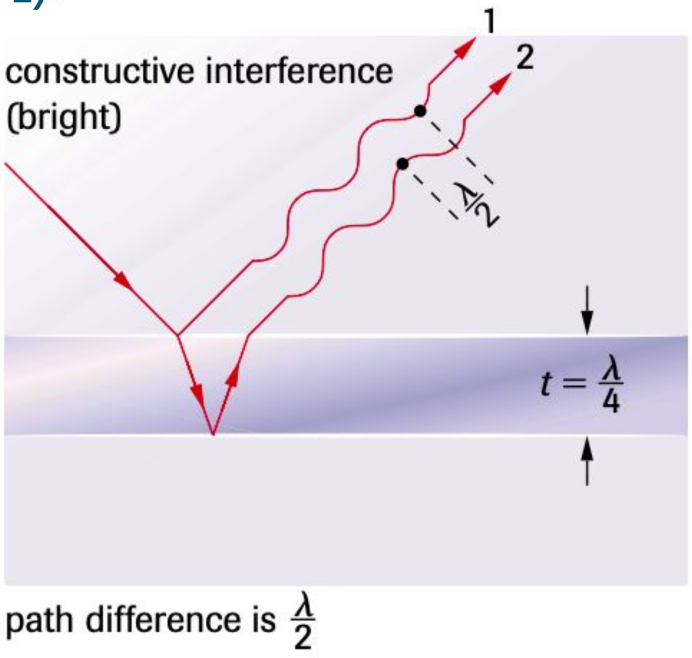
1)



- Since the film is very thin ($t << \lambda$), the path difference approaches 0
- Since the waves are not in sync, **destructive interference** is caused
- A dark area occurs as a result of destructive interference

Reflection: Constructive Interference

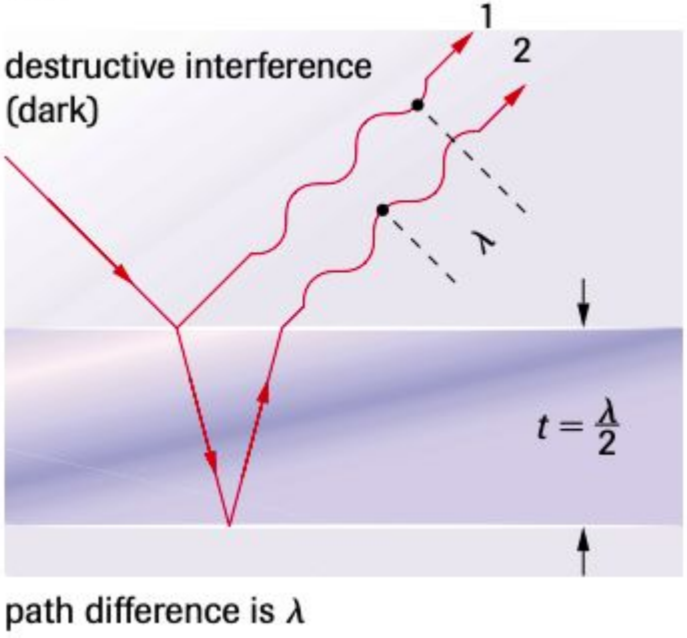
2)



- When t = λ/4, the path difference is λ/2 (twice the thickness of the film)
- Since the waves are in sync, **constructive interference** is caused
- A bright area occurs as a result of constructive interference

Reflection: Destructive Interference

3)



- When t = λ/2, the path difference is λ (twice the thickness of the film)

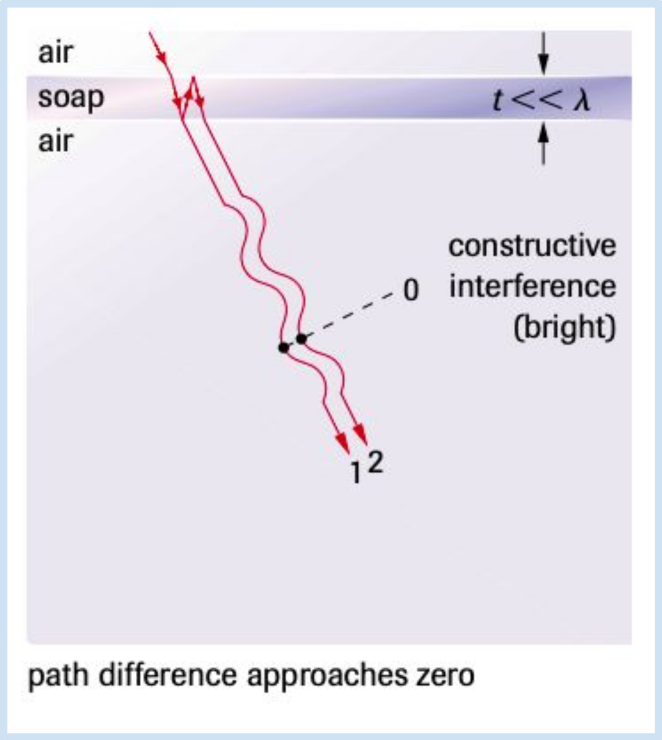
- Since the waves are not in sync, **destructive interference** is caused

- Dark and bright areas alternate
  - Dark areas: 2t = 0, λ, 2λ,...
  - Bright areas: 2t = λ/2, 3λ/2, 5λ/2,...

* λ is the wavelength of the light in the film, which is less than the wavelength of light in air by a factor of n

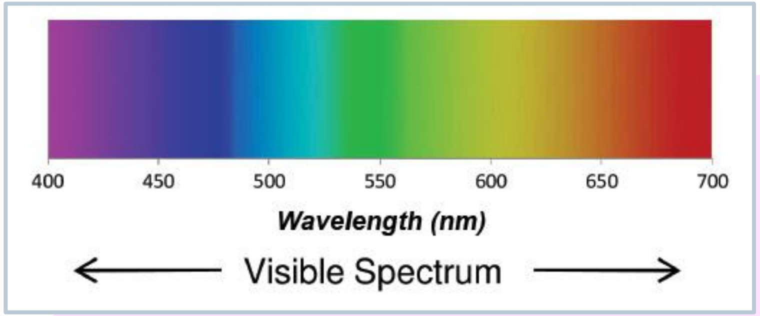
Transmission: Constructive Interference

- Same behaviours as reflection, but opposite
- Results in constructive or destructive interference depending on phase shift
- Since it's opposite of reflection, the formulas are flipped, now dark and bright areas continue to alternate but at:
  - Bright areas: $2t = 0, \lambda, 2\lambda, \ldots$
  - Dark areas $2t = \lambda/2, 3\lambda/2, 5\lambda/2, \ldots$



Appearance

- As a result of gravity, the film is thin at the top and gradually becomes thicker as it gets to the bottom
- When shown under a monochromatic light, the spectrum can be seen
- As each colour has different wavelengths, various thicknesses are required to see the spectrum



Equation

$$v = f\lambda$$

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

$$f_a = f_b$$

$$\frac{v_a}{\lambda_a} = \frac{v_b}{\lambda_b}$$

$$\lambda_b = \left(\frac{v_b}{v_a}\right)\lambda_a$$

$$\lambda_b = \frac{\frac{\left(\frac{c}{n_b}\right)}{\left(\frac{c}{n_a}\right)}}{\lambda_a}$$

$$\boxed{\lambda_b = \left(\frac{n_a}{n_b}\right)\lambda_a}$$

Cheat Sheet!

STEPS TO SOLVE:

1) Understand the question
2) Draw a diagram and list given information
3) Look for # of phase shifts

   → If index of refraction is greater than the previous one = one phase shift

4) Choose which formula to use

FORMULAS:

2 Phase shifts

Constructive: $2t = m\lambda$

Destructive: $2t = (m + 1/2)\lambda$

1 Phase shift

Constructive: $2t = (m + 1/2)\lambda$

Destructive: $2t = m\lambda$

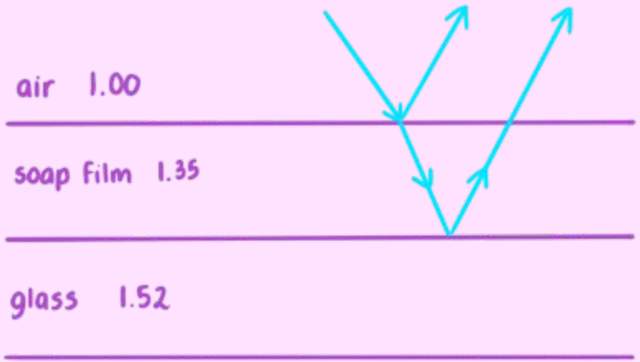
Find the missing wavelength

$\lambda_b = (n_a/n_b)\lambda_a$

Sample Problem #1!

Consider a soap film that is the thinnest film that will produce a bright blue light when illuminated with white light. The index of refraction of the soap film is 1.35, and the blue light is monochromatic with wavelength 411 nm.

a) Calculate the thickness of the film if the soap covers a piece of crown glass with index of refraction 1.52.



Givens:

$n_{glass} = 1.52$

$n_{film} = 1.35$

$\lambda_{blue} = 411 \text{ nm} = 4.11 \times 10^{-7} \text{ m}$

$t = ?$

$$\lambda_s = \left(\frac{n_a}{n_s}\right) \lambda_a$$

$$= \left(\frac{1}{1.35}\right) \times 4.11 \times 10^{-7}$$

$$= 3.04 \times 10^{-7}$$

$$2t = m\lambda_{soap}$$

$$t = \frac{(1)\, 3.04 \times 10^{-7}}{2}$$

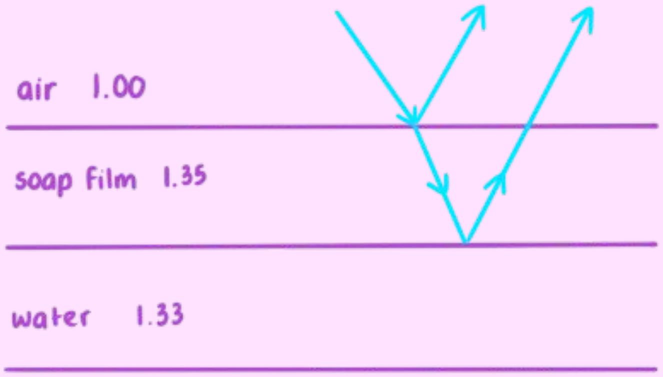
$$\boxed{t = 1.52 \times 10^{-7}}$$

Sample Problem #1!

Consider a soap film that is the thinnest film that will produce a bright blue light when illuminated with white light. The index of refraction of the soap film is 1.35, and the blue light is monochromatic with wavelength 411 nm.

b)

Suppose the reflections occur instead from a soap film on water with index of refraction 1.33. Determine the thickness of the film on water that will produce the same blue colour of reflected light



Givens:

$n_{\text{soap film}} = 1.33$

$n_{\text{water}} = 1.33$

$\lambda = 411\,\text{nm} = 4.11 \times 10^{-7}\,\text{m}$

$t = ?$

$$\lambda_s = \left(\frac{n_a}{n_s}\right)\lambda_a$$

$$= \left(\frac{1}{1.35}\right) \times 4.11 \times 10^{-7}$$

$$= 3.04 \times 10^{-7}$$

$$2t = \left(m + \tfrac{1}{2}\right)\lambda$$

$$t = \frac{\lambda}{4}$$

$$t = \frac{3.04 \times 10^{-7}}{4}$$

$$\boxed{t = 7.60 \times 10^{-8}}$$

Practice Problem #1!

Calculate the smallest thickness of a soap film on glass ($n = 1.52$) capable of producing reflective destructive interference with a wavelength of 745 nm in air.

(Assume that the index of refraction of soapy water is the same as that of pure water, 1.33.)

Givens:

$n_{soap\ film} = 1.33$

$n_{glass} = 1.52$

$\lambda = 750\ nm = 7.50 \times 10^{-7}\ m$

$t = ?$

$$\lambda_s = \left(\frac{n_a}{n_s}\right)\lambda_a$$

$$= \left(\frac{1}{1.33}\right) \times 7.50 \times 10^{-7}$$

$$= 5.63 \times 10^{-7}\ m$$

$$2t = \left(m + \tfrac{1}{2}\right)\lambda$$

$$t = \frac{\lambda}{4}$$

$$t = \frac{5.63 \times 10^{-7}\ m}{4}$$

$$\boxed{t = 1.40 \times 10^{-7}\ m}$$

Practice Problem #2!

A thin layer of glass (*n* = 1.50) floats on a transparent liquid (*n* = 1.35). The glass is illuminated from above by light with a wavelength, in air, of 5.80×10^2 nm. Calculate the minimum thickness of the glass, in nanometres, other than zero, capable of producing destructive interference in the reflected light.

Givens:

$n_{glass} = 1.50$

$n_{liquid} = 1.35$

$\lambda = 5.80 \times 10^2 \text{nm}$

$t = ?$

$$\lambda_g = \left(\frac{n_a}{n_g}\right)\lambda_a$$

$$= \left(\frac{1}{1.50}\right) \times 5.80 \times 10^2 \text{nm}$$

$$= 387 \text{nm}$$

$$2t = m\lambda_g$$

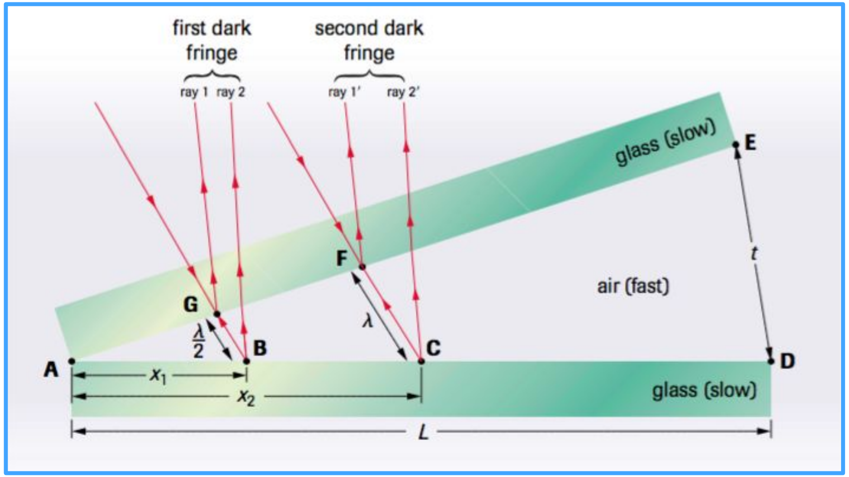
$$t = \frac{m\lambda_g}{2}$$

$$t = \frac{387\text{nm}}{2}$$

$$\boxed{t = 193\text{nm}}$$

Interference in an Air Wedge

- Can be used to find the incident light wavelength and measure the size of very small objects
- By using similar triangles, we can find the equation $\Delta x = L(\lambda/2t)$



Where:

- L = length of the air wedge
- t = thickness of the airwedge
- λ = wavelength of the light in the air wedge

Sample Problem #2!

(a) An air wedge between two microscope slides, **11.0 cm** long and separated at one end by a paper of thickness **0.091 mm**, is illuminated with red light of wavelength **663 nm**. What is the spacing of the dark fringes in the interference pattern reflected from the air wedge?

Givens:

$L = 11.0\ cm$

$\lambda = 663\ nm = 6.63 \times 10^{-5}\ cm$

$t = 0.091\ mm = 9.1 \times 10^{-3}\ cm$

a) In air:

$$\Delta x = L\left(\frac{\lambda}{2t}\right)$$

$$= 11.0\ cm\left(\frac{6.63 \times 10^{-5}\ cm}{2(9.1 \times 10^{-3}\ cm)}\right)$$

$$\boxed{\Delta x = 4.0 \times 10^{-2}\ cm}$$

Sample Problem #2!

(b) How would the spacing change if the wedge were filled with water (n =1.33)?

If the air was replaced by water:

$$\lambda_{water} = \left(\frac{n_a}{n_w}\right)\lambda_{air}$$

$$= \frac{1.00}{1.33}\left(6.63 \times 10^{-5} cm\right)$$

$$\lambda_{water} = 4.98 \times 10^{-5} cm$$

$$\Delta x = L\left(\frac{\lambda}{2t}\right)$$

$$= 11.0 cm \left(\frac{4.98 \times 10^{-5} cm}{2(9.1 \times 10^{-3} cm)}\right)$$

$$\boxed{\Delta x = 3.0 \times 10^{-2} cm}$$

Practice Problem #3!

Two pieces of glass forming an air wedge 9.8 cm long are separated at one end by a piece of paper 1.92×10^{-3} cm thick. When the wedge is illuminated by monochromatic light, the distance between centres of the first and eighth successive dark bands is 1.23 cm. Calculate the wavelength of the light.

$$\Delta x = \frac{1.23}{7} = 0.18\,\text{cm}$$

$L = 9.8\,\text{cm}$

$t = 1.92 \times 10^{-3}\,\text{cm}$

$\lambda = ?$

$$\Delta x = L\left(\frac{\lambda}{2t}\right)$$

$$\lambda = \frac{2t\Delta x}{L}$$

$$= \frac{2(1.92 \times 10^{-3})(0.18)}{9.8}$$

$$= 7.1 \times 10^{-5}\,\text{cm}$$

Practice Problem #4!

Light with a wavelength of 6.40×10^2 nm illuminates an air wedge 7.7 cm long, formed by separating two pieces of glass with a sheet of paper. The spacing between fringes is 0.19 cm. Calculate the thickness of the paper.

$\Delta x = 0.19\ \text{cm}$

$L = 7.7\ \text{cm}$

$\lambda = 6.4 \times 10^2\ \text{nm}$

$= 6.40 \times 10^{-5}\ \text{cm}$

$t = ?$

$$\Delta x = L\left(\frac{\lambda}{2t}\right)$$

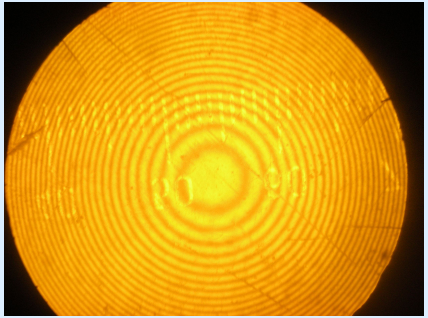
$$t = \frac{L\lambda}{2\Delta x}$$

$$= \frac{(7.7)(6.40 \times 10^{-5})}{2(0.19)}$$

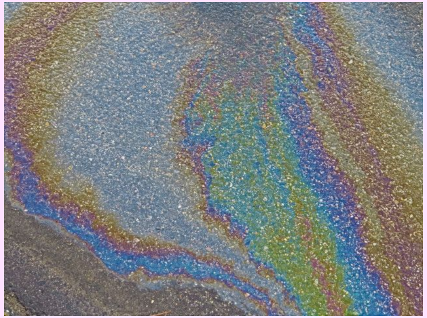
$$= 1.3 \times 10^{-3}\ \text{cm}$$

APPLICATIONS

Newton's Rings



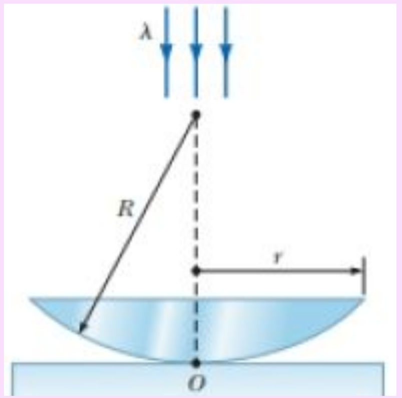
Oil

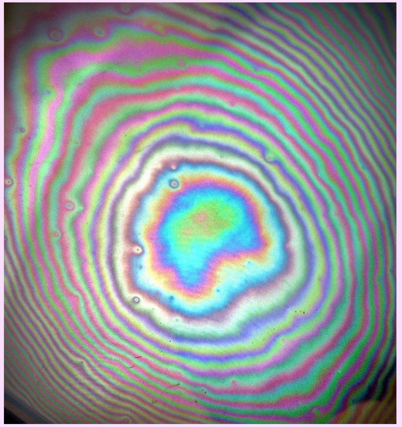


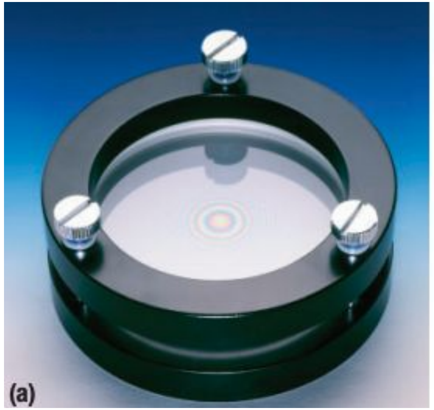
Glasses

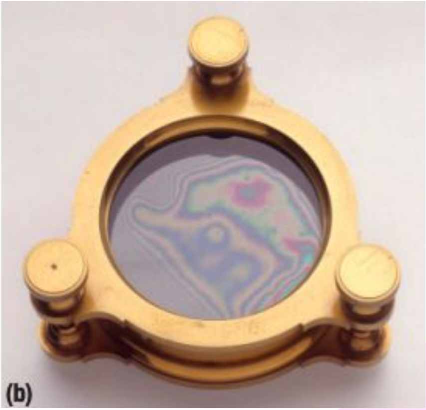
Newton's Rings

- Emerges when light is shined through a curved piece of glass placed on top of a flat piece of glass
- Rings are caused by the interference between the **top and bottom** of the air wedge between bottom of curved glass and the surface of the flat glass







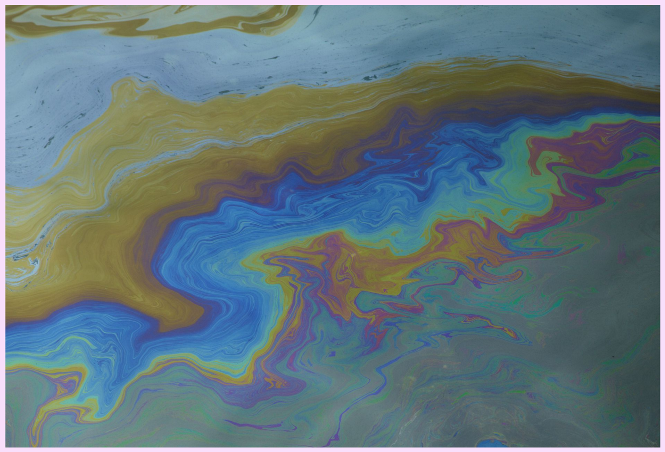


Oil Spill

- Colourful sheen comes from the interference between the light rays reflected from the surface of the water and the rays from the surface of the oil

- Thickness of the film varies due to evaporation

- Variation in thickness causes colours to shift



Lenses and Eyeglasses

- Thin films are used as anti-reflective coating on glasses and other optical instruments
- UV - resistant coating can be applied to sunglasses to counteract harmful absorption
- Used in other optical instruments as well such as cameras, microscopes, binoculars, etc. to minimize image blurring

References

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