→ similar to thin lenses.

5.5 Summary Notes - Mirrors

Plane mirrors form images that are

- virtual and appear to be equal distances behind the mirror as the objects are in the front of the mirror.
- the same height as the object.
- horizontally inverted.

Curved mirrors may be described using the following terminology:

The vertex (*V*) is the centre of the mirror.

The centre of curvature (*C*) The centre of the sphere that was used to cut the mirror.

The principal axis is a line drawn through the vertex and the centre of curvature.

The focal point (*F*) is halfway between the mirror and the centre of curvature. It is the place where all the light rays meet.

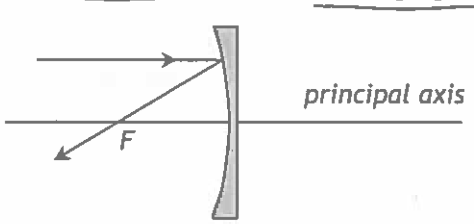
The focal length (*f*) is the distance from the mirror to the focal point.

Notes:

- any ray through focal point will reflect // to principle axis
- any ray // to principal axis will reflect + pass through focal point.

satellite dish

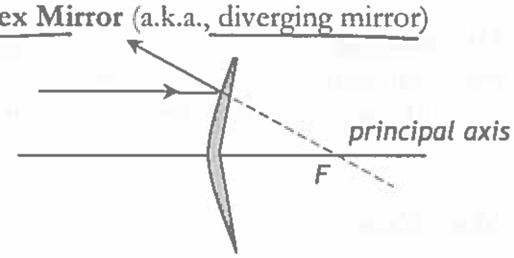
Concave Mirror: (a.k.a., converging mirror)



- wide beam of radio signals + focuses it in

opposite to lenses.

Convex Mirror (a.k.a., diverging mirror)



- All convex mirrors produce images that are smaller, upright and virtual.
- Convex mirrors have a negative focal length

- security mirror / back up mirror
- convex spread out
- convex mirrors have their focal point + centre behind the mirror

How to draw a ray diagram

i.	Draw the mirror showing the principal axis, the centre of curvature, and the principal focus.
ii.	Place a vertical arrow on the principal axis to indicate the position, size and orientation of the object.
iii.	Draw two rays from the tip of the arrow to the mirror. Where these two rays meet (real image) or appear to diverge from (virtual image) is the position of the image. Any two of the following three rays may be used: • The ray directly parallel to the principal axis will reflect through or appear to have come from *F*. • The ray directed through *F* will reflect parallel to the principal axis. • A ray passing through the centre of curvature is reflected back along the same path.

Notes:

The characteristics of an image in a mirror may be determined algebraically with the following equation.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Where:

d_o is the distance from the object to the mirror

d_i is the distance from the image to the mirror

f is the focal length of the mirror

Sign Convention:

Distance (d)		Height (h)	
real focal points or images	+	upright images	+
virtual focal points or images	-	inverted images	-

Magnification

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

N.B.,

- All real images are inverted and all virtual images are upright.
- Any units may be used as long as they are consistent.
- The negative sign is needed due to sign convention.

Examples

1. A 5.0 cm tall object is placed 22.0 cm in front of a concave mirror that has a focal length of 6.0 cm. Determine the characteristics and dimensions of the image (complete the charts) using
   a. a scale diagram.
   b. the curved mirror formula (algebraically).

1 div. = 1.0 cm

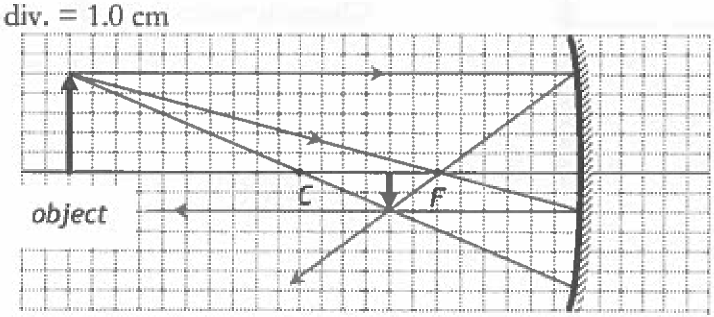


Image Dimensions

	Graphically	Algebraically
d_i	8.0 cm	8.3 cm
h_i	-2.0 cm	-1.9 cm
M	0.40 X	0.38 X

$h_o = 5cm$
$d_o = 22cm$
$f = 6cm$
$h_i = ?$
$d_i = ?$
$M = ?$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{6cm} - \frac{1}{22cm}$

$d_i = 8.25 cm$

$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$h_i = \frac{-d_i h_o}{d_o}$

$h_i = \frac{-(8.25cm)(5cm)}{22cm}$

$h_i = -1.875 cm$

$M = \frac{h_i}{h_o}$

$= \frac{1.875 cm}{5cm}$

$M = 0.375X$

Characteristics
inverted
smaller
real

2. A 5.0 cm tall object is placed 11.0 cm in front of a convex mirror that has a focal length of 5.0 cm. Determine the characteristics and dimensions of the image (complete the charts) using
   a. a scale diagram.
   b. the curved mirror formula (algebraically).

1 div. = 1.0 cm

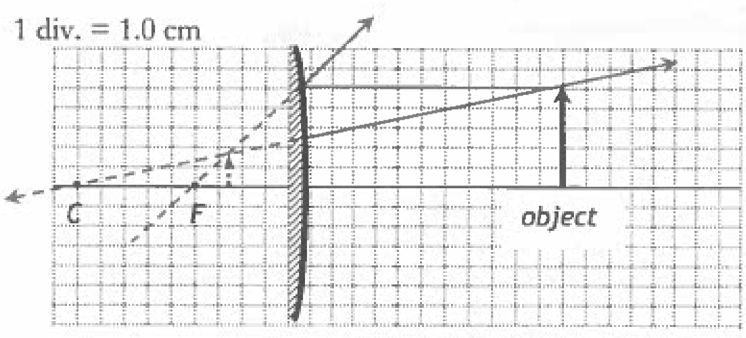


Image Dimensions

	Graphically	Algebraically
d_i	-3.6 cm	-3.4 cm
h_i	1.8 cm	1.6 cm
M	0.36 X	0.31 X

$f = -5cm$
$d_o = 11cm$
$h_o = 5cm$
$d_i = ?$
$h_i = ?$
$M = ?$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{-5cm} - \frac{1}{11cm}$

$d_i = -3.4375 cm$

$\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$h_i = \frac{-d_i h_o}{d_o}$

$= \frac{3.4cm \times 5cm}{11cm}$

$h_i = 1.5625 cm$

$M = \frac{h_i}{h_o}$

$= \frac{1.56cm}{5cm}$

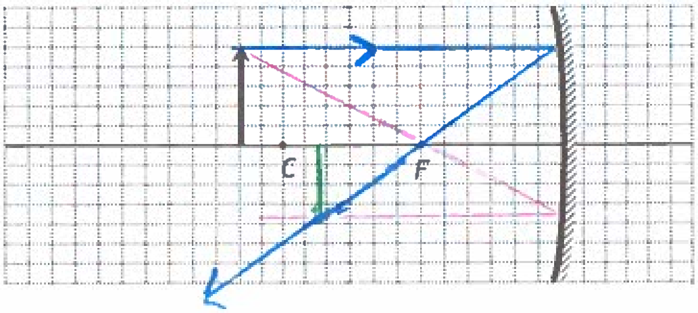
$M = 0.3125X$

Characteristics
upright
smaller
virtual

Problems

1. Locate the image and identify its characteristics by drawing ray diagrams for the following objects placed in front of a mirror. For each question assume 1 scale division = 1.0 m Complete the charts. [Appendix A]

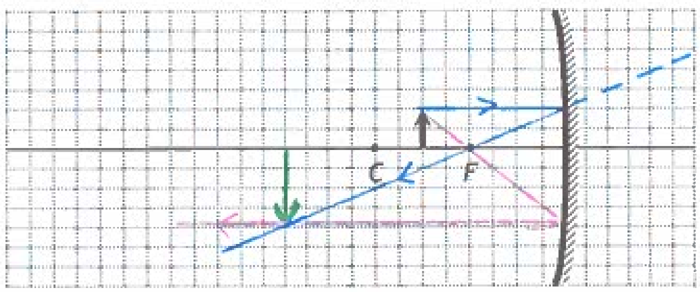
a. concave



Characteristics
inverted
real
smaller

Dimensions
d_i = 10.4cm
h_i = -3.8cm

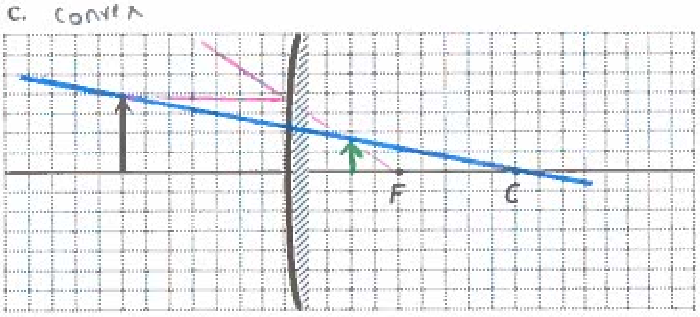
b. concave



Characteristics
inverted
real
larger

Dimensions
d_i = 12.0m
h_i = 4.0m

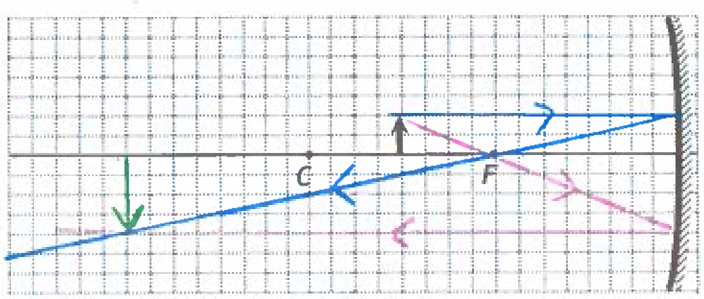
c. convex



Characteristics
upright
smaller
virtual

Dimensions
d_i = -3.0cm
h_i = 1.5cm

2. A 2.0 cm tall candle, is placed 12 cm in front of a concave mirror with a focal length of 8.0 cm. Use a scale diagram to determine the image's characteristics. Complete the chart. [Appendix A]



Characteristics
inverted
larger
real

Dimensions
d_i = 24.0cm
h_i = -4.0cm

3. An object, 5.0 cm high, is located 15.0 cm from a converging (concave) mirror with a focal length of 10.0 cm. Determine the characteristics and dimensions of the image (complete the charts) using

1 div = 2cm

a. a scale diagram.
b. the curved mirror formula (algebraically). [Appendix A]

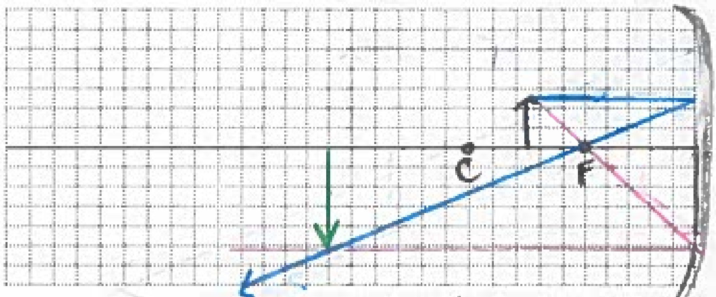


Image Dimensions

	Graphically	Algebraically
d_i	32cm	30cm
h_i	-10cm	-10cm
M	2.0X	2.0X

$m = \frac{h_i}{h_o} = \frac{-10}{5} = -2$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{10} - \frac{1}{15}$

$d_i = 30cm$

$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{h_i}{5} = \frac{-30}{15}$

$h_i = -10cm$

Characteristics
inverted
larger
real.

4. An object, 2.0 cm high, is located 3.0 cm from a diverging (convex) mirror with a focal length of 4.6 cm. Determine the characteristics and dimensions of the image (complete the charts) using

a. a scale diagram.
b. the curved mirror formula (algebraically). [Appendix A]

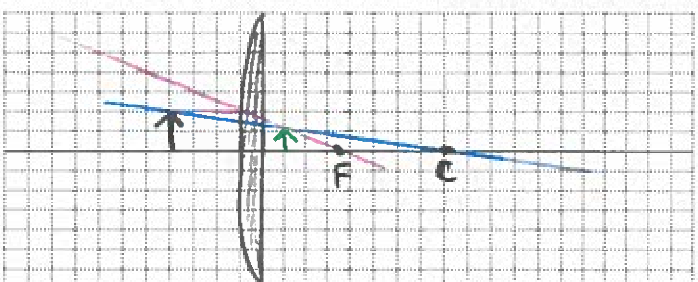


Image Dimensions

	Graphically	Algebraically
d_i	-2.0cm	-1.8cm
h_i	1cm	1.2cm
M	0.5X	0.61X

focal length = -4.6

$m_{graph} = \frac{h_i}{h_o} = \frac{1}{2}$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{-4.6} - \frac{1}{3}$

$d_i = -1.816$

$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{h_i}{2} = \frac{-(-1.816)}{3}$

$h_i = 1.211$

$m = \frac{h_i}{h_o} = \frac{1.211}{2}$

$= 0.6055$

Characteristics
upright
smaller
virtual

5. A 6.5 cm high object is 15 cm from a concave mirror with a 20.0 cm radius. Determine the
   a. image distance from the mirror. [30 cm]
   b. image size. [-13 cm]

$f = 10$

$h_o = 6.5$
$f = 10$
$d_o = 15$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$\frac{1}{d_i} = \frac{1}{10} - \frac{1}{15}$

$d_i = 30cm$

$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{h_i}{6.5} = \frac{-30}{15}$

$h_i = -13cm$

6. An object is placed 20 cm from a spherical concave mirror. It produces an image that is 15 cm away from the mirror. Determine the focal length of the mirror. [8.6 cm]

$d_o = 20$
$d_i = 15$

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$= \frac{1}{20} + \frac{1}{15}$

$f = 8.571$ $f = 8.6cm$

7. A 5.0 cm tall object is placed 4.0 cm in front of a mirror having a focal length of -6.0 cm.
   a. Identify the type of mirror used. [Appendix A]
   b. Identify the type of image produced. [Appendix A]
   c. Determine the distance to the image produced. [-2.4 cm]
   d. Determine the size of the image produced. [3.0 cm]

$h_o = 5cm$
$d_o = 4$
$f = -6$

a) convex mirror (⊖ focal length)
b) produce a virtual image

c) $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ $d_i = -2.4cm$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{-6} - \frac{1}{4}$

d) $\frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{h_i}{5} = \frac{-(-2.4)}{4}$

$h_i = 3cm$

8. Fill in the blank. The main mirror on the Hubble's Space Telescope has a radius of curvature of 115.2 m. Its focal length is 57.6 m. [Appendix A]

57.6
2 | 115.2
10
15
14
12

9. A 5.0 cm high object is 20.0 cm in front of a mirror with a -15 cm focal length. Determine the
   a. image distance from the mirror. [-8.6 cm]
   b. image size. [2.1 cm]

$h_o = 5$
$d_o = 20$
$f = -15$

a) $\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{-15} - \frac{1}{20}$

$d_i = -8.571 = -8.6\,cm$

b) $\frac{h_i}{h_o} = \frac{-d_i}{d_o}$

$\frac{h_i}{5} = \frac{-(-8.571)}{20}$

$h_i = 2.1429 = 2.1\,cm$

10. A 5.00 cm tall object is 10.3 cm from a concave mirror with a 10 cm focal length. Determine the
   a. distance to the image. [343 cm]
   b. size of the image. [-167 cm]

$h_o = 5$
$d_o = 10.3$
$f = 10$

a) $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

$= \frac{1}{10} - \frac{1}{10.3}$

$d_i = 343.\bar{3}\,cm$

$= 343\,cm$

b) $\frac{h_i}{h_o} = -\frac{d_i}{d_o}$

$\frac{h_i}{10.3} = \frac{-343}{10.3}$

$h_i = -166.6 = -167\,cm$

11. An object is placed at the focal point of a concave mirror. Will an image be observed? Explain. [Appendix A]

No. when the object is placed at the focal point the rays do not combine to form an image of the object (the light rays are parallel)

12. A 3.0 cm tall object is placed 6.0 cm in front of mirror. A virtual image is produced that is 1.0 cm tall.
   a. Determine the focal length. [-3.0 cm]
   b. Identify the type of mirror. [Appendix A]

$h_o = 3$
$d_o = 6$
$f = ?$
$h_i = 1$

$\frac{h_i}{h_o} = -\frac{d_i}{d_o} \rightarrow \frac{d_i}{d_o} = -\frac{h_i}{h_o}$

$\frac{d_i}{6} = \frac{-1}{3}$

$d_i = -2.0\,cm$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$= \frac{1}{-2} + \frac{1}{6}$

$f = -3\,cm$

c) convex mirror (negative focal length)

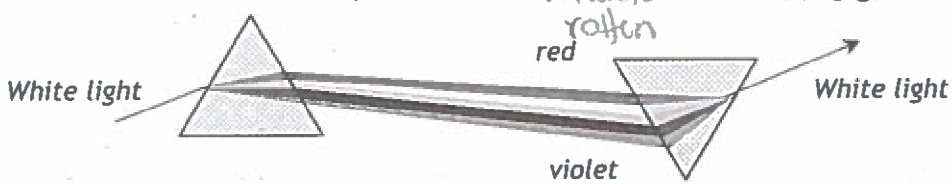
white light → combination of all colours
black light → absence of any colour

ddd
difraction is definitely different.

5.6 Summary Notes – Dispersion & Polarization

Newton explained that light is composed of many colours. He demonstrated this through the following experiment:

RRR BBB
redrefracts rotten
blue bends best



🗋 Notes:

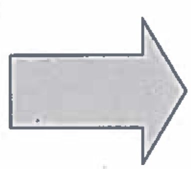
Dispersion is the separation of EMR into individual wavelengths.

A prism disperses EMR because the refractive index of an object is different for each wavelength causing each frequency (colour for visible light) to refract a different amount, thus spread out and separate.

The wavelength range of visible light is from approximately 4.00×10^{-7} m to 7.00×10^{-7} m (400 nm to 700 nm).
nanometre: 1 nm = 10^{-9} m

R O Y G B I V

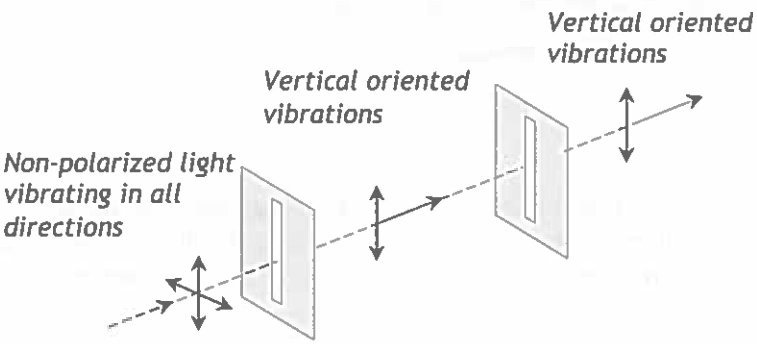
700 nm	**400 nm**
velocity	constant
wavelength	decreases
frequency	increases
bending (refraction)	increases
energy	increases
diffraction	decreases
scattering	increases



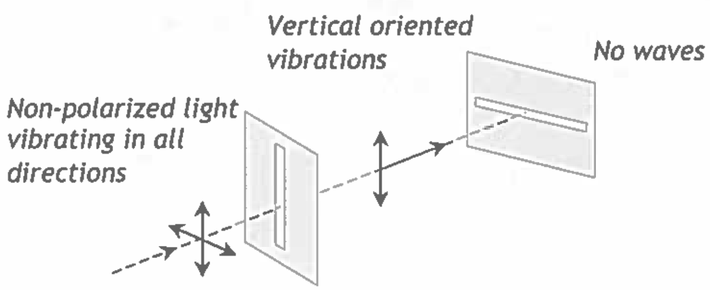
Polarization

🗋 Notes:

Polarized waves vibrate in one plane only. A wave on a rope can be produced so that the wave vibrates in all directions. It is possible to filter out all directions but one with the following arrangement:



When the filters are orientated at right angles relative to each other, no light will get through.



Polarized light may be produced naturally through:

Reflection: Light reflected from shiny surfaces is often polarized. This polarized light causes glare, which polarizing sunglasses can reduce.

Scattering: Blue light that is scattered by the atmosphere is polarized.

This works only for transverse waves. If, therefore, light is a transverse wave, it too should demonstrate these phenomena.

Example

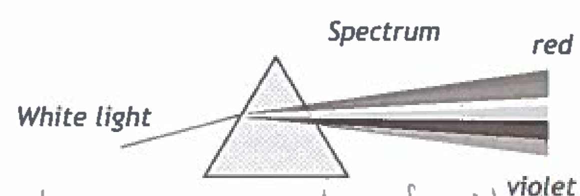
1. Sunglasses used as driving glasses or boating glasses are polarized to reduce glare. Describe a simple procedure (that could be done at the store when buying them) for testing sunglasses to make sure they are polarized.

   Hold two sets of identical glasses up to the light, both in line with your one eye, rotate one of the sets and if the intensity of light changes they are polarized.

Problems

1. A visible spectrum may be produced using a prism. The different wavelengths refract different amounts since the index of refraction is different for each wavelength. Use the diagram below to identify the colour (red or violet) that has the largest index of refraction in the glass prism. [Appendix A]

BBB
RRR



violet bends more therefore it has a larger refractive index

2. Define dispersion. [Appendix A]

The separation of the different frequencies of EMR due to their different refraction indexes.

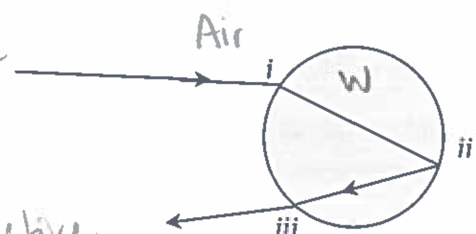
3. A ray of monochromatic light enters and exits a water droplet as shown in the diagram below. Identify the location (i, ii, or iii) where
   a. total internal reflection occurs.
   b. light crosses a boundary to a higher refractive index.
   c. light crosses a boundary to a lower refractive index.

[Appendix A]

i) → is travelling to a higher refractive index

ii) → is total internal reflection

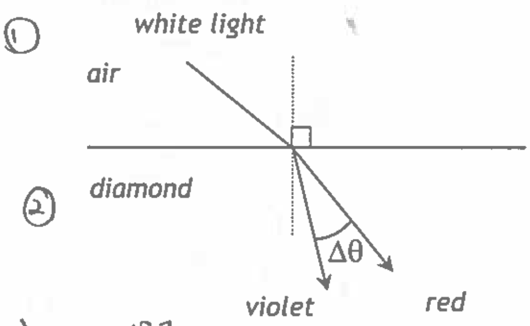
iii) is travelling to a lower refractive index



Use the information below to answer question 4.

The refractive index for a substance is different for different wavelengths, though often an average value is used. When white light from air enters a diamond it disperses to form a spectrum because each wavelength has its own refractive index and therefore bends to different angles.

4. Determine the difference in degrees ($\Delta\theta$) between a red light of 687 nm (n = 2.407) and a violet light of 431 nm (n = 2.452) if white light is incident on the diamond at 25° relative to the normal. [0.19°]



$\lambda_{red} = 687nm$
$n = 2.407$
$\theta_{red} =$

$\lambda_{violet} = 431nm$
$n = 2.452$
$\theta_{violet} = ?$

red

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$

$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$

$= \frac{1 \sin 25}{2.407}$

$\theta = 10.1123°$

violet

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$

$\sin\theta_2 = \frac{n_1 \sin\theta_1}{n_2}$

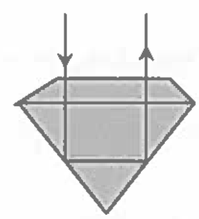
$= \frac{1 \sin 25°}{2.452}$

$\theta = 9.92486$

$\Delta\theta = 10.1123 - 9.92486$
$= 0.18744° = 0.19°$

5. The first use of diamonds as gemstones was in India during the fourth century B.C. Diamond cutting became possible in fifteenth century Europe that helped ensure their popularity. Diamonds are not rare but they are expensive due to effective marketing and control by a few large companies. Diamonds are extremely hard and have very high refractive index. The diamond is cut to ensure that light that enters it exits back out the top giving it a sparkle.

Light ray through a diamond



a. Explain why white light spreads out as it passes through the diamond to produce visible spectra. [Appendix A]
b. Explain why a high refractive index is important to make the light follow the path shown in the diagram. [Appendix A]

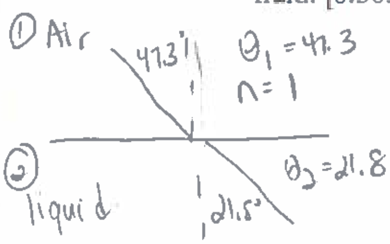
a) Each wavelength has its own unique refractive index so they will be separated from each other when they refract.

b) A high refractive index will help ensure that all light will reflect internally so it can better be directed out the top of the diamond.

6. Lap-top screens, calculator displays and flat panel monitors use liquid crystal displays (LCD) which use the phenomena of polarization to either let light through or to block it. The liquid crystal is a polarizer that is controlled using an electric field. Explain how you could test if the light coming from a flat panel monitor is polarized or non-polarized light. [Appendix A]

- Hold a polarizer in front + rotate it
- if the laptop light is polarized you should see the light change intensity as you rotate the polarizer through 180°.

7. A beam of light is incident upon a clear viscous fluid at an angle of 47.3°. Its refracted angle in the fluid is measured to be 21.8°. Determine the ratio of wavelengths ($\lambda_{fluid}/\lambda_{air}$) for this fluid. [0.505]



$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2}$

$\frac{\sin 47.3}{\sin 21.8} = \frac{\lambda_1}{\lambda_2}$

$1.9789 = \frac{\lambda_1}{\lambda_2}$

$\frac{\lambda_2}{\lambda_1} = \frac{1}{1.9789} = 0.5053$

$= 0.505$

8. Explain how the polarization of light can support the transverse wave nature of light. [Appendix A]

- the transverse wave nature of light allows it to be polarized
- longitudinal waves cannot be polarized.

9. Newton studied optics and realized one of the problems with Galileo's telescope was that the white light often separated out to produce a spectrum. This effect is called chromatic aberration. Explain why this effect occurs. [Appendix A]

- since wavelength of light has its own refractive index, each wavelength will focus at a slightly different point as the light undergoes dispersion.

5.7 Summary Notes – Diffraction & Interference

Diffraction is the spreading out of a wave as it passes a corner or through an opening. If light is a wave it should diffract.

For diffraction of a wave to be noticeable the wavelength should be larger than the opening it passes through. Since light has very small wavelengths, its diffraction can easily go undetected.

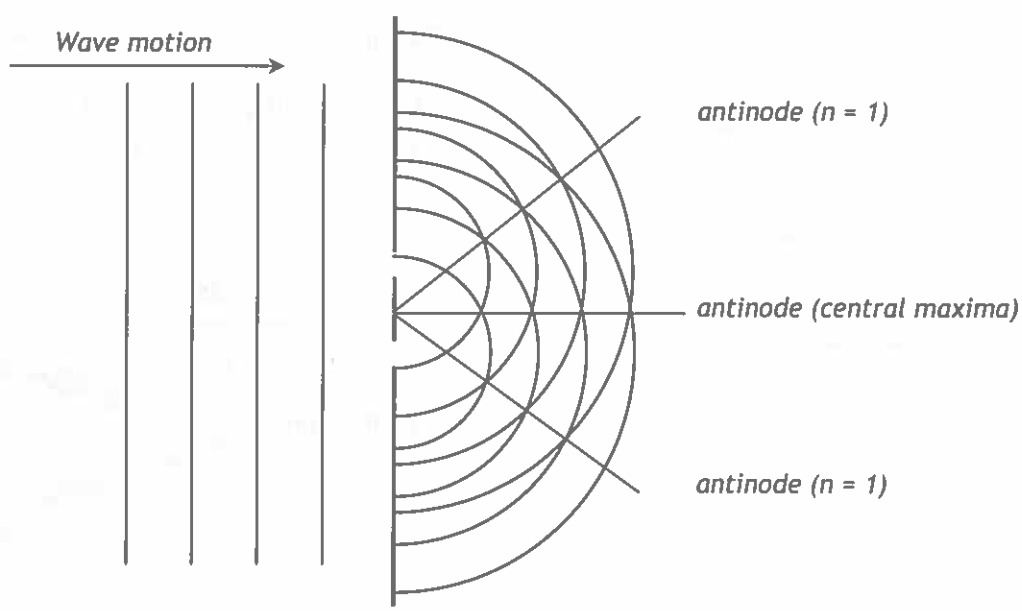
Wave **interference** occurs when two or more waves pass each other and superimpose to produce a new wave of different amplitude.

Thomas Young developed an experiment to show that light is a wave by having it diffract and interfere.

Notes:

Young's apparatus

- Maxima are bright areas called bright fringes (i.e., antinodal or areas of constructive interference). They occur at n = 1, 2, etc.
- Minima are dark areas (i.e., nodal or areas of destructive interference) between the bright areas.
- Alternating bright and dark lines are projected onto the screen.



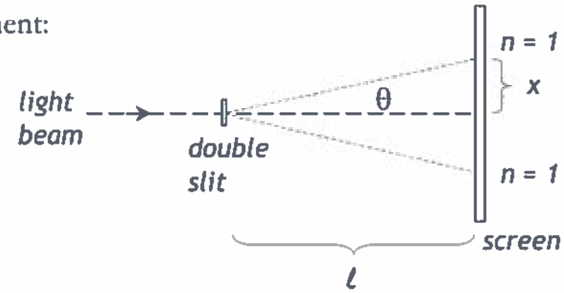
d\x

Two equations are used with Young's double slit experiment:

$$\lambda = \frac{dx}{nl}$$

$$\lambda = \frac{d \sin \theta}{n}$$

estimate - accurate with θ < 10°



Where:

- λ is the wavelength of the light (m)
- d is the distance between the two slits (m)
- θ is the angle from the centre of the two slits to the bright fringe in question (degrees)
- n is the order number of the bright fringe
- x is the distance from the central bright fringe to another bright fringe (m)
- l is the distance from the double slit to the screen (m) if the angle is small.

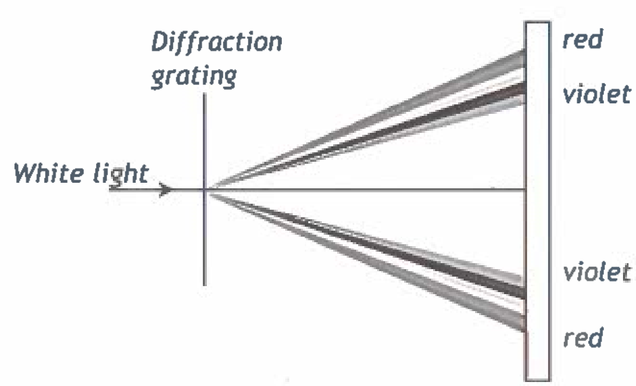
N.B., The derivation of the first equation relies on an approximation. It is assumed that d is very small in comparison to l. This approximation is good unless large angles (> 10°) or large n values are used. With the angle being less than 10°, the screen to slit distance is assumed to be identical to the path length of the light from double slit to screen.

Notes:

Diffraction Gratings (a.k.a. interference gratings)

Rather than a double slit to perform Young's experiment, multiple slits, called diffraction gratings, are more commonly used.

- The bright maxima are much sharper and narrower for a grating than for a double slit, and, therefore, better for measuring wavelength.
- The angle of diffraction depends on wavelength.
- If light of multiple wavelengths is used, the grating sorts out the wavelengths and produces a spectrum.

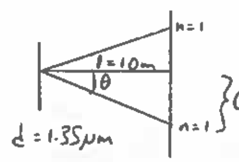


Examples

1. Light falls on a pair of slits 1.35 μm apart. The maxima are measured to be 41.0 cm apart and the screen is a distance of 1.00 m from the slits. Determine the wavelength of light using each diffraction equation:

   a. $\lambda = \dfrac{d \sin \theta}{n}$ b. $\lambda = \dfrac{dx}{n\ell}$

   c. Explain why the answers in part a and b are different.



$\tan\theta = opp/adj$

$\tan\theta = \dfrac{0.41m}{1.0m}$

$\theta = 22.29°$

a) $\lambda = \dfrac{d\sin\theta}{n}$

$\lambda = \dfrac{1.35\cdot10^{-6}m \sin 22.2936°}{(1)}$

$\lambda = 5.1213\cdot10^{-7}m$

b) $\lambda = \dfrac{dx}{ln}$

$\lambda = \dfrac{1.35\cdot10^{-6}m(0.41m)}{(1.0m)(1)}$

$\lambda = 5.535\cdot10^{-7}m$

a. The light's wavelength is 512 nm.
b. The light's wavelength is 554 nm.
c. Since the angle of deviation is greater than 10°, the small angle approximation gives large errors. Therefore the wavelength of 512 nm should be the better answer.

2. A glass grating is ruled with a line density of 5500 lines/cm. Monochromatic light striking the grating forms a second order image diffracted at 50.0°. Determine the wavelength of the light used.

$R = 5500\ lines/cm$

$n = 2$

$\theta = 50°$

$\lambda = ?$

$d = \dfrac{1}{R}$

$d = \dfrac{1}{5500\ lines/cm}$

$d = 1.81\times10^{-4}cm$

$\lambda = \dfrac{d\sin\theta}{n}$

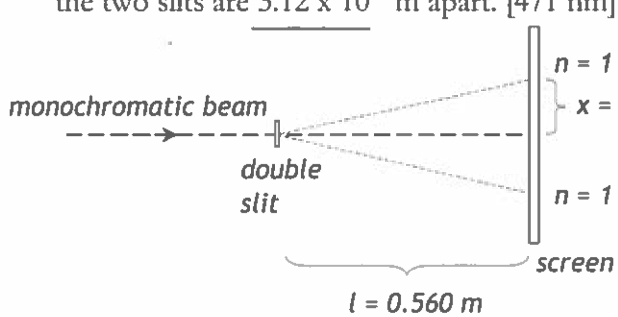
$\lambda = \dfrac{1.81\times10^{-4}cm\ \sin 50°}{(2)}$

$\lambda = 6.964\times10^{-5}cm$

The light has a wavelength of 696 nm.

Problems

1. A monochromatic beam of light travels through a double slit and produces a diffraction pattern on a screen as shown in the diagram below. Determine the wavelength of the light if the two slits are 3.12×10^{-6} m apart. [471 nm]



$\lambda = \dfrac{dx}{nl} = \dfrac{(3.12\times10^{-6}m)(0.0845m)}{1(0.560)}$

$= 4.7079\times10^{-7}m$

$\lambda_1 = 471nm$

2. The spacing between two slits is 5.90 x 10^{-3} m in a Young's double slit experiment. The distance from the slits to the screen is 1.00 m, and the distance from the central bright maximum to the third maxima is 2.50 x 10^{-4} m. Determine the wavelength of the incident light used in the experiment. [492 nm]

$d = 5.90\times10^{-3}$ m
$l = 1.00$ m
$x = 2.50\times10^{-3}$ m
$n = 3$
$\lambda = ?$

$\lambda = \frac{dx}{ln}$
$= \frac{(5.9\times10^{-3})(2.5\times10^{-3})}{1 \cdot 3}$
$= 4.917\times10^{-7}$ m $=$ **492nm**

3. A monochromatic beam of light is passed through two slits and forms an interference pattern on a screen. The distance between the slits is 0.0550 cm and the distance to the screen is 5.00 m. The distance from the central bright to the third bright fringe is 2.38 cm. 2.38×10^{-2} m
   a. Determine the wavelength of the incident light. [873 nm]
   b. Identify the colour of the incident light if it is visible. [Appendix A]

$d = 0.0550\times10^{-2}$ m
$l = 5$ m
$x = 2.38\times10^{-2}$ m
$n = 3$
$\lambda = ?$

a) $\lambda = \frac{dx}{ln} = \frac{(0.055\times10^{-2})(2.38\times10^{-2})}{3(5\text{m})}$
$\lambda = 8.726\times10^{-7}$ m
$\lambda = 873$ nm

b) the light is not visible → it is infra-red.

4. Monochromatic light of 520 nm is passed through two narrow slits imprinted onto a slide. The distance between the two slits is 0.75 mm and the screen is located 110 cm away from the slide. Determine the separation distance between bright lines in the interference pattern formed on the screen. [7.6 x 10^{-4} m]

$d = 0.75\times10^{-3}$
$l = 1.10$ m
$x = ?$
$n = 1$
$\lambda = 520\times10^{-9}$ m

$\lambda = \frac{dx}{ln}$
$x = \frac{\lambda l n}{d}$
$= \frac{(520\times10^{-9})(1.10)(1)}{0.75\times10^{-3}}$
$x = 0.0007627$ m

distance between dark lines is $= 7.6\times10^{-4}$ m

5. Determine the angle of deviation of the 1st order maxima produced when monochromatic light of 440 nm is directed through two slits that are 6.2 μm apart. [4.1°]

$\theta = ?$
$\lambda = 440 \times 10^{-9}$ m
$d = 6.2 \times 10^{-6}$ m
$n = 1$

$\lambda = \frac{d \sin\theta}{n}$

$\sin\theta = \frac{n\lambda}{d}$

$= \frac{1(440 \times 10^{-9})}{6.2 \times 10^{-6}}$

$\theta = 4.0696$

$= 4.1°$

6. Determine the spacing of the rulings on an interference grating if the third order maximum is observed to deviate 26° from the central maxima using monochromatic light of 548 nm. [3.8 x 10^{-6} m]

$\theta = 26°$
$\lambda = 548 \times 10^{-9}$
$d = ?$
$n = 3$

$\lambda = \frac{d \sin\theta}{n}$

$d = \frac{\lambda n}{\sin\theta}$

$= \frac{(548 \times 10^{-9})(3)}{\sin 26°}$

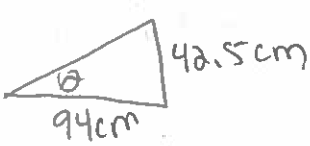
$d = 3.750 \times 10^{-6}$

$d = 3.8 \times 10^{-6}$ m

7. A CDROM acts as a diffraction grating as it reflects light since it has many small imprints lined up as a way of storing data. An experiment is performed to determine the line spacing on a CDROM using a pocket laser pointer. The following data was recorded:

wavelength of laser pointer:	680 nm
distance from the screen to the CDROM:	94.0 cm
distance from the bright central max to the first maximum:	42.5 cm

Determine the spacing of the lines on the CDROM. (Hint: is the angle greater than 10°?) [1.65 x 10^{-6} m]



$\tan\theta = \frac{42.5}{94}$

$\theta = 24.329°$

$\lambda = \frac{d \sin\theta}{n}$

$d = \frac{\lambda n}{\sin\theta}$

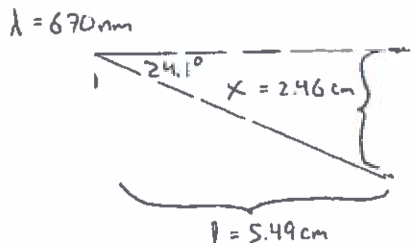
$= \frac{(680 \times 10^{-9})(1)}{\sin 24.329}$

$= 1.6506 \times 10^{-6}$

$= 1.65 \times 10^{-6}$ m or 1.65 μm.

8. A student is asked to determine the line spacing in a diffraction grating using a pen laser. The apparatus is set up as shown in the picture to the right. She sets the laser on a piece of paper so she can mark the locations of the laser, double slit, the screen and the bright lines on the screen.

She then uses the pen marks as shown in the diagram below to calculate the diffraction grating's line spacing. The label on the pen laser claimed a wavelength of 670 nm. [1.64×10^{-6} m]



$\lambda = \frac{d\sin\theta}{n}$

$d = \frac{\lambda n}{\sin\theta}$

$= \frac{(670\times10^{-9})(1)}{\sin 24.1°}$

$= 1.641\times10^{-6}$

$d = 1.64\times10^{-6}$ m or 1.64 μm

9. A diffraction experiment is performed where it is determined that the 2^{nd} order maxima is at an angle of deviation of 56.0° using a diffraction grating having a line density of 1.00×10^{6} lines/m.
   a. Determine the wavelength of light used. [415 nm]
   b. Identify the colour of the light if it is visible. [Appendix A]

$d = \frac{1}{\text{line density}}$

$R = 1\times10^{6}$ $d = \frac{1}{R}$

$d = \frac{1}{1.00\times10^{6} \text{ lines/m}}$

$d = 1.00\times10^{-6}$ m

a) $\lambda = \frac{d\sin\theta}{n} = \frac{1\times10^{-6}\sin 56°}{2}$

$\lambda = 4.145\times10^{-7}$ m

$= 415$ nm

b) color is violet

10. A grating ruled with 12 000 lines per cm produces a first order image at an angle of 32.0°. Determine the wavelength of light used. [442 nm]

$R = 12000$ L/cm

$d = \frac{1}{R}$

$= \frac{1}{12000 \text{ L/cm}}$

$d = 8.3\times10^{-5}$ cm

$= 8.3\times10^{-7}$ m

$\lambda = \frac{d\sin\theta}{n}$

$= \frac{8.\bar{3}\times10^{-7}\sin 32°}{1}$

$\lambda = 4.416\times10^{-7}$ m

$\lambda = 442$ nm

11. An argon laser used in retinal surgery has a frequency of 6.148×10^{14} Hz. It is incident on a diffraction grating ruled with 6000 lines/m. The diffraction grating and screen are 1.50 m apart. Determine the

a. wavelength of the argon laser. [488 nm]
b. angle between bright lines. [0.2°]
c. distance between the bright lines in the diffraction pattern. [4.39 mm]

$d = \frac{1}{k}$

$= \frac{1}{6000 \text{ lines/m}}$

$d = 1.\bar{6} \times 10^{-4} m$

a) $c = \lambda f$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{6.148 \times 10^{14}}$

$\lambda = 4.8796 \times 10^{-7} m$

$\lambda = 488 nm$

b) $\lambda = \frac{d \sin\theta}{n}$

$\sin\theta = \frac{n\lambda}{d}$

$= \frac{1(4.8796 \times 10^{-7})}{1.\bar{6} \times 10^{-4}}$

$\theta = 0.1677° = 0.17°$

c) $\lambda = \frac{dx}{\ell n}$

$x = \frac{\lambda \ell n}{d}$

$= \frac{(4.8796 \times 10^{-7})(1.5)(1)}{1.\bar{6} \times 10^{-4}}$

$= 0.004392 m = 4.39 mm$

12. Use the terms refraction and diffraction to fill in the blanks for the following statements. [Appendix A]

a. Blue light is affected more by refraction.
b. Red light is affected more by diffraction

RRR BBB DDD

13. Monochromatic laser light of 650 nm is directed through a diffraction grating that a line density of 4500 lines/cm. Determine the angle of the second order fringe relative to the central bright fringe. [35.8°]

$d = \frac{1}{k}$

$d = \frac{1}{4500 L/cm}$

$= 0.00022 cm$

$= 2.\bar{2} \times 10^{-4} cm$

$= 2.2 \times 10^{-6} m$

$\lambda = \frac{d \sin\theta}{n}$

$\sin\theta = \frac{\lambda n}{d}$

$= \frac{(650 \times 10^{-9})(2)}{2.\bar{22} \times 10^{-6} m}$

$\theta = 35.8°$

14. A glass grating is etched with 5400 lines/cm. Monochromatic light is incident on the grating and forms a second order image with a diffracted angle of 30.0°. Determine the wavelength of the monochromatic light used. [463 nm]

$d = \frac{1}{R}$

$d = \frac{1}{5400\ L/cm}$

$= 1.85 \times 10^{-4}\ cm$

$= 1.85 \times 10^{-6}\ m$

$\lambda = \frac{d \sin\theta}{n}$

$= \frac{(1.85 \times 10^{-6}\ m) \sin 30°}{2}$

$\lambda = 4.6296 \times 10^{-7} = \boxed{463\ nm}$

15. A second order image is formed by a diffraction grating at an angle of 64°. The grating is ruled with 10 000 lines/cm.

a. Calculate the wavelength of the light. [4.5×10^{-7} m]

b. Will an image also appear at a smaller angle? If so, what is the angle? [Yes, 27°]

c. Can a third order image be seen? Show your work to prove it either way. [Appendix A]

$d = \frac{1}{R}$

$d = \frac{1}{10000\ L/cm}$

$= 1 \times 10^{-4}\ cm$

$= 1 \times 10^{-6}\ m$

a) $\lambda = \frac{d \sin\theta}{n}$

$= \frac{1 \times 10^{-6} \sin 64°}{2}$

$\lambda = 4.494 \times 10^{-7}\ m$

$= 449\ nm$

b) $\sin\theta = \frac{\lambda n}{d}$

$= \frac{4.494 \times 10^{-7} (1)}{1 \times 10^{-6}}$

$\theta = 26.71 = 27°$, yes

c) $\sin\theta = \frac{\lambda n}{d} = \frac{4.494 \times 10^{-7} (3)}{1 \times 10^{-6}}$

θ = error, a third order image cannot be created.

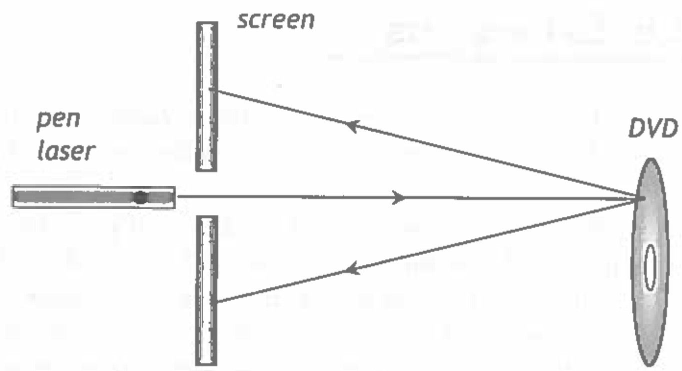
Use this information to answer question 16.

Sir Isaac Newton thought that light was composed of tiny particles which he referred to as "corpuscles". Christiaan Huygens proposed a wave theory for light. However the particle theory of light dominated science due to Newton's reputation.

16. Considering Thomas Young's observations of light interference, explain how these observations eventually changed common scientific knowledge or theory of his day. [Appendix A]

- scientists started to think of light as a wave instead of a particle

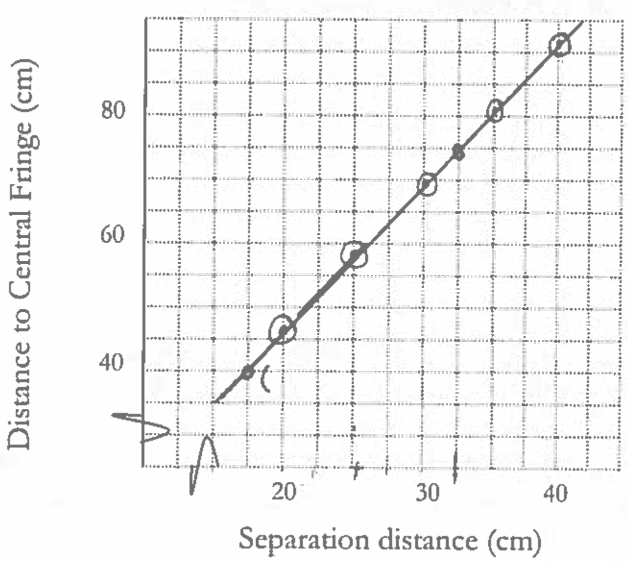
17. An experiment is done to determine the spacing between lines on a DVD video using a laser beam. The line spacing on a DVD is closer together than on a CD allowing DVDs to contain more data. The experimental set-up is shown below and the data collected is given in the chart.



Screen-disk separation distance (cm)	Distance from central bright fringe to n = 1 (cm)
20.0	46.6
25.0	58.2
30.0	69.9
35.0	81.5
40.0	93.1

a. Plot the data.

Distance to Central Fringe as a Function of Separation Distance



b. Determine the slope of the line. [~2.38]

slope $= \frac{\Delta y}{\Delta x} = \frac{93.1 - 46.6}{40 - 20} \sim 2.325$

c. Since the slope of the line is equal to the tangent of the angle, use the slope to calculate the angle. [~67.2°]

$\tan\theta = 2.325$

$\theta = 66.7° = 67°$

d. The angle calculated in part c may be considered an average angle for all the trials. Using a red laser with a wavelength of 680 nm and the angle found from the slope, determine the spacing between data lines on the DVD. [~7.38 x 10^{-7} m]

$\lambda = \frac{d\sin\theta}{n}$

$d = \frac{\lambda n}{\sin\theta} = \frac{680\times10^{-9}\cdot 1}{\sin 66.7127} = 7.3782\times10^{-7}$

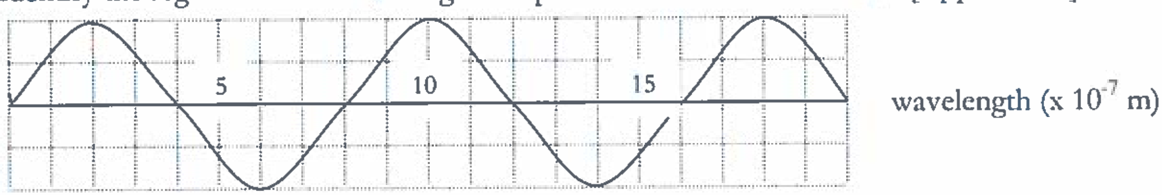
$d = 7.38\times10^{-7}$ m

5.8 Extensions

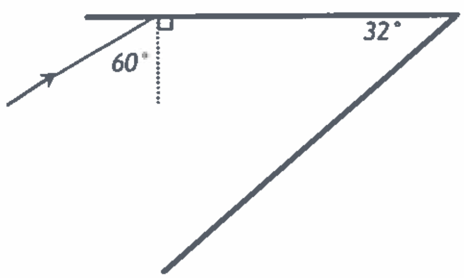
1. This is a research question. Why do radio waves travel further at night than during the day? (Hint: ionosphere.) Your explanation must include a diagram. [Appendix A]

2. Two hockey fans are watching a playoff game being played in Edmonton. The first fan is at the game in Edmonton and the second is at home in Dallas watching on satellite TV. The signal to Dallas is being sent via a communication satellite in a geosynchronous orbit 36 000 km above the earth's equator. How much sooner does the Edmonton fan hear the play-by-play than the Dallas fan? You'll have to make some approximations to answer this question. [0.24 s]

3. An oscilloscope can be attached to an antenna and represent EMR as a picture on a computer screen. The following electromagnetic wave is shown on an oscilloscope's cm grid.
   a. Determine the frequency of the wave being analyzed by the oscilloscope. [4.0×10^{14} Hz]
   b. Identify the region of the electromagnetic spectrum the wave is found in. [Appendix A]



4. A ray of light is reflected in series from two mirrors as shown below. Determine the angle of reflection off the second mirror. (The diagram is not drawn to scale.) [28°]



5. Some companies provide a service to track cell phones. For a small fee a cell phone can be "pinged" and located. Discuss the risks and benefits of this feature. [Appendix A]

6. Small microchip implants in called radio frequency identification (RFID) are useful for keeping track of people, animals and consumer goods and have been widely used in the 21 century. It has been shown, however, that they can carry and transmit computer viruses. Discuss the risks and benefits of the widespread use of RFIDs. [Appendix A]

7. Determine the angle of refraction or reflection as light strikes the opposite side of the equilateral piece of cut glass (n = 1.55). [41°, reflection]