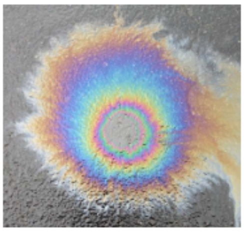
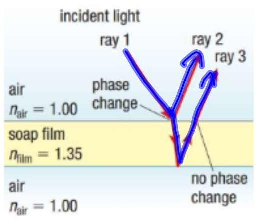
SPH4U 10.1 Interference in Thin Films

1. Thin films

Thin film:	a very thin layer of a substance.



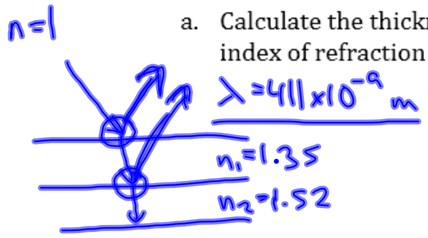
Reflection at a media boundary:	at a media boundary, some light goes through (transmitted) and some is reflected.
Phase change at a reflection:	depending on n of the 2 media, the reflected light may be inverted (or phase change of $\frac{\lambda}{2}$)
(✱) $n_1 < n_2$	faster medium → slower. reflection is inverted.
$n_1 > n_2$	slower medium → faster. reflection is not inverted.
importance	this affects constructive/destructive interference.

Interference:	some light reflects off the top of the film, some reflects off the bottom of the film. these reflections interfere with each other.
path difference	bottom reflection travels 2t further.
① ~~Same phase~~:	when both reflections are inverted:
constructive interference	$2t = n\frac{\lambda}{n_{film}}$ $n = 1, 2, 3, \ldots$
destructive interference	$2t = (m+\frac{1}{2})\frac{\lambda}{n_{film}}$ $m = 0, 1, 2, 3, \ldots$
② ~~Opposite phase~~:	when only one reflection is inverted, the equations switch for constructive/destructive.

2. Determining interference effects

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.



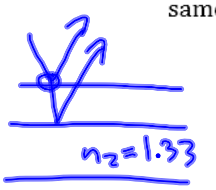
Both reflections are inverted.

$$2t = n\frac{\lambda}{n_{film}} = (1)\frac{(411\times10^{-9})}{1.35}$$

$$= 3.04\times10^{-7}$$

$$t = 1.52\times10^{-7}\ \text{m}$$

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.



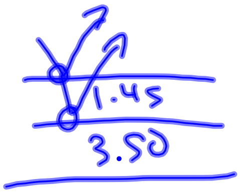
Different phase.

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

$$= \left(0+\tfrac{1}{2}\right)\frac{(411\times10^{-9})}{2(1.35)}$$

$$= 7.61\times10^{-8}\ \text{m}.$$

In solar cells, incoming light passes through an anti-reflective coating to increase the efficiency of the cell. The coating has n_1 = 1.45 and the material below has n_2 = 3.50. Determine the thickness of the anti-reflective coating that will minimize the reflection of light with a wavelength of 7.00 x 10^{-7} m.



Same phase, destructive.

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

$$t = \left(0+\tfrac{1}{2}\right)\frac{(7.00\times10^{-7})}{2(1.45)}$$

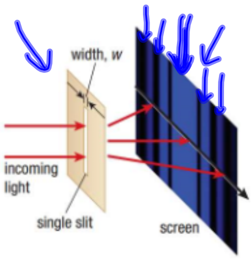
$$= 1.21\times10^{-7}\ \text{m}.$$

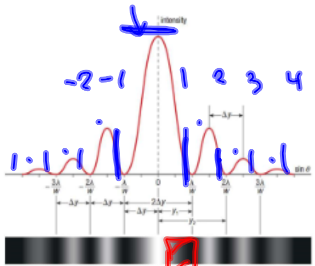
Homework: pg. 511 #1, 3-4, 7

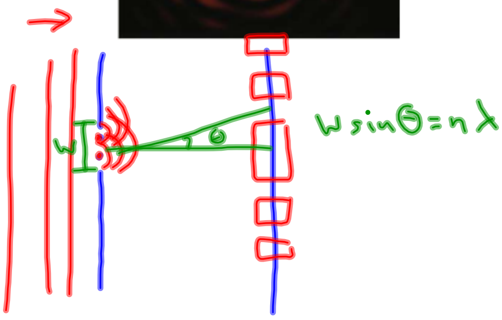
SPH4U 10.2 Single-Slit Diffraction

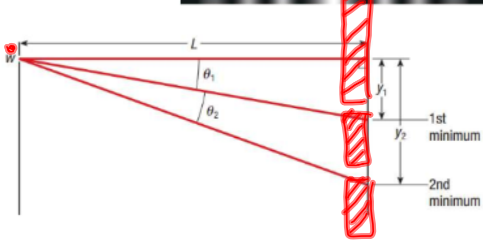
1. Single-slit diffraction

Single-slit diffraction:	when light passes through a small opening (width = w), it interferes with itself.
constructive interference	$w\sin\theta = (m+\frac{1}{2})\lambda$ (mth light fringe, m = 1, 2, ...)
destructive interference	$w\sin\theta = n\lambda$ (nth dark fringe, n = 1, 2, ...)
→ dark fringe location	$y_n = n\frac{L\lambda}{w}$. Separation: $\Delta y = \frac{L\lambda}{w}$.
central maximum	has a width of $2\Delta y = 2\frac{L\lambda}{w}$.



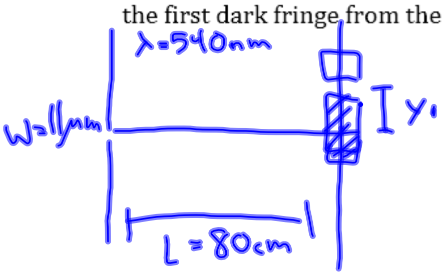






2. Analyzing single-slit interference

Light with a wavelength of 5.40 x 10^2 nm is incident on a slit of width 11 μm and produces a diffraction pattern on a screen located 80.0 cm behind the slit. Calculate the distance of the first dark fringe from the central maximum on the screen.



$y_n = n\frac{L\lambda}{w}$

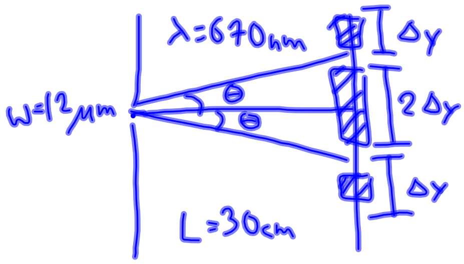
$y_1 = 1\left(\frac{(80cm)(540nm)}{11\mu m}\right)$

$= \frac{(80\times10^{-2})(540\times10^{-9})}{11\times10^{-6}}$

$= y_1 = 3.9\times10^{-2}$ m.

Light with a wavelength of 670 nm is incident on a slit of width 12 μm and produces a diffraction pattern on a screen that is 30.0 cm behind the slit.

a. Calculate the angular width and the absolute width, in centimetres, of the central maximum.



Dark band: $w\sin\theta = n\lambda$

$\theta = \sin^{-1}\left(\frac{n\lambda}{w}\right)$

$= \sin^{-1}\left(\frac{1(670\times10^{-9})}{12\times10^{-6}}\right)$

$= 3.201°$ Ang. width $= 2\theta = 6.40°$

Absolute width $= 2\Delta y = 2\frac{L\lambda}{w}$

$= 2\frac{(30\times10^{-2})(670\times10^{-9})}{12\times10^{-6}}$

$= 0.0335\text{m} = 3.35\text{cm}$

b. Calculate the distance between the first and second minima.

$\Delta y = \frac{L\lambda}{w}$

$= \frac{(30\times10^{-2})(670\times10^{-9})}{12\times10^{-6}}$

$= 1.7\text{cm}$

c. Determine the distance between the second and third maxima. Compare this answer to your answer in (b). Does this answer make sense? Explain why or why not.

$\Delta y = \frac{L\lambda}{w}$

$= 1.7\text{cm}$

→ the same as part (b).

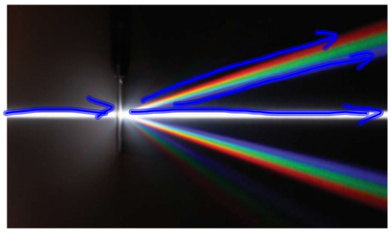
Yes it makes sense.

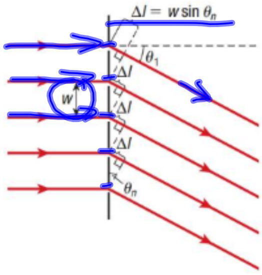
Homework: pg. 519 #1, 3, 5-8

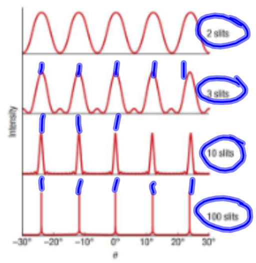
SPH4U 10.3 The Diffraction Grating

1. Diffraction gratings

Diffraction grating:	a surface with very many small, equally spaced parallel slits, to produce interference.
2 slits	remember Young's double-slit experiment.
more slits	Using more slits gives the exact same result, except the light bands become much more narrow, with more dark space in between.
equation	$w \sin\theta = m\lambda$. (Light bands. $m = 0, 1, 2, \ldots$)







Light with a wavelength of 540 nm is incident on a diffraction grating that has 8500 lines/cm. Calculate the angles of the maxima.

$\lambda = 540\text{ nm}$. $N = 8500\text{ lines/cm} \Rightarrow 850000\text{ lines/m}$.

$$w = \frac{1}{8500\text{ lines/cm}} \times \frac{1\text{ m}}{100\text{ cm}} = 1.176\times10^{-6}\text{ m}.$$

(0) $m = 0$, $\theta = 0°$.

(1) $m = 1$, $w\sin\theta = m\lambda$

$$\theta = \sin^{-1}\left(\frac{m\lambda}{w}\right) = \sin^{-1}\left(\frac{1(540\times10^{-9})}{1.176\times10^{-6}}\right) = 27°$$

(2) $m = 2$, $w\sin\theta = m\lambda$

$$\theta = \sin^{-1}\left(\frac{2(540\times10^{-9})}{1.176\times10^{-6}}\right) = 67°.$$

(3) $m = 3$, $w\sin\theta = m\lambda$.

$$\theta = \sin^{-1}\left(\frac{3(540\times10^{-9})}{1.176\times10^{-6}}\right) = \sin^{-1}(1.3776)$$

∴ no solutions.

∴ there are maxima at 0°, 27°, and 67°.

Light emitted by a particular source is incident on a diffraction grating with 9000 lines/cm and produces a first-order maximum at 32.0°. Determine the wavelength of the light.

$N = 9000$ lines/cm $= 900\,000$ lines/m.

$\theta_1 = 32.0°$.

$$w = \frac{1}{N} = \frac{1}{900000}$$

$$= 1.111 \times 10^{-6}\ m.$$

$$w \sin\theta = m\lambda$$

$$\lambda = \frac{w \sin\theta}{m}$$

$$= \frac{(1.111 \times 10^{-6}) \sin 32°}{1}$$

$$= 5.89 \times 10^{-7}\ m$$

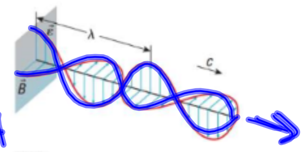
$$= 589\ nm.$$

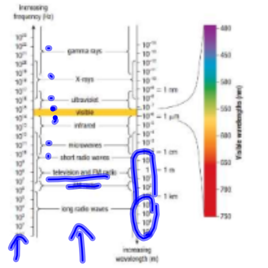
Homework: pg. 525 #2-5, 8

SPH4U 10.4 Electromagnetic Radiation

1. Electromagnetic radiation

Electromagnetic radiation:	combined electric and magnetic fields that oscillate perpendicular to each other and travel at speed of light
Electromagnetic spectrum:	the range of all possible electromagnetic waves.
equation	$v = f\lambda$. ($v = c$).





Microwaves with a wavelength of 1.5 cm carry television signals using a sequence of relay towers.

a. Determine the frequency of the microwave.

$$v = f\lambda$$
$$f = \frac{v}{\lambda} = \frac{3.0\times10^8}{0.015\,m} = 2.0\times10^{10}\ Hz.$$

b. How much time does it take for a microwave signal to travel 5.0 x 10³ km across Canada from St. John's, Newfoundland, to Victoria, British Columbia?

$$v = \frac{d}{t}$$
$$t = \frac{d}{v} = \frac{5.0\times10^3\times10^3}{3.0\times10^8} = 1.7\times10^{-2}\ s$$

The energy of an electromagnetic wave is proportional to its frequency. An X-ray with a wavelength of 0.025 nm transfers its energy to an electron to change its state. How does the energy of the electron transition compare with that of 540 nm visible light?

$$\frac{E_{x\text{-ray}}}{E_{visible}} = \frac{f_{x\text{-ray}}}{f_{visible}} = \frac{1.2\times10^{19}}{5.556\times10^{14}} = 22\,000 \qquad \left(= \frac{\lambda_{visible}}{\lambda_{x\text{-ray}}}\right)$$

$$v = f\lambda$$

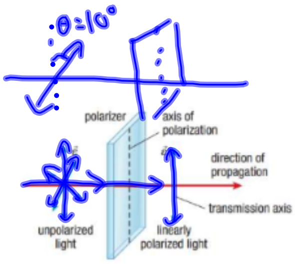
X-ray: $f = \frac{v}{\lambda} = \frac{3.0\times10^8}{0.025\times10^{-9}} = 1.2\times10^{19}\ Hz.$

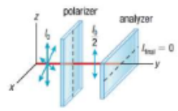
Visible: $f = \frac{v}{\lambda} = \frac{3.0\times10^8}{540\times10^{-9}} = 5.556\times10^{14}\ Hz$

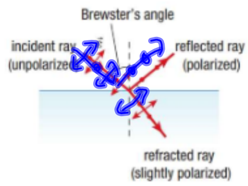
∴ $E_{x\text{-ray}} : E_{visible}$ is 22 000 : 1.

Homework: pg. 531 #1-8

SPH4U 10.5 Polarization of Light







1. Polarized light

Polarized light:	light that vibrates in a single plane
(1) Polarization by selective absorption:	only the component of light parallel to the axis of polarization gets through.
Malus' Law	$I_{out} = I_{in} \cos^2 \theta$
unpolarised input light	$I_{out} = \frac{1}{2} I_{in}$
(2) Polarization by reflection:	light can only travel perpendicular to its electric/magnetic fields. so, some polarities of light are forced to refract instead of reflect.
Brewster's angle	the incident angle where reflected light is maximally polarized.
Brewster's law	$\tan \theta_B = \frac{n_2}{n_1}$.

Homework: pg. 537 #2, 8-9

Name: SOLUTIONS

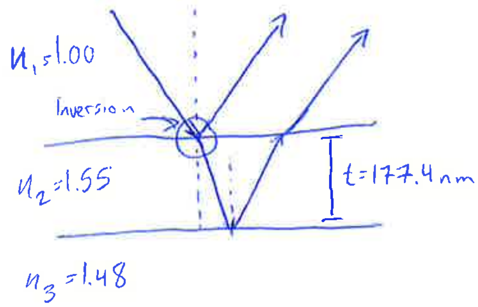
SPH4U: Chapter 10 Quiz – Applications of the Wave Nature of Light

Marks: **NOT FOR GRADES**

1. ***(Thin films)*** A coating, 177.4 nm thick, is applied to a lens to minimize reflections. The refractive indices of the coating and the lens material are 1.55 and 1.48, respectively. Calculate the wavelength in air that is minimally reflected for light rays that strike the lens along the normal. Include a diagram.

→ Destructive interference, 1 inversion (out of phase):

$2t = n\frac{\lambda}{n_{film}}$



$\lambda = \frac{2tn_{film}}{n}$, $n = 1$

$= \frac{2(177.4\times10^{-9})(1.55)}{1}$

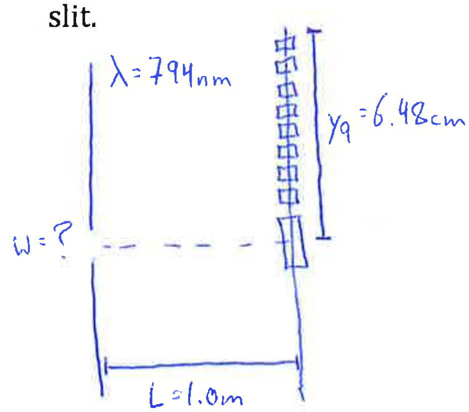
$= 5.4994\times10^{-7}\,m$

$= 5.50\times10^{-7}\,m$

$= \underline{550\,nm}$

∴ the wavelength that is minimally reflected is 550 nm.

2. ***(Single-slit diffraction)*** Light with a wavelength of 794 nm produces a single-slit diffraction pattern in which the ninth dark fringe lies at 6.48 cm from the direction of the central maximum. The distance to the screen is 1.0 m. Determine the width of the slit.



$y_n = n\frac{L\lambda}{w}$

$w = n\frac{L\lambda}{y_n}$

$w = 9\frac{(1.0)(794\times10^{-9})}{6.48\times10^{-2}}$

$= 1.1028\times10^{-4}\,m$

$= \underline{0.11\,mm}$

∴ the slit width is 0.11 mm.

Name: ______________________________

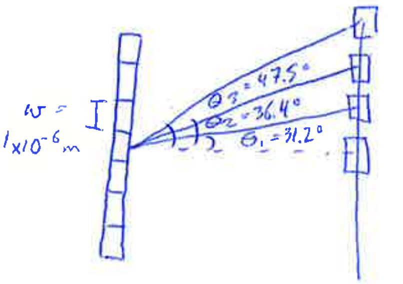
3. ***(Diffraction grating)*** Light incident on a diffraction grating with 10 000 lines/cm produces first-order, second-order, and third-order maxima at angles of 31.2°, 36.4°, and 47.5°, respectively. Determine the wavelength, in nanometres, of light that produces each maximum.

$N = 10000$ lines/cm $= 1\,000\,000$ lines/m.

$w = \frac{1}{N} = \frac{1}{1\,000\,000} = 1 \times 10^{-6}$ m

$w \sin\theta = m\lambda$

$\lambda = \frac{w \sin\theta}{m}$



(1) $\lambda = \frac{(1\times10^{-6})\sin 31.2°}{1} = 5.18\times10^{-7}$ m $=$ 518 nm

(2) $\lambda = \frac{(1\times10^{-6})\sin 36.4°}{2} = 2.97\times10^{-7}$ m $=$ 297 nm

(3) $\lambda = \frac{(1\times10^{-6})\sin 47.5°}{3} = 2.46\times10^{-7}$ m $=$ 246 nm

∴ the wavelengths of light are 518nm, 297nm, and 246nm.

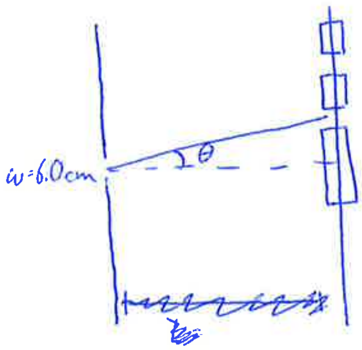
4. ***(Electromagnetic radiation)*** Microwaves with a frequency of 7.5 GHz are incident on a slit 6.0 cm wide. Determine the angle from the central maximum to the first diffraction minimum.

$f = 7.5$ GHz $= 7.5\times10^{9}$ Hz

$v = f\lambda \rightarrow \lambda = \frac{v}{f} = \frac{c}{7.5\times10^{9}}$

$= \frac{3.0\times10^{8}}{7.5\times10^{9}}$

$= 0.04$ m



Destructive: $w \sin\theta = n\lambda$

$\theta = \sin^{-1}\left(\frac{n\lambda}{w}\right) = \sin^{-1}\left(\frac{1(0.04)}{6.0\times10^{-2}}\right) = 42°$

∴ the angle to the first minimum is 42°.

5. ***(Polarization)*** You are viewing a selective polarization experiment through protective goggles. The original intensity of the incident polarized light is 250 candelas, and the resultant light is 17% as intense. Determine the polarization angle of the incident light with respect to the polarization angle of the filter.

$I_{out} = I_{in} \cos^2\theta$

$\cos^2\theta = \frac{I_{out}}{I_{in}}$

$\cos\theta = \sqrt{\frac{I_{out}}{I_{in}}}$

$\theta = \cos^{-1}\left(\sqrt{\frac{I_{out}}{I_{in}}}\right)$

$= \cos^{-1}\left(\sqrt{0.17}\right)$

$= 65.65 = 66°$

∴ the polarization angle is 66°.