Section 10.1: Interference in Thin Films

Tutorial 1 Practice, page 507

1. The second soap film is thicker. The longer wavelength of the second film means the film at that point must be thicker for constructive interference to occur.

2. Given: $n_{\text{soap film}} = 1.33$; $\lambda = 745\text{ nm} = 7.45\times10^{-7}\text{ m}$

Required: t

Analysis: Phase changes occur at both reflections, so use the formula for destructive interference; use $m = 0$;

$$2t = \frac{\left(m+\frac{1}{2}\right)\lambda}{n_{\text{soap film}}};\ t = \frac{\left(m+\frac{1}{2}\right)\lambda}{2n_{\text{soap film}}}$$

Solution:

$$\begin{aligned} t &= \frac{\left(m+\frac{1}{2}\right)\lambda}{2n_{\text{soap film}}} \\ &= \frac{\left(0+\frac{1}{2}\right)7.45\times10^{-7}\text{ m}}{2(1.33)} \end{aligned}$$

$$t = 1.40\times10^{-7}\text{ m}$$

Statement: The smallest thickness of soap film capable of producing reflective destructive interference with a wavelength of 745 nm in air is $1.40\times10^{-7}\text{ m}$.

3. Given: $n_{\text{oil}} = 1.50$; $\lambda = 510\text{ nm} = 5.10\times10^{-7}\text{ m}$

Required: t

Analysis: The yellow light undergoes a phase change at the air–oil reflection interface, but not at the oil–water interface. Since we do not want to see the yellow light, use the formula for destructive interference; use $n = 1$; $2t = \frac{n\lambda}{n_{\text{oil}}}$; $t = \frac{n\lambda}{2n_{\text{oil}}}$

Solution:

$$\begin{aligned} t &= \frac{n\lambda}{2n_{\text{oil}}} \\ &= \frac{(1)5.10\times10^{-7}\text{ m}}{2(1.50)} \end{aligned}$$

$$t = 1.70\times10^{-7}\text{ m}$$

Statement: The oil slick needs to be 1.70×10^{-7} m thick for the yellow light be invisible.

4. Given: $n_{\text{coating}} = 1.38$; $\lambda = 610 \text{ nm} = 6.1 \times 10^{-7} \text{ m}$

Required: t

Analysis: The red light undergoes a phase change at both the air–coating reflection interface and the coating–lens interface. Since we do not want to see the red light, use the formula for destructive interference; use $m = 0$;

$$2t = \frac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{coating}}};\ t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{coating}}}$$

Solution: $t = \dfrac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{coating}}}$

$$= \frac{(0.5)6.1 \times 10^{-7} \text{ m}}{2(1.38)}$$

$$t = 1.1 \times 10^{-7} \text{m}$$

Statement: The thickness of the magnesium fluoride anti-reflection coating needs to be 1.1×10^{-7} m.

Mini Investigation: Observing a Thin Film on Water, page 507

A. Sample answer: The dark areas represent areas where destructive interference occurs.

B. Sample answer: The patterns were caused by different thicknesses of the film and the different wavelengths of light.

C. Sample answer: The pattern changed when the colour of the light changed because the thicknesses of oil cause destructive interference for some colours.

Tutorial 2 Practice, page 510

1. Given: t = 0.012 cm = 1.2×10^{-4} m; L = 10.8 cm = 1.08×10^{-1} m;
2.4 mm = 7 cycles of alternating patterns; 2.4 mm = 2.4×10^{-3} m

Required: λ

Analysis: Calculate Δx, the separation between the fringes. Then rearrange the equation $\Delta x = \dfrac{L\lambda}{2t}$ to solve for wavelength; $\lambda = \dfrac{2t\Delta x}{L}$.

Solution: Calculate Δx:

$$\Delta x = \frac{2.4 \times 10^{-3} \text{ m}}{7}$$

$\Delta x = 3.43 \times 10^{-4}$ m (one extra digit carried)

$$\lambda = \frac{2t\Delta x}{L}$$
$$= \frac{2\left(1.2\times10^{-4}\text{ m}\right)\left(3.43\times10^{-4}\text{ }\cancel{\text{m}}\right)}{1.08\times10^{-1}\text{ }\cancel{\text{m}}}$$
$$\lambda = 7.6\times10^{-7}\text{ m}$$
Statement: The wavelength of the light is 7.6×10^{-7} m.

2. Given: L = 6.0 cm = 6.0×10^{-2} m; λ = 730 nm = 7.30×10^{-7} m; there are 62 cycles of alternating light patterns in L

Required: t

Analysis: Δx, the separation between the fringes, is given by $\frac{L}{62}$; $\Delta x = \frac{6.0\ \times10^{-2}\text{ m}}{62}$.

Rearrange the equation $\Delta x = \frac{L\lambda}{2t}$ to solve for thickness; $t = \frac{L\lambda}{2\Delta x}$.

Solution: $t = \frac{L\lambda}{2\Delta x}$
$$= \frac{\left(6.0\times10^{-2}\text{ m}\right)\left(7.3\times10^{-7}\text{ }\cancel{\text{m}}\right)}{2\left(\frac{6.0\times10^{-2}\text{ }\cancel{\text{m}}}{62}\right)}$$
$$t = 2.3\times10^{-7}\text{ m}$$
Statement: The thickness of the paper is 2.3×10^{-5} m.

Research This: Thin Films and Cellphones, page 510

A. Answers may vary. Sample answer: Cellphones have several layers of thin films. The infrared light incident on the screen enters the top layer, and the other layers turn this energy into visible light. The multiple layers amplify the light energy so that it is visible.

B. Answers may vary. Sample answer: As of late 2010, applying night vision technology to glasses and cellphones is still in the research phase. Given adequate financing, this technology could be implemented in cellphones within a year or two.

C. Answers may vary. Sample answer: For this technology to become usable, more research needs for the thin film technology to be practical to be added to glasses or cellphone screens. There may be a cost barrier as well, which is typical of new inventions. However, this barrier would be overcome as the application became more widespread.

D. Answers may vary. Presentations or summaries should include more information based on the research and could include images, schematics, and equations.

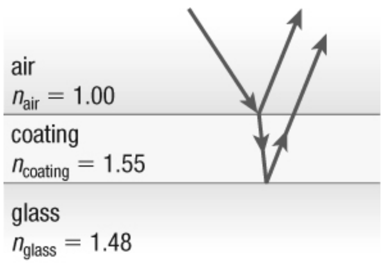
Section 10.1 Questions, page 511

1. Given: $n_{\text{coating}} = 1.55$; $n_{\text{lens}} = 1.48$; $t = 177.4 \text{ nm} = 1.774 \times 10^{-7} \text{ m}$

Required: λ

Analysis: Phase changes occur at the air–coating interface but not at the coating–lens interface. For minimal reflection, use the formula for destructive interference, $2t = \dfrac{n\lambda}{n_{\text{coating}}}$, to solve for wavelength; $\lambda = \dfrac{2t(n_{\text{coating}})}{n}$ use $n = 1$.

Solution:



$$\begin{aligned}\lambda &= \frac{2t(n_{\text{coating}})}{n} \\ &= \frac{2(1.774 \times 10^{-7} \text{ m})(1.55)}{1} \\ &= 5.50 \times 10^{-7} \text{ m}\end{aligned}$$

$$\lambda = 550 \text{ nm}$$

Statement: The wavelength of the light that is minimally reflected is 550 nm.

2. Given: $n_{\text{film}} = 1.29$; $\lambda = 7.00 \times 10^{-7} \text{ m}$; $n = 1$

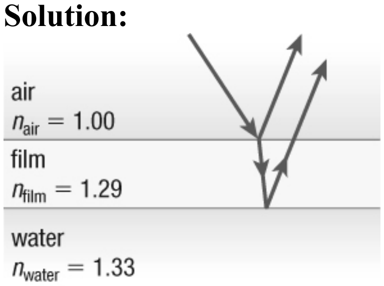
Required: t

Analysis: Phase changes occur at the air–film interface and at the film–water interface.

For maximum reflection, use the formula for constructive interference; $2t = \dfrac{n\lambda}{n_{\text{film}}}$;

$t = \dfrac{n\lambda}{2n_{\text{film}}}$.

Solution:



$$t = \frac{n\lambda}{2n_{\text{film}}}$$
$$= \frac{(1)7.00 \times 10^{-7}\ \text{m}}{2(1.29)}$$
$$t = 2.71 \times 10^{-7}\ \text{m}$$

Statement: The thickness of the film is 2.71×10^{-7} m.

3. Given: $n_{\text{film}} = 1.35$; $n_{\text{glass}} = 1.50$; $\lambda_{\text{red}} = 6.00 \times 10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface and at the film–glass interface. For maximum reflection, use the formula for constructive interference, $2t = \frac{n\lambda}{n_{\text{film}}}$; $t = \frac{n\lambda}{2n_{\text{film}}}$. Use $n = 1$.

Solution:

$$t = \frac{n\lambda}{2n_{\text{film}}}$$
$$= \frac{(1)6.00 \times 10^{-7}\ \text{m}}{2(1.35)}$$
$$t = 2.22 \times 10^{-7}\ \text{m}$$

Statement: The thickness of the soapy water film is 2.22×10^{-7} m.

4. Given: $n_{\text{film}} = 1.35$; $n_{\text{glass}} = 1.10$; $\lambda = 6.00 \times 10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface but not at the film–glass interface. For maximum reflection, use the formula for constructive interference, $2t = \frac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{film}}}$; $t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$. Use $m = 0$.

Solution: $t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$

$$t = \frac{\left(0 + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$$

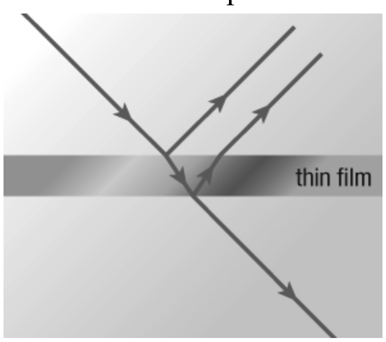
$$= \frac{(0.5)(6.00 \times 10^{-7}\ \text{m})}{2(1.35)}$$

$$t = 1.11 \times 10^{-7}\ \text{m}$$

Statement: When the index of refraction of the glass plate changes to 1.10, the thickness of the soapy water film becomes 1.11×10^{-7} m.

5. The interference between reflections on the top and bottom of the soap film produces the colours. No, the bubble is not of uniform thickness. It is thinnest in the blue bands because this is the condition for which there is constructive interference with the smallest thickness of film. The film is thickest in the red areas.

6. An incident ray of light reflects from both the top surface of a soap film and the bottom surface of the soap film. More light is reflected than passes through the film. This gives the appearance of brightness on the top of the soap film and less bright, or darker, on the bottom of the soap film.



7. Given: $n_{\text{glass}} = 1.55$; $n_{\text{water}} = 1.33$; $\lambda_1 = 5.60 \times 10^{-7}\ \text{m}$; $\lambda_2 = 4.00 \times 10^{-7}\ \text{m}$

Required: t

Analysis: Phase changes occur at the air–film interface but not at the film–glass interface. For maximum reflection, use the equation for constructive interference;

$2t = \frac{\left(m + \frac{1}{2}\right)\lambda}{n_{\text{film}}}$; $t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{film}}}$. Use $m = 0, 1, 2, 3, 4, ...$ for each wavelength to see which value produces a thickness that results in both lights being reflected.

Solution: $t = \frac{\left(m + \frac{1}{2}\right)\lambda}{2n_{\text{glass}}}$

For λ_1, there are a number of thicknesses that will reflect the light.

For $m = 0$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 0.903 \times 10^{-7}\ \text{m}$

For $m = 1$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 2.710 \times 10^{-7}\ \text{m}$

For $m = 2$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 4.516 \times 10^{-7}\ \text{m}$

For $m = 3$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(5.60 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 6.323 \times 10^{-7}\ \text{m}$

For λ_2, there are also a number of thicknesses that will reflect the light.

For $m = 0$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 0.645 \times 10^{-7}\ \text{m}$

For $m = 1$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 1.935 \times 10^{-7}\ \text{m}$

For $m = 2$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 3.226 \times 10^{-7}\ \text{m}$

For $m = 3$:

$$t = \frac{\left(m + \frac{1}{2}\right)\left(4.00 \times 10^{-7}\ \text{m}\right)}{2\left(1.55\right)}$$

$t = 4.516 \times 10^{-7}\ \text{m}$

The smallest common thickness is $4.516 \times 10^{-7}\ \text{m}$.

Statement: The smallest thickness of glass that will reflect both colours is 4.52×10^{-7} m.